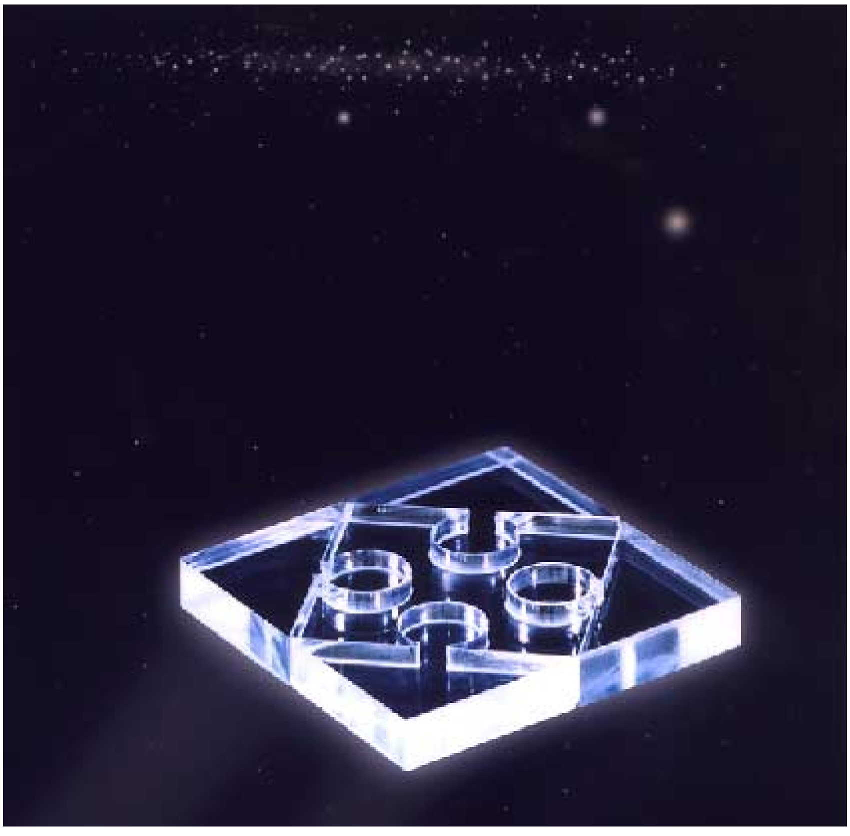
Axyz

System Concepts, Procedures and Definitions



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1. Introduction

1.1 About this document

This document takes an overview of the main components of ***Axyz***. It describes the design concepts which link them together into a working unit and how the measuring task has been conceived in order to use them effectively.

It assumes the reader has a knowledge of the basic optical measuring principles and mathematical techniques on which ***Axyz*** is based. See:

- Guidelines
- Mathematics for users

Detailed operation of the software is not discussed here. These details can be found in:

- ***Axyz*** Core Data Module: Software Reference Manual
- ***Axyz*** Data Manager: Software Reference Manual
- ***Axyz*** Theodolite Modules: Software Reference Manual
- ***Axyz*** Laser Tracker Module: Software Reference Manual

This document is structured as follows:

- Introduction
- Part 1 - ***Axyz*** data
- Part 2 - Core features
- Part 3 - Working with theodolites and Total Stations
- Part 4 - Working with laser trackers
- Appendix: General design concepts

1.2 What is Axyz?

Axyz (pronounced AX-IZ to rhyme with quiz) is essentially a system comprising a computer controlled set of optical instruments and related software which is used for large-scale 3D metrology. It can generate, on line, the 3D coordinates of selected object points and provides a wide range of analysis functions to process this object point data.

Computer control is implemented on a Personal Computer (PC) using an Intel 486 processor (or higher) and running under Microsoft's Windows 95 or Windows NT operating systems.

The optical instruments currently include precision electronic industrial theodolites, Total Stations and tracking laser interferometers.. High resolution video cameras are a likely future addition to this list.

These optical instruments utilize the techniques of triangulation, in the case of theodolites and cameras, or polar location, in the case of Total Stations and laser trackers, to derive the 3D coordinates of selected points on manufactured objects and components.

Previous systems have been designed to deal with each individual class of instrument (tracker, theodolite or Total Station) and have been relatively inflexible in their implementation. Examples are:

- ECDS and ManCAT - theodolites utilizing triangulation
- PCMS - Total Station utilizing polar location
- SMART - laser tracker utilizing polar location

Although different in design and method of operation these 3 classes of instrumentation have many similarities, as do the corresponding 3D measuring systems. It is because of this that ***Axyz*** aims to provide a single system which can accommodate any special needs of the different instrument types. This unified approach extends to the use of a standard software operating environment, in this case Microsoft Windows™. The intended result is that users can view ***Axyz*** as a standard optical measuring system in which they can freely choose the most appropriate measuring sensors for their application. Adding or changing to a different sensor will then only involve a small learning curve since most system features remain the same.

In addition to this major simplification ***Axyz*** is very flexible in its implementation. Users can configure measuring sequences which conform to their standard working practices and even directly program into ***Axyz*** their own specialist functions and features. This additional development is made possible by the use of scripts, similar to programming macros, and standard Microsoft applications such as Visual Basic for general programming and ACCESS for database development and manipulation.

When users are introduced to ***Axyz***, they are immediately aware of 3 significant components of the system:
1. The measured object
2. The measuring hardware
3. The controlling computer

Data: The measured object

From the system's point of view, the measured object is actually a collection of data which must be processed and manipulated. This not only includes the obvious 3D elements but also items such as the original measured angles and distances and administrative information such as the object's description and date of measurement. An extensive *database* for each measurement job must deal with this.

Instrument modules: The measuring hardware

Measuring hardware concerns the actual instruments, such as theodolites, which are directly used to measure the object. These however do not act independently of the other system components. Software and hardware interfaces are needed to connect them to the controlling computer, record their readings and convert these into 3D information. Since these sub-systems are more complex than individual instruments it is more appropriate to think of them as *instrument modules*.

Software modules: The controlling computer

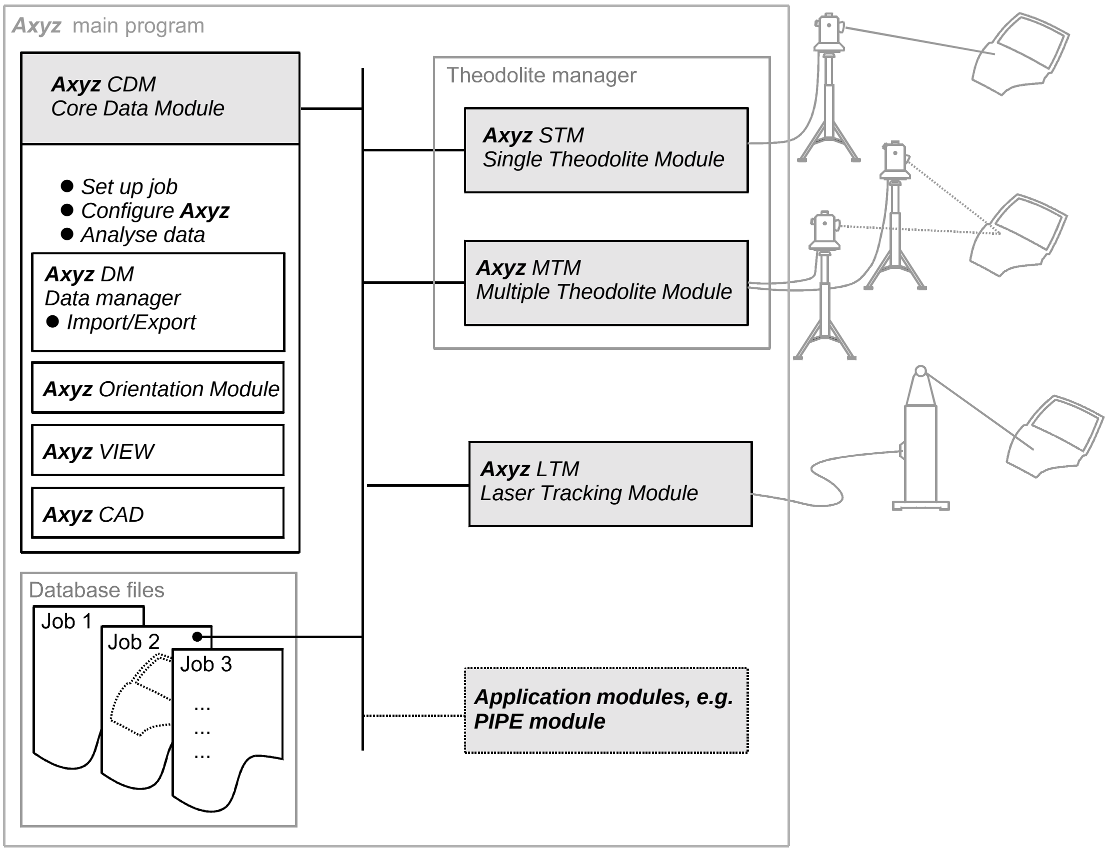
Whilst the controlling computer looks like a piece of hardware it is actually a complex system whose major feature, for the user, is the software which makes it function. Standard software modules enable the user to define the measurement job, specify units of measurement, geometrically analyse the data and generally manipulate the job's database. This collection of software modules does not change when different instruments are used and it is known as the *core module*.
(Remember that other software modules are part of the sub-systems represented by the instrument modules. It is convenient to associate them with the instrumentation since they change when the instrumentation changes.)

With this more detailed information we can revise our preliminary picture of ***Axyz*** as follows:

- The measured object
  A database for every measurement job
- The measuring instruments
  Optical hardware with software modules specific to it
- The controlling computer
  Core software to administer the database and geometrically analyse the data

Although the object is the most important item to the user, the objective of ***Axyz*** is to solve the measurement tasks associated with the object. In explaining ***Axyz*** the emphasis is therefore on techniques of data acquisition and analysis.

1.3 Axyz modules



*Structure of **Axyz** industrial measurement system* AXYZ.WMF

The diagram gives a simplified pictorial overview of ***Axyz*** , showing how core and optional instrument modules are housed within the ***Axyz*** Main Program. Some of the core functions are implemented as separate sub-programs. For instance, the Data Manager (DM) has a wide range of features for examining the data and selecting particular data items. (It is, in fact, also used by some of the instrument modules.) The theodolite modules have a number of common design features and are actually implemented using a Theodolite Manager The Orientation module is also an independent sub-program capable of processing both triangulation and polar data, including data from laser trackers. In the future it may also process video data. It is offered as a core function suitable for implementations where data is analysed rather than measured. (Measurement would take place at a remote site where the implementation of ***Axyz*** included an instrument module.) All these modules and sub-modules communicate with the database files where job information is stored.

2. AXYZ data

2.1 About this section

This section introduces some of the main features of ***Axyz*** data which help users of polar and triangulation modules organize their work in a logical, efficient fashion. It is not a complete statement of all the data recorded and administered by ***Axyz***

2.2 An overview of Axyz data

The measured object, the most important feature of any measuring task, is described by much more than a simple list of 3D coordinates. The data which ***Axyz*** generates and handles in order to deliver a properly documented, 3-dimensional description of the user's object is extensive and diverse. In order to provide users with an easily understood overview whilst ensuring that the data can be handled in a convenient way, ***Axyz*** places all the data for a particular measuring task into a *database*.

The measuring task is known to ***Axyz*** as a *job*. All the information related to the job, the measurements, calculated coordinates, administrative data and so on, are stored in the database which is a single self-contained file known as the *job file*. (The terms "database" and "job file" will both be used within the text of the current document.)

Although the data is different for every job, the structure of the database remains the same and in the case of ***Axyz*** has been implemented using Microsoft's ACCESS. Background information on this is available in "General design" on page 177.

Users are completely free to organize their own job files. For convenience, ***Axyz*** automatically creates a default folder called JOBS which can be used to store job files but any other convenient folder structure can be put in place using Windows 95 conventions.

The data elements described in the remainder of this section are all accommodated in the job file.

2.2.1 Data elements

A job may involve:

- A single object
- Individual components or sections of the same object
- The same object at different times
- Several objects (similar or different) at the same measurement site

(This description implies that a solid object is always measured. Occasionally this is not true. For example, the path of a robot's end effector as measured by a laser tracker is not itself a solid object. In any further discussion of a measured object, users should interpret the term "object" as widely as possible.)

To allow users a flexible level of organization which will accommodate many arrangements of objects, ***Axyz*** introduces a fundamental component of an object called a *workpiece*. This could be regarded as a physical component such as a car door or a more abstract "container" where a certain class of points are stored. All measured objects therefore become collections of one or more workpieces.

A workpiece mainly contains *measured points* such as hole centres, positions marked with special targets and temporary laser spotted surface points which are located by the instruments currently in use. The workpiece can also contain *shapes* such as circles and lines which are derived from the measured points. Shapes in turn can provide additional *calculated points* on the workpiece, for example at the intersection of two derived lines. Workpieces may also need to conform to a particular design. This can be achieved by adding a number of *control points* with known design coordinates to the object data or providing *reference points* for comparison purposes.

A measuring *network* of instruments surrounds the workpieces which make up the object or objects. This network could be as simple as a single setup of one Total Station but will often involve a number of instrument locations. Since instruments may be moved around when building a network, ***Axyz*** must distinguish between the actual instrument with its physical connection to the PC and the locations or *stations* which instruments occupy during the measurement job.

Furthermore, setting up a network and locating object points may involve other ancillary devices, such as:

- *scale bars* which provide the scale for pure triangulation networks
- *hidden point devices* to locate points not visible from some instrument positions
- reflector *prisms* for Total Stations
- *retro-reflectors* for laser trackers

These ancillary devices may require a surprisingly large amount of information for their definition. For example, the apparently simple scale bar needs some identifying description and a record of its coefficient of expansion. Its most obvious parameter, length, may be defined by 2 or more targets, with a list of calibrated distances between pairs of targets.

Instruments make *measurements* which are the angles and distances used to locate points and construct networks. Before an instrument network can be used for measurement, the relative positions and angular attitudes of the instruments must be known. Positions are defined by 3 *coordinates* and angular attitude by 3 *rotational components*. These 6 quantities are the *orientation parameters* of the instruments. Calculating orientation parameters is a simple task when polar methods are used but triangulation methods require assisted techniques. In order to support this, measurements are internally provided with a classification to identify which, for example, were used for collimation pointings between theodolites.

Once oriented instruments exist, their measurements can be used to derive the coordinates of points. Shapes also have coordinates defining their location in space (e.g. the centre of a circle) as well as rotational parameters defining their angular attitude in space (e.g. a tilted plane on which a circle lies). Shapes must also, of course, have parameters which define their size or form (e.g. the radius of the circle).

Coordinates and rotational parameters can only exist in the context of a *coordinate system.* This has an *origin* and *orthogonal axes* from where coordinates and rotational components of stations, points and shapes are measured. ***Axyz*** is particularly flexible in the way coordinate systems can be used to view the data.

Firstly, all measurements are recorded in a common *base coordinate system*. This is the very first coordinate system defined in a job. Depending on how it is created, its origin and axes will be defined by an arbitrary instrument location or fixed somewhere on the object. Users can subsequently create other origins and axes which may be more convenient. Data can then be transformed into these other coordinate systems for viewing and output.

Every new coordinate system is named and defined by the 3 coordinates of its origin and 3 rotational components, measured with respect to the base system. As already stated, these 6 parameters are also defined for every shape. ***Axyz*** therefore permits users to view data in coordinate systems defined by shapes.

As a further refinement, ***Axyz*** offers a choice of *coordinate types* in addition to a choice of coordinate systems. Coordinates are normally the rectangular XYZ components along the reference axes but these can be converted into another format, such as cylindrical coordinates. Cylindrical coordinates, for example, consist of a height along the Z axis, a radial distance out from the Z axis and a rotation angle measured from the X axis.

Despite the frequent use in this manual of the common axis labels "X","Y" and "Z", users are free to label axes as they wish.

Users also have a choice of measurement units. For convenience, ***Axyz*** internally uses metres for distances and other linear values and radians for angular values. When users display data however, they have a choice which includes, amongst others, inches and millimetres, gons and sexagesimal degrees.

The measured data does not exist in isolation. A major objective of many tasks is to ensure that the constructed or measured object conforms to design. As mentioned, design data is provided in the form of *control points* and *reference points*. ***Axyz*** must be able to import this data from another source and, for full flexibility, to export it as well. Facilities therefore exist to import and export data in standard formats.

Finally, it may be convenient for documentation purposes or to trace problems if the actions taken during a *measurement session* were recorded. Disk and printed log files are available for this purpose, with options for users to control the amount of recorded detail.

Given the extensive and diverse range of data which ***Axyz*** must handle there is a clear need for a database which will efficiently organize it, but where does the user start?

Axyz provides a template or *master job file* prepared with a *default workpiece* and pre-defined items such as units. This enables the user to easily create a new job and immediately start work. Each job file is fully self-contained, even to the extend of repeating definitions for, say, scale bars which are also used in other jobs.

The following sections provide more detail on the features and handling of ***Axyz*** data. All data can be viewed in a spreadsheet format with the *Data Manager (DM).*

2.3 Units

Units of length and angle are required for instrument readings, coordinates and various analysis functions. Units of pressure and temperature are also required when recording environmental effects, such as expansion, during the measurement process.

Axyz allows the user to work in different units which can be altered at any stage. The units currently available are listed below.

A change of units does not alter values stored in the job file. Selected units only change the way the user views data. See also:

- "Units used for recorded instrument readings" on page 18
- "Base coordinate system" on page 32

2.3.1 Length units

- Feet
- Inch
- Metre
- Millimetre

2.3.2 Angle units

- Decimal degree
- Degree Minute Second (sexagesimal degrees)
- Gon
- Radian

2.3.3 Temperature units

- Celsius
- Fahrenheit

2.3.4 Pressure units

- Millibar
- Millimetres of mercury

2.3.5 Units definable by the user

see DM manual

Different units are implemented by specifying a conversion factor to be applied when viewing internal units. Users can create new units by specifying their own names and conversion factors.

2.4 Measurements

All the optical instruments which can be used by ***Axyz*** are effectively devices which measure directions to target points and, in some cases, distances as well. Each measurement is composed of 3 elements, two of which indicate direction such as horizontal and vertical angle and one which indicates distance.

A function is available to calculate a point's 3D coordinates from its measurements, see "Locating points: the Single Point Solution" on page 168. In the database, the 3D values are linked with the measurements from which they were derived. Measurements to a point may be available from up to 99 stations.

In a theodolite triangulation system at least 2 pairs of horizontal and vertical angles (h1,v1) (h2,v2) are needed to generate a 3D point.

Polar methods require at least 1 triplet of horizontal angle, vertical angle and distance (h1,v1,d1) to generate a 3D point. Total Stations and laser trackers generate this type of measurement.

Although measurements must be further processed to obtain 3D coordinates in an orthogonal coordinate system, they have themselves already been processed in order to compensate for systematic instrument errors. (This assumes that proper checking and calibration routines have been carried out by the user.)

The following sections give further details of:

- Units used for recording measurements
- Ways of making multiple measurements to the same target
- Classification of measurements into 3 basic groups
    - Standard measurements
    - Collimation and orientation measurements
    - Scale bar measurements

The different measurement classes are stored in different parts of the database.

2.4.1 Units used for recorded instrument readings

Internally ***Axyz*** stores angular readings in radians and distance readings in metres.

2.4.2 Multiple measurements of the same target

Depending on the type of instrument and measurement technique, ***Axyz*** will correctly take account of multiple measurements whose purpose is to generate a single result. For example:

- Repeated theodolite pointings in one face are stored as a single averaged value with a record of the number of pointings.
- Bolt hole pointings are made on the edge of the hole and averaged to a single value representing a pointing to the centre of the hole.
- Theodolite pointings in two faces are stored separately but combined into one single face pointing for computing point coordinates.

See further details in "Multiple target pointings" on page 105.

2.4.3 Standard measurements

Most of the 3D data describing an object is derived from measurements made by the user. These will be measurements made to laser spotted surface points, targeted or well-defined object features or offset targets on hidden point devices in cases where the object point cannot be directly sighted. Two measurement types cover these possibilities:

1. Normal measurements
2. Hidden point measurements

Standard measurements can be viewed with the DM by either looking up the workpiece in which object point data is stored or by selecting a station. In the workpiece data you will find all the measurements made to a particular point from a range of stations and in the station data you will find all the points sighted by a particular station.

Notes
Measurements of type "normal" produce 3D points of type "normal".

Measurements of type "hidden point" are made to the device points (the offset targets). When converted into 3D data they create 3D points of type "device". These 3D device points in turn generate the actual 3D hidden point which is stored as type "hidden".

Both normal and hidden point measurements are used in the optimizing section (bundle adjustment) of the Orientation Module to create the measurement network

2.4.4 Collimation and orientation measurements

When triangulation methods are used it is necessary to provide the Orientation Module with information which enables it to calculate approximately where the stations are located.

Axyz identifies special *collimation* and *orientation* measurements for this purpose. Although many types of orientation techniques are possible the ones employed here are those familiar to ManCAT and ECDS users.

Collimation measurements can be viewed with the DM by selecting a particular station.

Notes
With one exception, none of the orientation measurements are used in the optimizing section (bundle adjustment) of the Orientation Module. They are only used in the initial calculation of approximate position. Users must still ensure that sufficient standard measurements have been made to enable a network to be computed.

The exception to the rule is accurate collimation measurements which can strengthen a measurement network and improve measurement quality.

Collimation

Collimation measurements are pointings made from one instrument to another. Ideally it would be possible to directly sight the rotation centre of a target instrument, since this is the point to which its coordinates are assigned. This is rarely possible so either an offset target must be sighted accurately in two faces by two instruments doing reciprocal pointing, or the sighting can only be approximate.

3 measurement types cover the possibilities
1. Approximate collimation
2. Accurate forward collimation (reciprocal collimation in face 1)
3. Accurate reverse collimation (reciprocal collimation in face 2)

Local and object

These measurement types are required for approximate orientation procedures based on ECDS methods.

Object orientation is also known as *controlled* orientation and involves measurements to *control points* which have known values in some design or reference coordinate system, usually directly related to the object.

Local orientation is also known as *relative* orientation and does not involve any design coordinates. It results in a coordinate system based on the local axes of the first instrument in the network.

Each technique requires several measurement components to enable a full and approximate orientation to be computed.

In both techniques the instrument being oriented identifies the axes of the common coordinate system by sighting along them. Local measurements then additionally require an approximate distance from the measuring station back to the first station. Object measurements additionally require an approximate distance to an object point.

The procedures are covered by 2 measurement types, local and object, and the following 5 sub-categories of measurement .
1. Distance to a station (for local/relative type)
2. Distance to a named point (for object/controlled type)
3. Direction of X axis
4. Direction of Y axis
5. Direction of Z axis

2.4.5 Scale bar measurements

If triangulation methods are employed, i.e. instruments measure angles only, accurate scale can be introduced by moving one or more scale bars to different positions throughout the workspace. Scale bar measurements are the pointings made to scale bar targets.

2.4.6 Summary of measurement types

Axyz stores each of the following classes of measurement in a separate part of the database:

- Standard measurements
- Collimation and orientation measurements
- Scale bar measurements

The full list of measurement types is as follows:

Standard measurements

Type	Description
Normal	A direct measurement to a target point from an instrument
Hidden point	A measurement of a selected offset target on a hidden point device.

Collimation and orientation measurements

Type	Sub-category	Description
Approx. coll.		Rough pointing from one instrument to another
Forward coll.		Accurate collimation in one telescope position
Reverse coll.		Accurate collimation in the other telescope position
Relative	Dist. to stn. 1	Approx. distance from the current station to station 1.
	X axis	Approx. pointing along the local x axis.
	Y axis	Approx. pointing along the local y axis.
	Z axis	Approx. pointing along the local z axis.
Object	Dist. to point	Approx. dist. to the chosen object point.
	X axis	Approx. pointing along the object's x axis.
	Y axis	Approx. pointing along the object's y axis.
	Z axis	Approx. pointing along the object's z axis.

Scale bar measurements

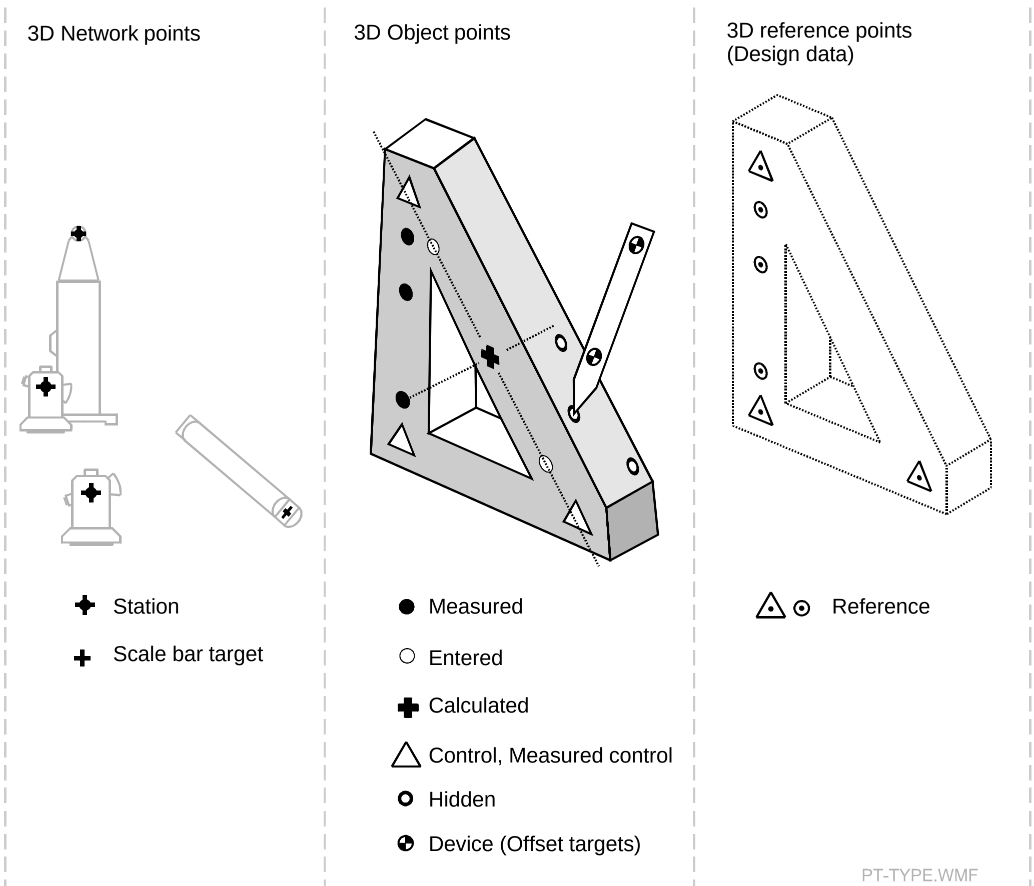
Type	Description
Scale bar	A pointing to a selected target on a scale bar.

2.5 3D points

The most important data to the user are the 3D coordinates of the points which make up the object. However the object can only be measured by the network of instruments which locate the points using angle and distance measurements. The instruments, including scale bars, also have coordinates which locate them in 3D space. In addition, the measured object points are normally required to conform to some theoretical design which represents another set of relevant 3D data.

There are therefore three classes of point data relevant to the measured object:
1. Object points
2. Reference points (design data)
3. Network points

2.5.1 Diagram: Axyz 3D point data



2.5.2 Contrasting features of 3D data

The various sources of 3D data have different requirements and different parameters to describe them. Here are some examples:

Example 1: Measured points
The measured object must allow for indirect measurement of a point using a hidden point device. The database must therefore keep track of groups of related points which make up such a device.

Example 2: Network points
Stations need 3 rotational elements in addition to 3 coordinates in order to fully locate them in space. Scale bar targets are related to a particular bar and the same bar may be used at several different locations in the workspace.

Example 3: Reference points
Reference data from a CAD system may also attach surface information to point coordinates, such as the direction of the normal vector at the point. The coordinate system may also be different from the base system created by the orientation module and which applies to network and object points.

2.5.3 Storage and usage of 3D data

Rather than adopt a unified but complex structure for all types of 3D data, ***Axyz*** maintains a data classification and stores different types in different parts of the database. This has an effect on the way some operations are executed and affects the scope of others.

Most analysis functions, such as circle calculation, only operate on data in the object area, i.e. on object points and the shapes and coordinate systems derived from them. (The exception is the comparison of object with reference coordinates.) Most object points are *measured* and some are *hidden.* The *device* points corresponding to the hidden points are included in the object points and are also available for analysis. Any *calculated* points derived from an analysis are also added to the object points and are then available for further analysis. To improve flexibility, any other point may be *entered* into the list of object points, manually or by importing from a file, and then further processed. *Control* points have the special property that they are an integral part of the orientation process, during which their coordinates remain fixed. They are also therefore stored with the object points.

Control points and reference points normally represent design data. They therefore ultimately come from the same source and are known in the same coordinate system. Both need to be manually entered into the database or imported from a file. In the diagram, the triangles in both the object and reference areas indicate this connection.

Reference data is frequently used to calculate transformations from the base coordinate system of the object points into the coordinate system of the reference data, if this has not been done directly by the inclusion of control. Until the transformation is calculated, object and reference data exist in independent, unconnected coordinate systems, which is a reason for keeping them separate. Once a transformation exists, coordinates in both the object and the reference areas can be directly compared for three principal tasks:

- On-line, point by point building of an object to design
- On-line, point by point inspection of an object for conformance with design
- Comparison of sets of object points with design (off-line inspection)

CDM Edit/Swap points

Since reference points are stored separately from the object points, a mechanism is available to *swap* points between the two areas of the database. With this facility you can:

- Create reference data by swapping object points into the reference area
- Use analysis functions on reference points by swapping reference data into the object area

There is no facility to swap network points into the object area but given the relatively small amount of network data this could be done by manually creating corresponding *entered* points.

Notes
Only normal and device points have measurements associated with them. Hidden points are derived from device points and control and entered points can only be inserted into the object data without any associated measurements. Calculated points are derived from all the other object points, including other calculated points.

2.5.4 3D Object points

Object points are the main component of the ***Axyz*** database. The most common object points are the specific locations which you directly sight on an object and which define its shape. These *measured points* may be marked by specially manufactured targets which are inserted into the object or are stuck to it but they can also include the reflector positions used by laser trackers and Total Stations.

Optical methods depend on a line of sight which is not always available, hence the need for indirect measurement of surface points and target locations using hidden point devices. Here the tip of a targeted rod or frame can be held against the point and visible targets on the device can be measured instead. See "Hidden point devices" on page 109 for a full discussion. This technique generates coordinates for both the offset targets on the device as well as the hidden point itself and gives rise to point types *hidden* and *device.*

Measured and hidden points may form shapes which are calculated using shape fits. From the fitted shapes further object points can be calculated. For example, the centre of a fitted circle can be added to the list of points or two computed lines on the object can be subsequently intersected to create a new calculated intersection point. Points created in this way are *calculated points.*

Finally, information about points on an object may be available from external sources and it is possible to enter this information by hand or from a file. For general use these are known as *entered points.* Where they have the specific purpose of controlling an orientation procedure they are identified as *control points*.

For naming points, see "Using and naming workpieces, points and shapes" on page 41.

Orientation points

Many users are familiar with orientation points which help create a triangulation network and which are often convenient points located off the object. However, object points can also be used in orientation procedures and some techniques employed by video cameras do not distinguish between object and orientation points. For this reason, points included for orientation purposes are treated as normal measured points.

Shape origins

Shapes are also stored under the defined workpieces and every shape has an origin which is a 3D point. As indicated, this point can be placed in the list of object points when the shape is created. If this is not done you can still access shape origins and use them in analysis routines.

Corrections to measured object points

Corrections are simple directional offsets and the relevant information is stored with the object point. ***Axyz*** deals with the following situations.

Target thickness
If a measured point is defined by an adhesive target, a correction to the point's coordinates may be needed if the target thickness is significant. ***Axyz*** enables target thickness to be defined and applied. Use of a simple stand-off target requires the same type of correction. See "Target thickness and reflector offset correction" on page 117.

Reflector offset
An offset correction is also required when a laser tracker measures a reflector's position as it is physically tracked across an object's surface. Here the measured points are at the centre of the reflector housing and not on the surface. See "Correcting for offsets" on page 147.

Summary of object point types

Point type	Remarks
Measured	The most common type of point which is directly measured by theodolite intersection of a target or polar measurement to a target. The point is linked to the list of measurements from which it was derived.
Entered	Point data which are input manually or by importing from a file. They provide a general purpose facility for checks and calculations.
Control	Control points are design coordinates which are used exclusively to modify or "control" the effects of an orientation procedure during the phase of bundle adjustment. They represent fixed information which is not significantly altered and are frequently used to created orientations which have a coordinate system based in the object. Control points can be manually entered or imported from a file

Summary of object point types (cont.)

Point type	Remarks
Measured Control	Once measured, control points are subject to measurement tolerances and their calculated locations will not, in general, exactly match the design values. This point type reminds the user that the measured values are being viewed, not the design values. Note that the design values are separately recorded and are always used when the point is included in an orientation.
Calculated	When shapes are measured, some point defines a local origin such as the centre of a circle. Shapes may also be used to derive other points, such as the intersection between two measured lines. Local shape origins and other derived points may be optionally added to the list of calculated points.
Hidden	These represent the tip of a hidden point device, derived from the positions of the device (offset) points.
Device	These are the coordinates of the offset targets on a hidden point device. If the hidden point is calculated on line they are identified by the corresponding hidden point name combined with an integer offset identifier If the device (offset) points measured for off-line calculation of the hidden point, they are named and recorded as normal points.

