DESIGNING COILS TO PRESERVE GOOD MAGNETIC SURFACES

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NCSX PROJECT MEETING
12 JULY 2000

THE NEED

•THE NCSX PROJECT'S OVERALL APPROACH TO MAGNETICS DESIGN DIVIDES WORK INTO TWO CONSECUTIVE TASKS:

(1) -THE FIRST TASK DESIGNS A 3-D PLASMA MAGNETIC FIELD, ASSUMING EXTERNAL COILS WILL PROVIDE PRECISELY THE MAGNETIC FIELD REQUIRED OF THEM. A <u>GOOD</u> PLASMA DESIGN CONTAINS A SINGLE SET OF NESTED MAGNETIC SURFACES, MOSTLY FREE OF BLEMISHES (E.G., MAGNETIC ISLANDS OR STOCHASTIC REGIONS).

(2) -THE SECOND TASK DESIGNS A PRACTICAL SET OF EXTERNAL COILS WHICH APPROXIMATELY PROVIDE THE REQUIRED EXTERNAL MAGNETIC FIELD, AS DETERMINED BY THE FIRST TASK.

•PRACTICAL COIL DESIGN APPROXIMATIONS PRODUCE FIELD ERRORS, WITH SOME ERRORS DAMAGING MAGNETIC SURFACES WHILE OTHERS ARE HARMLESS. THERE NEEDS TO BE A WAY TO "STEER" THE COIL DESIGN AWAY FROM MAKING DESTRUCTIVE APPROXIMATIONS.

THE PRESENT APPROACH TO COIL DESIGN (1)

•PLASMA DESIGNS EMERGING FROM THE VMEC CODE ARE ACCOMPANIED BY THE PLASMA'S REQUIRED SURFACE NORMAL MAGNETIC FIELD TO BE PRODUCED BY EXTERNAL COIL CURRENTS.

•THE NESCOIL CODE CALCULATES A DISTRIBUTED CURRENT STREAM FUNCTION, Φ , FOR A PLASMA-ENCLOSING "COIL WINDING SURFACE".

•THE NESCOIL CODE DETERMINES Φ TO APPROXIMATELY DRIVE BERR, THE ERROR BETWEEN THE REQUIRED SURFACE NORMAL FIELD AND THE FIELD PRODUCED BY THE DISTRIBUTED CURRENT, TO ZERO.

•ALTERNATIVELY, NESCOIL CAN DETERMINE Φ TO APPROXIMATELY DRIVE XERR, THE EXTENT OF FIELD LINE WANDERING FROM VMEC'S PLASMA SURFACE DUE TO NORMAL FIELD ERRORS, TO ZERO.

THE PRESENT APPROACH TO COIL DESIGN (2)

•THE LEVEL SET OF Φ APPEARING IN A CONTOUR PLOT, WITH CONSTANT $\Delta\Phi$ INCREMENTS BETWEEN CONTOUR LEVELS, IS A SET OF CLOSED FILAMENTARY CURVES. THESE ARE POSSIBLE NCSX COIL SHAPE DESIGNS, AND ARE SAVED.

• WITH MANY CONTOUR LEVELS INCLUDED, THE MAGNETIC FIELD APPROACHES THE DISTRIBUTED CURRENT'S FIELD.

•THE "GENETIC ALGORITHM" (GA) CONSIDERS A LARGE SET OF COILS RESULTING FROM ONE CONTOUR PLOT OF Φ . IT EVALUATES SUBSETS OF THE COILS FOR USE AS THE NCSX COIL SET.

•FOR EACH SUBSET IT OPTIMUMIZES COIL CURRENTS TO MINIMIZE EITHER BERR OR XERR ON THE PLASMA SURFACE. IT STEPS THROUGH SUBSETS USING GA HEURISTICS, AND EVALUATES SEVERAL "FITNESS PARAMETERS" (BUT NONE TO AVOID ISLANDS). THE BEST SUBSET FOUND BECOMES THE NCSX COIL DESIGN.

NEW ALGORITHM CONCEPT (1)

•THE DISTRIBUTED COIL WINDING SURFACE CURRENT CALCULATED BY NESCOIL COULD ALSO BE USED TO CALCULATE THE FIELD REQUIRED FROM EXTERNAL COILS AT LOCATIONS INSIDE THE PLASMA.

•FOR ANY PROPOSED COIL DESIGN, THE "VACUUM" ERROR BETWEEN ITS FIELD AND THE FIELD REQUIRED FROM EXTERNAL COILS COULD THUS BE CALCULATED FOR ARBITRARY LOCATIONS IN THE PLASMA.