2.5.5 Reference files (3D Design data)

Reference files contain 3D design coordinates for specific points. They are required for the following purposes:

- Locating object points in a design coordinate system by a best-fit transformation
- Building or inspecting critical object locations on line. Reference coordinates should generate zero differences with the measured values if the object is correctly built
- Comparing a set of point coordinates with design values, which is effectively a form of off-line inspection

See also "Reference and control points" on page 63 for more information. For identifying reference data, see "Identifying reference points" on page 45.

2.5.6 3D network points (stations and scale bar locations)

Stations build a measuring network around an object but their positions do not form part of the measured object. Scale bars provide triangulation networks with scale and their targets are measured in the same way as any other points. However, these positions are also part of the measuring network, not the object.

In both cases separate storage areas are provided in the database for the coordinates and related information. Network data is not associated with a workpiece.

2.6 Shapes

Axyz can create a number of standard shapes which are defined by the parameters of a local origin, a set of 3 local reference axes and possibly one other parameter of size or form. If 3 local axes are more than the minimum necessary, the excess axes are generated by default. Most 3D shapes require at least one main axis which is designated the local z axis.

Example

A circle is defined by:

- Coordinates of the centre of the circle which is the local origin
- Local xy axes in the plane of the circle
- A local z axis normal to the plane of the circle and which is the main axis
- The radius (or diameter) of the circle

Shapes are created in several ways by:

- Form fitting to measured points using a best-fit, least squares technique
- Intersection of existing shapes
- Geometric constructions using existing points and shapes
- Manual definition using the DM

Best fitting shapes can be created from any type of object point. A point can also be specified by naming an existing shape in the list of points to be fitted. In this case ***Axyz*** assumes the shape's origin is the required point. For example, if you fit a circle to a list of points consisting of the names of 3 existing circles, the new circle will be constructed through the centres of the existing circles.

Fitted points can be chosen from several workpieces. The created shape will be assigned to a specified workpiece or, by default, the currently active workpiece.

Since shapes have their own local coordinate system, for many analysis purposes shapes and coordinate systems are treated as equivalent types of element.

For naming shapes, see "Using and naming workpieces, points and shapes" on page 41.

2.6.1 Summary of standard shapes created by Axyz

Axyz permits the computation of the following 7 standard shapes using best fitting routines:

- Line
- Plane
- Circle
- Sphere
- Cylinder
- Cone
- Paraboloid

2.6.2 Vectors

When a best fitting shape is created its origin may be separately stored as a point and its main z axis may be stored as a vector.

A vector is regarded as a further type of shape but it does not have an associated local origin or reference axes. Only the unit vector components (direction cosines) are stored.

2.7 Measurement and coordinate sets

Groups of points may be related in some way and it may be more convenient to treat them as a single entity, rather than individual elements. The motivation for *measurement sets* and *coordinate sets* comes from tracker applications but also has application to triangulation and other polar measurements.

See also "Sets: Multiple related locations" on page 131.

2.7.1 Measurement sets

Measurement sets represent data from a single laser tracker. Tracker measurements are polar measurements which individually represent a 3D point. However the data cannot be incorporated into the actual measurement network (base coordinate system) until the instrument station has been oriented. When that has been done, this very local 3D information can be viewed as final point coordinates.

Measurement sets normally define a group of related but spatially distributed points obtained by dynamically tracking a reflector as it moves along a spatial curve or surface.

Example 1
Set of measurements made to a moving reflector attached to a robot arm.

Example 2
Set of measurements made as a reflector is scanned across a free-form surface.

Unlike measurements of fixed locations, these sets cannot be reduced to a corresponding single representative value as it is the individual points which describe the corresponding spatial curve or surface.

If used to measure a free-form surface, these measurement sets can be processed to create a corresponding coordinate set. See:
"***Axyz*** View/CAD - Graphics Modules Software Reference Manual"
Graphic menu/ Surface offset

When viewed in the Data Manager, each measurement in the set will show the corresponding orthogonal 3D values provided the associated station has been oriented.

The individual points in these measurement sets can be used for 3D analysis.

For naming convention see "Identifying measurement sets" on page 46.

2.7.2 Coordinate sets

Coordinate sets are groups of points with fully known 3D data in the base coordinate system.

Example of coordinate set
Points on a curving free-form surface which represent a digitized version of the surface.

Coordinate sets can be created in several ways:
- By calculating surface points from a distributed measurement set of a free-form surface (Graphics Module)
- By importing from an external file (Data Manager)
- By manually creating the individual elements (Data Manager)

Individual points in coordinate sets can be used for 3D analysis, for example to measure point separations or fit lines.

For naming convention see "Identifying coordinate sets" on page 46.

2.8 Coordinates and coordinate systems

Measurements are processed into coordinates of points and it is these points which are actually used to make up the workpieces and the object. Although object data is very commonly presented in a rectangular system of XYZ values, using metres as the unit of length, alternative ways of viewing the data are required.

One common alternative uses different units such as inches instead of metres.

Another alternative is to view coordinates in a different, more convenient format. For example, if a large cylindrical component is measured it may be much more useful to specify positions radially from the best fitting axis, with a distance along this axis.

Lastly users frequently need to change the location and orientation of the coordinate system axes so that, for instance, a different point becomes the origin. ***Axyz*** has a number of methods for creating alternative coordinate systems. See "Creating alternative coordinate systems" on page 61.

2.8.1 Base coordinate system

Axyz operates by storing all coordinate data in a standard *base coordinate system.* This is the first coordinate system which is created. It is automatically generated by the Orientation Module and its location depends on how the user has configured the measurement network. It will be located either at an instrument station or on the object.

Data in the base system is then transformed into an output format specified or calculated by the user. Transformation is a filtering process used for viewing and display only. Internally the stored data is not altered.

The base system always stores coordinates in units of metres in a right-handed, rectangular coordinate system.

2.8.2 Object coordinate systems

An object coordinate system is a descriptive term for a coordinate system located in the measured object and which has some direct meaning to the object. For example it may correspond to the coordinate system originally used to design the object.

Object coordinate systems can be created by either a controlled orientation or a transformation onto design values.

2.8.3 Local coordinate systems

A local coordinate system is a descriptive term which implies that its corresponding coordinate values are primarily of local interest. Normally the term will be applied to some specific object feature such as a measured circle whose centre defines a local origin.

It may also relate to a coordinate system defined by one of the stations in a network. This normally results from a relative orientation which does not make use of object coordinates and arbitrarily uses the first station in a network to define the base coordinate system.

2.8.4 ECDS "local" and "object" coordinates

ECDS users distinguish only between a "local" system created by a relative orientation and local to a particular station, and an "object" system which use control points related to the object. Since ***Axyz*** permits the definition of many more than two coordinate systems this simple differentiation cannot be easily maintained. The terms are therefore now descriptive rather than definitive and where there is potential ambiguity the user can refer to the name assigned to every coordinate system.

2.8.5 Shapes as coordinate systems

Standard shapes have their own local origin and set of orthogonal axes which means that every shape also defines a coordinate system. It is therefore possible to view all data in the coordinate system defined by any shape.

Vectors are an exception and cannot be used as coordinate systems since they have no associated origin and axes.

2.8.6 Active (default) coordinate system

At any time, one of the existing coordinate systems is the *active coordinate system* and its name is displayed on the status bar of the main screen. Coordinate and orientation data is then displayed or output in this default system unless this choice is temporarily overridden.

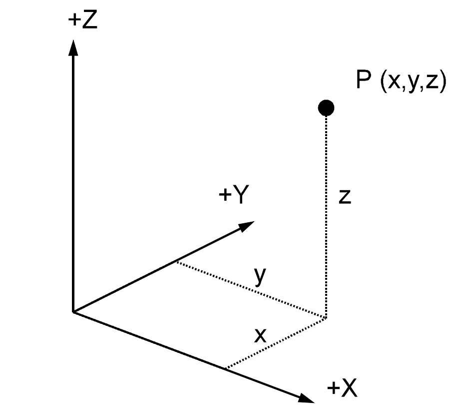
2.8.7 Display coordinate system

When 3D data is created and stored, the name of the coordinate system active at the time of creation is stored with the point data as the *display coordinate system*.

2.8.8 Coordinate types

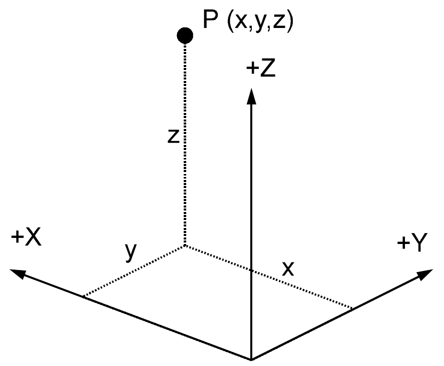
πr²
Maths for Users s. 5, p.55

It is not always convenient to view data using the conventional right-handed rectangular (Cartesian) coordinates defined by the base system. ***Axyz*** permits the user to alter the coordinate type to one of the following:



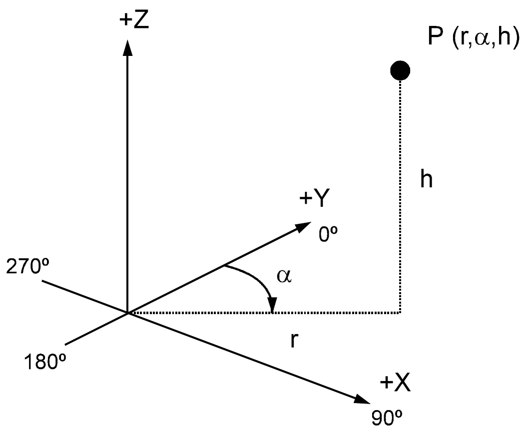
Right-handed Cartesian (rectangular)

AXREC-R.WMF



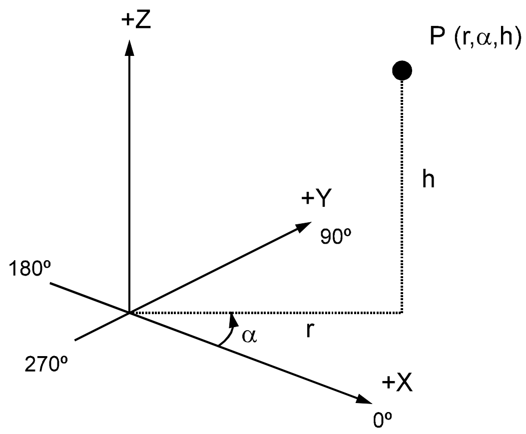
Left-handed Cartesian (rectangular)

AXREC-L.WMF



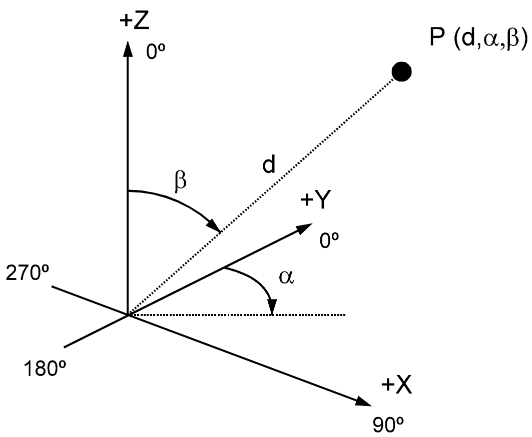
Cylindrical clockwise

AXCYL-C.WMF



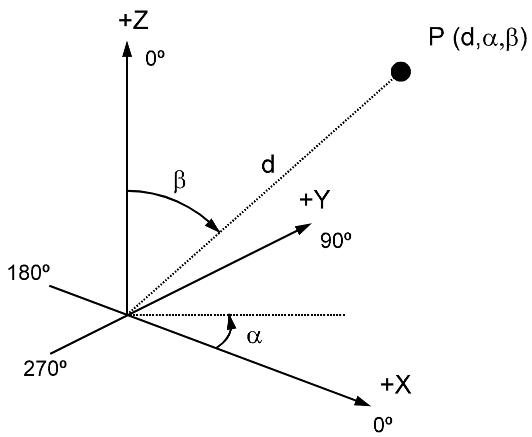
Cylindrical counter clockwise

AXCYL-A.WMF



Spherical clockwise

AXSPH-C.WMF



Spherical counter clockwise

AXSPH-A.WMF

A change of coordinate values is only applied on output and display. Internally coordinates remain unchanged.

A change of coordinate type can be combined with any transformation of coordinates into another coordinate system.

2.8.9 Instrument coordinates

Instrument coordinates are provided by the Laser tracking module to show rectangular coordinates of points measured from stations which are not yet linked into the measurement network (oriented). Unlike other coordinate systems which can be used to view any measured data, instrument coordinates only apply to points measured from a single station.

In effect instrument coordinates offer another way of viewing the measurements made at that station. A tracker measures angles and distances which are effectively a set of spherical coordinates. These are easily converted to right-handed rectangular values in a local system defined by the instrument.

These coordinates do not exist in a named coordinate system and are not stored. However the corresponding measurements are stored.

2.8.10 Summary of types of coordinate system

The origin and axes of any standard shape can be directly used as a coordinate system. The coordinate system type in this case is the shape type.

Coordinate systems can also be directly created by the user. See "Creating alternative coordinate systems" on page 61.The names assigned to the types indicate how the systems were created. Currently the following can exist:

Type	Description
Base	This is the first system created by a measurement network and the one used internally to store data. It is generated automatically by the Orientation Module.
Alignment	A system created by aligning axes to points and planes defined by the object.
Bestfit	A system defined by the coordinates of reference points and created by a best-fit transformation onto these points.
Scale	A system created by re-scaling an existing system.
Rotation	A system created by rotating an existing system.
Translation	A system created by translating (shifting) an existing system.

2.9 Organizing, naming and identifying data

2.9.1 Introduction

Everything in ***Axyz*** requires a unique identifier or name. A measurement connects a named station to a named target point, a transformation matches object points to reference points by having the same name in each set and so on.

The structures that are possible such as files, workpieces, points and offset targets are reflected in their names. This section explains what conventions and restrictions are in force when applying names to these structures.

2.9.2 Axyz files and file names

File names follow the Windows 95 convention, i.e. up to 256 alpha-numeric characters which can optionally include a final dot followed by an "extension". Typically users will be aware of the following files.

Job files (*.axyz)

Each job file is a complete database of information about a job and contains diverse types of data. By default, job file names have the format *.axyz, e.g.

CAR_BODY.axyz
An example of a job which measures parts of a car body

Files can be stored in any folder created by the user but are otherwise stored in a default folder called JOBS which is automatically created when

Axyz is installed. This is a sub-folder of the default folder used to store ***Axyz*** data and scripts, i.e.

C:\Axyzdata\Jobs

Master database (Axyz.axyz)

The master database is the default job file used to create a new job. It is named:

AXYZ.axyz

The master database is by default located in a sub-folder within the ***Axyz*** programs folder, i.e.

C:\Program files\Leica\Axyz\Masterdb

The ***Axyz*** master database and all job files are databases created using Microsoft ACCESS. Typically ACCESS files have the default extension "mdb" (meaning Microsoft Database) but this is not a requirement and ***Axyz*** uses the extension "Axyz".

ACCESS can read files which it has created but these may be locked by a password to prevent unauthorized modifications. ***Axyz*** files have been protected in this way.

Tracker database (TRKnnnnn.mdb)

Laser trackers require extensive calibration data. All calibrations are recorded so that there is a complete history relating to a particular instrument. For every laser tracker with a serial number in the format "nnnnn", there exists a tracker database of the form:

TRKnnnnn.mdb

These files are stored in a sub-folder within the ***Axyz*** programs folder, i.e.

C:\Program Files\Leica\Axyz\Tracker

The tracker database is a standard Microsoft ACCESS database.

Axyz configuration files (.acg)*

These files define the rights of the current user to access commands and modify data. They can be stored in any folder specified by the user.

Logfiles (.log)*

These are created when the user logs the activities during a measurement session to a file, e.g.

DEFAULT.LOG
The default name of the log file

CAR_BODY.LOG
An example of a log created whilst measuring a car body

Scripts (.exe, *.vbp)*

Scripts are Visual Basic programs which users can create and employ to tailor the operation of ***Axyz*** for their own specific requirements. See "Taking control of *Axyz*" on page 75.

Standard data file extensions

Users will find the following types of data file in use by ***Axyz***:

*.axyz	***Axyz*** job file
*. log	***Axyz*** log file
*.xyz	An ASCII text file created by VSTARS (video system)
*.dat	ASCII data files created by ManCAT and ECDS systems

This list does not include other file types created by external systems and which ***Axyz*** can import and export.

Users are recommended to make use of standard file extensions such as *.axyz, *.log but are not forced to do so.

Import-Export Descriptions (.ied)*

When data is imported into or exported from an ***Axyz*** job file, a template is used to identify which components of the individual records are to be exchanged. For example, an export template for measured 3D point data might define the output of point name, X, Y, Z values only, although the individual point records contain much more data than that.

Templates apply to specific data types and a single IED file contains both import and export templates.

These files are stored in a sub-folder within the ***Axyz*** programs folder, i.e.

C:\Program Files\Leica\Axyz\Ied

Report templates (.rpt)*

Data can be selected from the job file and presented in a formatted layout suitable for printing and inclusion in professional presentations and high-quality reports.

The format and layout is defined in a special report form created with a 3rd. party product, Crystal Reports ™.

These files are stored in a sub-folder within the ***Axyz*** programs folder, i.e.

C:\Program Files\Leica\Axyz\RepForms

2.9.3 General format for names and identifiers

Two types of names or identifiers are used within a job:
- Purely numeric identifiers
- Alpha-numeric identifiers

An identifier is a descriptive label defined by a user to assist in uniquely identifying some feature of the job, such as the name of a point or workpiece. Identifiers can be manipulated and used by the software in various processing routines.

The ***Axyz*** software often permits the user to enter some purely descriptive comment, such as the name of the operator or a reminder of an event which may affect results. This type of input is purely intended for the user's own purposes and is irrelevant to the software. It is not further discussed here.

Also within ***Axyz*** many other descriptive labels are in use but these are pre-set and not definable by the user. Examples are the names in a list of types of theodolite or the generic term "workpiece".

Alpha-numeric identifiers

These are used to name:

- Reference data sets
- Workpieces
- Object and reference points
- Shapes
- Coordinate systems

These identifiers have a maximum of 16 alpha-numeric characters.

Permitted characters are:

- numerals 0 - 9
- letters a - z
- underscore character "_"

Numeric identifiers

ManCAT users with Wild theodolites can do much of their work from the theodolite keyboard. Unfortunately, older theodolite keyboards only permit the input of numeric values, although alphabetic characters can, within limits, be displayed.

Much of the effort in dealing with named elements revolves around the network components, stations and scale bars, as well as ancillary devices such as hidden point bars. Routine data collection with alpha-numeric identifiers is much less of a problem when the identifier has an alpha component and an incrementing numeric component, the latter being accessible from the keyboard.

For reasons of backward compatibility therefore, purely numeric identifiers have been preserved for the following elements. Restrictions on the numeric range, and choice within the range, are indicated in brackets. Numeric identifiers apply to:

- theodolite stations (1-99, random choice)
- Total Station stations(1-99, random choice)
- laser tracking stations(1-99, random choice)
- video camera stations(1-99, random choice)

- scale bars
  - scale bar identifier (any positive integer)
  - locations of scale bar (any positive integer)
  - target number on scale bar (starting with 1, up to the number specified)
- hidden point devices
  - device identifier (any positive integer)
  - device point (offset target) number (starting with 1, up to the number specified)

2.9.4 Using and naming workpieces, points and shapes

The following sections clarify the options when naming workpieces, object points and shapes. Note that division into workpieces does not restrict the use of points and shapes to a particular workpiece. For example, the user can fit shapes to points taken from several workpieces.

General usage

Internally, ***Axyz*** points and shapes are identified by specifying the name of the workpiece to which they were assigned plus the name of the point or shape used within the workpiece. Each element is therefore actually referenced by one of the combinations:

- Point identifier: workpiece name/ point name
- Shape identifier: workpiece name/ shape name

Each component of the identifier can have up to16 characters as explained in “Alpha-numeric identifiers” on page 40. A slash separates the components of the name.

To allow for the possibility that a point might be measured by a hidden point device, the identifier for points is extended to the form:

workpiece name / point name : device point number

where the device point number is the positive number of the measured offset target on the hidden point device. The number zero is reserved for the hidden point itself. In the database all directly measured object points are assigned device number zero to ensure compatibility. Device point numbers cannot be assigned by users. In most cases users can ignore this extended form of the identifier.

Default workpiece and active workpiece

All new measurement jobs are provided with a data structure which includes one pre-defined workpiece named *default*. In order to ensure that the database maintains its structure, this name cannot be changed or removed.

However, operators are not obliged to use the default workpiece and can define others. Alternatively, if they do not wish to make use of workpieces they can ignore this feature and all their point and shape data will be stored in the default workpiece.

The workpiece currently in use is the *active workpiece* and its name appears in the status bar of the main ***Axyz*** screen. Point and shape data are automatically prefixed by the currently active workpiece name unless another workpiece name is explicitly used.

Naming workpieces

The following example shows how users might divide their measuring task into workpieces.

Astra Spacecraft AB uses ***Axyz*** for regular checks on the nose cone and tail fin of their ASX executive space shuttle. Nose cones and tail fins are examples of measured objects. Astra can organize their work in different ways, for example:

- Job 1 relates to successive measurements of the same nose cone as it passes through a series of structural tests.
  Workpieces are: NOSE_01_99, NOSE_02_99, NOSE_03_99, etc
- Job 2 relates to measurements of tail fins for different shuttles.
  Workpieces are: FIN_TYPE_A, FIN_TYPE_B, FIN_TYPE_C, etc
- Job 3 is for one particular shuttle and contains information for one nose cone and one tail fin.
  Workpieces are: NOSE, FIN
- Job 4 is the measurement of a single tail fin but it is convenient to divide it into two components, the left and right side.
  Workpieces are: FIN_LEFT, FIN_RIGHT

Using and overriding the active workpiece name

Most of the time, when users are asked for point and shape names it is not necessary to specify the full identifier. As explained, during a measurement session there is always a currently active workpiece which may be altered at any time. If a workpiece name is not explicitly given, ***Axyz*** will automatically assume that the identifying prefix is the currently active workpiece name.

Example:

Active workpiece:	NOSE_CONE
Point name typed in by user:	HOLE_29
Name assumed by system:	NOSE_CONE / HOLE_29

Alternatively the user can override the currently defined workpiece name if this is more convenient.

Example:

Active workpiece:	NOSE_CONE
Point name typed in by user:	REAR_PANEL / HOLE_29
Name assumed by system:	REAR_PANEL / HOLE_29

Users who never want more than one workpiece in a job can ignore workpiece identifiers and concentrate purely on names for points and shapes. The workpiece named "default", which is automatically provided when the job is created, is always the active workpiece and this name will always be automatically prefixed to point and shape identifiers.

Example:

Active workpiece:	default
Point name typed in by user:	HOLE_29
Name assumed by system:	default / HOLE_29

When choosing data for some operation such as a shape fit the user is not restricted to items in the active workpiece but can select data from any workpiece provided it is valid for the operation. However any derived data will be stored in the active workpiece unless the user overrides this.

Example:

Active workpiece:	NOSE_CONE
Fit CIRCLE1 to points in:	REAR_PANEL
Circle stored as:	NOSE_CONE / CIRCLE1

Unique naming of points and shapes

Since ***Axyz*** always combines a workpiece name with a point name or shape name, the same point and shape names can be re-used in different workpieces without causing confusion.

Example:

workpiece name:	NOSE_CONE
point name:	HOLE_29
The full name is:	NOSE_CONE / HOLE_29

If the same job includes a workpiece identified, for example, as REAR_PANEL, then this is also permitted a target with the name HOLE_29.

Now the full target name is: REAR_PANEL / HOLE_29

However, for reasons of compatibility with older measuring systems such as ManCAT, shapes and points can have the same names within the same workpiece.

Example:

REAR_PANEL/P1	meaning "point 1" on the rear panel
REAR_PANEL/P1	meaning "plane 1" on the rear panel

Since shape and point data are stored in separate locations within the job file this feature does not create internal problems but ***Axyz*** may occasionally have to ask users to distinguish between a named shape or named point in order to confirm that the right piece of information is being accessed.

Incrementing names

Every measured point must be identified with a name but ***Axyz*** can automate the procedure of specifying a name by appending a numeric increment to the name last used at a particular measuring station.

Example:
At station 33, point LEFT_SIDE/DOOR22 is measured.
Axyz then assumes that the next point to be measured from station 33 is LEFT_SIDE/DOOR23.

This sequence will continue at station 33 until the operator changes the name. A complete change of name is only possible at the controlling computer but theodolites and Total Stations with keyboards (Wild T series instruments but not Kern E2) permit the operator to alter the incrementing numeric section at the instrument. (Alphabetic characters cannot be directly entered on these keyboards, hence the restriction.)

Auto incrementing only works if there is space for the numerical increment, i.e. the first name in a sequence must have less than 16 characters.

2.9.5 Identifying coordinate systems

Coordinate systems and shapes have common parameters and are stored in the same part of the database. In many ways they are treated in the same way. Coordinate systems have the same naming convention as object points and shapes, i.e.

workpiece name / coordinate system name

Each component of the full name follows the standard format of 10 alpha-numeric characters.

The workpiece name is the name of the workpiece active when the coordinate system was created. The base coordinate system is stored in the "default" workpiece.

Coordinate systems and shapes are separately displayed by the Data Manager. Shapes appear under the relevant workpiece but all coordinate systems are displayed together, with their full name.

2.9.6 Identifying reference points

Reference data (design or blueprint coordinates) are imported from external files produced, for example, by a CAD system. They are organized under *reference IDs*, also called *reference files*. Each reference file contains one or more *reference workpieces* and the workpieces each contain a table of *reference points.*

Compared with object points, there is an additional level of identification and a reference point therefore has an identifier of the form:

reference ID / reference workpiece name / reference point name

2.9.7 Identifying measurement sets

Measurement sets have standard 16 character alpha-numeric IDs and are fully identified using the standard convention:

workpiece ID / set ID

Individual measurements in the set do not have individual identifiers.

Measurement sets for stationary points

Measurement sets for single stationary points have a corresponding single averaged measurement stored as a normal direct measurement. For oriented stations a corresponding standard 3D point will exist.

The averaged point position will have a point name which is the same as the set ID.

2.9.8 Identifying coordinate sets

Coordinate sets have standard 16 character alpha-numeric IDs and are fully identified using the standard convention:

workpiece ID / set ID

Individual points in the set do not have individual identifiers.

Coordinate sets are treated as independent data and are not linked to any measurement set from which they may be derived.

2.9.9 Identifying measured scale bar targets

Scale bars can be moved around the workplace and the same scale bar can therefore be used many times in a single network to improve the determination of scale. For additional details see "Scale bars" on page 115.

The scale is actually defined by the distances between pairs of targets on the bar and so the target coordinates are critical values. The corresponding 3D points need to be uniquely identified and for this 3 components are needed to fully identify a scale bar target's location:

scale bar ID / current location of bar / ID number of target measured

The identifiers have the following format:

- The scale bar identifier is numeric and can be any positive integer.
- The location identifier is numeric and can be any positive integer.
- The target number on the bar is numeric. Targets are numbered sequentially starting at 1 and increasing.

Note
Target numbers on scale bars cannot be assigned by the user.

Suppose you own some carbon fibre and Invar bars, each supporting two targets. You might name them as follows:

100, 101, 102 ..	Carbon fibre bars use 100s as identifiers
200, 201, 202 ..	Invar bars use 200s as identifiers

You have no choice on the naming of the two targets. These are targets 1 and 2.

You now use Invar bar 201 at 3 different locations which you decide to name as follows:

10, 11	A location in the 10s is on the left hand side of the object
20	A location in the 20s is on the right hand side of the object

The following 6 target locations will therefore be measured.
201 / 10 / 1 and 201 / 10 / 2
201 / 11 / 1 and 201 / 11 / 2
201 / 20 / 1 and 201 / 20 / 2

2.9.10 Identifying hidden points

Hidden point devices are fully discussed under "Hidden point devices" on page 109.

A hidden point device is defined with its own set of offset targets (device points). The identifiers have the following format:

- The device identifier is numeric and can be any positive integer.
- The offset target number is numeric. Targets are numbered sequentially starting at 1 and increasing.

Notes
Device point number zero is assigned to the hidden point and to every other type of object point in order to maintain compatibility in the database.

Device point numbers cannot be assigned by the user.

The purpose of the device is to locate a target point which cannot be directly measured. This "hidden" point is named as it would be if it could be directly observed, i.e. using 16 alpha-numeric characters.

Prior to use the operator defines a hidden point device and the dimensions of its offset targets (device points).

Suppose the user has 2 hidden point rods, one with 3 targets, one with 4 targets named, for example, as follows:
- Device number 300 is the one with 3 targets.
- Device number 400 is the one with 4 targets.

To use a hidden point rod, where the targets and tip lie in a line, only 2 targets are measured. The further use of names then depends on whether the device is used on line or off line.

Hidden point devices used on line

The following is an example of naming when using a hidden point rod (linear device) on line.

Current workpiece (where hidden point is stored), e.g. LEFT-WING
Decide on the name for the hidden point, e.g. RIB-23
Choose which device to use, e.g. 300
Measure 2 offset targets (device points), e.g. 2 and 3

The measurements will then be stored under the names:
LEFT-WING / RIB-23 : 2
LEFT-WING / RIB-23 : 3

Each measurement will also record the device identifier, 300 in this case.

When enough measurements are available to generate coordinates for the device points, the hidden point itself will be computed and stored in the object points as:
LEFT-WING / RIB-23 : 0
The device identifier will again be recorded.

Hidden points computed off line

When using a hidden point device off line each offset target (device point) is recorded as a normal object point and permitted a full 16 alpha-numeric character name. After measurement is complete the user calculates the hidden point by indicating which device was used and which device point numbers correspond to the measured targets.

For example, using device number 300 the operators measure 2 targets named as follows:

Current workpiece, e.g.	LEFT-WING
First target is the device point 2, e.g.	RIB-23-302
Second target is the device point 3, e.g.	RIB-23-303

In this example the operators have deliberately incorporated the device identifier and offset target number into the names, but this is not a requirement.

In the job file these targets are recorded as:
LEFT-WING / RIB-23-302 : 0
LEFT-WING / RIB-23-303 : 0

So far the system can only recognize these as normal measured points.

The hidden point can then be computed using an analysis function specifically for that purpose which requires the actions:

Check the current workpiece name, e.g.	LEFT-WING
Name the hidden point, e.g.	RIB-23
Identify the device, i.e.	300
Link the device number to the target name:	2 > RIB-23-302
	3 > RIB-23-303

The hidden point will then be calculated and stored as:
LEFT-WING / RIB-23 : 0 of type "hidden"
The types of the offset targets will change form "normal" to "calculated"

2.9.11 Renaming data

Names and identifiers can be changed. Altering the names and locations of job files is done using standard Windows functions. Most other elements within a job can be renamed with ***Axyz***, but changes must be done with care.

Renaming comes within the scope of *data integrity* which aims to ensure that inconsistencies do not arise. Restrictions are in force. For example station numbers cannot be changed and the name of the default workpiece must remain "default". This is part of the security concept. See "Security features" on page 70.

3. Core features and options

3.1 In brief: The Axyz workplace

Core Data Module (CDM) Main menu and toolbar

SYST CDM menu+toolbar.BMP

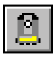
When the ***Axyz*** package is operating you are involved in a *measurement session*. This is time which you spend on a particular measurement task but it is not necessary to complete a job within a single session. You can initiate jobs, store the data in a job file and return to the job at a later stage. However ***Axyz*** can only deal with one job at a time and if you wish to deal with another job you have to close the current one.

You may therefore be involved in several jobs at once, moving from site to site and possibly moving the instruments as well. It is your responsibility to ensure that the instrument connections and station assignments for each job are valid. Assume, for example, that every job uses the same two theodolites connected in the same way to the interface board. On an automatic scan of the connections, ***Axyz*** will always assume you are returning to the same geometric configuration whenever an existing job is opened. This may of course be true if you have a fixed measuring site with theodolites and Total Stations mounted semipermenantly on stable pillars. However it is more often the case that instruments will be moved around and in this case you will need to define new instrument stations when returning to existing jobs.

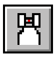
Each new job is empty of measurements and point data but is provided with default values for a range of settings such as units, axis labels and threshold warning values. Any scale bars and hidden point devices can also be copied into the new job file. The source of this information is the master job file or an existing job file.

DM

You can further modify these settings and definitions via the "Settings" menu and Data Manager (DM).



MTM/STM



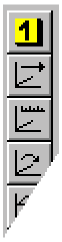
LTM

etc

To create measurements you access your instrument module using the CDM "Tools" menu or appropriate toolbar button. The operational details will depend on the chosen module and the corresponding module descriptions provide an overview. You will be able to:

- Operate one or more instruments simultaneously
- Define measuring stations and move instruments between them
- Work on different parts of your object at the same time
- Modify parameters relevant to the type of instrument

Measurements can be made before instrument stations are oriented together into a common network but, once oriented, 3D point data can be generated. You can display 3D point coordinates on line, in different measurement windows. Up to 10 measurement windows can be simultaneously opened, each of which can make use of different coordinate systems and different instruments. You could, for example, monitor on line two groups of instruments each measuring a different side of an object or display the coordinates of the same point in different coordinate systems.



Once point data is available you can break off measurement to analyse data using the "Analysis" menu or the palette buttons and organize data with the Integrated Data Manager.

At any stage you will have:

- An active workpiece to which new measurements and point coordinates will be assigned if an alternative workpiece is not specified
- An active coordinate system which is the default for coordinate display
- A coordinate type which is also the default for coordinate display

During a measurement session you can change the default settings, define new workpieces and establish new stations. Once enough measurements are available to orient the new station into the base coordinate system it can start generating on-line coordinates.

As your work progresses information is constantly recorded:

- The instrument module writes new measurements immediately into the job file
- Results of data analysis are sent immediately to the job file
- If specified, all actions taken during the measurement session are continuously logged.

3.2 Organizing jobs

Axyz is installed with a <JOBS> folder for storing job files, but any other folders can be created and used. This default folder can be found at:

C:\AXYZDATA\JOBS

Axyz is configured by the user to start up either with a new job or the most recently used job. Any other existing job can be selected with an “Open” command.

New jobs created automatically on startup do not require any definition by the user. They are simply copies of the master database which is effectively a template file containing default information.

It is also possible to use an existing job to provide alternative default information for a new job and so overwrite or add to the basic information in the master database. In this case the user must explicitly request a new job in order to be able to select which existing job should provide this information.

New jobs are provisionally given the name "Untitled" and the user will be prompted to save any untitled job where measurements or changes have been made.

3.2.1 Master database

As part of the ***Axyz*** installation a standard master database is provided. This is named Axyz.axyz and located at :

C:\Program Files\Leica\Axyz\Masterdb

This master database provides a basic template for a new job. It contains the default workpiece named DEFAULT and default parameters for a number of the measurement settings. For more details on these see "Tailoring the measurement session with default settings" on page 55.

The master database can also contain definitions for the user’s scale bars, hidden point devices and reflectors as well as common reference data. In order to create this data, and modify the default measurement settings if wished, you will need to change the standard master database.

The master database is a job file like any other but it has been "locked" to prevent direct editing. However you can create a different master database by first creating a new job with the existing master. You can then alter default settings, define scale bars, hidden point devices and reflectors, and import any standard reference information you require.

Once a job has been tailored in this way it may be stored and then defined as the new master database. Once a file becomes the master database it cannot be modified directly in ***Axyz*** but can again be used as the template for creating further potential master databases.

3.2.2 Using existing jobs to modify parameters of a new job

The master database may still not meet all your needs, particularly if you want access to a range of alternative settings and definitions. It is therefore possible to import parameters and orientations from an existing job.

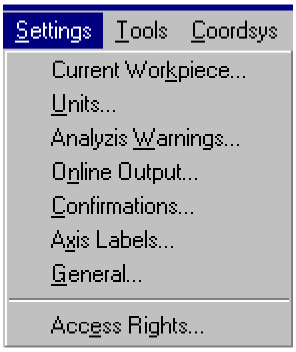
To provide a choice of modifying templates it is therefore only necessary to create dummy new jobs with the required settings and definitions. These can then be used to modify any other new jobs which require the corresponding defaults.

Modifying parameters in this way is only possible if the new job is created by explicitly choosing "New" from the CDM's "File" menu, rather than automatically creating a new job on start-up or by clicking the CDM's "New job" toolbar button.

3.2.3 Fully self-contained files

Every job file is completely self-contained. Even if the same accessories and reference data are used for every job they must be separately defined in each job file.

3.3 Tailoring the measurement session with default settings



Syst - CDM Settings menu.bmp

If the software configuration defined by the master database is not exactly what you want for the current measurement session, you can vary a wide range of parameters.

This section outlines some of these.

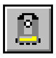
- Units
  Choose the length, angle and temperature units which will be used to display values.
  (If necessary you can add to the list of available units by defining your own units using the DM.)

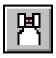
- Warning values
  Set threshold values for analysis functions which will trigger a warnings, for example:
  - Elements not parallel within a certain angle
  - Large offset between nominally intersecting elements

- Axis (coordinate) labels
  If it is helpful to use axis (coordinate) labels other than "X", "Y", "Z" then do this here. Different labels can be defined for all types of coordinates.

- General
  Diverse settings, for example:
  - Show shapes with circular parameters in terms of radius or diameter
  - Display directional parameters in terms of unit vectors or rotation angles

3.4 Measuring data


MTM/STM


LTM

This is the responsibility of the individual instrument module which the user has selected. These modules calculate the measured 3D data and insert it, together with the associated measurements, into the job file (database). Here it can be accessed for further analysis.

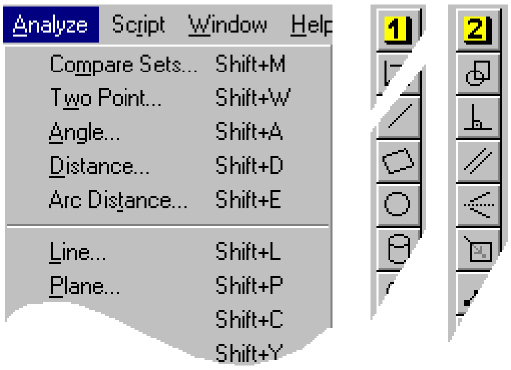
See the documentation for the instrument module installed on your system.

- ***Axyz*** reference manual for the theodolite modules MTM,STM
- ***Axyz*** reference manual for the laser tracking module LTM

In the current document, see also:

- "Working with theodolites and Total Stations" on page 78.
- "Working with laser trackers" on page 124.

3.5 Analysing and constructing data



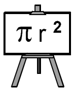
Syst - CDM Analysis menu + palettes.bmp

Axyz has a number of built-in functions for analysing and creating data. There are functions for creating shapes from individual point data of any type, extracting dimensional information between data elements and comparing point coordinates. In summary you can:

- Create one of 7 standard shapes + vectors derived from shapes
- Calculate intersections between lines and shape surfaces
- Construct lines and planes parallel to existing lines, planes and circles
- Construct lines perpendicular to surfaces and other lines
- Calculate bisecting points, lines and planes
- Calculate vector data between two points
- Calculate distances from points to lines and surfaces
- Calculate angles between lines and vectors
- Calculate arc distance

- Compare sets of points with nominally equivalent coordinates
- Compute point locations by the single point solution
- Compute hidden points off line
- Generate evenly spaced points between two end points

3.5.1 Shape fitting



Maths for Users

Error! Not a valid link.

Shapes are created by fitting them to selected points. The standard shapes which can be generated and the parameters used to define them have been introduced in "Shapes" on page 28.

Vectors derived from the standard shapes can also be created.

Fitting shapes to other shape origins

Once shapes have been created, their origins may be used as additional points to which further shapes can be fitted. For example, suppose 4 circles have been computed from measured data and their centres must also lie on a circle. By using the names of the existing circles as the list of points to be fitted, the new circle can be computed. It is a general feature that if you use a shape name in a list of points, ***Axyz*** will assume you mean the shape origin.

Shapes can also be created using a number of the shape intersection functions, see "Shape intersections" on page 57.

3.5.2 Shape intersections

Intersecting elements can be calculated for the following combinations:

- Shape axis - shape axis (line - line)
  (z axes of any shape or coordinate system)
- Shape axis - surface (line - surface)
  (z axis of any shape with line, plane, circle, sphere, cylinder, cone, paraboloid. Results are points)
- Surface - surface
  (Plane intersected with line, plane, circle, sphere, cylinder)

3.5.3 Perpendicular lines, parallel elements, bisecting elements

Bisectors

Bisecting elements are centre points, centre lines or centre planes and can be calculated for the following combinations:

- Point - point
- Point - shape axis (line)
  (z axis of any standard shape or coordinate system, result is a point)
- Point - plane
  (result is a point)
- Shape axis - shape axis (line - line)
  (z axes of any standard shape or coordinate system, result is a line)
- Shape axis - plane (line - plane)
  (z axis of any standard shape or coordinate system, result is a line)
- Plane - plane
  (result is a plane)

Some of these calculations generate points. See also "Creating additional object points" on page 60.

Perpendiculars

The calculations between the following combinations result in a line and the length of the perpendicular between the elements.

- Point - shape axis (line)
  (Point to z axis of any standard shape or coordinate system)
- Shape axis - Shape axis (Line - line)
  (z axes of any standard shape or coordinate system)
- Point - shape surface
  (From point to line, plane, sphere, cylinder, cone, paraboloid, but **not** circle)

Parallels

These calculations create one of the following:

- A line through a specified point which is parallel to the z axis of any shape or coordinate system
- A plane through a specified point which is parallel to another plane or circle

3.5.4 Extracting angles and distances between points and vectors

Two point analysis

A two point analysis provides full information on the vector between two specified points. This involves:

- The distance between the points (also given by the "Distance" function for point to point)
- The components of the unit vector between the points

Distances

Computed distances are calculated along perpendicular connections between the following elements.

- Point - Point
- Point - shape axis
  (z axis of any standard shape or coordinate system)
- Point - shape surface
  (plane, sphere, cylinder, cone, paraboloid, **not** circle)
- Shape axis - shape axis
  (z axes of any standard shape or coordinate system)
- Plane - plane
- Shape axis - plane
  (z axis of any standard shape or coordinate system)

Angles

The angle subtended by any two vectors can be computed. The vectors may be chosen in 3 ways:

- By specifying 2 points
- By selecting a shape axis or coordinate system axis (z axis implied)
- By selecting a vector

Arc distances

This function calculates the distance along a circular arc connecting 2 points. The 2 points and the corresponding circle radius must be input. The function supplies the following additional information:

- Chord length (distance between points)
- Subtended angle

3.5.5 Comparing data sets

There are several common objectives for comparing data sets including:

- Conformance of an object with design or another similar object
- Changes to an object's shape over time
- Fitting of one component to another at matching contact points

Axyz offers a function to compare corresponding sets of points. Typically this compares measured values with design values as follows. It takes a *reference file* of design data and makes a simple comparison between the coordinates of a selected set of points in the job file with the coordinates of the same points in the reference file.

This comparison is only meaningful if the measured data is located in the same coordinate system as the design data. Both coordinate systems should therefore be the same. If there is an exact match the points will have identical coordinate values in each and therefore zero differences.

To create a suitable object coordinate system for the selected points before the comparison is made, you can use one of the techniques outlined in "Creating alternative coordinate systems" on page 61.

Although it is common to compare measured object points with design values, it is also possible to compare object points with other object points and reference points with other reference points.

3.5.6 Creating additional object points

A group of analysis functions enable you to do the following:

- Re-calculate the single point solution for a target point using the measurements to that point. You can examine the effect on target coordinates of using a sub-set of the measurements.
- Calculate hidden points off line by *mapping* selected target points onto a hidden point device. This assumes the identified points were offset device points.
- Creating one or more evenly spaced points between two end points. The creation of a single point is equivalent to calculating the bisector between two points.

3.5.7 Analysis warnings

It is convenient to define threshold warning values for certain geometrical conditions. These can be used by some of the analysis routines summarized in this section in order to warn the user that an assumption may be invalid. For example, when lines or axes are intersected there is an underlying assumption that they at, or very near, the same point. If the offset between the lines exceeds the tolerance level set by the user, a warning is issued. Analysis warnings can be set for:

- Lack of intersection between lines
- Elements which are close to parallel
- Mismatch of coordinates after a comparison test

Note
Warning values may also be used by instrument modules. For example, in the Multi-Theodolite Module (MTM) you can set a warning for a small intersection angle. These additional warnings are separately defined in the relevant module.

3.6 Creating alternative coordinate systems

Once a base system has been established and some point data exists, other coordinate systems can be defined. Coordinates can then be *transformed* from the base system into an alternative coordinate system so that data can be viewed with respect to the new origin and set of axes.

Converting to a new coordinate system requires 6 or 7 parameters for the transformation

- translations or shifts which move the origin from the base system to the new system
- rotations which rotate the base axes parallel to the new axes
- scale factor which re-scales all coordinate values

One method of creating a new coordinate system is to create a shape such as a 3D circle. The parameters of the shape provide the necessary shift and rotational parameters and the scale factor is taken to be 1.

Transformation parameters can also be directly computed by one of several methods (see below). These follow the format set by shape parameters. These transformations, once computed, are named in the same way as shapes and stored together with shapes.

Transformation into a different coordinate system is therefore implemented by selecting the appropriate shape or transformation from the list of shapes.

Transformation of coordinates can be combined with any change of coordinate type.

The following methods are available for creating transformations.

3.6.1 Manual transformation

Axyz provides functions to separately:

- Re-scale current coordinates
- Translate (shift along each axis) the current origin
- Rotate current axes

3.6.2 Alignment of axes

The new reference axes can be aligned to a particular set of points. For example:

- Point A should be the origin (0,0,0)
- The X axis should pass through point B
- The XY plane should pass through point C

3.6.3 Transformation onto reference coordinates

A new coordinate system can be defined by transforming the coordinates of at least 3 measured points onto their design values.

Axyz uses design values located in a *reference file*. The set of points selected for calculating the transformation must contain at least 3 points which form a triangle. The transformation then uses a best-fitting, least squares technique to calculate the necessary shifts, rotations and scale changes.

There are options to hold the transformation parameters fixed at values defined by the user. A typical option, for example, is to request no change of scale by fixing the scale factor = 1.

3.6.4 Use of computed shapes

The new coordinate system can be the local coordinate system of any computed shape.

3.7 Reference and control points

This section summarizes the different attributes of reference and control points, how they are used and their different effects.

Reference points and files provide information about the design of an object. Control points very commonly also relate to the object's design but might occasionally define another set of fixed points such as a set of permanent targets in a dedicated measurement area.

3.7.1 Reference points

Reference points exist within their own coordinate system, which may not be the same as the base coordinate system in which all measured 3D data are stored.

Reference points are imported without any modification into the job file, except to convert to internal units of metres and radians. They are not transformed in any way.

Reference data can then be used together with measured data to locate the reference coordinate system with respect to the measured points by *transformation*. Once the reference coordinate system has been established in this way, other reference points can be used to check object points against design, also known as *comparison* or *inspection*. Alternatively you can then *build* object points to design.

3.7.2 Control points

If used, control points directly influence the shape of the measurement network and define the base coordinate system. They are stored in the object area.

Since control points directly define the base system, their values on importing are directly inserted into the database without change.

3.8 Logging actions during a measurement session

During a measurement session users can log the results of analysis and transformation functions. It is also possible to record any commands issued from the following menus:

- Settings
- Coordsys
- Analyse
- Script

An example of recording a command is:
Cmd> Coordsys: Set current coordinate system: DEFAULT/REARPLANE

3 different levels of detail can be logged:

- Full information
- Reduced information
- No information

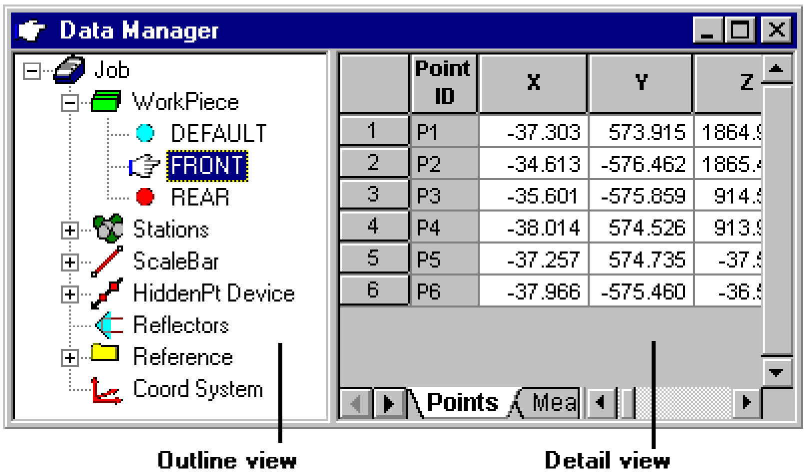
The information can be directed either to a log file or an online printer or both. Users might, for instance, log minimal detail to the printer to have a ready overview of previous actions and send full information to the log file in order to review any critical periods.

If a job takes several measurement sessions, logged data can be either appended to the log file or existing data can be overwritten.

The log file is an ASCII (plain text) file. The user can define the layout of the logged information using template files, although this layout does not have the sophistication offered by the Data Manager for report generation. Logging is not seen as a substitute for report generation.

A printed log file will look the same as if the log had been directed online to the printer.

3.9 The Data Manager (DM)



SYST - DM overview.BMP

The Data Manager (DM) provides a structured overview of all data stored within the job file and combines this with detailed viewing, editing and reporting options. The DM window has two panes providing an *outline view* and a *detail view*. The outline view is similar to the expandable outline provided by the Windows "Explorer" and the detailed view is similar to a spreadsheet.

The DM permits the user to:

- Display numerical and descriptive details of selected items
- Edit parts of the displayed data
- Manually create new data

The DM is also a selection tool which allows users to specify data for:

- Mathematical analysis
- Presentation in a report
- Import and export to and from the database

Several DM windows may be open at once. You can, for example, use this option to view two different types of data on the screen.

3.9.1 Select ID - locating items in the database

Very frequently the user is asked to identify one or more items in the data base, for example to select a coordinate system or specify which points are to be used by a shape fit.

A tool called Select ID is available for this purpose. Select ID is actually a version of the DM which offers a restricted or "filtered" view of the data. The purpose is to present to the user only data relevant to the current choice. For example, when choosing a new active coordinate system, only shapes and coordinate systems will be offered as a choice. Clearly it makes no sense to offer, for example, a list of stations.

In addition, since the objective is to make a selection for further processing, the DM's editing functions are not active in Select ID.

Select ID is typically accessed via a button in a dialogue box but may also be available on the right mouse click in an input box.

3.9.2 Data exchange (Import/Export)

Axyz provides facilities for importing and exporting point and shape data in the following standard formats:

- Axyz
- Delimiter
- ECDS, PCMS, SPACE
- Fixed
- ISOMET-APP
- ManCAT
- V-STARS

Export concept

Axyz permits the user to export selected records from the job file to an external text file. Records are exported using an *export file type* or template which defines which fields from the selected records are to be written to the output file, together with their order and format. One internal record produces a single output line.

Only records of a single data type can be selected for export, such as 3D measured points or shape definitions. Templates can therefore only be used for a single data type. If records are selected and the incorrect template chosen, then a status message informs the user that zero records of the correct type are available for export.

Records must be selected for processing before the export function can be activated.

Axyz provides standard templates for exporting data but the export function itself allows the user to either define completely new templates or modify existing templates. A *wizard* is provided to assist in preparing these.

Import concept

Axyz permits the user to insert records into the database from an external text file. Records are imported using an *import file type* or template which defines which parts of the external record correspond to which fields of the internal record. One line of the external file is an external record and it creates a single internal record.

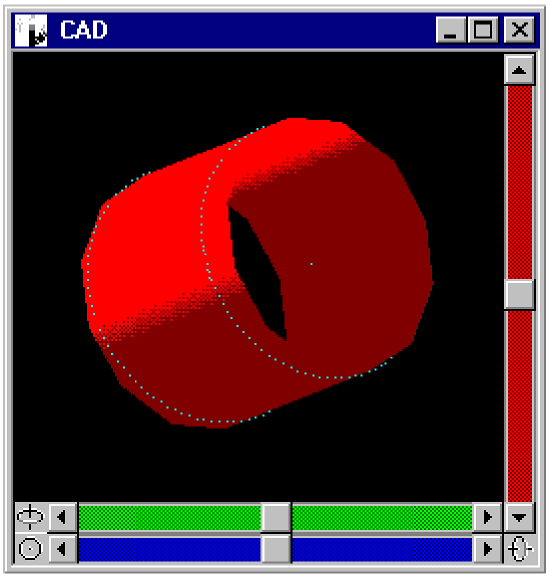
External files can only generate internal records of a single data type, such as 3D points with the classification "entered".

In order to identify individual fields in the external data records, ***Axyz*** permits the use of *delimiter* characters such as semi-colons or tabs which separate the fields. Alternatively the data can be input in *fixed width* columns. External files with this format have elements which line up vertically when printed.

If data is required for internal use but is missing from the external data, default values can be substituted. This feature can be used to replace external data fields by preferred default values. External data fields can also be conditionally altered, for example to convert an external value "-999" to the internal value "FIXED". Finally individual external records can be completely ignored.

Axyz provides standard templates for importing data but the import function itself allows the user to define new templates. A *wizard* is provided to assist in preparing these.

3.10 The View and CAD Graphics Modules



Syst - Graphical display.BMP

Unlike the Data Manager, the Graphics Modules are optional components and not a standard part of the Core Data Module.

In contrast to the Data Manager which offers a numerical view of the job data, ***Axyz*** View and ***Axyz*** CAD offer a pictorial representation via a graphics window. A single graphics window is possible in each module showing 2D and 3D orthographic views, with options to rotate, translate and zoom into the graphics.

It is not necessary to display all the data in the job file. Users can decide which data to display depending on *filter* criteria. Data which do not meet the selected criteria will not be displayed. For example, only data belonging to a particular workpiece need be shown. Other filter options are possible.

Like the Data Manager, the graphics modules allow you to select data items for detailed viewing and analysis, although data must be edited with the Data Manager.

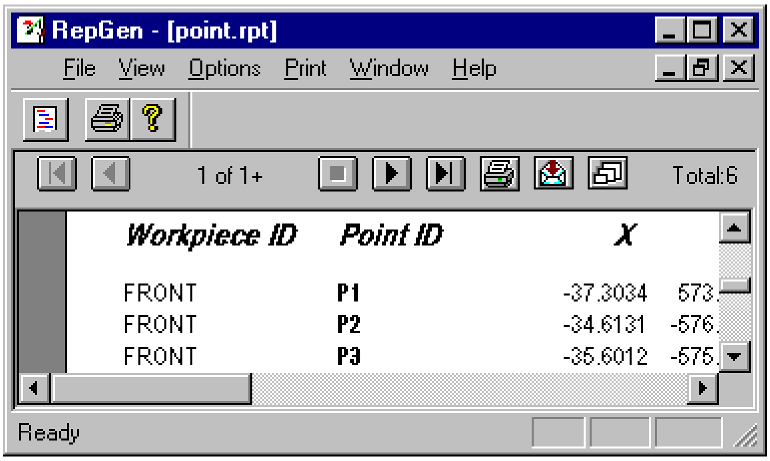
The graphical view can also present an immediate visual feedback of the results of on-line measurements. Although measured data is immediately entered into the database, the Data Manager cannot provide such an immediate and intuitive feedback.

Axyz CAD goes beyond the features of both ***Axyz*** View and the Data Manager by offering the possibility of importing and interacting with a

CAD model. CAD models, which are defined by points, curves and surfaces, can be imported in various file formats such as IGES, VDA-FS and DXF. Once imported, measured data can be compared against a CAD model in various ways. However, an imported CAD model does not become part of the ***Axyz*** database.

For full information see:
Axyz View/CAD - Graphics Modules Software Reference Manual

3.11 Report generation



Syst - Report.BMP

A report is a professionally formatted presentation of a selected set of data, for example a list of points making up a circle, together with their coordinates and standard errors. The quality of the presentation makes it suitable for printing and inclusion in reports.

The sequence of operations in creating a report is as follows. Using the DM a number of records of one or more *data types* are selected, for example some *point* records and some *shape* records. These are placed in an intermediate database. One or more *templates* can then be applied to this data. A template specifies which parts or *fields* in a record are to be used in the final report. It also defines the layout of a report, such as which standard header information to include, where columns are located and the precision to which numerical data is displayed.

Different templates can be applied to the same data to produce alternative presentations. For example, one template could take point records and produce a list showing only point name and coordinates. Another template also operating on point data could additionally present the statistical information which is available in the selected records.

Each template presents its results in a separate *report window* inside the Report Generator. If several data types have been selected then several windows are normally opened, one for each type. Some templates can combine different data types in one window. For example, a template is available to present a list of workpiece names, each followed by a list of points in that workpiece. This template requires data selected from the "Workpieces" table as well as data from corresponding "Points" tables.

A default assignment of a particular template to a particular data type or combination also exists and can be changed at any time. When the Report Generator receives a data selection this feature ensures that report windows are automatically generated for the selected data types or combinations.

The Report Generator is also designed as a stand-alone program. It has functions to open any ***Axyz*** job file and to use the DM as a Select ID tool in order to select records from the chosen job file.

Report generation is made possible with a third party product, Crystal Report Generator ™. The standard ***Axyz*** implementation provides a *runtime* version of this product which is sufficient to generate reports with the templates supplied.

3.12 Security features

Security here implies the control of access to the software package and its functions as well as ensuring that data is not lost or corrupted or accidentally modified.

In particular, data in the database is controlled by the concept of *data integrity* which deals with the following issues:

- **Data access**
  The ability to modify data or access certain functions should be optionally restricted
- **Data protection**
  Data should not be lost, or overwritten without proper controls
- **Data consistency**
  The data in the job file should accurately reflect the current state of measurement and not present confusing or inconsistent results

The consequences of modifying or deleting data are particularly important. Changes do not necessarily affect only the item concerned since other data elements may be linked to it.

Examples

- Deletion of a station logically implies the deletion of all measurements made at that station.
- Modification of point coordinates would change the parameters of a circle fitted to that point.

3.12.1 Hardware key (dongle)

Axyz requires a hardware key attached to the parallel printer port in order to operate. Without this the software cannot be operated.

3.12.2 "Locked" databases

The master database and all job files are MS Access™ database files. They can therefore in principle be read and modified using MS Access or MS EXCEL To prevent users modifying fundamental measurements and related data in a completely uncontrolled way, the files are protected by password without which they cannot be opened by MS Access or EXCEL.

3.12.3 Rights to access menu items and modify data

When the ***Axyz*** system is installed, all menu functions (commands) are available in all the installed modules, as are all options for modifying data.

The system administrator can then define a *user access profile.* This specifies which menu options or commands are accessible and which options are available for modifying and editing data. This profile is protected by a *password* and can only be altered if the password is known.

Only one profile can be defined for an installation. However the profile can also be stored in an ***Axyz*** configuration file *.acg of which there may be more than one version. This feature enables the system administrator to define a profile at one location and copy it to a number of others, for example to unify a series of shop floor installations. Although different installations can have different profiles this does not mean that different users can log on with different access rights at the same installation.

3.12.4 Protecting data

Job files

A job file is a database and is therefore continuously kept up to date as modifications are made. It does not need to be specifically saved at specified times or when the job is closed.

The user is prompted to save new jobs which have not yet been named and which are given the provisional label “Untitled”. These files are also continuously maintained but will be discarded if they are not given a proper name.

CDM File/Save As

Only one version of each job file exists and ***Axyz*** does not make use of temporary copies. During a measurement session the user works directly on this file. If a user needs to recover the state of a job file at any particular time, then the file at that time should be separately saved under another name.

Measurements

Measurements are the principal source of all remaining data in the job file. In all instrument modules, measurements in standard mode are recorded directly into the data base by the relevant module as soon as they are made. Users can subsequently delete or overwrite measurements.

Confirmation of overwriting or deleting data

CDM Settings/ Confirmations

New data relating to an existing item will automatically overwrite the corresponding existing data unless the user has set the option to confirm this action before it is completed.

Data could be overwritten, for example, when an operator decides to re-measure a point or re-calculate a shape fit having added more points.

CDM Settings/ Confirmations

The user can also set an option to confirm the deletion of certain types of data before the deletion is carried out, otherwise the deletion happens as soon as the user has requested it.

3.12.5 Data consistency (consequences of modification and deletion)

Not all changes to numerical values and not all deletions will result in changes to other data which were originally influenced by the modified or deleted data. For example, if an orientation calculation used certain measurements, deletion of those measurements would not cause a new orientation to be calculated.

On the other hand, some changes are filtered through the database. For example, deletion of a point results in the deletion of any associated measurements to that point.

Workpieces

Deletion of a workpiece will cause the entire contents of a workpiece to be deleted, i.e. all

- Points
- Measurements
- Shapes
- Coordinate systems

Any additional consequences associated with deletion of elements of the above type will also be implemented.

It is not possible to delete:

- The workpiece named "Default"
- The currently active workpiece

Stations

If a station is deleted:

- All measurements made from the station are deleted
- For each deleted measurement, the consequences of a measurement deletion are implemented

Station parameters cannot be modified except by re-calculation using the Orientation Module.

Stations can only be created under control of the corresponding instrument module (**Setup** menu).

Points

The following types of *simple point* are either independent of particular measurements or can easily be recreated from other elements. They can therefore be deleted without further consequence.

1. Entered
2. Reference
3. Control
4. Hidden
5. Calculated
6. Coordinate set

The following types of *complex point* are derived from measurements. Deletion will also cause all associated measurements to be deleted.

1. Measured
2. Measured control
3. Device points
4. Set

Modification has no practical use for the following point types and is therefore not allowed:

1. Coordinate set
2. Set

Modification of the following simple point types is permitted and has no further consequences:

1. Entered
2. Reference
3. Control
4. Hidden
5. Calculated

Modifying the following complex point types has additional consequences:

1. Measured
2. Measured control
3. Device points

The consequences of modification are:

- Point type is converted to "Entered", so that they then become simple point types
- All associated measurements are deleted

Measurements

If measurements are deleted, the following consequences apply to the 3D points associated with the measurement.

- If the corresponding 3D point cannot be re-calculated after deletion of the measurement, then the point is deleted.
- If the corresponding 3D point can be re-calculated after deletion of the measurement, then the point is re-calculated using the Single Point Solution. In this case the point type remains the same as before.

Note
If deleted measurements were previously used by the Orientation Module, a new orientation is not automatically executed.

Measurement values can only be changed by physical re-measurement and overwriting. They cannot be manually changed.

Shape history

Users can optionally choose to maintain a *shape history*, i.e. a record of the other data elements used to create a particular shape. If this is done, any changes to the shape's source elements will cause the shape's parameters to be re-calculated.

See the ***Axyz*** Core Data Module Software Reference Manual
Settings menu/General

3.13 Taking control of Axyz

Experience with previous systems shows that it is very difficult to provide a single solution which will satisfy the needs of all users' applications. The range of options is always limited in some way. ***Axyz*** is therefore designed to be programmable.

LEICA has chosen a standard Microsoft programming language, Visual Basic ™, and added the elements necessary to program an optical measuring system. These tools have been used to create the standard program and the same tools are available to users who wish to modify the system, add new functions or methods of operation, or even completely replace the standard program with their own.

This approach is consistent with the philosophy applied to the database design, which uses MS ACCESS ™ as its programming language.

3.13.1 Macros and scripts

Macros are a tool familiar to users of many standard Windows applications, particularly word processors and spreadsheets. They are used to record a frequently used sequence of actions. This sequence may then be replayed by initiating the macro in one of several simple ways. The end result is considerable convenience and improved ease of use.

Axyz goes beyond macros by making use of *scripts*. A script is a *Visual Basic* program which can also control another program and make use of its functions. For example you can use scripts to take control of MS WORD and MS EXCEL and directly manipulate existing or new documents.

To take control of ***Axyz,*** the library of Visual Basic commands and functions has been extended to enable the instrumentation to be addressed and to utilize functions specific to ***Axyz***.
Two types of ***Axyz*** VB functions are implemented and they enable ***Axyz*** to operate in two fundamentally different ways:

1. High level commands: "Show" the function
   This displays the corresponding ***Axyz*** dialogue box and enables the user to react with it in the normal way. A sequence of these functions can produce a result like a macro, allowing the user to repeat standard operations. In each step the user reacts with the corresponding dialogue box, providing input and selecting options.
2. Low level commands: Call the function with input parameters.
   Here the dialogue box is not displayed but input parameters are supplied within the script. This permits a high degree of automation and gives the impression of new functions.

Scripts can be assigned to keys and buttons to further automate procedures.

Developing scripts

Sample scripts are provided with the ***Axyz*** installation. You can edit these scripts or create your own scripts provided you obtain a Visual Basic licence and install the Visual Basic programming environment on your controlling PC.

Guided measurement procedures

Scripts can be used to implement guided measurement sequences. This is an advantage to new users of the system and to companies which want to implement standard procedures.

3.13.2 Process Automation Module (PAM)

The Process Automation Module (PAM) was originally developed for applications in the car manufacturing industry where there was a need to automate relative complex but standard operational sequences.

PAM provides a "drag and drop" interface which enables the operator to put together a sequence of commands such as "Create new tracker station", "Import reference points" without the need to create a Visual Basic program. Flexibility is further provided with options to create loops and make decisions.

3.14 Using 3rd. party software

You can take direct control of your work in another way, by using other software packages to analyse and present your data. If you wish to use a 3rd. party package you will require a licence for it. None of the packages listed here is supplied as part of the ***Axyz*** system.

3.14.1 Managing Axyz data using MS EXCEL

It is a simple matter to copy cells from the DM grid and past them into EXCEL or some other spreadsheet program. See:
Axyz Data Manager: Software Reference Manual

3.14.2 Modifying report generation with the Crystal Report Generator

The standard ***Axyz*** implementation provides a *runtime* version of Crystal Report but only the full version can be used to create templates.

If the default layout in the standard templates does not meet your requirements and you would prefer, for example, to have your own company logo and your own standard data selection making up the report, you have two options.

1. You can commission templates to your specification from a Leica engineering team
2. You can purchase your own full featured copy of Crystal Report Generator ™ and use this to develop other report templates. You may additionally want a Leica training course to speed up your learning curve.

4. Working with theodolites and Total Stations

4.1 Measuring networks and point location

The measuring *network* is the linked collection of stations which defines the current measurement volume and within which point coordinates are created.

Orientation is the technique of linking the stations together into a single, accurate measuring network. Until orientation is complete, 3D point coordinates cannot be generated and stored.

This task is carried out by the Orientation Module which can handle triangulation, polar or mixed measuring methods. It processes measurements from theodolites, Total Stations and laser trackers and is separately discussed in "Combining STM, MTM and LTM in a common network" on page 165.

A network can be as simple as a single station, for example a Total Station using polar measurement. This single instrument can be moved to other stations in order to complete coverage of the measured object, if required. This form of operation is covered by the Single Theodolite Module (STM).

A network can be based on pure triangulation techniques of which the simplest is a dual theodolite configuration. These instruments can be moved to other stations, or additional instruments set up, in order to provide fuller coverage of the measured object. This form of operation is covered by the Multiple Theodolite Module (MTM).

Both polar and triangulation methods can be mixed and for this form of operation a combined instrument module is available (STM/MTM).

Further information is available in "Theodolite Manager and Theodolite Modules" on page 83.

4.1.1 Physically connecting and operating a network

There is a distinction between a particular instrument and the spatial position which it occupies for measurements. This position known as the *station* and the same instrument can be moved between different stations in a network.

Up to 16 instruments can be physically connected to the computer at any one time and a complete measurement network can contain 1 - 99 stations.

This means that instruments can physically occupy up to 99 different locations but on-line measurements are only possible from a maximum of 16 of these at any one time.

Axyz communicates with instruments via serial COM ports to which they are connected. Users who operate a single Total Station or a simple dual theodolite configuration can use the two serial ports provided by most PCs (COM1, COM2). If more instruments must be operated simultaneously a Digiboard ™, Rocketport ™ or STB ™ expansion board, offering additional serial ports, must be added to the system.

Although it is possible for ***Axyz*** to detect if an instrument is connected to a port and determine the type of instrument, only the user can identify individual stations. There is therefore a need for the user to specify the current connections and a setup procedure is available for this purpose.

STM/MTM

During the setup procedure the user defines which type of instrument is attached to which port and which station this defines. This can be automated to a certain extent. See "autoscan" below.

Assigning instruments and ports to stations

Once a system has been configured with any additional COM boards, a range of COM ports with sequential numbers is available, for example:

- COM1, COM2 in a simple system with no additional boards
- COM1, COM2, .. COM6 in a system with 4 additional ports

Axyz must first be told the maximum number of instruments which will be connected at any time and the first COM port number in the sequence of COM ports used for the connections. (If an expansion board has been added, it is not recommended that the existing COM ports on the controlling computer be used for connecting instruments.) For example:

- Max. instruments 2, first COM port at COM1.
- Max. instruments 4, first COM port at COM3

This defines a range of ports currently accessible to ***Axyz***. The range can be altered at any time.

Two tasks then remain:

1. Identify which type of instrument is connected to a particular port in order to ensure correct communication
2. Provide an identifier for the station which this connection represents (Station identifiers are numbers in the range 1 - 99.)

Operators can either manually identify which type of instrument is connected to which port and which station number this represents or else they can use the “Autoscan” feature to automatically detect what is connected at all the ports within the defined range. Autoscan will automatically choose an unused station number for a new connection but the user can re-set this to some other valid number.

It is not necessary for an instrument to be connected to every COM port within the range and an unused port connection is permitted.

During the measurement job operators will typically need to create new stations, either because of some accidental shift which makes existing stations invalid or because different parts of an object can only be seen from new locations. When measurements have been completed at one station the corresponding instrument and port connection can be *re-assigned* to a new station after the instrument has been re-located. Alternatively a completely new connection can be made by connecting an additional instrument to an unused port in the range.

Once a connection has been re-assigned the old station is registered as "not on line", i.e. not connected to ***Axyz***. It is possible to re-occupy an old station by editing a station assignment to bring it back on line again. Further measurements made at that station will then be added to the previous ones. However this only makes sense if the instrument occupying the station has not moved since it was last used.

A similar situation can occur when an old job is viewed. If you start the Theodolite Manager and some of the instrument connections correspond to the last used settings, the corresponding old stations will be brought back on line. ***Axyz*** has no way of detecting that the current locations of the instruments are no longer the same and only the operator can decide what is a valid or invalid station.

Station numbering

Remember that ***Axyz*** only permits stations to be identified by an integer number in the range 1 - 99. The numbers do not have to be used sequentially in the order in which stations are created. This also means you can use any numbers from within the range even if you have less than 99 stations, e.g. a 4-station network can have stations numbered 91, 92, 93, 94.

The numbers of existing stations cannot be changed and the numbers for new stations added to a network can only be chosen from the unused numbers in the range.

Orientation status

At any time a station has an orientation status, colour-coded on screen as follows:

- Not oriented - red
- Oriented - green
- Not on line and not oriented - yellow
- Not on line and oriented - yellow with small "o"

See also "Orient status" on page 97.

Returning to an existing station

If a station is marked as "not on line" it is no longer connected and further measurements cannot be made from it. Additional measurements can only be made from stations which are on line, i.e. "not oriented" or "oriented". The station can be brought back on line by editing an existing station assignment. However, before adding any measurements to a station which has not been in use for a period of time, the user should always make checks that there has been no significant changes to instrument position or rotation.

Moving an instrument

A new station should be created when an instrument is moved. Movement could be accidental, in which case the location of the new station is almost identical to the old one. More likely, the movement is to a completely different location.

Creating 3D object points from measurements

Before measurements can be used to locate object features or targets in 3D, the associated station must be oriented in a common measuring network which is located in the base coordinate system.
However, stations can make and record measurements to object features before they are oriented. These measurements are then automatically processed into 3D values once an orientation is available.

Deleting stations

Using the editing functions of the DM it is possible to delete stations but if a station is deleted, all its measurements are lost.

4.1.2 Controlling operations from the instruments

Theodolite modules are designed to allow operators to work independently and permit them to initiate measurements directly at the instruments. The Theodolite Manager is therefore designed to accept data asynchronously from all connected instruments.

However, from the controlling computer measurements can be triggered "simultaneously" at all connected instruments. This function makes possible the continuous updating of target coordinates, which is particularly convenient when moving targets into specific locations.

Some instruments have limited computing facilities and from the instrument the operator can do little more than send the values of the current pointings. A number of Leica instruments, however, allow operators a high degree of control over the measurement process. This is possible by sending command or *code* sequences from the instrument to the controlling computer. For example, operators can initiate a particular type of orientation measurement from their own instrument. Most recent instruments have a full computer interface for many ***Axyz*** functions.

4.1.3 How points are identified during measurement

A measurement connects a station to a point and a measurement must always contain at least these components:

- instrument readings
- station ID
- point ID

STM/MTM

Since ***Axyz*** records the readings from the stations, the first two items are unambiguously connected. Most of the time the operator of the station chooses the ID of the next point to be measured (presumably following an agreed procedure with other team members).

Occasionally ***Axyz*** may guide operators to measure particular points, for example when a particular orientation procedure has been selected. Sometimes lists of points are pre-defined and the operators simply move through this list. This happens when building and inspecting locations.

For standard measurements it is more than adequate to define point names with an initial alpha component followed by a numeric component. The numeric part can be automatically incremented by the ***Axyz*** software to provide an name for the next point.

Since ***Axyz*** accepts data asynchronously from instruments, point identification is independent at every station. Operators therefore have options to re-define the next point names at the instrument. Although it would be most convenient for operators to define full alpha-numeric names directly at the instrument, this is not possible with older Leica instruments. Older Wild instruments only permit numeric input at the instrument, so it is only possible to change the numeric component of a name at such an instrument. Kern instruments do not permit any alpha-numeric input. Where such restrictions exist, complete definition of names must be done at the controlling PC.

See also "Incrementing names" on page 44.

4.2 Theodolite Manager and Theodolite Modules

As its name implies, the theodolite manager supervises the communications with the theodolites and organizes their actions. Its main tasks are:

- Define the measurement configuration
- Read data from instruments and store in the job file
- Calculate and update the Single Point Solution and record the coordinates in the job file
- Display coordinates or coordinate differences in multiple windows

4.2.1 Single Theodolite Module (STM)

The STM is designed to operate a single Total Station. Measurements made with an STM are therefore always based on the polar method of point location.

The STM will only accept one Total Station on line although more than one may be connected. Theodolites may also be connected but will be ignored. Since only one instrument is ever used it is sufficient to connect this to the standard COM1 port on the controlling PC.

The STM allows you to move this single Total Station to different locations when measuring an object. Up to 99 stations are possible.

If the first station in a network is a Total Station, this is immediately assigned the status of "oriented". This enables the user to generate 3D coordinates with a single Total Station and without the need to perform an orientation.

Each new station can be added into the network provided sufficient measurements are made to conform with one of the standard orientation methods. For example, one method is equivalent to a 3D transformation and requires the measurement of at least 3 points which are already defined in the existing network..

4.2.2 Multiple Theodolite Module (MTM)

The MTM is intended to permit operators to connect two or more theodolites or Total Stations to the controlling computer. Any mixture of theodolites and Total Stations is permitted from the lists of acceptable instruments. However this module only collects angle measurements from the connected instruments. Any distance data is ignored.

If only two instruments are ever operated simultaneously, then a controlling computer with two standard COM ports (COM1, COM2) is sufficient to connect the instruments to the ***Axyz*** system. To operate more than two instruments simultaneously the controlling computer must have an additional expansion board offering more COM ports. Digiboard ™ and Rocketport ™ are recommended for this purpose.

Up to 16 instruments can be operated simultaneously and a measurement network can contain up to 99 different stations.

Instruments can be operated individually and sub-groups of instruments can be operated co-operatively to enable operators to work independently on different parts of an object. Connected sub-groups can display their on-line results in different display windows at the controlling computer.

It is even possible to operate the MTM with a single theodolite, moving it from station to station. However, unlike the STM or MTM operated with at least two instruments simultaneously, on-line coordinate display and Build and Inspect modes are not then possible.

4.2.3 Combined theodolite module (STM+MTM)

A mixture of theodolites and Total Stations may be connected on line. The maximum number of measurements, angle and/or distance, will be collected from every instrument.

This combination implements all the features of the individual modules, STM and MTM.

4.3 Operational modes

Once oriented stations exist they can be used to make measurements which are classified into different *modes* of operation. A measurement mode implies a particular way of making measurements.

4.3.1 Modes in brief

All modes are available to both STM and MTM but some can only be accessed if tracking Total Stations (TDA series) are active in the network.

All connected instruments operate in the same mode. Although sub-groups of instruments can be defined and can present their results in separate measurement windows, it is not possible to have different groups of instruments operating in different modes.

A mode can only be selected when a measurement window is open.

Since modes imply different types of task, their results are presented in different types of measurement window.

Measurement windows and instrument groups are discussed in more detail in "Windows for monitoring measurements and coordinates" on page 96.

In brief: Standard mode

Standard mode is used to make 3D point measurements on an object, either by directly sighting a point or by using a hidden point device.

In brief: Build and Inspect

Build points and **Inspect points** are used to either set out (build) specific points on an object to match a design (reference) location or to check (inspect) that specific points agree with reference information. Build and Inspect modes essentially display the difference between a measured location and a reference location and the only real difference is in the presentation of the results.

In brief: Build/Inspect CAD

Users of the ***Axyz*** CAD module can also **Build** and **Inspect** points on a CAD surface. This mode essentially measures the perpendicular offset of the current point from the CAD surface.

In brief: Auto Inspect

Auto Inspect mode can automatically check a set of fixed reflector locations. This mode requires motorized (tracking) Total Stations with Automatic Target Recognition (ATR). This is currently provided by the TDA series of instruments.

4.3.2 Tracking Total Stations with Automatic Target Recognition (ATR)

The TDA series of Total Stations has a feature called Automatic Target Recognition (ATR). ATR requires use of a hollow corner cube reflector. Part of the infra-red EDM beam reflected back from this reflector is diverted to a CCD chip and its centre of gravity detected. This provides correction angles to enable the instrument to point accurately at the reflector centre. Exact manual pointing is not then required. The size of reflector affects the maximum range. Larger reflectors enable longer ranges to be used.

ATR may be optionally enabled. When disabled, the instrument has the same capability as other motorized Total Stations. With ATR enabled other functions are possible.

A **find** function enables a reflector to be found by spiral search. In this case the reflector should initially be reasonably close to the line of sight.

This feature, for example, enables a set of fixed targets to be continuously monitored.

When a reflector has been found, activation of **lock-in** will cause the instrument to follow the reflector as it is moved. This provides a tracking function similar to that of a laser tracker and enables operators to work from point to point at the object.

Lock-in does not provide a real-time update of the coordinate display in a measurement window during tracking. Tracking is an angular function, not a distance function. Distances require a finite time (seconds) to update and this cannot be done at tracking rates.

These features can only be used with a single instrument, which must be specified if more than one is available in the network.

4.3.3 Standard mode

The most common mode and used for normal shape measurement. This mode can display and record a point's 3D coordinates in any defined coordinate system.

This mode offers on-line correction for target thickness or offset and on-line calculation of hidden points with hidden point rods and frames.

Directly measured targets and derived hidden points result in a measurement type **normal** .

4.3.4 Build and Inspect points

These modes enable an operator to measure the coordinates of a targeted point on line and compare these with reference coordinates for the target. In **Build** mode the target is physically moved to make the difference zero.

A list of build/inspection points is selected from the reference area of the database. The order of selection defines the sequence of measurement.

In order to be able to set out or check these locations the measuring stations must "know" where the corresponding reference coordinate system is. If the reference coordinate system has not yet been established, it must be created, for example by transformation or axis alignment.

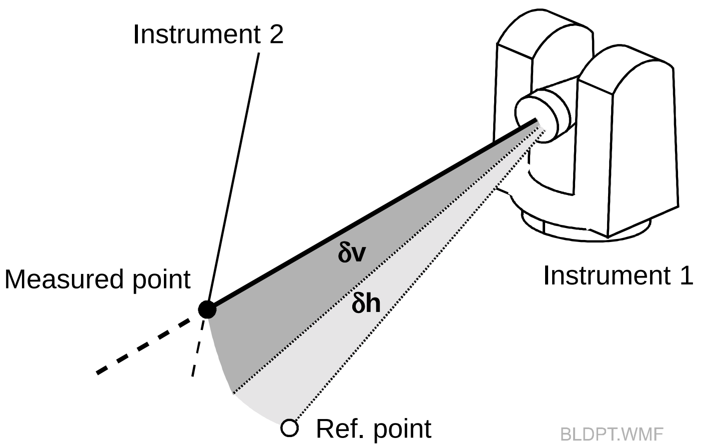
Creating the reference coordinate system in the measurement area simply ensures that the reference points are correctly located with respect to the measuring stations. The actual build or inspection procedure can take place in any other coordinate system known to the system, if that is more convenient.

When a point is built, the operators move a target into position. If a point is inspected, an existing target or well defined object feature will be measured. In both cases a measured location is compared with a reference location and the difference should be zero.

For a new build/inspect point, instruments with motor drives will be set to point at the calculated reference location. For an inspection point operators need then only make small corrections to the pointing to sight the actual target. For a build point the instruments can then be locked and the target moved into position.

In the measurement window, the offset between measured and reference location is shown as components in the currently active coordinate system. In addition, a pointing difference in angular terms is shown on the display of each instrument.

Diagram: Angular build/inspect differences



Angular build/inspect differences

The diagram shows a point intersected by two instruments. The measured location is different from the reference location. For each instrument the pointing to the measured location and the computed pointing to the reference location are compared. Two angular corrections are then generated, δv in the vertical plane and δh in the horizontal plane. These differences are displayed at the instrument. If zero, then the instrument is correctly pointing at the reference location.

Build points

In the **Build** measurement window difference coordinates are displayed on line as (Reference - Measured).

At each instrument angular offsets are displayed to 4 places of decimals for maximum accuracy.

Once positioned, the coordinates of a built point can be recorded and stored as a standard measured point.

If required, every connected instrument can be assigned a different starting point name in the sequence of points to be built. The assignment can be altered at any time. This means that different connected sub-groups of instruments can independently build different parts of the object.

Once a point is built, operators can automatically move to the next point in the sequence or jump backwards and forwards from this location in the list.

Inspect points

In the **Inspect** measurement window difference coordinates are displayed on line as (Measured - Reference).

> **Note**
> Measured points can also be checked off line using the **Comparison** function in the CDM.

At each instrument angular offsets are displayed to 2 places of decimals.

Different sequences of inspection points can be assigned to different instruments and the operators can move backwards and forwards within the file to select the current point to be "inspected".

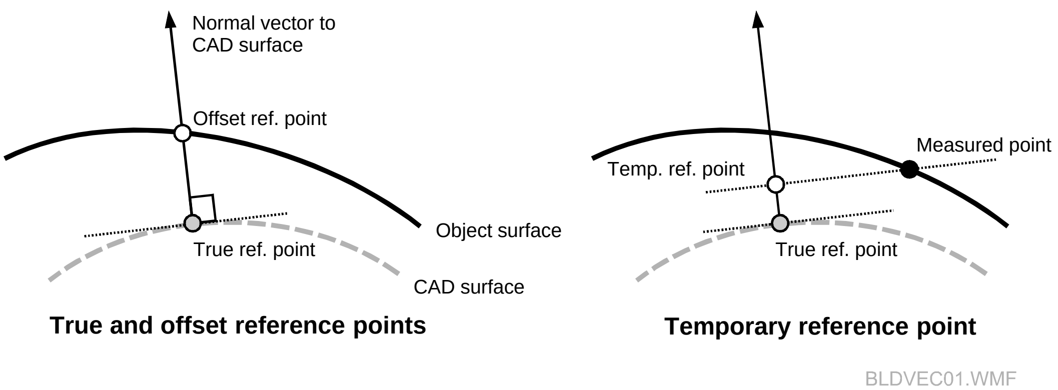
By selecting continuous update, angular differences are continuously updated at the instrument. By arranging for zeros to be displayed, the operator can quickly locate the selected point.

4.3.5 Vector mode

Vector mode is a variation of **Build points** in which the reference point is offset along the vector perpendicular to the CAD surface where the point is located. It is intended to deal with a situation in which a CAD model does not exactly coincide with the actual object surface. In this case it may be more useful to use an alternative reference point which is a point on the actual surface close to the true reference point. This could, for example, be the best location to drill a reference hole.

Vector mode can only be applied if the reference points have the associated normal vector.

Diagram: Offset reference point in vector mode



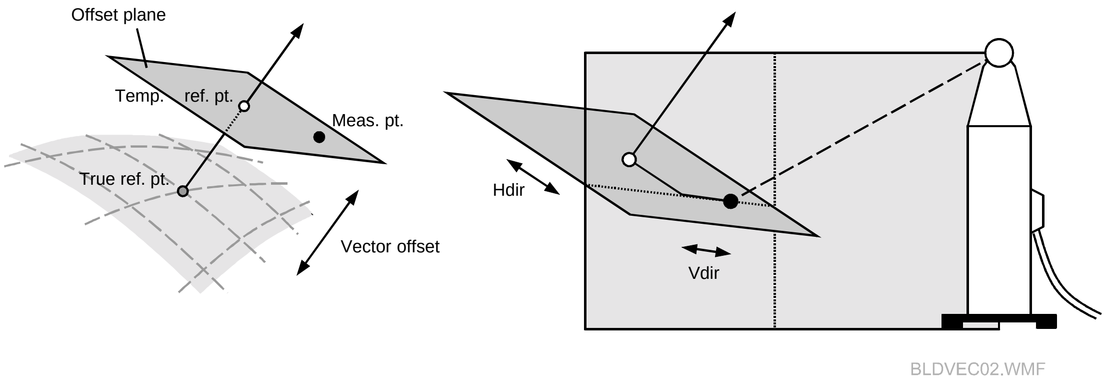
Offset point in vector mode

The simplified diagram shows the true and offset reference points. The current measured point is somewhere nearby on the object surface. It might, for example, be a projected laser spot.

Since the exact tilt of the object surface cannot be determined from the single point measurement, the measured point is projected onto the normal vector to create a temporary reference point as indicated. The temporary point is the foot of the perpendicular from the measured point to the normal vector.

During the build process the measured point will be moved closer and closer to the offset reference point until the temporary reference point in effect becomes the offset reference point.

Diagram: Local coordinate system for vector mode



Local coordinate system for vector mode

The measurement window in **Vector mode** shows the current offset of the temporary reference point from the true reference point.

Two other offset components are shown in the offset plane. These are the values Vdir and Hdir. The direction of Vdir is created by intersecting the offset plane with a plane through the measuring point and the measuring instrument. The direction of Hdir is in the offset plane and perpendicular to the direction of Vdir.

If the measuring instrument is levelled, the intersecting plane is a vertical plane through the instrument and measured point.

If the instrument is not levelled, the intersecting plane is through the primary (standing) axis of the instrument and the measured point.

If the measured point is located from more than one station, the instrument at the lowest numbered station defines the intersecting plane.

4.3.6 Build and Inspect standard shape surfaces

This mode of operation is available in the Laser Trackers Module (LTM) but not in the theodolite modules.

4.3.7 CAD Build and Inspect

CAD Build and **Inspect** requires an imported CAD model. The objective is to set out or check points on the surface of this model. The measurement window shows the perpendicular offset of the current target or reflector position from the CAD surface. The offset is not displayed as a single offset value but as components in the current coordinate system. These values should be zero.

Corrections may be applied for target thickness or reflector offset. When a zero offset from the surface is shown this means:

- If correction not applied:
  Target/reflector centre is on the CAD surface
- If correction is applied:
  Target's back surface or reflector housing touches the CAD surface

The offset is calculated as a vector and its components in the currently active coordinate system are displayed. The offset is calculated as follows:

- For **Build**, offset = (Measured value minus reference value)
- For **Inspect**, offset = (Reference value minus measured value)

The reference value is the current foot of the perpendicular from the measured point to the CAD surface. and its location changes as the target point is moved.

Note
CAD Build does not set out specific points on the CAD surface. To do this you must either import points which lie on the CAD surface or create points on the CAD surface. You can then use **Build points** mode to set out these specific locations. Functions are available in ***Axyz*** CAD to extract points from a CAD model or create points on the surface of a CAD model.

4.3.8 Auto Inspection

Auto-inspection is only available to instruments with ATR.

This technique checks coordinates at a number of locations semi-automatically. A hollow corner cube reflector is expected at each location but different reflector sizes can be used. Checking is done by recording the actual reflector location and showing its differences with a nominal value. At each location a spiral search is used to find the optimal pointing.

A file of point names and reference coordinates indicates the points and order of measurement.

Limited number of reflectors - use of PAUSE

The operator may not have sufficient reflectors to occupy all points to be inspected. In this case it is possible to pause the sequence whilst the operator moves reflectors from points already measured to points yet to be measured.

Repeat passes

With Auto Inspect it is possible to repeat passes through the file of points to be inspected. The repeat measurements may either be averaged or the latest measurement can overwrite the previous measurement.

Error conditions

If there is an error condition, for example when a reflector is not found, there are options to:

- Automatically skip to the next point in the list
- Provide a warning message and allow the operator to choose a corrective action

4.4 Recording buttons

Measurements can be triggered at all connected instruments from the the controlling computer or from individual instruments using the instrument's own keyboard or *pickle switch* .

Measuring means reading angle and distance values from one or more instruments and converting these to one or more 3D point coordinates. Depending on the configuration, the measurements and 3D values may simply be displayed only, displayed and stored or stored and not displayed.

Triggering a measurement from an instrument causes a single set of measurements (h,v) or (h,v,d) to be sent to the controlling computer where the information is stored and processed into 3D data for display and/or storage.

4.4.1 REC: Store h and v

Reads and stores angle values of one or more connected instruments. Only horizontal and vertical angles are read, even if one or more instruments is a Total Station.

Measurements are subsequently combined with any existing measurements to the target points and any corresponding 3D coordinates are calculated or updated, if possible. This action may cause more than one 3D point to be created.

Normal operation:
- Stores measurements
- Stores related 3D data
- Increments point numbers at stations just read.

If **Try** is active:
- Data is not stored
- Point numbers are not incremented

Conditions
- The instruments need not be oriented
- A measurement window need not be open
- If a measurement window is open and active, only the instruments at stations assigned to the window are read
- If no measurement windows are open or no open measurement window is active, then all connected instruments are read

4.4.2 ALL: Store h, v and d

Reads and stores angles and distances.

This performs the same actions as REC except that any distance data is also read from an instrument, if available. If only theodolites are connected then this button has the same function as REC.

Conditions
- Only available when a Total Station is connected to the system.
- Other conditions as for **REC**

4.4.3 TRY

"Try" results without storing.

This is useful for checking a location as you home in on a target position and so can only be used with an open measurement window.

Try is used in conjunction with **REC** and **ALL** and modifies their actions.

As long as **Try** is active it applies to all connected stations and blocks the following actions by **REC** and **ALL**, as well as measurements triggered directly at the instruments:

- Storage of measurements and any derived 3D coordinates
- Incrementing point ID for next measurement

To use this recording feature therefore, you click on **Try** then use **REC** or **ALL** as required in order to update results on screen.

Conditions

- Not available if **Continuous** update is operating
- A measurement window must be open

Note
The MTM **Try** button functions slightly differently from the **Try** button in the LTM. In the MTM it blocks some actions of the **REC** and **ALL** buttons as long as it is active. In the LTM, **Try** is used as an alternative to **Start** (which is roughly equivalent to **REC/ALL** in the MTM).

TRY recording, set from instrument

Any instrument of the correct type can toggle **TRY** recording on and off.

Code definition:

12 **Try mode for all stations**
Try mode ON/OFF (toggle)
CODE 12 RUN REC

4.4.4 CONTINUOUS update

Provides a "continuous" coordinate display, triggered at regular intervals definable by the user.
This is convenient for monitoring target coordinates on a regular basis and is particularly useful in a **Build** process as a target is moved into its reference location. Since the objective is to see current coordinates, a measurement window must be open.

CONTINUOUS update provides a capability for theodolites similar to laser trackers where the current target location is displayed and updated at all times. Because the instrumentation is completely different, theodolite readings can only be updated every few seconds, rather than at millisecond intervals.

The **REC** and **ALL** buttons retain their normal recording functions when **Continuous** is active and are used to record and store data. Unlike the **Try** function, **Continuous** does not block any actions of **REC** and **ALL**.

To be of practical use, all connected instruments should maintain accurate pointings at their respective targets. If triangulation is used to locate points then targets should have at least 2 rays intersecting them.

Displays are updated in either the active or all open measurement windows, as well as the individual instrument displays.

Conditions

- Not available if **TRY** is active
- Not available in STM, only MTM or STM/MTM
- A measurement window must be open

CONTINUOUS updating, set from instrument

Any one instrument of the correct type can toggle **CONTINUOUS** updating on and off.

Code definition:

11 **Continuous display for all stations**

Continuous display with time interval of **n** seconds

CODE 11 RUN **n** RUN REC **n** (3 - 99) (0=OFF)

4.4.5 Set and read

For complete flexibility, the software enables the recording to be specified individually for each connected station. A comprehensive "Set and Read" dialogue box is provided in the "Measurement" menu.

4.5 Windows for monitoring measurements and coordinates

Axyz theodolite modules provide different windows in which data can be displayed as networks are built and measurements made.

Windows are provided to display the following types of information:

- Running data
- Orientation status
- On-line measurements

The window used for on-line measurement depends on the *mode* of operation.

4.5.1 Running data window

STM/MTM

This window is typically used to provide a simple sequential display of any instrument readings as they are generated and brought into the system.

It can also show coordinates as they are created or coordinate differences as they are generated in *Build mode*.

The window must be explicitly requested by the operator.

4.5.2 Orient status

This window is always present when the Theodolite Manager is started and cannot be explicitly requested by the operator. It shows the orientation status of all the stations on the network.

As a measurement network is constructed stations must be added to it by some orientation procedure. This is implemented in two stages:

- Make sufficient measurements so that the station can be oriented
- Apply the Bundle Adjustment to calculate the orientation parameters and make the station available for on-line measurements

STM/MTM

When a new station is created it is initially registered as *not oriented*. (Unless it is a Total Station and the first in the network.). Once sufficient measurements have been made to enable the station to be oriented into the network, the operator can call the *Orientation Module*.

Successful orientation will register the station as *oriented* and further measurements are subsequently used to calculate on-line coordinates.

If the instrument is moved to establish a new station, the existing station is no longer available and is registered as *off-line*.

A summary of the situation at every station in the network is shown in the Orient Status window, where a colour-coded list of the stations indicates for each:

- Not oriented - red
- Oriented - green
- Not on line and not oriented - yellow
- Not on line and oriented - yellow with small "o"

The measurement history of any station can be seen by clicking on the station concerned.

4.5.3 Standard mode measurement windows and station groups

STM/MTM

A primary purpose of ***Axyz*** is to provide coordinates on line. ***Axyz*** allows you to group together a sub-set of the available oriented and on-line stations and display any 3D measurements made by this group in a separate *measurement window*. This feature allows you to monitor the activities of different sub-groups working around an object.

A maximum of 10 such measurement windows (sub-groups) can be defined. Each window can use a different coordinate system for displaying its results.

There are no restrictions on which instruments may be grouped together, but it would make little sense to group together stations which do not measure common points. In this case, the group would never create 3D data, unless it was composed of a single Total Station. In practice users would define groups responsible for some sub-set of the 3D object data, for example a group which measures one workpiece and a group which measures another. However, groups are not restricted to specific workpieces either, since an operator can use a station to measure points on any accessible workpiece.

Multiple assignment

A station can be placed in more than one measurement group. This feature is known as *multiple assignment* and enables results, for example, to appear in more than one measurement window but in different coordinate systems.

For users operating a single Total Station with the STM it may be convenient to restrict the number of measurement windows to one. In this case multiple assignment can be switched off. Since there is only one on-line instrument in this case, only one measurement group and therefore only one measurement window can then be created.

Coordinate system used by measurement window

Each measurement window can display results in a different coordinate system.

Since a measurement group can contain exactly the same stations as another group, this option is useful for displaying the same results in alternative ways.

Some users like to force the use of the currently active coordinate system for all measurement windows. An option can therefore be set which does not allow a choice of existing coordinate systems for the window. In this case, if the currently active system is changed in the Core Module then any open measurement windows are closed and the user must re-create them with the new active coordinate system.

It is also possible to delete a coordinate system in the Data Manager which may currently be in use by a measurement window. Once a coordinate system ceases to exist it cannot be used to display results. In this case again the measurement window is closed. When re-created, only the new reduced choice of coordinate systems is offered.

Coordinate type and units used by measurement windows

Different coordinate types and units are not possible for each window. This is a global setting which is applied to all measurement and analysis displays.

Which stations and coordinates are displayed?

The controlling factor in a measurement window display is the current target point. Whenever a measurement to the point is recorded by any connected instrument, ***Axyz*** checks in the job file to see what other measurements have been made to this point. If its 3D coordinates can be created for the first time, or can be updated because of the new additional measurement, then the values are changed in the job file. For consistency they must also change in all measurement windows which show this point.

In addition, the relevant measurement windows lists all the stations whose measurements contributed to the calculation of the point's coordinates. These can be on-line or off-line stations and stations not in the measurement group assigned to a particular window. In fact, the stations in a particular group will not be listed if they do not actually measure the point.

In practice, most points displayed in a measurement window are only measured by the stations assigned to the corresponding measurement group. This means that for most of the time the stations shown in a measurement window are the stations in the measurement group.

Displayed station IDs have a background colour which indicates the quality of the pointing.

Measurement windows and recording buttons

Recording buttons operated from the controlling PC trigger measurements from instruments assigned to the currently active measurement window.

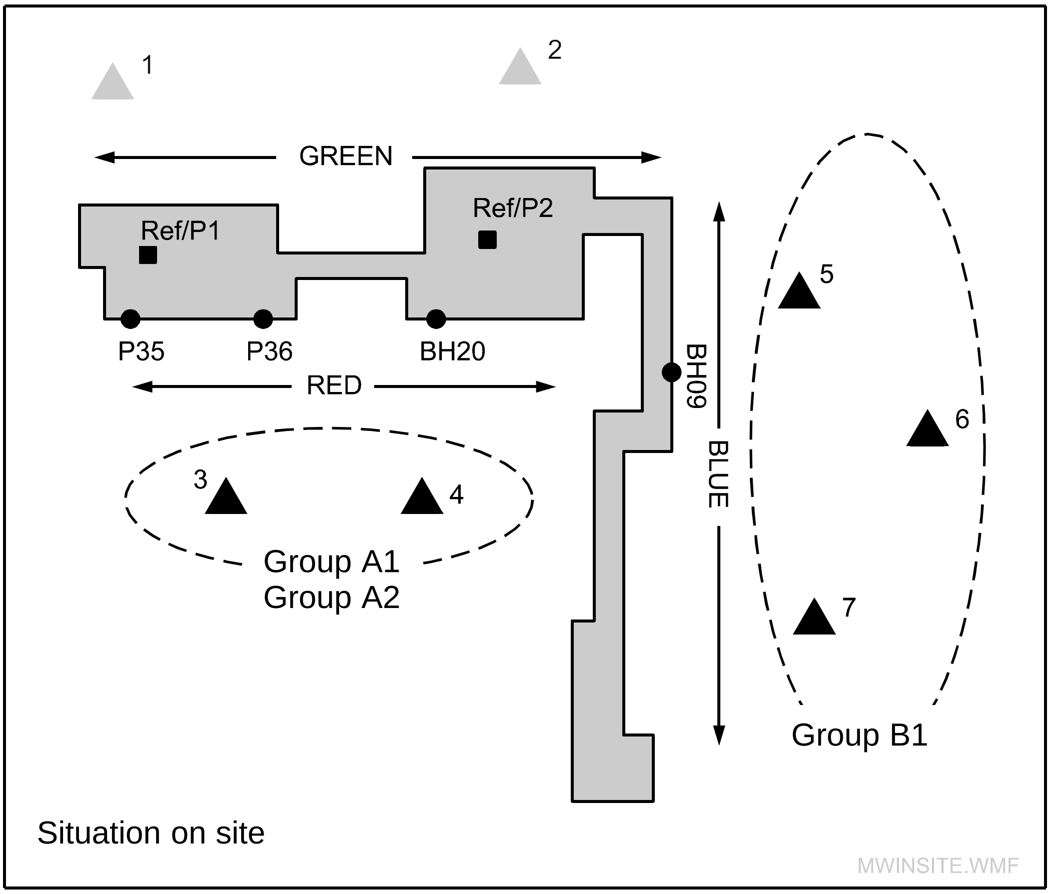
If there is any doubt about the stations contributing to a measurement group, a dummy measurement can be made to a completely new point, triggered by the PC recording buttons. Only instruments in the currently active measurement group will generate values, and the corresponding stations will be displayed in the window.

4.5.4 Stations displayed in measurement windows (standard mode)

A measurement configuration is shown in the diagram.

The example measurement windows indicate which stations numbers will be displayed when a particular point is measured. These station numbers do not necessarily correspond exactly to the stations assigned to a particular measurement window.

Station numbers are displayed with colour coded backgrounds to indicate the quality of the pointing from each station.



Site description

The situation on site shows a complex L-shaped object measured by 7 stations. For convenience the object has been split into workpieces named RED, GREEN, BLUE. These indicate 3 critical sides of the object.

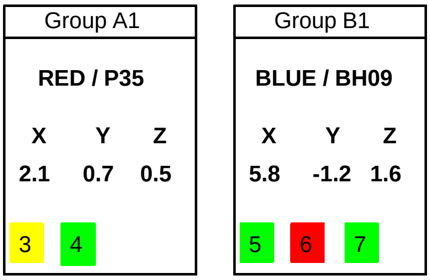
Stations 1 and 2 are now off line and make no new measurements. Stations 3,4,5,6 and 7 are on line.

Measurement groups have been established.

- Group A1 contains stations 3 and 4
- Group A2 also contains stations 3 and 4, the same as group A1
- Group B1 contains stations 5,6 and 7

The general intention is that group A1 shows results of measurements on the RED side and group B1 shows results on the BLUE side.

Example: Normal operation



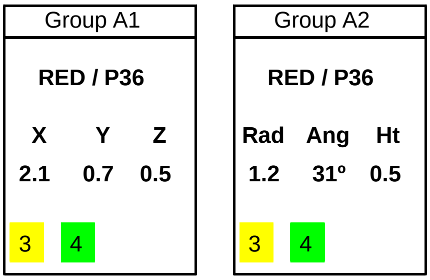
Normal operation:

Stations 3,4 in group A1 independently measure points on the "RED" side of the object. Point "RED / P35" just measured.

Stations 5,6,7 in group B1 independently measure points on the "BLUE" side of the object. Point "BLUE / BH09" just measured.

MWIN-01.WMF

Example: Different coordinate systems



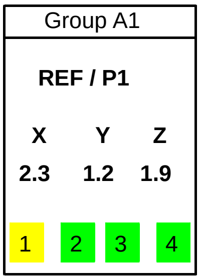
Different coordinate systems:

Stations 3,4 are assigned to group A1 and display results in a rectangular coordinate system (X,Y,Z).

Stations 3,4 are also assigned to group A2 and display the <u>same results</u> in a cylindrical coordinate system (Rad, Ang,

MWIN-02.WMF

Example: Measurement of an old point



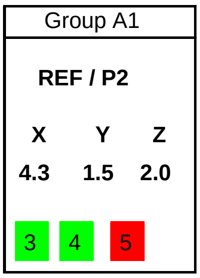
Measurement of old point:

Stations 3,4 in group A1 measure an existing point "REF / P1" This was already measured by stations 1,2 which are currently <u>off line.</u>

Updated coordinates are calculated for the point based on measurements from all stations, not just group stations 3 and 4.

MWIN-03.WMF

Example: Accidental measurement from outside the group



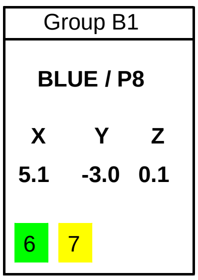
Accidental measurement outside group:

Station 5 is not one of the stations assigned to group A1.

By accident, station 5 measures point "REF / P2". This point is automatically re-calculated using data from all the stations which have currently measured it, i.e. 3, 4, 5.

MWIN-04.WMF

Example: Not all stations in a group measure a point



Not all group stations measure point:

Group B1 has stations 5,6,7 assigned to it.

Only 6 and 7 measure point "BLUE / P8" so only these stations are shown in the displayed measurement results.

MWIN-05.WMF

4.5.5 Asynchronous operation

Data is collected from connected stations asynchronously and this may cause the same point data to be displayed several times, but with revised coordinates each time.

Assume there are 4 stations T1, T2, T3 ,T4 measuring points A, B, C, D.

Running data window	**Internal action by *Axyz***
Meas. T1 ➔ A	Store measurement T1:A
Meas. T2 ➔ A	Store measurement T2:A Calculate coords. of A using T1:A, T2:A Show T1, T2 in any window displaying A
Meas. T1 ➔ B	Store measurement T1:B
Meas. T2 ➔ B	Store measurement T2:B Calculate coords. of B using T1:B, T2:B Show T1, T2 in any window displaying B
Meas. T1 ➔ C	Store measurement T1:C
Meas. T2 ➔ C	Store measurement T2:C Calculate coords. of C using T1:C, T2:C Show T1, T2 in any window displaying C
Meas. T3 ➔ A	Store measurement T3:A Calc. coords. of A using T1:A, T2:A, T3:A Show T1, T2, T3 in any window displaying A Update coords. of A in any window displaying A
Meas. T1 ➔ D	Store measurement T1:D
Meas. T2 ➔ D	Store measurement T2:D Calculate coords. of D using T1:D, T2:D Show T1, T2 in any window displaying D
Meas. T4 ➔ A	Store measurement T4:A Calc. coords. of A using T1:A, T2:A, T3:A, T4:A Show T1, T2, T3, T4 in any window displaying A Update coords. of A in any window displaying A

Depending on which measurement windows are open, coordinates of points will appear in the order:

A, B, C, A, D, A

Coordinates for A appear 3 times, with slightly different values each time. The interval between changes in the coordinate displays will depend on how fast the operators work.

4.5.6 Measurement windows for Building and Inspecting points

This window shows the 3D difference between the current target position and a reference location.

Sub-groups of instruments can be defined for each measurement window.

In Build and Inspect mode, only a single list of build points is used but each sub-group can build or inspect different points on the list.

4.5.7 Measurement windows for Vector mode

This type of window is similar to windows for Build and Inspect modes. Vector mode is used for placing points on CAD surfaces. There are two display differences between vector mode and normal build mode:

Vector mode;

- Shows the 3D difference between the current target position and a temporary offset reference location
- The 3D difference is displayed in a local coordinate system
- Shows an additional offset of the temporary location from the true reference location, along the normal vector to the surface

Sub-groups of instruments can be defined for each measurement window.

4.5.8 Measurement windows for CAD Build and Inspect

Users of ***Axyz*** CAD can monitor the perpendicular offset of a measured point from the surface of an imported CAD model. The offset is not displayed as a single value but as components within the currently active coordinate system.

Sub-groups of instruments can be defined for each measurement window.

4.6 Multiple target pointings

Object points must be well-defined features or targeted in some way in order to be measured. Most targets, like features, are fixed and semipermanent but some targets such as laser spots may be temporary.

Object features could include:
- Hole centres
- Crossed and scribed lines

Fixed targets could include:
- Adhesive retro-reflective discs
- Adhesive bulls eyes, crosses or similar
- Manufactured marks on the object surface
- Inserted target adapters

Temporary targets could include:
- Projected laser spots

Fixed targets may be measured with multiple pointings in both telescope positions and some, such as hole centres and hidden points, may have to be measured indirectly. Temporary targets can only be measured once, in one telescope position.

4.6.1 Multiple pointings reduced to a single value for analysis

Whenever multiple pointings are made to an individual target from one station, ***Axyz*** always averages or reduces these to a single representative pointing before processing them in the Bundle Adjustment or the Single Point Solution. These are the two programs which actually generate measured 3D values.

Weights and standard deviations of reduced multiple pointings

In all cases of multiple pointings the final single representative value is given the same weight and standard deviation as an individual single face measurement. An improved quality figure is not generated.

Default values for horizontal angle, vertical angle and distance are separately defined for each station in the station setup. All readings of each measurement type made at the station have the same standard deviation.

4.6.2 Averaged measurements

Axyz allows operators to make multiple pointings to a target and stores a single average value in the job file. A separate average is stored for multiple pointings in each face.

Operators must define the maximum number of pointings (1 - 99) which will be made to a target but are not forced to make them all. Once defined for a particular instrument, the maximum remains in force until altered.

As measurements to a particular point are made, ***Axyz*** computes a running average for each face and records how many pointings have been made so far. Pointings in excess of the defined maximum will cause previous data to be overwritten.

4.6.3 Mixed face measurements

Some users want the ultimate in accuracy and make every pointing twice - once in each face. This procedure eliminates most systematic pointing errors which still remain. Other users are happy to make a careful calibration and then point using either face. However, in this case they may wish to use either face one or two as convenient.

Axyz permits pointings in either face. The operator does not have to identify which face is used since ***Axyz*** can automatically deduce this from the vertical circle reading.

Averaged values for face left and face right readings are stored separately in the data base, but the averaged face right value is converted to an equivalent face left value. When coordinates are calculated these two averages are converted to a single face left pointing.

It is not necessary to specify in advance that two-face measurements will be made. However multiple measurements in each face must be specified in advance.

Calculating the average of two-face pointings

Two-face pointings are treated the same way as multiple pointings. Since face right values are already stored as equivalent face left readings all the face left and right values can be averaged and weighted according to the total number of face left and face right measurements.

Assume N measurements in face left create a face left average = AL.
Assume M measurements in face right create a face right average = AR.
(AR is stored as an equivalent face left value so that further conversion is not required.)

The final average value used for further computation is then:
(N * AL + M * AR) / (N + M)

In the simple case of a single face left and face right pointing, the average value is (AL + AR) / 2

4.6.4 Repeat measurements

Operators always have the option of repeating measurements to a particular point if they wish to correct earlier measurements.

If averaged pointings are in use and the full set of pointings has not been made, repeat pointings will simply add to the existing average.

CDM

To guard against typing in the wrong point name, an option can be set which confirms any overwriting action before it is done.

4.6.5 Bolt holes

The objective of a bolt hole measurement is to combine several pointings from one instrument into a single pointing to the centre of the bolt hole. This procedure is necessary where it would be too inaccurate to estimate the centre of the hole directly with a single pointing, see diag. (a).

The method involves setting the cross-hairs tangential to the hole edge. Normally two diametrically opposite settings are made, as indicated in diagram (b). The mean of the horizontal and vertical angles is calculated and stored in the job file.

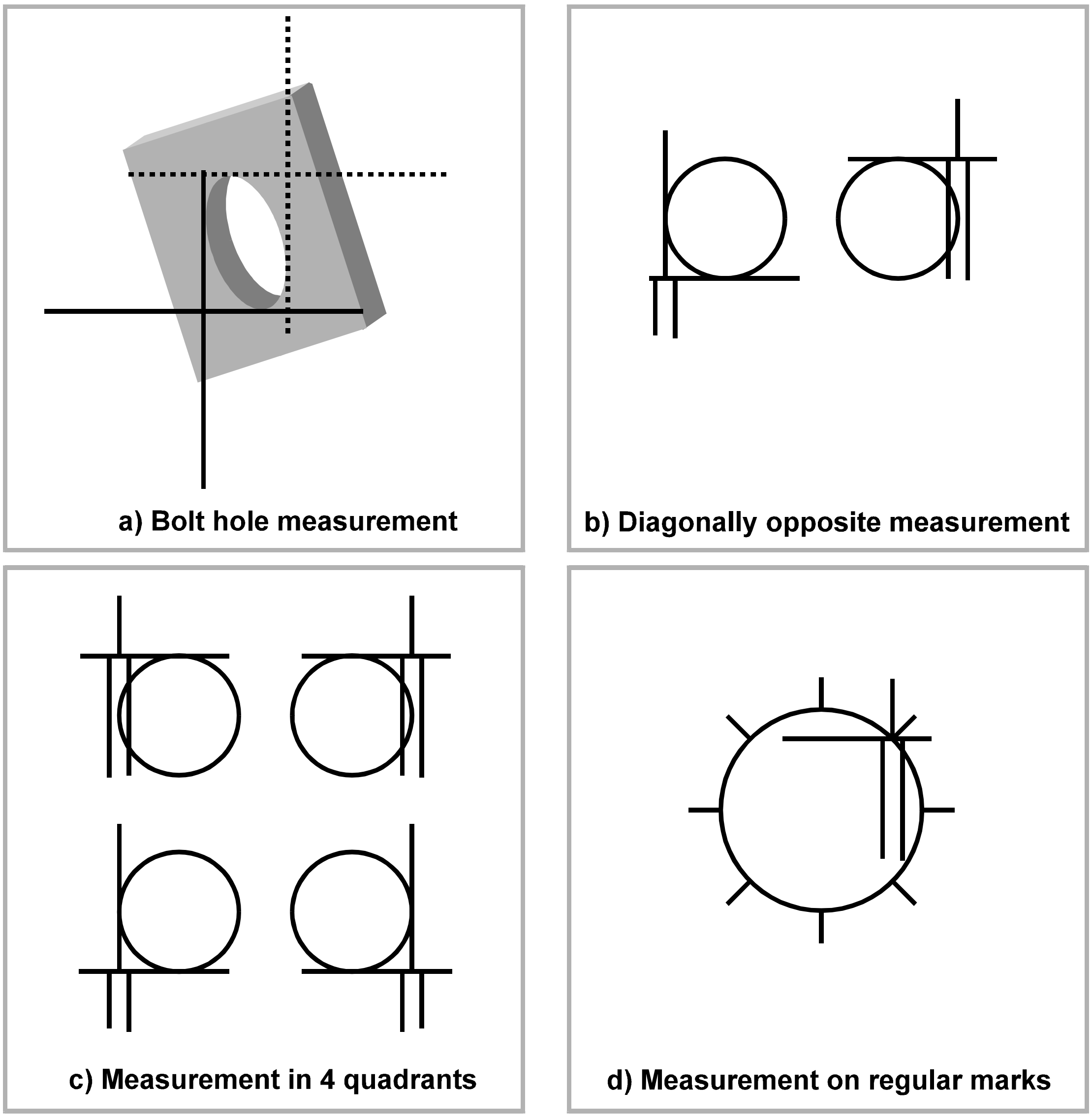
For greater accuracy measurement can be made in 4 quadrants as indicated in diag. (c). In fact, the stipulation is that there must be an even number of measurements regularly spaced around the hole centre. If a hole is marked with an even number of scribed lines as shown in diag. (d), then this is also permitted.

The measurements need not be made in the same face and can be made in any order. Face right values are converted to equivalent face left values and the bolt hole pointing is assigned the mean of the resulting horizontal and vertical pointings.

Note in the diagrams how the use of a double cross-hair requires the operator to estimate the centre.

To distinguish between measurements made in this way and those made directly to the target point concerned, ***Axyz*** refers to *bolt hole* and *single point* measurements.

Diagram: Bolt hole measurement



BOLT-HLE.WMF

Weights of bolt hole measurements

Like other multiple pointings, bolt hole measurements are not given any additional weights. The final reduced pointing to the centre of the bolt hole is given the same weight as a single direct pointing to the centre.

4.7 Hidden point devices

Hidden point devices are rods or more complex 3D frames which have a *tip* and a number of *offset targets*, also called *device points*, located away from the tip. The dimensional relationship between the tip and the offset targets is known by prior calibration of the device.

By placing the tip on a point which is not visible from all instruments it is possible to measure instead some or all of the offset targets. From the coordinates of the offset targets the coordinates of the hidden point can be calculated.

Unlike a bolt hole measurement which reduces a number of pointings at one instrument into a single representative value, 3D coordinates of the offset targets must first be calculated using pointings from different instruments before the hidden point itself may be computed.

Note
No simulated pointings, corresponding to the hidden point's location, are created.

Axyz permits users to locate hidden points as an on-line procedure or by post-processing data off line.

Hidden point bars for use in any job can be defined using the DM. The bars must be correctly calibrated in order to assign coordinates to the offset targets. Dimensions must be defined at a known temperature and the coefficient of expansion of the material must be recorded.

4.7.1 Simple linear rod

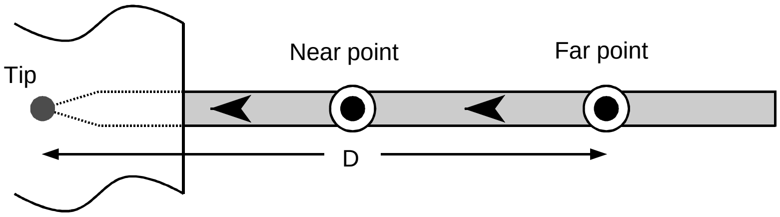
Often called an *offset rod* or *hidden point rod* this has two targets, known as the *near point* and *far point*, depending on their distance from the tip. It requires a single parameter which is the *offset distance D* of the far point from the tip.
The far point is first measured. When the near point is then measured it is used simply to indicate the direction <u>from</u> the far point <u>to</u> the hidden point.

Given the offset distance along this direction, the hidden point is easily calculated.

The near point is only used to define direction so its distance from the tip or the far point is not required. The requirement is only that it lies on the line joining the tip to the far point.

This type of definition is not directly used in ***Axyz***. Simple linear rods must be defined as multi-target rods which have two targets.

Diagram: Simple linear rod



Simple hidden point rod (linear device)

HIDPT-A.WMF

4.7.2 Multi-target linear rod

A multi-target linear hidden point rod has two or more targets arranged so that the tip and all the offset targets lie on a straight line. The offset targets are numbered in an increasing sequence, starting at 1. Only two of these targets are used to locate the hidden point, in the same way as the two targets on a simple linear offset rod.

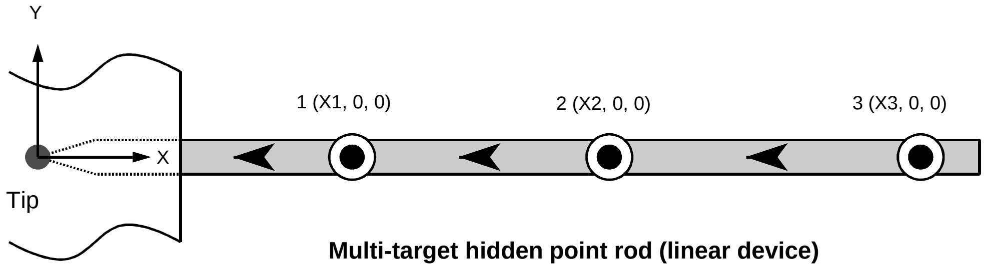
Although the rod can be manufactured with only two offset targets, the advantage of having more than two targets is to avoid difficult situations where one or more targets is obscured. Provided two other targets can still be seen, the hidden point can be calculated.

To enable all the targets to be used, the distance of each target from the tip must be defined. To further provide a uniform method of definition which is the same for non-linear devices a full set of coordinates is provided for each target in a local coordinate system.

The local coordinate system has its origin at the tip (0,0,0) and the local x axis runs along the line of the targets. The offset targets therefore only require x values which are equivalent to offset distances. Their y and z values are zero.
Targets have increasing numbers away from the tip so that the higher numbered target always represents the far point and the lower numbered

target represents the near point. The tip is always located by direction <u>from</u> the far point <u>to</u> the near point.

Diagram: multi-target linear rod



Multi-target hidden point rod (linear device)

HIDPT-B.WMF

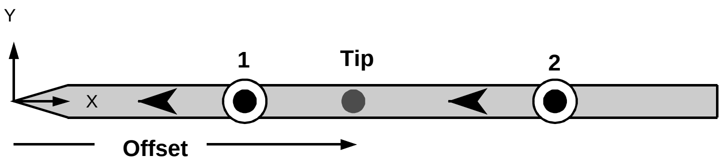
4.7.3 Sine bars

A *sine bar* is an American term for a type of hidden point device which has two targets and a hidden point lying between the targets. It is typically inserted into a gap where a central position between the sides is the critical point of interest.

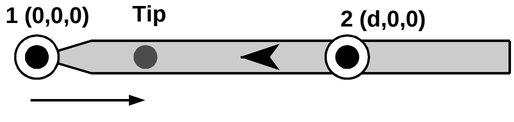
The sine bar requires the definition of an *offset* to re-position the hidden point between the targets.

When calculating the hidden point, its standard position is first computed and then the offset applied. Since the offset is normally calculated in the reverse direction in order to place the tip between the targets, the offset is normally a negative value.

Diagram: Sine bar



A sine bar requires an offset to place the tip between the targets



Typical Sine Bar definition

HIDPT-F.WMF

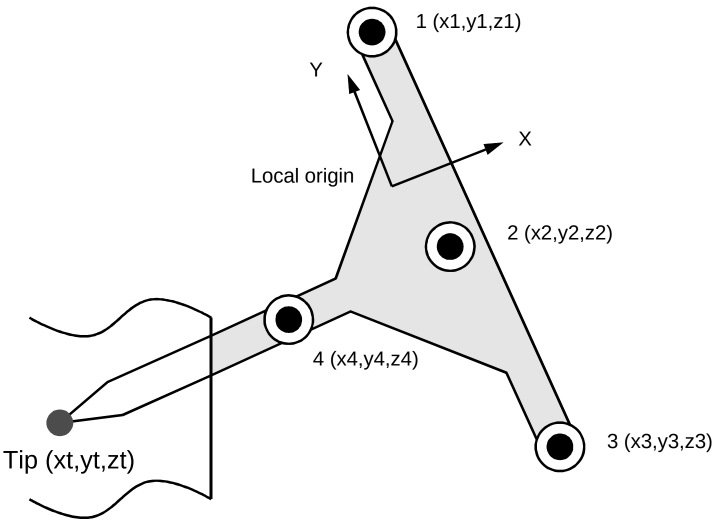
4.7.4 3D non-linear device

Non-linear hidden point devices are the most general type of hidden point device. These rigid frames have a probe tip and at least 3 offset targets which do not lie on a straight line. The offset targets are numbered in an increasing sequence, starting at 1.

The device is calibrated in a local coordinate system. Every offset target has full 3D coordinates in this local system. The corresponding hidden point does not need to lie at the local origin but it must also have known coordinates in the same system. If at least 3 offset targets, which must define a triangle, can be measured from the instruments in some existing coordinate system, a transformation can be computed between the local coordinate system of the device and the measurement system. This enables any other point on the device, in particular the hidden point, to have its coordinates transformed into the measurement system.

The transformation method is the same as the one used to create new coordinate systems by a best fitting 3D transformation.

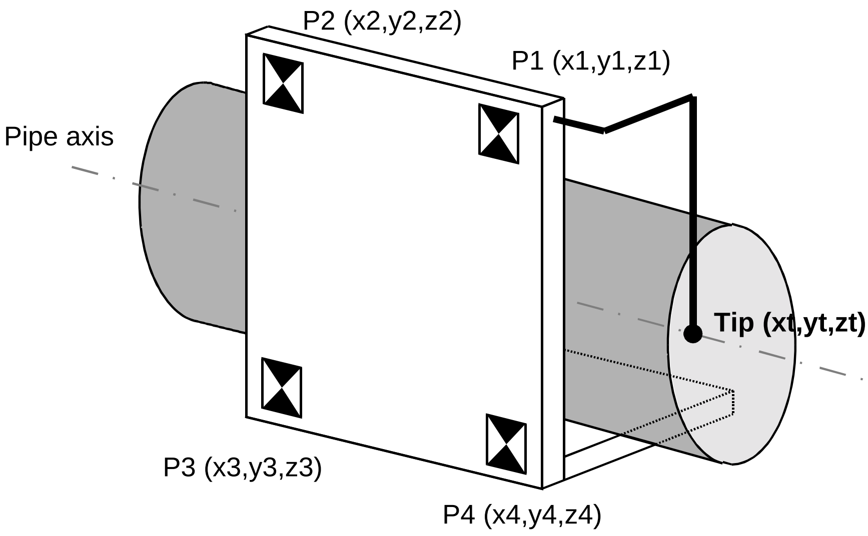
Diagram: 3D non-linear device



Multi-target hidden point frame (non-linear device)

HIDPT-C.WMF

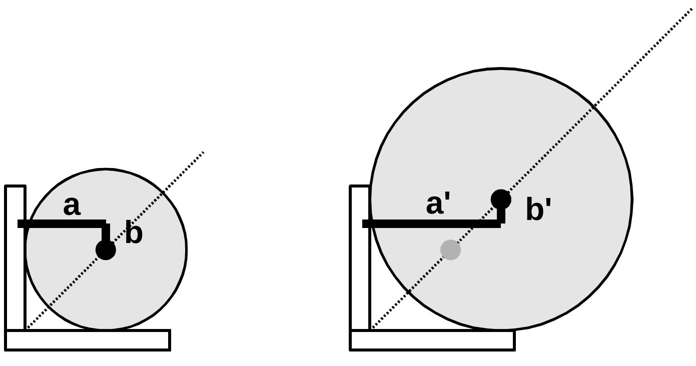
Diagram: Device for pipe centre location



Hidden point frame for locating pipe centres

HIDPT-D.WMF

Diagram: One device for different pipe centres



The same device can be used for different pipes if the tip coordinates are changed.

HIDPT-E.WMF

4.7.5 Hidden points on-line.

For on-line measurements offset targets are known as device points by ***Axyz*** and assigned a *device point number* which acts as an extension to the hidden point identifier. The device point number is a sequential positive number in a range starting at 1 and cannot be defined by the user. This number is recorded with both the measurements and the calculated 3D coordinates of device points.

To ensure compatibility in the database, device point number zero is assigned to the following:

- Normal measurements
- All 3D point types
- The hidden points calculated from their corresponding device points

Device point numbers are displayed by the Data Manager.

When measuring a point with a hidden point device, the point is named according to the standard rules. Since the point is measured indirectly and different hidden point devices may be available, each measurement must record:

• Point name:	16 chars, α-numeric
• Device number	numeric
• Device point number (offset target number)	numeric

Coordinates of the hidden and device (offset) points are stored in the same part of the job file as other measured points. Device points as well as hidden points can be used for further analysis although the only really practical use of device points is to calculate the hidden point.

A small degree of automation is available when deciding when sufficient points have been measured. This must be a manual choice for non-linear devices, since only the user can decide how many points beyond 3 should be used in a transformation. In contrast, a linear device only permits the measurement of two offset points. If the second measured offset target has a higher number than the first, the dialogue box for hidden point measurement is automatically closed and the hidden point immediately calculated.

See also "Hidden point devices used on line" on page 48.

Sequence of operation

- Identify the rod being used
- Name the hidden point, e.g. POINT-H
- Measure the required number of points on the device, indicating to ***Axyz*** which offset target number is next, e.g. (1), (5).
- When 3D coordinates of enough offset points have been computed, calculate the hidden point (see comments below).
- The offset points are stored as POINT-H:1, POINT-H:5 and the hidden point is stored as POINT-H:0.

4.7.6 Post-processed hidden points

Offset points are identified as normal points during measurement and subsequently "mapped" onto a hidden point device using the "Hidden point" function in the "Analyse" menu. The hidden point device need only be identified at the analysis stage.

Unlike on-line usage, the offset targets are recorded as normal points with device number zero and can have any names the operator wishes. However it may be convenient to choose names which:

- Incorporate the device point numbers in the name
- Identify the actual hidden point device as part of the device point name

Neither action restricts the final name chosen for the hidden point itself.

As with the on-line procedure, hidden and offset points are available for further analysis.

See also "Hidden points computed off line" on page 49.

Example: Calculate hidden point HOLE-31

Select offset targets:
HP1-1-H31
HP1-5-H31

"Map" these onto hidden point device number 1.
HP1-1-H31 maps onto device point 1
HP1-5-H31 maps onto device point 5

HOLE-31 can then be calculated and is stored internally as HOLE-31:0

4.8 Scale bars

Scale bars are often used to introduce scale when stations make angle measurements only, i.e. when the MTM is used to build a network. As an alternative to scale bars the following techniques can be used:

- Inclusion of control points
- Inclusion of stations with polar measurements (STM/MTM and/or LTM)

4.8.1 The Axyz multi-target scale bar

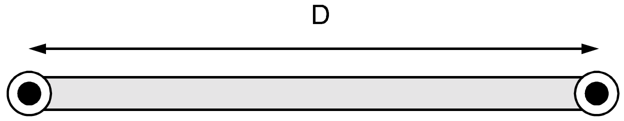
A conventional scale bar is a device with two targets having a calibrated separation. The diagram shows how this simple concept has been extended to a general purpose device which effectively defines one or more 2-point bars.

A scale bar in ***Axyz*** has the following properties:

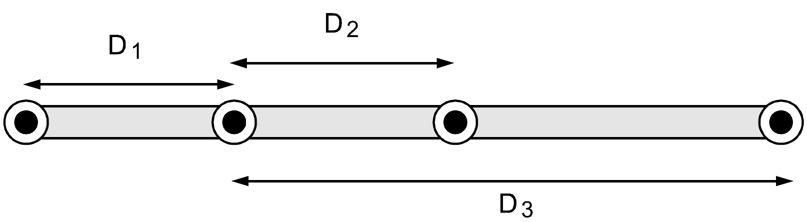
- It is a rigid device with 2 or more targets which need not be in line
- Pairs of targets define separate scale lengths.
- Not all possible lengths need to be defined.

Scale bars for any job can be defined using the DM. Lengths must be defined at a known temperature and the coefficient of expansion of the material must be recorded.

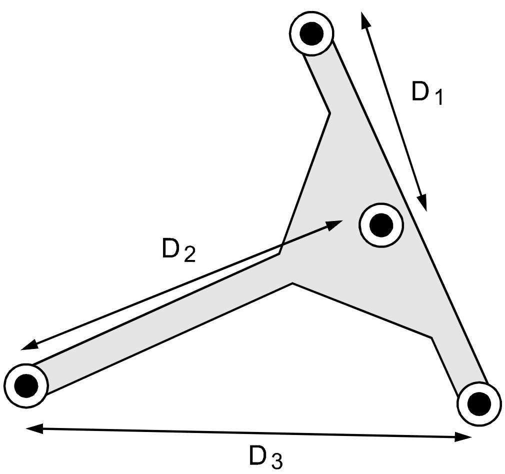
Diagram: Multi-target scale bar



Typical scale bar defining a single distance



A multi-target scale bar defines several reference lengths



General *Axyz* scale bar concept:
A device which combines several standard bars in one unit

SCALEBAR.WMF

4.8.2 Scale bars in the network

Scale bars are used by either moving the same bar to different locations or using different bars at different locations. Once in position, selected targets on the bars are measured and they obtain coordinates like any other points. However these coordinates are stored in a separate location from measured points, although they can be viewed in the DM.

The separation of these target locations must correspond to the defined scale lengths and the targets have 3 components for their identification:

scale bar identifier / current location of bar / number of target measured

The identifiers have the following format:

- The scale bar identifier is numeric and can be any positive integer.
- The location identifier is numeric and can be any positive integer.
- The target number on the bar is numeric. Targets are numbered sequentially starting at 1 and increasing.

This is explored in more detail in "Identifying measured scale bar targets" on page 46.

4.9 Target thickness and reflector offset correction

When targets are attached to the surface of an object, the purpose is to identify a point on the object's surface.

Measurements to a reflector clearly locate the reflector centre and not the surface point or object feature with which the reflector is in contact.

Some other mechanical targets clearly have an offset from the surface but even adhesive targets may have a significant thickness which should be taken into account.

If target thickness and reflector offsets are not taken into account, individual surface points will be incorrectly identified and any shapes defined by such offset targets will have incorrect parameters.

The purpose of these corrections is therefore to:

- Correct selected target points to the equivalent object surface point.
- Correct the parameters of standard shapes fitted to targets which have a significant thickness.

Two items of information are required to implement correction:
- The amount of the thickness or offset
- The direction in which the thickness is applied

The direction of the correction is the more complex item. Currently it can be specified in one of two ways.
- Along the axes of a particular coordinate system
- Perpendicular to the surface of a fitted shape

When correcting along axes, corrective components can be defined for all 3 axes.
When correcting to the surface of a shape, the relevant direction is the direction of the perpendicular offset from the target point to the surface.

Internally ***Axyz*** stores the coordinates of the actual target point, together with the information required to implement a correction. This information comprises:
- The amount of correction
- The name of the coordinate system or shape used to define the direction
- A label which indicates if the direction is a surface perpendicular (shapes only) or along the axes (shapes or coordinate systems).

It is possible that the coordinate system or shape does not exist. For example, this can happen when:
- The shape whose surface defines the direction of correction has not yet been calculated
- The shape or coordinate system has been deleted.

4.9.1 Recording and displaying target corrections on line

Target thickness and reflector offset corrections can be recorded for any point during measurement by setting a switch in the relevant theodolite module which records the associated thickness, shape or coordinate system name and the name of the relevant direction. The same correction data will then be recorded with every point subsequently measured until the switch is altered. On complex objects where several operators work simultaneously it is therefore important to coordinate the schedule of work so that targets with the same correction data are measured at the same time, otherwise there would be constant delays whilst individual settings were made.

It is not necessary for the shape or coordinate system to exist at the time of recording but if it does not exist a correction cannot be calculated and displayed until the operator creates it. The identifier for a non-existent shape or coordinate system is only recorded with the point information and is not added to the list of shapes and coordinate systems until it is actually created. It is the operator's responsibility to keep track of identifiers in these cases.

During on-line measurement, ***Axyz*** recognizes 3 situations and labels the measurement window accordingly.

1. Standard situation, no correction.
   No labelling is used.
2. Correction defined, corrective coordinate system known.
   "Tc" (target thickness) or "Rc" (reflector offset) correction is active and the correction is applied.
3. Correction defined, corrective coordinate system not yet defined.
   "T" (target thickness) or "R" (reflector offset) correction is active but the correction is not applied.

4.9.2 Recording and displaying a target correction off line

Using the DM, it is possible to record a thickness correction during post-processing of data. At this point the operator can also modify the definition of an existing correction. However, it is currently only possible to select a corrective coordinate system which already exists, since the choice is made from a list of all existing coordinate systems and shapes.

The DM always displays corrected coordinates if this is possible, i.e. if the defined corrective coordinate system exists. If the corrective coordinate system does not exist, the original target coordinates are displayed.

Corrections are calculated using the most recent parameter values for the corrective shape or coordinate system. This deals with the case that some values may have changed. For example, correction may be normal to a plane. If additional points are measured on the plane its parameters will change and so any associated target thickness corrections should also change.

4.9.3 Applying corrections during shape fitting

When fitting a shape where corrections applie, two situations arise.

1. If the direction of the corrective offsets is not defined by the shape being fitted, then the corrections are calculated using the information provided (e.g. along the X axis of an existing coordinate system). The shape is then fitted to the corrected points.
2. If the shape being fitted itself defines the directions of the corrective offsets then an iterative procedure is involved. The shape is first fitted to the actual target points after which a very good estimate can be made of the offset directions by using the perpendiculars through the fitted points. The corrections are then calculated using these directions and the shape re-calculated using the corrected points. The process is further iterated until the shape parameters do not significantly change.

In situation (2) there is a difficulty when fitting a line in space because it has no surface which uniquely indicates a perpendicular direction through the target point. The iterative procedure is therefore not followed in this case. Note that there is no problem for a line fit in case (1) since the implication is that the corrective direction is indeed known.

4.9.4 Corrections for polar targets

Target thickness correction allows for different corrective shifts along all three axes of a coordinate system. This enables the use of cylindrically shaped targets which are offset from the required point in two or three directions. The feature is particular useful in polar systems (STM).

4.10 Instruments

This section lists the instruments which are supported by the STM and MTM and discusses features relevant to their operation.

4.10.1 Supported theodolites and Total Stations

The ***Axyz*** **STM** Single Theodolite Module supports the following Leica total stations:

- TC 2002
- TDM 5000
- TC(M) 1800
- TC(M) 1700

Future total stations in the TCxxx range will be added to this list.

The ***Axyz*** **MTM** Multiple Theodolite Module supports the following Leica theodolites:

- All instruments supported by STM, but only for angle measurements. The distance measuring functions are ignored.
- T2002, T2000
- T3000, T3000A
- TM5000
- T(M) 1700
- E2, E2-I, E20, E20-I

The combined ***Axyz*** **STM/MTM** Theodolite Module supports the following instruments:

- E2 with E2/E20, E2-I/E20-I
- T/TC2000 with EPROM 1/10/84 or later (only angle measurements)
- T/TC/TM/TDM5000 without restrictions
- T/TC2002/T3000 without restrictions.

TPS1000 family.

4.10.2 Information displays

All instruments used by ***Axyz*** can display their readings at the instrument and transmit this data, together with other values, to the controlling computer.

Most instruments can also display other information relating to the current status of the measurement. Typically the operator will also see information at the instrument which indicates the name of the next point to be measured. This is unlikely to be the full "workpiece/point name" identifier and may only be the numerical increment.

The information display may also be able to indicate where the operator is in the current chain of measurements. For example, the display may indicate that the next measurement should be a scale bar point because that is required for a particular orientation sequence. Again, some instruments may not be able to display this information.

The complete measurement status of any instrument can always be reviewed at the controlling computer.

Wild Txxx series

- Accepts and displays numerical characters
- Accepts and displays some alpha characters
- Can send numerical characters only
- Warning tone at instrument

Code sequences can be input at theodolite keyboard which allow the measurement sequence to be completely controlled from the theodolite. For example, an operator can initiate a new sequence of point names from the instrument.

Kern Exx series

- Can accept and display numerical characters only
- Can send numerical characters only
- No warning tone at instrument

Measurement sequences cannot be initiated at the instrument.. For example to alter the current sequence of point names at a particular instrument, the operator must do this at the controlling computer.

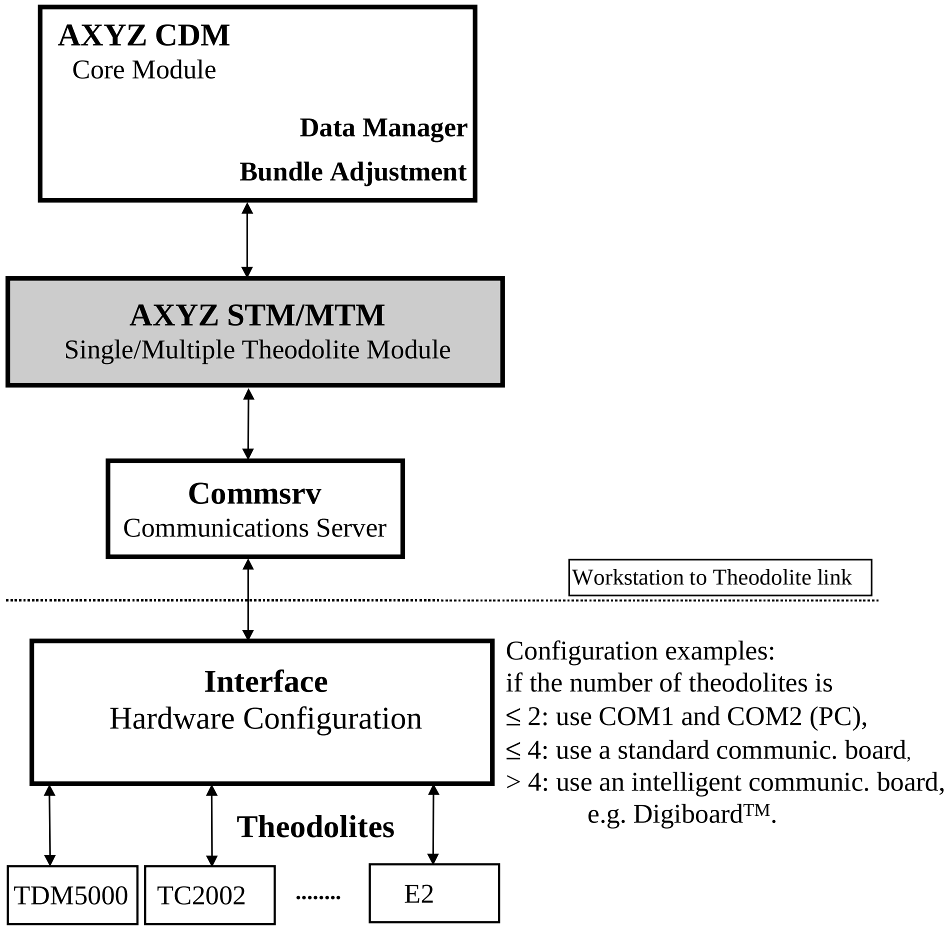
The E2 cannot “remember” the direction of a local horizontal zero setting when switched off. It is therefore advisable to keep the instrument switched on and connected for <u>all</u> measurements at any particular station. If measurements are interrupted and the instrument must be re-initialized, it is possible, but not recommended, to re-set the horizontal angle reading to the previous value at an existing pointing. (See manual for E2.)

You can then continue to make further additional pointings at the station. However, some small errors will always be introduced by this technique. It is better to create a new station and use this to add the further measurements.

Notes
If the E2 is unplugged at the COM port whilst still connected, this is equivalent to switching it off. When the plug is re-connected the instrument must be re-initialized. This is not a suitable method of changing stations!

The E2 can be configured at the instrument to display angles in gons, decimal degrees or degs. mins. secs. ***Axyz*** can also display angles in a variety of angle units. The two types of units may not be the same and different numbers may appear at the controlling computer and on the instrument's display panel. No errors are caused by this but you may wish to ensure that the same units are used in both places.

4.10.3 Interfacing with Axyz



The diagram shows the principal interfaces required for data acquisition and communication between the software modules.

Commsrv Communications Server

The Communications Server is the platform which transforms standardized theodolite data formats from the STM/MTM into the corresponding data formats of each theodolite type and vice versa.

Interface / Hardware Configuration

Communications between theodolites and workstations are handled by a built in serial port or Rocketport™ . Different configurations are possible.

5. Working with laser trackers

5.1 An introduction to measurement with the LTM

The laser tracker derives its name from its original configuration. This was a laser interferometer (IFM) which tracked a moving retro-reflector via a motorized mirror. The interferometer permits dynamic distance measurement, i.e. continuous real-time distance measurement. Once locked onto a reflector, it tracks and displays the reflector's position in all modes of operation until the beam is broken.

Although the IFM inherently works dynamically, it can equally well be used to measure fixed points in order to create a single data entity. Alternatively its tracking capabilities can be used to track a moving reflector and create a data entity which is a related set of measurements.

The interferometer can only measure a change of distance and must remain in continuous contact with the retro-reflector. It supplies absolute distance by starting from a known location. If the beam is interrupted its distance reading can be re-initialized by returning the reflector to a known point. A fixed location known as the *Home Point* or *"Birdbath"* is provided on the instrument itself for establishing the starting distance, although other existing points can also be used for this purpose.

Using an existing known position to deal with beam breaks may be inconvenient and so an optional, high precision Absolute Distance Meter (ADM) was developed. Inside a few seconds this device can establish absolute distance to <u>any</u> fixed reflector, whether or not its location is already known. The ADM can therefore be used to automatically re-initialize the IFM and also enables the tracker to be used as a single point, polar measuring instrument, like a very accurate Total Station.

Prior to use a tracker must be warmed up, initialized and assigned to a station before measurements can be made. However measurements can be made and stored in the job file before the station is oriented into the measurement network.

A tracker always operates with a reflector and it is the centre of the reflector which is always measured. Normally some form of correction is required to derive the location of an object point from one or more reflector locations. Since reflectors have different dimensions and optical properties these must be defined and a specific reflector selected for measurement.

By attaching a NIVEL electronic tilt sensor, stations can also be referenced to the vertical (levelled) if required.

Once preparations are complete, you choose an operating mode and method to achieve what you want to do.

Measurements are initiated and completed with the start/stop buttons and results viewed on screen in one or more *measurement windows*.

Further stations can be created by moving the tracker to a new location or switching to another on-line tracker. The Orientation Module makes the necessary computations to add these to the network. For orientation to work, the new station must measure some existing points.

Special orientation requirements are not required if the measurement network consists of a single station. Once preparations are complete and the instrument is in good adjustment, coordinates can be immediately generated.

Although multiple trackers can be connected to the system, only one can be the *active tracker* and make measurements.

5.1.1 The components of a tracker system

The LTM software runs on a controlling PC called the *Application Processor (AP)*. The ***Axyz*** core module (CDM) and any other installed modules, e.g. MTM, also run on this PC.

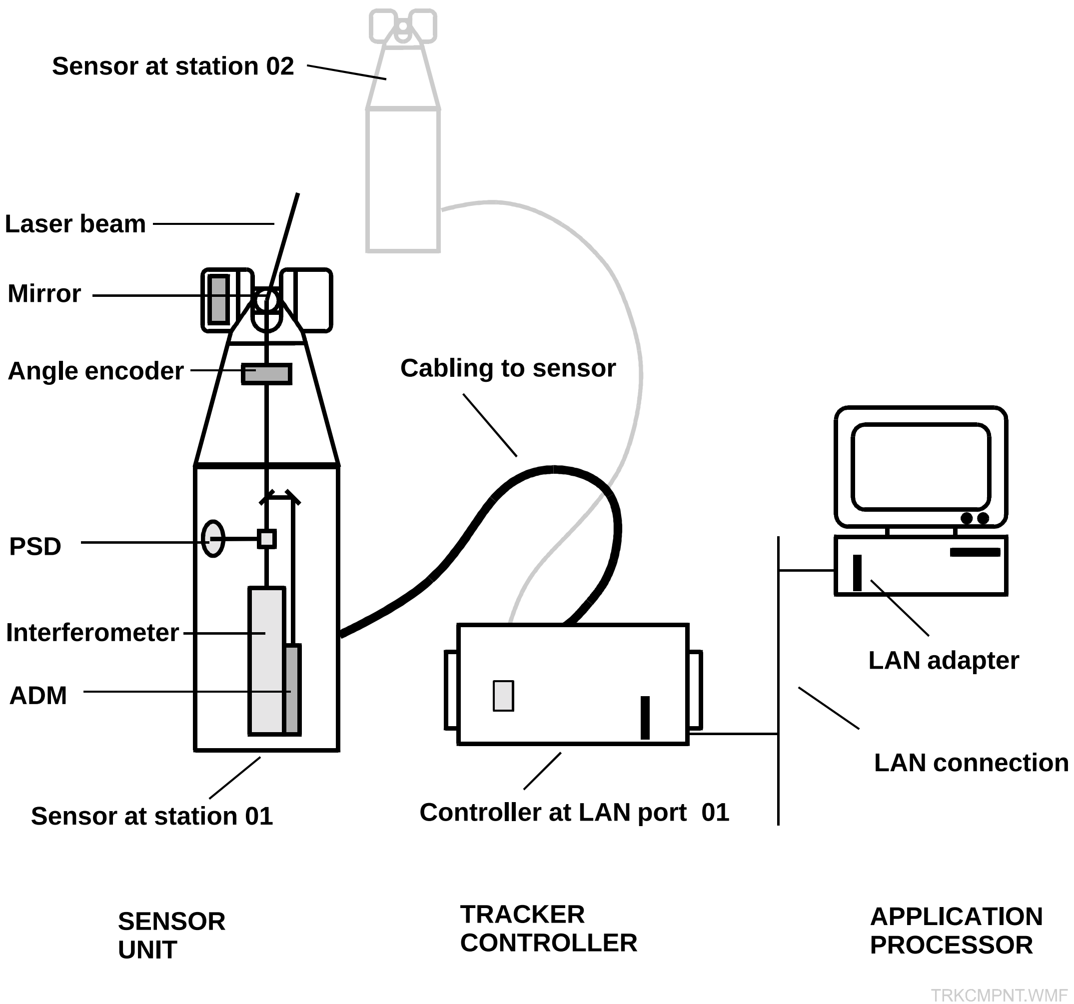
The Application Processor communicates with any connected trackers via a *Local Area Network (LAN)*. Commands sent to a tracker, and measured data received from it, are all transmitted over the LAN. Connection to a LAN is through a LAN adapter, which is a PC card housed in the box of the Application Processor. The AP may be connected to more than one LAN, for example an office e-mail network as well. It may be necessary to establish the correct *LAN adapter number* during installation to ensure that the LTM recognizes the correct network.

Communication with a tracker is not done directly with the *tracker sensor unit*, which houses the IFM, ADM, angle encoders etc, but with another

PC known as the *Tracker Processor (TP)*. The TP is housed separately from the AP and sensor unit. It supervises the operation of the individual components in the sensor unit and from them reads the raw measurement data, compensates for lack of alignment, and returns corrected and filtered data to the AP.

The sensor unit contains a unique *serial number*, often called *tracker number*, which identifies it and ensures that the correct alignment parameters are employed. This unit need not be permanently attached to a particular TP since the TP identifies which sensor is attached via the tracker number. This ID ensures that the correct alignment parameters are downloaded from the AP during initialization.

Diagram: Tracker components



Operating multiple trackers from one Application Processor

Multiple trackers can be connected to the LAN, although the LTM will only communicate with one tracker at a time. This is known as the *active* *tracker* and can be freely chosen by switching between the available instruments.

This operation contrasts with the MTM which accepts measurement data from multiple on-line instruments in a quasi-simultaneous fashion. However, the LTM supplies data at a very much higher rate than theodolites and Total Stations and the simultaneous recording of continuous data streams from several on-line trackers would be technically very demanding.

Addressing individual components

As indicated above, each tracker attached to the LAN is actually represented by a Tracker Processor (TP) and the Application Processor (AP) communicates with an individual TP.

To ensure correct communication, each TP on the LAN must have a unique *LAN address*. In analogy with the COM port to which a theodolite is connected in the MTM, this may be called the *LAN port* for a particular instrument. The address is set on the TP itself.

A LAN address can be a multiple alpha-numeric character string which allows for a large number of addresses. ***Axyz*** currently uses the integers 0 – 9 as addresses. Address 0 is the AP itself and addresses 1 – 9 are used for individual TPs.

All trackers are delivered from the factory with a default TP address = 1. If you purchase more than one instrument for multiple on-line use, further instruments must have the TP's LAN address changed. A utility program, RENAMER.EXE, is available to do this.

Attaching a NIVEL via the LAN

A NIVEL dual-axis tilt sensor can be attached to a tracker for general monitoring purposes or to enable it to be referenced to the vertical. See also "Gravity reference with the NIVEL" on page 148.

If it connects via the LAN then it does so through the corresponding TP and it effectively becomes another component of the sensor unit.

5.1.2 Data rates and filtering data (IFM)

The tracking interferometer has a fundamental *data collection rate*. This is the number of corrected measurements supplied by the *Tracker Processor* per second. A corrected measurement is one reading of horizontal angle, vertical angle and interferometer distance, corrected for the tracker's error model.

Normally the collection rate is much higher than a user requires and the stream of 3D data must be *filtered* by the Application Processor according to time or distance criteria. For example you might choose to accept data only every half second or select data points which are separated in 3D space by some minimum amount. In some cases it may also be relevant to specify, in addition, the total number of points to be recorded.

The maximum rate of data collection is 1000 points (h,v,d measurements) per second or one point every 0.001 second.

Under certain conditions the system may not be able to handle this and some information will be lost. For example, if the Application Processor is busy with computationally intensive tasks such as graphics display, it may not have the capacity to handle a large data stream.

The loss of a small percentage of points will not usually be a problem but it is possible to set a lower collection rate to ensure that no data is lost. (This is an additional filtering process carried out by the Tracker Processor.) The need for this will depend on the user's own system configuration and power and so the software does not make any recommendations.

Clearly, the data collection rate places a limit on the maximum amount of data which can be filtered for recording. If the collection rate is set to one point every 0.01 seconds then you cannot set a shorter time interval for filtering data.

5.1.3 Features of absolute distance measurement (ADM)

The ADM does not function at close range, approximately less than 2m from the mirror.

The ADM does not operate dynamically. It requires a few seconds to calculate distances and can only be used with stationary point measurements and in Auto Inspect Mode. Auto Inspect mode is therefore only available if the instrument has ADM.

The function to find and lock onto a reflector at an unknown position will only work if ADM is available.

Stationary point measurement with the ADM active automatically re-sets the IFM distance.

The ADM is not used as an independent device but only as a device for re-setting the IFM distance. If a single point measurement is made with the ADM the sequence is this:

- Measure distance with ADM
- Reset IFM distance with ADM distance
- Record reading as a normal IFM reading

For this reason data filtering is always defined, even with the ADM active.

5.1.4 Building a measurement network

If the first station in a network is a laser tracker, this is immediately assigned the status of "oriented". This enables the user to generate 3D coordinates with a single laser tracker and without the need to perform an *orientation*.

Further stations can be added sequentially in order to build up an extensive measurement network with a maximum of 99 stations. If the theodolite module (MTM/STM) is also used on the same network, some of these stations may be occupied by theodolites or Total Stations.

New tracker stations are oriented into the network by measuring some existing points:

- Non levelled stations must measure at least 3 points, not all on a straight line, are required
- If both station and coordinate system are levelled, at least 2 points with some horizontal separation are required

5.2 Preparing for measurement

5.2.1 Warm-up

Before a tracker can be used it must be switched on and allowed to warm up. At least 30 minutes are recommended for this phase.

5.2.2 Laser on or off

A warm-up phase is required to allow all internal components to stabilize before the tracker can be used for measurement. If the tracker is not in use you may wish to keep it switched on and warm, but this may reduce the life of the laser tube. It is therefore possible to switch the laser independently on or off whilst keeping the rest of the system live.

In addition, the warm-up time for the tube itself is about 15 minutes, shorter than the time for the complete system.

5.2.3 Initialization

A number of components and parameters of a laser tracking system require checking and/or initialization with specific values in order for measurement to be possible.

Initialization is largely automated although it can also be activated by the operator. During the initialization procedure the operator may have to supply information or take actions as directed.

Temperature and pressure

Temperature and pressure values are needed to adjust the refractive index for the laser and ensure that it generates accurate distances.

These can be manually input or read on line from sensors connected to the COM ports.

5.3 Recording buttons

Once an operational mode for a particular type of measuring task has been specified, the recording buttons initiate the measurement process. The buttons are also offered as menu choices.

5.3.1 Start

The **Start** button has a function similar to the **REC** and **ALL** buttons in the MTM.

Since a tracker normally obtains its data dynamically, even determining a single fixed reflector location depends on a sequence of measurements which take a short time to record. Many procedures require a significant amount of time to complete the defined measurement. For this reason the button is named "Start" to indicate that a measurement sequence is initiated.

For sequences which have no built-in limit, for example a fixed time interval or a fixed number of individual measurements, an explicit **Stop** is required to end the sequence.

During a measurement sequence, or when the sequence is complete, coordinates are calculated and stored.

5.3.2 Try

It is often convenient to calculate and display the current reflector coordinates without actually storing them. This is the purpose of the **Try** button.

Try is an alternative to **Start** and has the same function except that it does not store any data in the database. It is used simply to make a quick check.

> **Note**
> The LTM **Try** button functions slightly differently from the **Try** button in the MTM. In the LTM it is used as an alternative to **Start**. In the MTM, **Try** blocks the storage action of the **REC** and **ALL** buttons as long as it is active.

5.3.3 Pause

Currently only applicable to Auto Inspect mode.

The Auto Inspect mode moves from point to point in a defined list of points. The Pause option allows the operator to interrupt this sequence and set up reflectors at the next few points in the list.

5.3.4 Stop

This button stops a recording sequence, such as Continuous measurement.

5.4 Sets: Multiple related locations

Theodolites, Total Stations and the tracker's ADM can only record measurements to fixed points in space. In contrast the interferometer can operate dynamically.

When continuously tracking with the IFM the tracker can record up to 1000 locations per second. Each record is an individual measurement (h,v,d) of a particular point in 3D space. Because of the potentially high data rate and the ability to make multiple measurements of a particular feature within a short period of time, it is convenient to introduce the concepts of *measurement sets* and *coordinate sets.*

5.4.1 Examples of measurement and coordinate sets

Tracking a reflector moving on a spatial curve

A reflector can be attached, say, to the end effector of a robot and continuously tracked. Each record in the resultant *measurement set* represents a 3D polar location of a point on the robot's track. When viewed in the Data Manager the corresponding 3D network coordinates will be displayed if the associated station has been oriented.

These individual polar measurements can be used in 3D analysis functions.

Scanning the surface of a large object

A reflector can be moved across and in contact with a large smooth surface. This generates a *measurement set* of (h,v,d) values. However the objective here is to compute a set of 3D spatial locations on the surface so the measurement set, relating to the reflector centre locations, must be further processed. This can be done by calculating a surface offset in the Graphics Module which in turn produces an associated *coordinate set* of (x,y,z) values.

Both sets can be used for 3D analysis.

5.4.2 Measurement sets

A measurement set is a stream of continuous measurement triplets (h,v,d) to the current reflector position from a single tracker and represents the dynamic measurement of a moving reflector.

A measurement set is generated in **Standard** mode using the **Continuous** and **Grid** methods.

5.4.3 Coordinate sets

A coordinate set is a related group of coordinate values, typically (x,y,z) values, located within the measurement network. It has three sources.

1. It is a stream of coordinate values derived from a measurement set generated by the **Continuous** or **Grid** methods in **Standard** mode. For a scanned surface, the measurement set acts as the input data for calculating the corresponding coordinate set using the **Surface Offset** function in the **Graphics Module**.
2. It is a set of coordinates imported via the **Data Manager** from an external source, for example from a surface fit using 3rd. party software or a CAD model.
3. It is manually created in the **Data Manager**.

5.5 In brief: Measurement modes and methods

When measuring with the tracker there are some common techniques identified with various classes of application, for example:

- Locating stationary points such as fixed reflector positions
- Recording continuously to evaluate movement such as the sweep of a robot arm
- Setting out locations to match design coordinates (building)
- Recording points on a Ball Bar to help calibrate an instrument

These techniques have their own particular requirements, for example:

- Averaging values to calculate an accurate stationary location
- Data filtering for optimal points on the 3D track of a robot
- A list of reference coordinates for the build points
- Separate recording of the Ball Bar measurements because they refer to a circle

Axyz identifies operational modes, individual methods and recording options which reflect the general way you want the system to operate.

Modes display results on line in measurement windows configured for each type of mode. When a mode is selected any open measurement window changes its display to reflect the new mode.

5.5.1 Summary of modes

Standard mode

This mode is used to acquire basic 3D point information. It offers several methods for locating single fixed points and distributed sets of points recorded by a moving reflector.

Standard mode is found on the **Mode** menu and the method of data acquisition is found on the **Measure** menu.

The following methods are available for 3D data acquisition.

- **Stationary**
  Direct measurement to the centre of a reflector at a fixed location.
- **Sphere**
  Measurement of a fixed location using an adapter which puts the reflector on a spherical surface whose centre is the required fixed point.
- **Circle**
  Measurement of a fixed location using an adapter which puts the reflector on a circle whose centre is the required fixed point.
- **Continuous**
  Continuous recording of locations of a freely moving reflector. Various time and spatial criteria can be used to filter the data.
- **Grid**
  Continuous recording of a freely moving reflector as it moves through the surfaces of a spatial grid.

Build (and inspect) points mode

This mode is used for manually setting out new points (Build) or manually checking the positions of existing points (Inspect).

Build points mode is found on the **Mode** menu.

Build Shapes mode

This mode is used to manually set out points on a standard ***Axyz*** shape surface (e.g. cylinder) or check the offsets of existing points from a standard surface.

Build Shapes mode is found on the **Mode** menu.

Auto Inspect mode

This mode can automatically check a set of fixed reflector locations by direct, individual measurement to each. The mode requires ADM.

Auto Inspect mode is found on the **Mode** menu.

CAD Build/Inspect mode

Users of the ***Axyz*** CAD module can **Build** and **Inspect** points on a **CAD** surface. **CAD Build** is used to manually set out points on the surface of an imported CAD model. **CAD Inspect** mode is used to manually check the offsets of points from the surface of an imported CAD model.

CAD Build/Inspect mode is found on the **Mode** menu.

On-line compare mode

Users of the ***Axyz*** CAD module can scan points continuously on a surface and automatically compare these on line, as they are created, with the surface of an imported CAD model.

On-line compare mode is found on the **Mode** menu.

Check and alignment modes

To make instrument checks and calculate instrument alignment parameters, special measurements must be made. The following types of measurement are required and are separately recorded:

- **Two face measurements**
  A fixed point is measured in both mirror positions. This option can be found on the **Align** and **Setup** menus.
- **Ball Bar measurements**
  A Ball Bar moves a reflector around a very precise circle. Sets of Ball Bar points can be recorded using options on the the **Align** and **Setup** menus.
- **ADM/IFM distance pairs**
  To ensure consistency between ADM and IFM readings, paired measurements to fixed points are required.

5.5.2 Filtering and other measurement criteria

The following options are available to filter the measurement data. A number of filter options can be combined. For example, measurements can be triggered on a spatial grid and only within a defined area.

Measurement count

The number of 3D data items filtered from the data stream can be defined. Once collected, measurement automatically stops.

Alternatively a **Continuous** stream can be chosen. In this case measurement must be stopped by the operator.

Time separation

The time interval between measurements filtered out of the data stream can be varied, with a minimum interval of 0.001 secs.

Distance separation

For continuous measurements, data can be filtered according to spatial criteria:

- Absolute separation in space by a defined amount
- Separation along a defined axis by a defined amount

Recording on a grid

Data can be filtered during dynamic measurement by recording a 3D measurement as the reflector's position changes by specified amounts along each axis.

For each axis this effectively implies a set of parallel planes perpendicular to the axis. As the reflector moves through the planes a measurement is triggered.

Recording inside or outside a boundary

All the dynamic scanning methods permit the operator to record data in a specific volume or region of the working space. This may be a spherical volume or a rectangular box and measurements may be recorded outside or inside this volume.

- A spherical region is defined with a centre point and radius.
- A box is defined by 2 points on diagonally opposite corners.

5.6 Measuring fixed locations

Fixed locations can be measured in several ways by:

- Averaging measurements to a stationary reflector (Stationary method)
- Indirect location of the point by the circle centre routine (Circle method)
- Indirect location of the point by the sphere centre routine (Sphere method)

Points located by the stationary method are the direct equivalent of points measured by theodolites and Total Stations. The averaging method produces a single representative pointing which can be used by the Orientation Module to build the measurement network. If the same location is measured by this method from another station, then the averaged pointings can be used by the Single Point Solution to calculate an optimal 3D position.

Fixed points indirectly measured by the circle and sphere methods are similar to hidden points. They do not generate an equivalent single pointing and cannot be used by the Orientation Module or Single Point Solution. The centre points, when calculated, are recorded in the job file as points of type "entered". If the locations are measured from other stations, the later measurements will optionally overwrite the current ones.

5.6.1 Stationary point (reflector centre) with IFM

With this technique, stationary points are computed by averaging a series of tracker measurements to a stationary reflector. Horizontal angles, vertical angles and distances are separately averaged to create a single measurement triplet which is stored as a measurement of type **normal.** This can be used by the Orientation Module and Single Point Solution for network construction and optimal point location.

The only relevant filter options are time separation and number count.

5.6.2 Stationary point (reflector centre) with ADM

If ADM is available, the technique is the same as for measurement with the IFM, except that the IFM distance is first re-set by an ADM distance measurement.

5.6.3 Sphere centres

A fixed point such as a hole centre can be measured indirectly with an adapter which has a spherical surface. This locates on the point to be measured such that the centre of the sphere occupies the point. The operator records a reflector's position as it is scanned across and in contact with the sphere's surface.

The measured reflector positions also lie on a spherical surface with the same centre as the adapter. After measurement is complete this centre is the required point location. It is automatically calculated using a least squares fit to a spherical surface and stored as a 3D point of type **entered**.

The only relevant filter options are time separation and number count.

5.6.4 Circle centres

A stepped cylindrical adapter can be used to locate a point indirectly. By scanning a reflector around the step, reflector positions on a circle can be recorded. The centre of the circle lies on the axis of the cylinder. After measurement is complete this centre is the required point location. It is automatically calculated using a least squares fit to a spherical surface and stored as a 3D point of type **entered**.

The only relevant filter options are time separation and number count.

5.7 Dynamic measurements and applications

The laser tracker is fundamentally a device which measures dynamically. It can be used to locate fixed points in 3D space but one of its most useful features is to record the 3D path of a moving reflector.

5.7.1 Continuous scanning

This is one of the methods of data recording offered within **Standard** mode and is used to continuously record the location of a moving reflector. The individual point locations are stored as a **measurement set**.

The following criteria can be used to filter the points from the data stream:

- Measurement count
- Time
- Distance
- Boundary

To record data:

- Start procedure with **Start** button.
- Stop procedure with **Stop** button.

5.7.2 Scanning data on a 3D grid

This is one of the methods of data recording offered within **Standard** mode and is used to trigger measurements of a moving reflector as it moves through a defined spatial grid. This is a form of continuous measurement with a different filtering specification.

The individual point locations are stored as a **measurement set**.

The following criteria can be used to filter the points from the data stream:

- Measurement count
- Time
- Grid
- Boundary

To record data:

- Start procedure with **Start** button.
- Stop procedure with **Stop** button.

5.7.3 Simple free form surface digitizing (Axyz CAD)

Axyz provides functions for calculating the parameters of some relatively simple, standard shapes such as planes, spheres and cones which are fitted to measured points. There are no functions to find parameters describing more complex free-form surfaces such as car body panels and engine cowlings. Instead these surfaces can be digitized and the set of 3D data passed onto another system for further processing if required.

A surface can be digitized by first tracking a moving reflector which is manually scanned across and in contact with the surface. The recording of suitable points is triggered using either the **Continuous** or **Grid** methods of **Standard** mode. The result is a measurement set of points which are all offset from the surface by the radius of the reflector.

Users of ***Axyz*** CAD have a **Surface Offset** function which can then take this data and automatically create a coordinate set of points which are offset from the measurement set. This coordinate set represents locations on the actual surface.

Offset correction

The correction is done by calculating a perpendicular to the surface through each point and then applying a correction along this perpendicular. For each measured point there is therefore one corresponding corrected point.

Note
If the measured points are distributed in an irregular pattern, so are the corrected points.

The direction of this correction must be known. Currently the perpendicular has a positive direction defined by the viewing position for the graphics window, i.e. the closest point to the user in the list of points to be offset defines the positive side of the surface. If an offset is defined as positive this means that the target is positively shifted along the local perpendicular. Any correction must be made in the opposite direction.

If the shift must be made in the other direction then either the viewing position must be altered or the offset must be entered as a negative value.

5.8 Building and inspection techniques

Build and inspection techniques evaluate how close the current measured location is to a reference location or surface.

5.8.1 Offset tolerances

Offset tolerances help the system and the operator recognize if the reference position has been reached. The current offsets are compared with the tolerance values to see how close the reflector is to the reference position. The system recognizes the following conditions:

- Offset within tolerance
- Offset 1 - 2 times tolerance
- Offset 2 - 3 times tolerance
- Offset > 3 times tolerance

The display is colour-coded to indicate the first 3 levels, otherwise there is no colour coding.

5.8.2 Concept of Build/Inspect points

This mode is used for manually setting out new points (Build) or manually checking the positions of existing points (Inspect).

The objective is to show the spatial differences between the current reflector position and a reference position.
Unlike the MTM, build and inspection are effectively combined in the LTM.

The dialogue box initiates the process. Once options are specified, further progress is monitored in the relevant measurement windows.

A list of points to be built is selected from the reference points. If a point is input manually, the list only contains the one point. The manually input point is not stored in the reference area but can be stored in the object area by subsequent measurement as a normal measured point.

Sequential point building

Currently only one on-line station is possible. The station works sequentially down the list. By default the starting point is the top of the list but a point within the list can be chosen as the starting point. Points are then measured sequentially down to the bottom and continue again from the top. To change the order of the build points, select them in the required order from the Data Manager using CTRL + left click.

Build to closest point

As the reflector is moved, the system refers to the closest build point and shows the offsets to that point. It is not therefore necessary for the operator to recognize individual points nor to be restricted to a particular build order.

Recording and display

The **Start** button initiates the build process and the **Stop** button ends it.

Whilst the process is active there is a continuous display of the coordinate differences between the current reflector position and the current reference point.

To measure a point the operator clicks again on the **Start** button. The measured point takes the workpiece name and point ID from the corresponding reference point.

After measuring a stationary point the display returns to continuous display.

Since **Build** mode uses both continuous display and stationary point measurement, parameters must be set to cover both forms of operation.

Build to closest point
The points on the build list always remain active. The operator can return to any point at any time to compare reflector and reference coordinates or to measure the current reflector position.

Build sequentially
To move to the next point on the list the operator must make a measurement of the current point. To return to previously measured points the procedure must be re-started.

Build or Inspect?

Build mode is initially assumed. Differences are displayed as (Meas - Ref). If Inspect mode is specified, differences are displayed as (Ref - Meas).

5.8.3 Vector mode

This is a variation of Build/Inspect points. It follows the same procedures outlined in Vector Mode for theodolite systems.

5.8.4 Concept of Build/Inspect shapes

Build/inspect shapes has two objectives:

1. To check how an existing object surface conforms to one of the standard ***Axyz*** shapes such as a sphere or cylinder.
2. To set out points on one of these standard surfaces.

When a reference shape has been defined the reflector is tracked and the measurement view shows the perpendicular offset of the current reflector position from the defined surface. A reflector offset may be optionally taken into account. When a zero offset is shown this means:

- If offset not applied: Reflector centre is on the surface of the shape
- If offset is applied: Reflector housing touches the surface of the shape

A shape is defined by the currently active coordinate system and, if necessary, an additional size parameter.

Build to a new shape

1. First create a coordinate system which represents the local origin and axes of the new shape.
2. Make this the currently active coordinate system
3. Specify any size parameter, e.g. radius if a cylinder.

Inspect an existing shape

1. Make the coordinate system of the shape the currently active coordinate system.
2. Manually input any size parameter relating to this shape.

Note
It is not possible to directly select an existing shape from the database.

5.8.5 Concept of Build/Inspect CAD models

CAD Build is very similar to **Build shape**. Where **Build shape** uses the surface of a standard ***Axyz*** shape, **CAD Build** uses the surface of a CAD mode.

Unlike **Build shape** where the user defines the shape surface, **CAD Build** requires an imported CAD model. The objective is then to set out points on the surface of this model.

Points are set out by tracking the reflector. The measurement window shows the perpendicular offset of the current reflector position from the CAD surface which should be zero. A reflector offset may be optionally taken into account. When a zero offset is shown this means:

- If offset not applied: Reflector centre is on the CAD surface
- If offset is applied: Reflector housing touches the CAD surface

In contrast to **Build shape** mode, the perpendicular offset is not displayed as a single value. Instead the offset is calculated as a vector and its components in the currently active coordinate system are displayed.

For **CAD build**, offset = (Measured value minus reference value)
For **CAD inspect**, offset = (Reference value minus measured value)

The reference value is the current foot of the perpendicular from the measured point to the CAD surface and its location changes as the reflector moves.

Note
This mode does not set out specific points on the CAD surface. To do this you must either import points which lie on the CAD surface or create points on the CAD surface. You can then use **Build points** mode to set out these specific locations. Functions are available in ***Axyz*** CAD to extract points from a CAD model or create points on the surface of a CAD model.

5.8.6 Concept of Auto Inspection (points)

Auto-inspection is only available to instruments with ADM.

This technique uses the ADM to check the coordinates at a number of locations semi-automatically. A reflector is expected at each location but different reflector types can be used. Checking is done by recording the actual reflector location and showing its differences with a nominal value.

A file of point names and reference coordinates indicates the points and order of measurement.

The tracker moves independently from one location to the next, pausing at each to allow time for the results to be displayed and viewed on screen. At each location it does a spiral search to find the reflector and measures the position using the ADM. In this technique, therefore, points are not measured by tracking a single reflector from one point to the next and the method is only available to trackers with an ADM.

Limited number of reflectors - use of PAUSE

The operator may not have sufficient reflectors to occupy all points to be inspected. In this case it is possible to pause the sequence whilst the operator moves reflectors from points already measured to points yet to be measured.

Clearly it would be possible to work with a single reflector, pausing between each point. The alternative would be to use Build and Inspect points mode and track the single reflector from point to point. The former option may be more attractive if the measurement site has many obstructions which would keep causing beam interruptions.

Repeat passes

With Auto Inspect it is possible to repeat passes through the file of points to be inspected. The repeat measurements may either be averaged or the latest measurement can overwrite the previous measurement.

Error conditions

If there is an error condition, for example when a reflector is not found, there are options to:

- Automatically skip to the next point in the list
- Provide a warning message and allow the operator to choose a corrective action

5.9 Monitoring measurements and coordinates

The various measuring modes present their results in different measuring windows.

Only one mode can be active at any one time but multiple measuring windows may be open.

Each window can display results in a different coordinate system.

5.9.1 Continuous display of 3D values

Measurement windows always show a real-time display of the current reflector location or offset, depending on the type of window. Unlike the MTM, there is no need to explicitly select continuous coordinate display to monitor location before recording and storing data.

5.9.2 Display of individual measurements

Unlike the MTM, the LTM does not show measurements as they come in, i.e. there is no Running Data Window. In addition there is no display of measurements in the Station Status Window. This is because the tracker can potentially supply data at a very high rate and this would not provide meaningful visual information to the operator.

5.9.3 Station status window

This window is always present when the LTM is started and cannot be explicitly requested by the operator.

The station status window provides a colour-coded list of all stations currently in the network, as well as the status of any station selected from the list.

Almost all the status information relates specifically to laser trackers and will display N/A if the selected station is a theodolite or Total Station.

5.9.4 Measurement windows

To see the results of any measurement task on line it is necessary to open up a *measurement window.* A measurement window shows the results of measurements made by stations assigned to that window. A station cannot be assigned to a window until the tracker at that station is initialized. However the station need not be oriented.

> **Note**
> You need a measurement window in order to make and store measurements and coordinates (if the station is oriented)

Multiple measurement views are possible but currently only one tracker can be attached on line. Each view, therefore, can only show the same station. However, measurement views are still useful for viewing the same data in different coordinate systems.

> **Note**
> Different coordinate types are not possible for each window. This is a global setting which applies to all windows.

Measurement windows display different types of information depending on the mode of operation. See individual modes for more details.

Measurement windows can also display their information in two ways. One way presents full information, the other shows less information but the most important coordinate or dimensional data is displayed at a large scale for easy viewing from a distance.

The **Zoom** function corresponds to the **Full display** function in the MTM.

Local instrument coordinates for stations not oriented

Unlike stations occupied by theodolites or Total Stations, a tracker station does not have to be oriented before it can be assigned to a measurement window. It is a technically requirement to have a measurement window in order to be able to read data from the corresponding tracker.

However it is also convenient to see some coordinates once a window is open. Since the tracker has not yet been oriented into the measurement network it is only possible to calculate reflector coordinates in a local coordinate system defined by the tracker's own axes.

These coordinates are created for purposes of display only and are not stored. The display window clearly indicates that the coordinates are only temporary.

5.10 Correcting for offsets

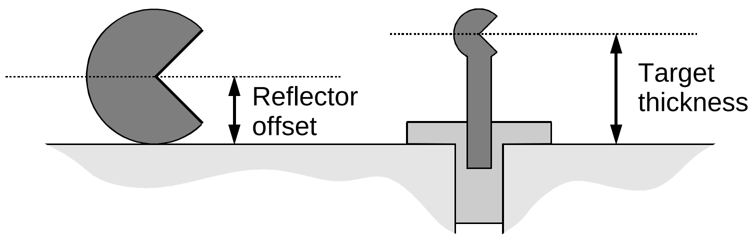
5.10.1 Reflector offset and target thickness

Tracker measurements are always made to the centre of a reflector. Occasionally this may be the point of interest, for example when a reflector is attached to a moving robot and it is sufficient to track a point in a particular area rather than a specific feature on the robot.

Normally, however, the user wants to measure a point on an object's surface or a particular object feature such as a hole centre. This can be achieved using a *surface reflector*, which is a corner cube combined with a plane mirror.

With this attachment you touch the required object point with the tip and measure the *virtual image* of the reflector. Since the centre of the virtual image is designed to coincide with the tip, this attachment allows you to directly measure to an object feature.

When this is not available a correction must be made from the reflector centre to the object surface or feature. This correction is either due to the radius of the reflector housing or is an offset dependent on the design of the target adapter currently in use. An offset due to the housing is known as a *reflector offset* and an offset due to an adapter is known as a *target thickness correction*. Mathematically both are processed in the same way.



The reflector offset is equal to the radius of the housing and is part of the definition of every reflector. It is not necessary to specify its value when choosing to apply this correction as the value appropriate to the current reflector will be automatically used.

Target thickness depends on the design of the adapter and must be explicitly defined when applying this type of correction.

Both types of correction may be combined if an adapter can accept different reflectors. In this case the adapter design must either ensure that the change in offset is equal to the change in radius of the reflector housing, or a properly calibrated offset value is available for every reflector which can be attached to the adapter.

5.10.2 Direction of reflector and thickness corrections

Reflector and thickness corrections can be applied either along the axes of a specified coordinate system or perpendicular to a shape surface.

Correcting to a surface means correcting to one of the standard ***Axyz*** surfaces (sphere, plane, etc). This is not the same as correcting to a surface using the Surface Calculation which is designed to deal with free form shapes.

5.10.3 Correcting to a free form surface

See "Simple free form surface digitizing (Axyz CAD)" on page 139.

5.11 Gravity reference with the NIVEL

One or more NIVEL electronic tilt sensors can be attached to the ***Axyz*** measurement system. These can be used for general tilt monitoring and it is up to the operator to take any necessary action in response to critical tilts.

If NIVEL sensors are attached to trackers rather than critical locations within the workspace, it is also possible to reference the tracker to the vertical and hence use this information to help orient the measurement network to gravity.

NIVEL tilt sensors can be attached in the following ways:
1. A single Nivel can be attached to a COM port and positioned to monitor movements of any critical part of the network.
2. A single Nivel can be attached to a COM port and mounted on a tracker, in order to reference it to the vertical. This applies to older instruments.
3. Newer designs permit a NIVEL to be mounted on a tracker and its readings transmitted through the internal LAN, along with the angle and distance measurements. Stations with trackers operating in this way can again be referenced to the vertical.

It is currently only possible to monitor one NIVEL, just as only one tracker can be monitored. However an individual NIVEL can be selected from a multiple tracker/NIVEL configuration.

5.11.1 Levelling a tracker station with an attached Nivel

One or more tracker stations can be referenced to the vertical with a NIVEL electronic level. This is achieved by attaching a NIVEL to measure any residual tilt of the primary axis (standing axis) with respect to the direction of gravity. The Orientation Module then includes this measured tilt information when calculating the network.

In contrast, the concept of levelling using theodolites or Total Stations is slightly different. Here the instrument's tilt sensor has two purposes:
1. It is used to set the instrument's primary (standing) axis very close to the vertical.
2. Any residual tilt is compensated by correcting the measured angles such that they appear to come from an exactly levelled instrument

A tracker need only be sufficiently well levelled such that the Nivel keeps within its operating range for all tracker pointings. Any residual tilt is measured by the Nivel and there is no compensation of the angles. In effect, levelled theodolites and Total Stations are set to have a residual tilt of zero and a "levelled" tracker has a residual tilt of some measured value.

5.12 Monitoring the external environment

External (ambient) temperature and pressure are potentially required for:

- Calculating accurate refractive indices for IFM and ADM
- Monitoring general thermal changes which may distort an object or cause it to move

It is not necessary to operate the system with monitors attached for automatically measuring external temperature and pressure. Values can be manually input but some measuring device is still required to supply the actual readings.

The following pressure and temperature monitors are supported:

- Leica WM (Omega or Haenny pressure sensors)
- Davis Perception II
- Thommen HM30

It is possible to automatically monitor refractive index with a Spindler & Hoyer LR 1 refractometer, for which a suitable IEEE interface board is required.

5.13 Home points and “Birdbath”

An interferometer only measures a change of distance. In order for it to provide the absolute distance to a reflector it must start or re-start measurement from a location whose distance is already known.

The tracker is equipped with a fixture which ensures that such a location is always available. In the previous SMART software for Leica's laser trackers this point was officially called *Home Point Zero*. For convenience it was possible to establish additional numbered *home points* by simply storing the pointings to other fixed locations. When it was necessary to re-initialize the interferometer distance, typically because of an interrupted beam, any available home point could be used.

The concept of additional home points is not part of ***Axyz*** since any point can, in principle, be a home point. Various methods are provided to re-set the IFM distance and only one official Home Point exists in the ***Axyz*** system. This is the on-board fixture which is often called the "Birdbath" because of its visual similarity to a Birdbath you might place in the garden.

In summary the following methods are available to re-establish the IFM distance:

1. The reflector can be set in the Home Point (Birdbath).
2. Any point which has already been measured and which can be re-occupied by a reflector can be used.
3. If a point has not been previously measured but its coordinates are known, for example a reference point, it can also be used. In this case the angles and distance from the current tracker location to the point can be derived and used to re-set the IFM.
4. If the tracker has an ADM this can be used to measure the distance to any unknown or known point and the IFM will be automatically re-set.

The Birdbath distance is one of the critical tracker parameters. Since reflectors have housings of different sizes and may have different internal optical path lengths (glass prisms, cat's eye elements), the Birdbath distance is different for every type of reflector.

5.14 Finding and locking on to reflectors

It is often necessary to re-establishing the connection to a reflector after loss of tracking. This is typically caused by a beam break but the facility may also be used to locate a point without tracking to it.

5.14.1 Re-establish tracking after a beam break

The following functions are available for re-setting the IFM in order to re-establish the tracking function:

Go Birdbath
The reflector is placed back in the Birdbath where it can be automatically detected.

Go Location
The reflector is placed at an existing measured location, specified by point ID, where the IFM distance can be automatically re-set.

Location point
A general purpose function to locate a reflector in one of three ways:

- In the Birdbath
- At an existing measured location, specified by point ID
- At an unmeasured location whose 3D coordinates can be manually input. This provides the information necessary to re-calculate the distance to the point and re-set the IFM.

Find
A reflector at any stable location can be found by manually pointing the beam. An overview camera can be used to assist. The distance is re-established with the ADM.

Keep last position
This is one of the **Autopoint** features, summarized below. It is particularly useful when tracking a moving reflector, e.g. during a surface scan.

When the beam is broken the tracker remains pointing in the same direction. The beam is then automatically re-captured for tracking if the reflector is brought back onto the beam. The location need not be exact but the reflector must then be moved to a stable location, if not already at one. When the tracker detects that a stable location has been reached (by monitoring interferometric changes), distance is automatically re-established with the ADM.

Autopoint
This is feature can be disabled or enabled to automatically point the beam back at a standard location or **Keep last position**. Autopoint can:

- Find a reflector in the Birdbath
- Find a reflector at the last measured fixed location
- Find a reflector at a standard existing location, specified by ID
- Find a reflector using the **Keep last position** function

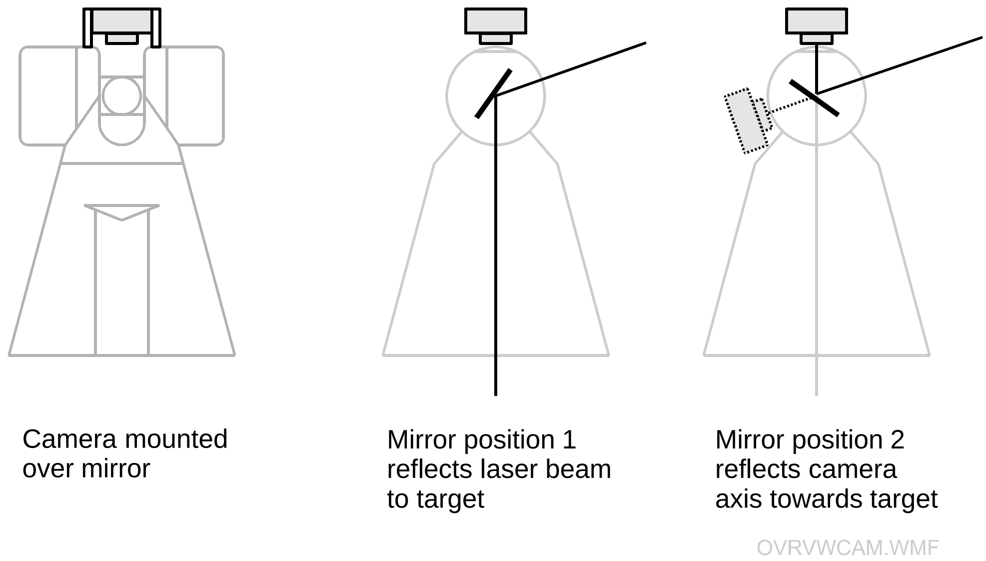
5.14.2 Overview camera

The overview camera is an optional accessory which can assist the operator in finding a target reflector. It fits above the tracker mirror. The camera image can be viewed on a separate external monitor, or through an internal video window if driven by Coreco Vision's "Bandit" card.

This camera supports the **Find** command. If available, the mirror switches position to allow the camera to look along the line of the laser beam towards the measured object. This is an automatic action after a beam break.

An illuminating light provides a bright return image for any reflectors in the field of view. The operator can manually move the head, or position it with the arrow keys on the keyboard, in order to bring the required reflector to the centre of the field of view.

Diagram: Overview camera



5.15 Distance measurement

This section summarizes features relevant to distance measurement.

5.15.1 Refractive index

Accurate distance measurement depends on an accurate estimate of refractive index. The index is different for different frequencies of light and so a separate value is required for IFM and ADM, which work in different ways and use different light sources.

Calculation of refractive index is critically dependent on ambient temperature and pressure. These values can be manually input.

Alternatively there is provision for attaching external environment monitors which can directly measure these values.

It is also possible to attach a refractometer to directly measure refractive index.

5.15.2 Distance offset parameters and constants

The following distance parameters are required:

Home point (Birdbath) distance for IFM.
Defined using either:

- 2 point method
- Scale bar method

ADM instrument constant.
Defined using comparison with calibrated IFM.

ADM additive constants for different reflectors.
Defined using comparison with calibrated IFM.

These constants can only be set using the ***Axyz*** calibration routines.

5.15.3 Temporary distance offsets

Various functions can be used to set the current distance of the IFM and ADM but none of the following causes a permanent change to the internal distance parameters.

Define reflector

This defines the home point for the reflector by recording the current values of (h,v,d) when the chosen reflector is in the Birdbath.

When you subsequently issue the command "Go Birdbath" the tracker moves to these angles and the distance is set if reflector is found in the Birdbath.

ADM stationary point measurement

Any ADM stationary point measurement will reset the IFM measurement to the current ADM distance.

"Location point" command

This is a general purpose function which will re-set the IFM on a reflector at a known position which may be one of the following:
- The Birdbath (equivalent to "Go Birdbath")
- An existing known point
- A point whose position can be manually input

If an ADM is available, an ADM stationary point measurement is made if a reflector is found.

"Go location" command

This function will re-set the IFM on a reflector at a known location which may also be the Birdbath.

If an ADM is available, an ADM stationary point measurement is made if a reflector is found.

5.16 Tracking Instruments

5.16.1 Tracker types

The LTM supports the following tracker types:

- SMART 310: IFM only
- SMART/ADM: ADM and IFM
- LT500: IFM only
- LTD500: ADM and IFM

5.16.2 Service and maintenance

A full set of functions is available to allow service and maintenance checks to be made. These functions are available on a Service Menu which is normally hidden from the user.

However the HELP menu provides access to status, diagnostics and hardware configuration options which enable operators to perform some routine checks on the operation of individual components.

5.16.3 Alignment and check measurements

Each tracker has its own set of parameters defining the *alignment* of its internal components. These parameters include the reference distance for initiating IFM measurements.

Further parameters are required to relate ADM values to IFM values in order to ensure consistency, as well as reflector parameters which can affect distance measurement.

The different groups of parameters can be separately calculated by the operator based on defined sequences of measurement. Based on these parameters, software compensation can modify the instrument readings so that they appear to come from a "perfect" instrument.

Axyz records all sets of alignment parameters when produced, so maintaining a history of changes. It is possible to apply any previously created set of parameters to the instrument.

To complement parameter calculation, routine checks can be made using similar measurement procedures to ensure that the current parameters are valid and optimal accuracy is maintained.

This section summarizes the alignment techniques which are explained in detail elsewhere.

Background

The tracker is a complex mechanical arrangement of laser beams, mirrors, rotating axes, mixed metal types, etc. Ideally it should conform to a perfect design. For example the primary (standing) axis should intersect the transit axis at right angles. It is impossible to manufacture the tracker exactly according to design and the small deviations from design give rise to systematic errors. These deviations can be calculated by making suitable measurements and their effects eliminated by software compensation. Corrected measurements then only show small random effects.

The tracker can be accurately modelled with 15 parameters which all have a physical meaning. These are known as the parameters of the tracker's error model (alignment parameters).

The tracker's distance measurements are mainly based on an interferometer which can only measure a change of distance. What is required is the absolute distance from the centre of the mirror. Interferometric distance measurements can be converted to absolute distance measurements if tracking is initialized at a point whose absolute distance from the mirror is already known. The tracker is provided with a Home Point or Birdbath to ensure that such a distance is always available, but this distance must be carefully calculated and is different for every type of reflector in use. The calculation can be made here.

Finally an absolute distance measuring device is available which can independently and directly measure the absolute distance to a reflector. However it, too, requires the definition of a number of parameters for its definition, such as the offset of its datum (zero point) from the mirror. This can also be calculated here.

Ball Bar and 2-face measurements

Two fundamental techniques are used to calculate and check tracker parameters:

1. Measurement of an accurate reference shape, in this case a reflector attached to a *Ball Bar* which rotates it on a very precise circle in space. Calculated tracker parameters must therefore ensure that the measured points fall on a circle.
2. *2-face measurement* which locates the same fixed target in both mirror positions. This reverses the effects of many parameters which are then easily detected. Calculated tracker parameters must ensure that the pointing is the same in both mirror positions.

These measurement types provide basic information for calculating or checking tracker parameters. Unlike normal measurements made for metrology purposes they are therefore stored in the database in their uncorrected state, i.e. no tracker model is applied when they are stored. The effects of different models on these measurements can therefore be examined by subsequent processing. The best model for producing optimal accuracy can then selected or computed.

Using the same or different tracker stations

A number of alignment techniques may involve movement of the tracker to obtain a favourable geometric arrangement for determining the various parameters. The requirement here is merely to place test objects in different relative positions and it does not matter mathematically if the tracker is moved or the object is moved. If the tracker is moved it is therefore possible to assign all measurements to the same station. Operators may therefore find it convenient to use a job only for purposes of checking or calculation of parameters and use only one station within this job.

In contrast, normal object measurement must always be done from fixed stations and if the tracker is moved a new station must be defined. Unlike the reference lengths, Ball Bars or temporary targets used for alignment, the measured object is normally a single entity, not a collection of independent components whose position relative to the other components is irrelevant.

Calculating the tracker alignment parameters

In order to calculate the tracker model parameters which define the alignment of the internal components, it is necessary to make a number of Ball Bar and 2-face measurements. These should be distributed in such a way that the parameters have a significant effect on the measurements, in order that they can be accurately calculated. In practice this means that measurements must be made throughout the tracker's measurement space.

To record suitable Ball Bar and 2-face measurements, the tracker must switched into the correct recording mode.

Calculating the Home Point (Birdbath) distance

The interferometer can only measure a change of distance, not an absolute distance. By starting interferometric measurement from a point whose distance is already known, interferometric changes can be converted to absolute distances. The Birdbath offers a convenient fixed location on the tracker housing which provides this reference distance.

> **Note**
> The Birdbath distance depends on the physical dimensions of the reflector and its location in the Birdbath itself. The distance is therefore different for different reflector types.

Calculation of Birdbath distance is separate from the calculation of the tracker instrument parameters which must, however, be reasonably accurate. It may therefore be advisable to implement the full alignment procedure before calculating this distance.

The recommended technique involves measuring 2 normal stationary points from two tracker locations and is called the *2-point method*.

> **Note**
> Measurement of a stationary point with the ADM automatically re-sets the IFM to the current ADM distance. However, this is not a determination of the Home Point (Birdbath) distance and it does not modify this parameter.

Calculating the ADM instrument parameter

Although the ADM can measure absolute distance to a fixed reflector, the datum position for this distance must be established. The measuring unit itself has an unknown position within the tracker housing and the components within the unit have an unknown datum position. What is required is to set a total datum offset so that absolute distance measurement is zero at the tracker's rotation centre.

Because of its higher accuracy the IFM is used as a reference for the ADM. The technique compares ADM distances with IFM distances to the same fixed points and calculates an *instrument offset* and *scale factor* to make the ADM values match the IFM values as closely as possible.

Since reflectors with glass prisms (Tooling Ball Reflectors) affect distance measurement, the relevant measurements must be made with a hollow (air-path) corner cube reflector which has no adverse effect on distance.

To ensure optimum accuracy, the Birdbath distance for the selected reflector should first be calculated.

To record suitable measurement pairs, the tracker must be switched into the correct recording mode.

Calculating internal reflector offsets for the ADM

This follows the same procedure as for the ADM instrument offset but the instrument offset must first be accurately measured using an air-path corner cube. The only unknown parameter in the procedure is then the reflector offset.

This procedure must be calculated for every type of corner cube except an air-path corner cube.

To record suitable measurement pairs, the tracker must be switched into the correct recording mode.

Note
In practice the factory value should be good enough as a special laboratory based on interferometric methods is used. This calculation should therefore only be very occasionally required.

Re-calculation of Birdbath and ADM parameters after alignment

Once the full set of parameters has been modified, a slightly different tracker has thereby been defined. Logically other critical parameters should also be re-defined, in particular the Birdbath distance and ADM parameters.

Field checks (on-site or workshop checks)

When a measurement is made in face 2 it is converted into an equivalent face 1 measurement. If the tracker has good alignment parameters then pointings to a fixed reflector in both faces should be equal, apart from small random deviations.

When a reflector on a slowly rotating Ball Bar is tracked, the resulting set of points should fit very well to a circle.

Field checks (on-site or workshop checks) simply test the above conditions and should tell you if the system is producing good results. If 2-face checks start to show large angular differences or the Ball Bar test indicates a bad circle, then it may be time to re-calculate the parameters.

Field checks can also be made for ADM parameters and the Birdbath distance.

Field check measurements are essentially the same as measurements made for alignment purposes. These are:

- 2-face measurements
- Ball Bar measurements
- Measurements to calculate Birdbath distance
- Measurements to calculate ADM parameters

The differences with the same measurements made for alignment purposes are that field checks:

- Do not need to be so comprehensive and well distributed
- Do not enable you to re-define parameters

Although field checks do not permit users to re-define parameters they should indicate if a new alignment is necessary. Some recommendations follow.

Parameter storage in tracker database

For every laser tracker with a serial number in the format "nnnnn", most parameters are stored in a tracker database named "TRKnnnnn.mdb".

This is located in a sub-folder of the folder used to store ***Axyz*** programs, i.e.

C:\Program Files\Leica\Axyz\Tracker

The tracker database is a standard Microsoft ACCESS database.

The reflector parameter which corrects distance measurements is stored with other reflector information in the ***Axyz*** job file and can be displayed by the Data Manager.

Separate workpieces for alignment and field check data

When alignment and field check measurements are made, it is convenient to store them in workpieces named according to the type of measurements, e.g. "TWOFACE" or "BALLBAR".

Normally, placing measurements in a particular workpiece means that this becomes the currently active workpiece. This would be inconvenient when returning to normal measurement. In this case, return to normal measurement means a return to the previously active workpiece. If you normally only use one workpiece, i.e. "DEFAULT", then this is where further measurements are stored.

5.17 Reflectors

Both interferometer and Absolute Distance Meter can only operate with a reflector. Different types of reflector are available. They have different optical properties and are available in different sized housings. Acceptance angle of the incoming beam and the physical size and weight are deciding factors in choosing a particular reflector.

During measurement, the user can change to a different reflector at any time. The next sections briefly describe reflector types and some relevant properties.

5.17.1 Cateye

This type of reflector operates on the principle of the *cat's-eye*. It has a small glass sphere concentric with a glass hemisphere which has a silvered outer surface. The two glass elements have different refractive indices. An incoming beam is refracted in such a way that it reflects off the silvered surface and exits parallel to its original direction.

Because of its symmetry, the reflector has a unique target point which is the centre of the glass spheres. However the glass elements cause some aberration of the beam. This type of reflector is not ideal for use with the ADM.

The reflector has an acceptance angle of ±60° but tends to be large and heavy. It is available in the following sizes:

- 3.5 inch

5.17.2 Corner cube

The corner cube is a well established retro-reflector which uses 3 plane mirrors set at right angles to one another. These correspond to 3 planes at the corner of a cube, hence the name.

An incoming ray is, in general, reflected off each of the 3 mirror faces and returns on a parallel path. The reflected beam is offset from the incident beam.

The cube corner represents the target point. It is always positioned half way between the incident and reflected beams and the distance from the cube corner to the transmitting device is always twice the measured optical path length.

This type of reflector requires no ADM correction.

The reflector has an acceptance angle of ±20° and is relatively lightweight. It is available in housings with the following diameters:

- 75 mm
- 1.5 inch

5.17.3 Tooling ball prism (TB prism)

The tooling ball prism is based on a solid glass prism with a plane entry face and 3 rear silvered surfaces ground at right angles to one another. An incoming beam is refracted at the entry face and reflected off each of the rear surfaces. It exist parallel to the incoming direction.

Because the light passes through glass inside the prism, the effective target point varies depending on the angle of incidence. This variation is small and in many cases may be neglected. However for optimal accuracy operators should always ensure that the prism is pointing back towards the tracker, with and incident angle close to zero (entry at right angles to the front surface).

The tooling ball prism is very small and lightweight and has a wide acceptance angle of ±60°.

Because the beam is reflected within a glass element and the target point varies depending on incident angle, this type of reflector requires an ADM correction (additive constant).

Since the housing is small, some operators may not find it convenient to hold the reflector between thumb and forefinger when re-positioning or manually measuring. A holder is available to make it simpler to handle.

5.17.4 Tooling ball corner cube (TB corner cube)

The tooling ball corner cube is a miniature version of the standard corner cube reflector.

5.17.5 Surface reflector

This type of reflector has no offset because a virtual image is measured and the centre of this image is on the surface of the object being measured.

It is a combination of a corner cube reflector and plane mirror. The virtual image of the reflector is behind the mirror with its centre at the same position as the tip of a measuring spike. The tracker locates the virtual reflector and by touching the spike against the surface of a point to be measured, the surface position can be directly recorded.

5.17.6 Offset due to housing

When used for surface or feature measurement, the target point of reflection is normally offset from the actual point of interest. A correction must be applied. See "Reflector offset and target thickness" on page 147.

5.17.7 Home point (Birdbath) distance

Because of their different housings, each design of reflector has a different Birdbath distance. See "Home points and “Birdbath”" on page 150.

5.18 Remote operation via wireless LAN

The LTM is designed to be operable from a remote hand-held computer via wireless communication. This does not offer access to all functions and options but enables users to carry out a range of measurement tasks at the measured object.

In particular, measurement modes require the definition of recording parameters and may also make use of reference coordinate lists. Modes may be switched remotely and this enables, for example, changing from auto inspection of a set of targets to the measurement of a new single location. However, the relevant parameters for these modes must be set at the controlling PC using the main LTM program.

6. Constructing the measurement network

6.1 Combining STM, MTM and LTM in a common network

It is possible in any job to be running a mixture of instruments which in turn requires the appropriate software module. The theodolite and tracker managers do not directly communicate with one another but their measurements are added into the common database. The instruments therefore form a single measurement network for the job and any 3D point data is generated by an optimized calculation based on all available measurements, regardless of type of instrument.

The total maximum number of stations in the network is 99. Once one of the modules has assigned an instrument to a station, that station number is no longer available to any of the modules. For example, a station already occupied by a theodolite cannot be occupied by a tracker.

When measurements are made from an oriented station each module checks in the database to see what other oriented stations have measured the point concerned. If 3D coordinates can be created then the module sends all the measurements, regardless of origin, to the single point function for calculation of coordinates.

Theodolites and total stations are connected to serial COM ports and trackers are connected to a LAN. The theodolite and tracker managers are both aware of all stations in the network, including those occupied by other types of instrument. However each can only read data from the instrument type relevant to it and can only group its own type of instrument into the measurement windows which it presents.

6.2 Orientation Module

3D coordinates cannot be generated until all the stations involved in measuring all or part of an object are linked together into a common measuring network in which their positions and tilts are known. This procedure is known as *orientation.*

Although measurements can obviously be made without prior orientation, coordinates cannot be generated until orientation is complete. Measuring without orientation cannot provide on-line display of target values in a common coordinate system.

It is unfortunately not possible simply to sight points of interest and then request a solution for the coordinates. This works only in the very simplest case of a network composed of a single Total Station or laser tracker. Triangulation methods, for example, require pointings from at least two stations before coordinates can be generated. However even this is not sufficient since the relative positions of both instruments, i.e. their orientation, must also be known. This can only be calculated if measurements meet certain minimum requirements and, often, some additional measurements have been made purely for orientation purposes.

Orientation is straightforward when polar methods are used. Total Stations and trackers generate full 3D data and can be linked into a network provided they measure 2 or 3 points which have already been measured or which have known design coordinates (control points). A standard 3D transformation can then be used to calculate the orientation.

Triangulation techniques are more complex and many methods have been designed to calculate a station's orientation. ***Axyz*** offers orientation methods which are familiar to users of ManCAT, ECDS and SMART systems. These do not represent all mathematically possible techniques but are sufficient to deal with most applications.

Orientation methods for theodolites, Total Stations and trackers are summarized in:

- "Relative orientation methods" on page 170
- "Controlled orientation methods" on page 174

These orientation methods sometimes make use of approximate measurements as well as accurate measurements. Generally, therefore, initial orientation is not sufficiently accurate for high quality measurement. However once an approximate orientation is known it may be optimized by a least squares method known as a *bundle adjustment.* Even initial orientations based on high quality measurements benefit from optimization.

The *Orientation Module* which constructs a network operates in two stages:

1. Calculation of approximate station orientations (and any associated point coordinates) using one of the standard orientation methods provided
2. Optimization of orientations using least-squares (bundle adjustment)

The primary purpose of orientation methods is to prime the optimizing stage with an approximate description of the network. It is important to realize that optimization will only function if the trial information is reasonably close to the finally accepted value. Badly made orientation measurements may make it impossible to create an oriented network because the resulting approximate values are too far out. Since a network is built up station by station it may also happen that individual approximations, although reasonable, generate unreasonable values at the end of a chain. However, experience shows that the methods are robust and if an occasional problem develops strategies are available to find a solution.

The user is not required to record explicitly which technique was used to link a station into the network. Instead the Orientation Module recognizes particular methods by the type of measurement recorded at a station and by a knowledge of the network constructed so far. For example a theodolite can be linked into a network by sighting 3 points with known coordinates, a method known as horizontal resection. If these are common points already located by earlier stations in the chain then the method will work. If the Orientation Module detects the condition favourable for a horizontal resection it will implement the corresponding algorithm.

Users will either record the individual measurements which will ensure that a particular orientation method can be used at a station, or will use a *script* to guide them through the procedure.

Since an orientation method is detected by evaluating measurements and the current status of the network, it is possible that a method will be used which is not the one originally intended by the operator. It is good practice to make more than the minimum number of measurements and this may enable more than one orientation method to be used. However this is not a cause for concern since the objective is simply to obtain approximate orientation data for the final optimization. Any approximation will work provided it is reasonably close to the final result.

Orientation can be applied to some or all stations in a network. Typically users who operate a network of more than a few stations will build this up gradually. They will often complete the orientation for the first group of stations and then re-calculate it when more stations are ready to come on line.

6.3 Locating points: the Single Point Solution

Orientation includes measurements to arbitrary fixed targets as well as actual object points of interest. It is in fact possible to make measurements to all object points of interest before orienting the network. The Orientation Module will simply calculate optimized coordinates for these points as well as optimized positions and tilts for the stations.

However, in practice users make relatively small numbers of measurements in order to create an accurate measurement network and then locate further object points on line by measuring from oriented stations. Another function called the *Single Point Solution* calculates the coordinates of points located in this way. The Single Point Solution is a general algorithm which calculates the coordinates of a point measured from one or more stations. It handles the following cases:

- A single polar location
- A conventional intersection in a triangulation network
- Multiple mixed polar locations and intersections of an object point

The Single Point Solution can be used on line or off line.

When used on line, point coordinates are continuously updated. Readings from oriented stations come in asynchronously and this new data is immediately matched against existing data. Once there is sufficient data to compute a single point solution this is immediately done. If a single point solution has already been calculated for a point, new measurement data for the same point is used to update the solution. This operation can be seen if suitable measuring windows are open. See "Stations displayed in measurement windows (standard mode" on page 100 for more fully detailed operation in the MTM.

The solution is also available off line as one of the analysis functions. In this case the function does not only supply the results of a calculation using all measurements to a particular point, but also allows the user to select a sub-set of these points. This may be useful when detecting bad pointings.

6.4 Scale in a network

Coordinates are only properly meaningful if they represent the true size of an object rather than a scaled version. If required, scale factors can be applied to these values. Scale can be introduced in a number of ways.

Polar distance values

If the network contains at least one polar station (Total Station or tracker) then scale is automatically introduced because measurements include accurate distance values.

Scale bars

A pure triangulation network, in which only measured angles are recorded (MTM), will normally include scale by measuring points on a scale bar which contains targets with known separations. (If scale bars are not measured then control points must be measured instead.)

The ***Axyz*** scale bar concept is outlined in more detail in "Scale bars" on page 115.

In the measurement network the same bar can be used in many different locations or different bars can be used at different locations

There is no limit to the number of scale bars and scale bar locations used in a network.

Control points

Control points have accurately known coordinates usually known in a coordinate system used to design the object being measured. They modify or "control" the effects of an orientation procedure during the optimizing phase (bundle adjustment). Since they have known coordinates they effectively have known separations and therefore directly implement scale.

If included in triangulation measurements, additional scale bars are not necessary, although they may also be included.

Assumed scale

If true scale cannot be calculated, the Orientation Module issues a warning. However the analysis continues by automatically setting the distance between the first two stations in the network to be equal to 10 cm. This provides an *assumed scale* and prevents the solution from failing because scale is unknown. By choosing an impossibly short separation between the stations the resulting coordinates are much too small to be realistic. This serves as an additional reminder to the user that scale information is not provided.

6.5 Orientation methods

Orientations have a descriptive classification to indicate if *control points* are used or not. See "Control points" on page 174.

Controlled (object) orientation
A controlled orientation makes use of control points which force the results into the coordinate system of the control and influences (controls) the shape of the measurement network.

It may be called an object orientation since the control coordinate system generally has some direct meaning to the object. For example it represents the coordinate system used in the design and manufacture of the object.

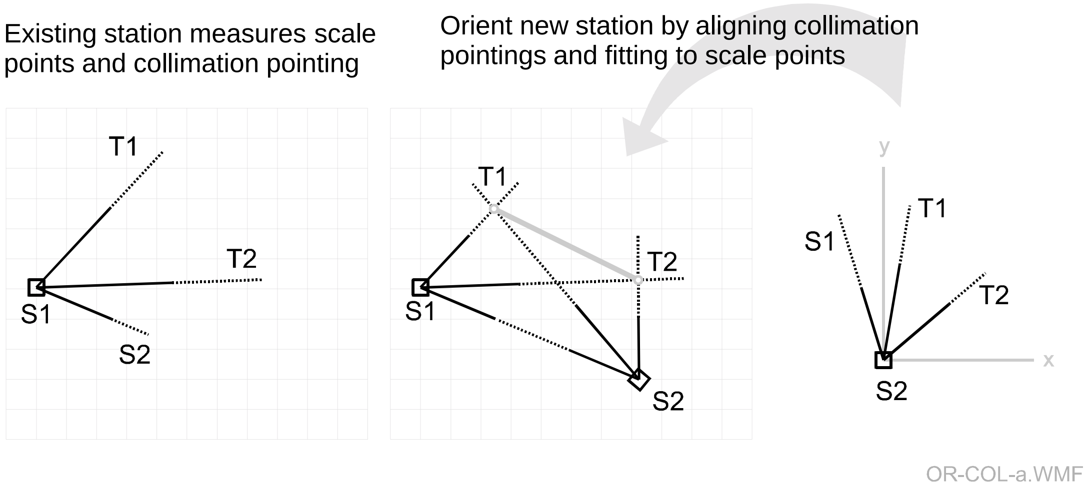
Relative (local) orientation
A relative orientation does not make use of control points and the coordinate system is initially arbitrarily defined by the first station processed, which is the lowest numbered station.

Choosing the option for a balanced station network will cause the origin to drift slightly away from this initial position.

It may be called a local orientation because the local axes of a station define the final coordinate system which is "local" to the network itself.

6.5.1 Relative orientation methods

Collimation (accurate)



This calculation assumes that the instruments are approximately levelled.

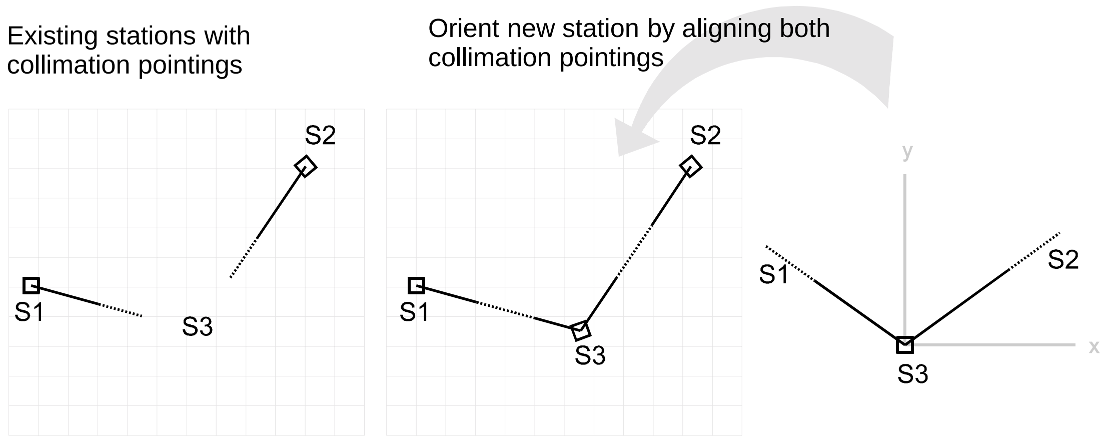
Accurate collimation pointings are sufficiently good to be used in the optimized orientation.

Collimation (approximate)

This is essentially the same technique as accurate collimation except that the collimation pointings are only made approximately. These measurements are therefore not used in the optimized orientation.

This calculation assumes that the instruments are approximately levelled.

Collimation to two instruments

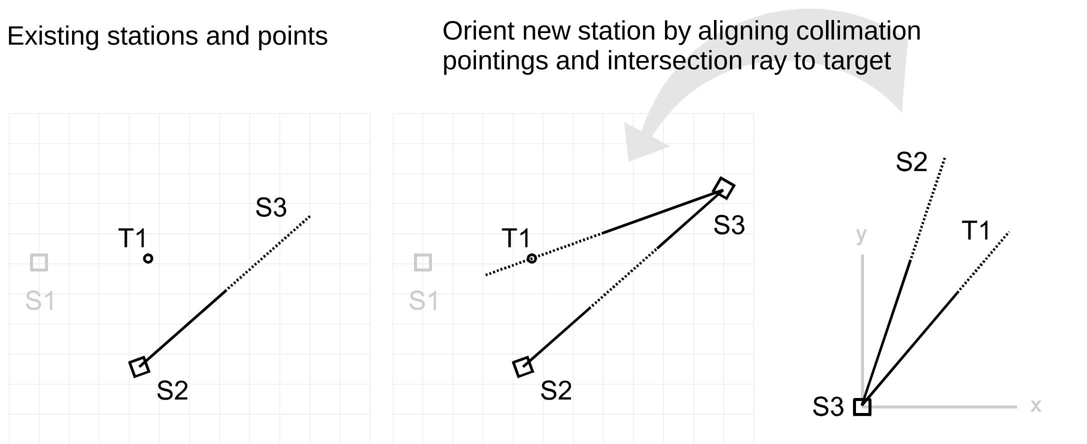


OR-COL-b.WMF

This calculation assumes that the instruments are approximately levelled.

Any collimation measurements which are accurate will be further used in the optimized orientation.

Collimation with common point



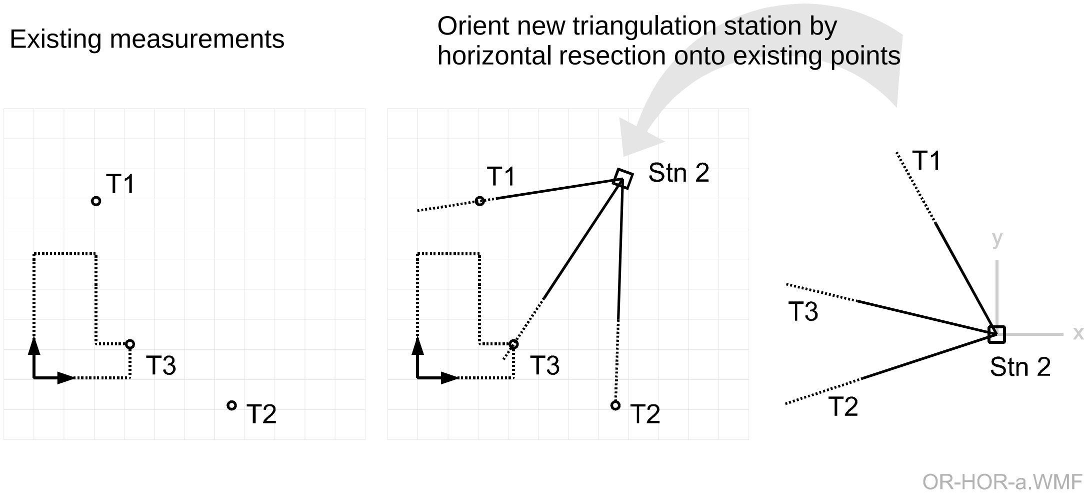
OR-COL-c.WMF

This calculation assumes that the instruments are approximately levelled.

If the collimation measurement is accurate it is included in the optimized orientation.

The target measurement should be accurate and will be included in the optimized orientation.

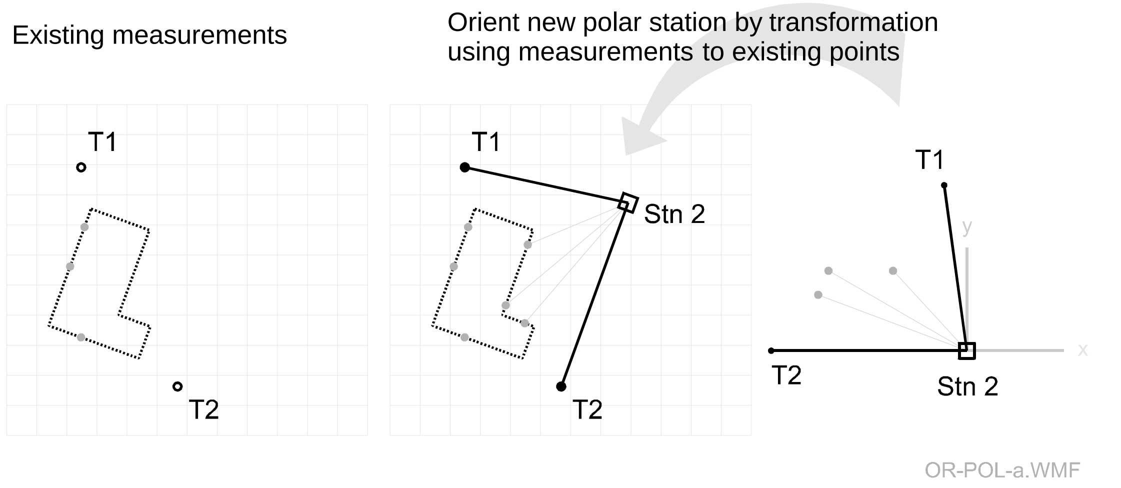
Horizontal resection



This calculation assumes that the network is approximately levelled by inclusion of approximately levelled instruments at one or more previously oriented stations. Any existing target coordinates are therefore located in a coordinate system referenced to gravity.

The target measurements are assumed to be accurate and are included in the optimized orientation.

Orientation of polar measuring instrument



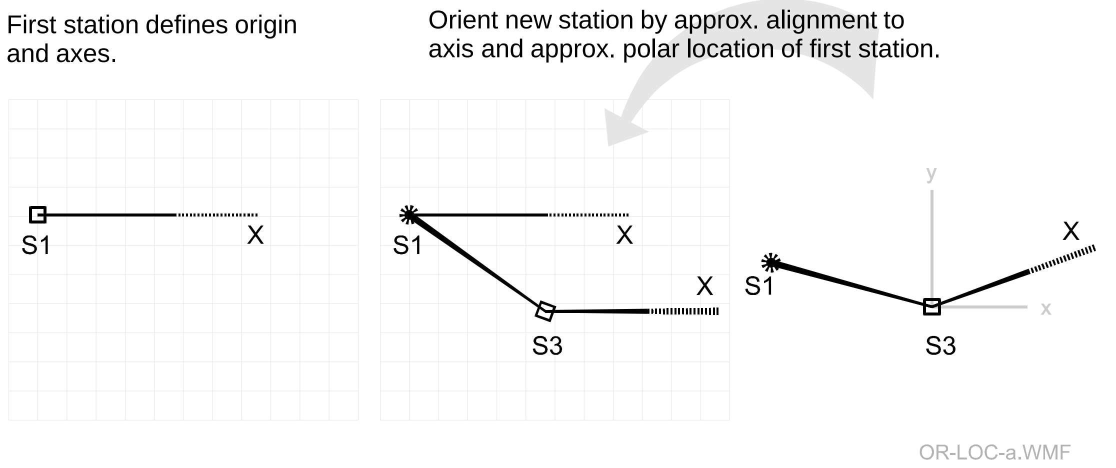
This technique applies to Total Stations and laser trackers.

The diagram shows the simple situation where contact points and station are approximately referenced to gravity. In this case it is only necessary to measure two contact points.

If there is a relative tilt between the existing coordinate system of the contact points and the local coordinate system at the station, then 3 existing contact points must be measured. The station is then linked into the existing network by the same method as used for a 3D transformation.

The target measurements are assumed to be accurate and are included in the optimized orientation.

ECDS "local" orientation



One "key" station (S1) defines the origin and local axes and measures the local X axis.

Further stations measure the X direction and the approximate polar location of the key station, i.e. by angular pointing (h,v) and manual estimation of distance (d).

None of the axial pointings or polar estimations are accurate and so none of these measurements are used in the optimized orientation.

6.5.2 Controlled orientation methods

Control points

Control points are locations with accurately known coordinates. It is very common for control points to be object features which have known *design (CAD)* or *blueprint* coordinates. Control points are included in orientation methods for two purposes.

- They force the results of the orientation into the coordinate system defined by the control, for example the CAD coordinates used to manufacture the object. This is convenient for further data comparison.
- They influence or *control* the results of an orientation, i.e. they affect the shape of a measurement network. This can improve accuracy when the geometry of the measurement network is not ideal.

Controlled orientation versus transformation onto control

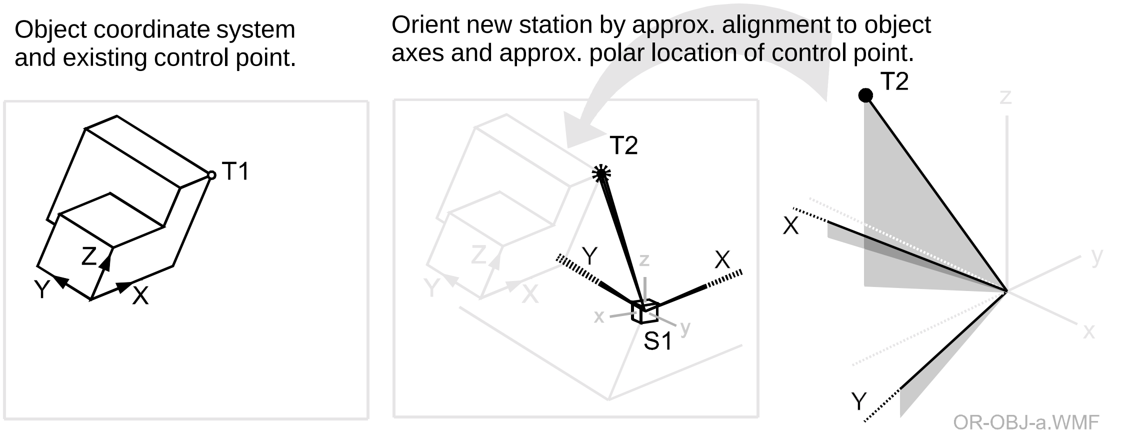
Coordinates can be viewed in the coordinate system of the control by first calculating a relative orientation (no control points used) and then calculating a 3D transformation onto reference points.

This transformation does not alter the shape of the network. At most there may be a small scale change. However when the reference points are used as control points in the actual orientation procedure they will distort the network. If the control information is accurate this distortion will be beneficial, i.e. it will make the network correspond more closely to the actual situation.

Orientation to control from a relative orientation

This technique assumes that some of the relative orientation methods have first created an oriented network. This complete network is then oriented to the control points by a 3D transformation.

ECDS object orientation



No assumption is made about stations being levelled. They may or may not be levelled. The basic assumption is that the coordinate system of the control points may be tilted with respect to the local coordinate system of the station.

Stations are therefore approximately oriented to the object's control points by two measurement components.

Firstly a station approximately measures the directions of two of the object axes (X,Y or X,Z or Y,Z). This enables it to be given the correct angular tilt with respect to the object.

Secondly a station locates a control point on the object by approximate polar location, i.e. by angular pointing (h,v) and manual estimation of distance (d). This enables the station to be given the approximately correct position with respect to the object.

None of the axial pointings or polar estimations are accurate and so none of these measurements are used in the optimized orientation.

This is currently the only method which creates a provisional object orientation in a single step.

6.5.3 Guided orientations

By using scripts the operator can be forced to make the correct measurements at any station which will ensure that a particular orientation method is chosen by the bundle adjustment for that station.

However guided orientations are not required for experienced operators who know which measurements to make.

6.6 The bundle adjustment

The purpose of the bundle adjustment is to optimize the approximate network of stations and orientation targets and generate accurate values for the corresponding location and tilt parameters.

The user must ensure that the bundle adjustment has sufficient orientation measurements to calculate parameters for the selected stations. However checks are made internally and the user will be warned of some of the major failings such as too few measurements.

6.6.1 Selected features of the Axyz bundle adjustment

- Network may have 1 - 99 stations
- Angle and distance measurements processed
- Unlimited object points (subject to computer's disk capacity)
- Unlimited scale bars (subject to computer's disk capacity)
- Optional use of weighted control points
- "Partial" control points can be used (only 1 or 2 coordinate values known)
- Optional "balanced station network" for more optimal statistical analysis
- Detection of single "blunders" (measurements which are badly incorrect)

Editing features:

- Disable a single measurement
- Disable all measurements from one station

Other options:

- Use as an end result to generate optimized values for all target points
- Hold an existing network fixed and add new stations (update)

7. General design concepts

7.1 Operating system and user interface

Axyz has been designed to run on personal computers (PCs) using the Intel 486 processor or higher and Microsoft's Windows 95 operating system. There are a number of reasons for this.

LEICA's principal activity in the field of industrial measurement is the design and manufacture of high-precision opto-electronic measuring instruments and their integration with computers. The end result is a complex system which generates 3D coordinates.

To create this complex system, LEICA has developed a large software package. Like an old-fashioned mechanical watch this should be complex only on the inside but simple on the outside - one glance and you can tell the time.

To achieve this aim Leica uses standard tools and software packages where these offer practical solutions. This saves on development time and cost and may additionally provide users with a more flexible solution to the problems of their particular applications.

The PC is a readily available, cost-effective and very powerful computer. As such it is ideal for developing a package such as ***Axyz***. On this computer the Microsoft windows interface, and underlying DOS operating system, has become one of the most widely recognized computer interfaces. For a very extensive range of commercial software packages it is, in practice, a standard interface offering some considerable ease of use. Because of its familiarity and the benefits this brings, LEICA have adopted it as the standard for ***Axyz***.

Windows also offers OLE technology which enables ***Axyz*** to be programmed using Microsoft's Visual Basic programming language.

7.1.1 Object Linking and Embedding (OLE)

Windows uses a technology called OLE, pronounced "oh-lay" with emphasis on the second syllable. The name was originally an acronym for Object Linking and Embedding but today the technology goes beyond that.

OLE allows different programs or applications to share *objects* which are often data. For example, a word processing document can use a chart (the "object") created by a spreadsheet program. This can be done by either establishing a *link* to the chart or by *embedding* the chart in the text document.

If the chart is linked, any changes to it which are made at source can be seen in the text document since this, in effect, simply points to the latest version of the chart. If the chart is embedded, a copy is stored in the text document. Although changes at source cannot then be reflected in the text, the copy can be edited directly from the text. In this case the functions of the original spreadsheet appear in your text processing program to enable you to do this.

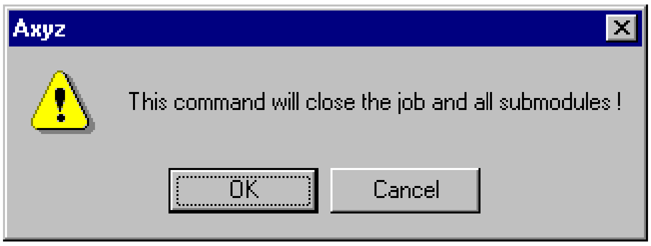
This technology can also be used within single applications, allowing independent sub-programs to exchange and manipulate your data

OLE technology can also enable the components of an application to be incorporated into Visual Basic so that users, employing a real and flexible programming language, can drive the application in their own way.

7.1.2 Axyz software modules

The ***Axyz*** software design makes use of OLE techniques and is therefore based on independent modules. Some of these modules could indeed run in a restricted way entirely independently but they are, in fact, designed to operate together as a team. Like all teams there is a chain of command.

Everything is accessed through the Core Data Module (CDM), including the individual instrument modules, i.e. the Single/Multiple Theodolite Module (STM/MTM) and the Laser Tracker Module (LTM). You will notice that these are independent modules at the end of a measurement session where more than one is running. The following message then appears:



Syst - Message - Close submodules.bmp

This is simply a warning that the other nominally independent programs will also be closed down since they are only accessible through the CDM.

These 3 *main modules* can call on other independent *sub-modules* to perform certain functions. For example they can call up the Orientation Module to calculate a measurement network or call on the Data Manager to provide a numerical view of the information in the job file. In this case they act as *host modules* to the sub-modules which are called. When the host module is closed the activities of the sub-modules must be closed. Normally this is automatic but some sub-modules may have to be explicitly closed. For example, if the MTM has started the Running Data Window and it is then closed whilst the Running Data Window is still open, you will get this message:

Syst - Message - Close OLE connection.bmp

7.1.3 Viewing data through the Multiple Document Interface (MDI)

It is not the purpose of this document to explain in detail how to use and operate the Windows 95 interface. This is presented in Microsoft's own documentation.

However one important feature of windows operation, employed by the **Axyz** developers, may initially confuse new users. This is the *Multiple Document Interface (MDI).*

MDI allows you to open several documents or files at the same time and view a document through several *windows*. Users familiar with word processing software will know that they can open more than one document at a time, for example a report and a separate cover letter. Both can be simultaneously viewed on screen, each in its own window. The window on each individual document can be further split into *panes* so that you can, for example, look at both the report's introduction at the start and its conclusion at the end. You can even create another window for the same document.

In the word processing example, the windows are all designed to present text. In contrast, windows in a spread-sheet program may be designed to show data in different ways, for example one window may show document data as a chart whilst another shows it as a table.

The ***Axyz*** software is also an MDI application, although it does not implement all aspects of this concept. You can, in fact, only open one job file at a time. However, you can view this job file through different windows. For example, the Data Manager allows you to view the file through an window which shows both a structured overview and tables of values in the format of a spreadsheet grid. In contrast the Graphics Module enables you to view the data in a pictorial way.

Dynamic menus and toolbars

In an MDI program the menu bar is a *shared resource*. This means that the menu items on offer depend on which type of window is currently active, i.e. the window where your actions currently take effect.

When alternately activating the window of the host module (CDM, MTM or LTM), a Data Manager window or a Graphics window, you will notice changes to the menu bar. In some cases the contents of individual menus change, i.e. the menus

- View
- Edit
- Help

For example, "View" offers a zoom function for a graphics window but not for a Data Manager window. The menu bar also adds further options, i.e.

- Data menu for a Data Manager window
- Graphic menu for a Graphics window

Note also that toolbars provide direct access to selected menu items. A common feature of windows programs is that any associated toolbars can be optionally displayed. This facility is offered in the "View" menu and the choice of toolbars which can be displayed relates to the active window. Further, since the menu changes when a DM or Graphics window is active, the associated toolbars disappear when the window is inactive.

This process may lead to a small but easily solved problem. For example, if the CDM analysis toolbars do not appear when you are selecting items for analysis from a DM window, you cannot re-display them by choosing an option from the "View" menu. This is because the option to display toolbars currently only relates to the Data Manager. You must first activate the CDM's main window, then choose the relevant option from the "View" menu.

How many windows can be open and active?

From the discussion it should be clear that the windows for viewing the contents of a job file can be switched on and off. It is not necessary to have both a Graphics and a Data Manager window open. In fact, it is possible to open the job file and have no windows providing a view of the file's contents.

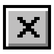
Only one window from all the open windows in a main module can be active at any one time.

A main module can have a maximum of:
- 1 graphics window
- 10 DM windows

Instrument modules can additionally have a maximum of:
- 1 station status window
- 10 measurement windows

Activating and closing windows

Click on a window to activate it. To activate the host module itself do one of the following:
- Click on the background display area, if any is visible
- Close the Data Manager and Graphics windows
- Minimize the Data Manager and Graphics windows
- In the "Window" menu, select the name of the job file from the list of open windows

To close a DM or Graphics window, do one of the following:
- Click the  button on the right of the window's title bar
- Click the icon on the left of the title bar, select "Close" from the popup menu
- Type CTRL+F4

Note that you can also activate each window in a cyclic fashion, including the host module's window, by one of the following:

- Click the icon on the left of the DM or Graphics window, select "Next" from the popup menu. Repeat to reach the required window.
- Type CTRL+F6, repeat as necessary.
- Type CTRL+TAB, repeat as necessary.

7.2 The ACCESS database

7.2.1 What is ACCESS?

ACCESS is a toolbox for creating a stand-alone database package.

It is also a type of programming language for manipulating databases.

ACCESS not required by the user. In principle it can be used to manipulate the job file but as a security measure this feature has been disabled by "locking".

7.2.2 What does ACCESS offer?

ACCESS was chosen because:

- It is consistent with using standard Windows packages.
- It provides Open DataBase Connectivity (ODBC). This is a database standard which ensures that a wide range of applications such as EXCEL can, with a suitable driver, exchange information directly with the database
- It provides Object Linking and Embedding (OLE) which allows other Windows applications to include ACCESS data in their documents. This data can be automatically updated when changes are made to it.
- Licence fees are not required, which reduces costs and simplifies administration of registered versions of ***Axyz***.
- It provides an excellent solution to the need for flexible report generation.

The last point is particularly critical since LEICA's experience has shown that users frequently want data presented in their own unique formats. ACCESS provides a toolbox for creating reports in almost any format a user specifies. If users require alternatives they can either approach LEICA for assistance or create the reports themselves by using any tools which conform to the ODBC standard.

7.3 Where Axyz is installed

Axyz program files and master database:

Stored in C:\Program Files\Leica\Axyz

Axyz data files (job files and scripts)

By default stored in c:\axyzdata

Job files stored in c:\axyzdata\jobs
Scripts stored in c:\axyzdata\scripts

Note
There is no restriction on storing data files in other folders.

7.4 System requirements to run the Axyz software

For versions higher than 1.3, the operating system must be Windows 95 or Windows NT

32 MB RAM is recommended, but the system can run on less.

100MB hard disk space is recommended.

Processor speed at least 133MHz is recommended.

A CD ROM drive is recommended to install the software and a floppy disk drive to enable updates via floppy disk.

A parallel printer port is required for the software protection key or "dongle".

Connected on-line measuring instruments have their own hardware requirements which the controlling PC must be able to handle.