•NORMAL FIELD ERROR COULD THUS BE CALCULATED AT LOCATIONS DISTRIBUTED ON ANY VMEC INTERNAL PLASMA MAGNETIC SURFACE.

•MAGNETIC ISLANDS COULD FORM BY RESONANCE BETWEEN PERTURBING NORMAL FIELD ERROR AND RATIONAL VALUE OF "ɩ" .

•EXISTING XERR CODE DOES NOT MODEL ISLANDS; IT ESTIMATES FIELD LINE WANDERING, INCLUDING RESONANCE EFFECTS. BUT ITS' XERR AMPLITUDE MAY CORRELATE WITH MAGNETIC ISLAND FORMATION.

ALGORITHM DETAILS (1)

• NEW CODE MODULE WILL BE USED WITH A COIL DESIGN OPTIMIZER SUCH AS THE GA. IT HAS NO STAND-ALONE FUNCTION.

•MANY OF THE NEW CALCULATIONS ARE DONE ONLY ONCE, AS A PRECALCULATION BEFORE THE OPTIMIZER BEGINS ITERATING.

•THE NEW CODE MODULE IDENTIFIES WHICH INTERNAL MAGNETIC SURFACES TO USE, BASED ON THEIR VALUES OF "ι" .

-THE NEW CODE READS DATA FROM VMEC'S OUTPUT FILE, WOUT.

- "S" VS. "ι" FOR INTERNAL SURFACES FORM A CUBIC SPLINE, AND WORRYSOME "ι" VALUES DETERMINE CRITICAL SURFACE LABELS, "S".

-"S" VS. SURFACE SHAPE FOURIER COEFFICIENTS FORM CUBIC SPLINES, PROVIDE FOURIER COEFFICIENTS ON CRITICAL SURFACES.

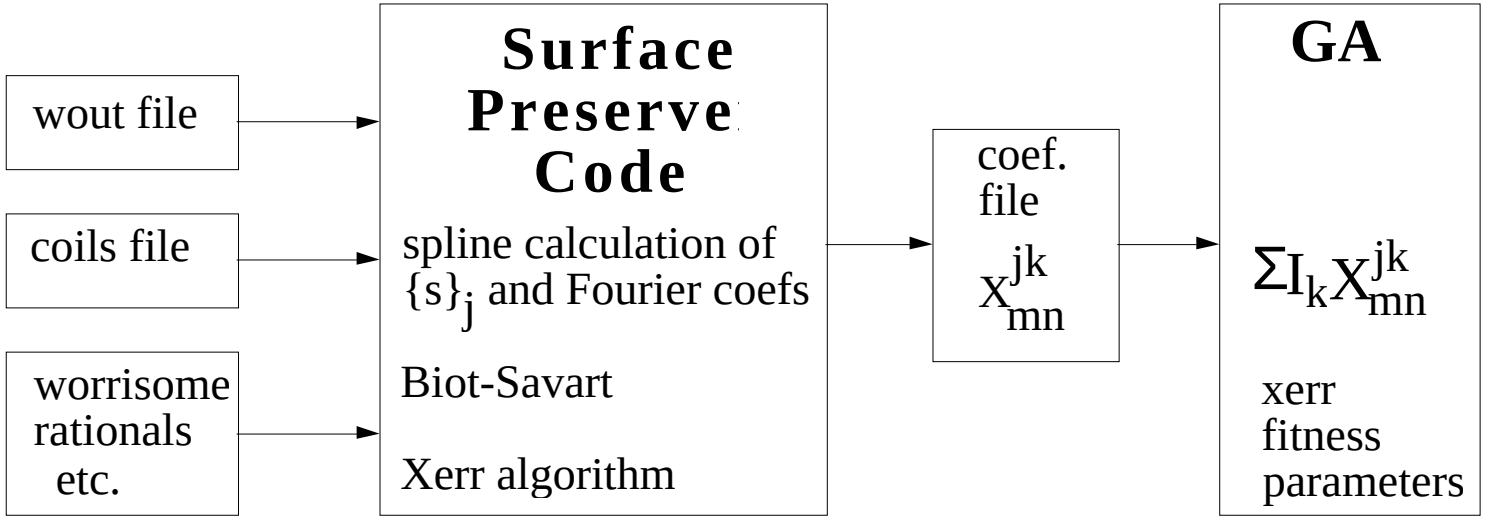
ALGORITHM DETAILS (2)

•THE GA DOES NOT MODIFY ANY OF ITS INITIALLY SPECIFIED COILS, NOR DOES IT GENERATE ANY NEW COILS DURING ITS ITERATIONS. THEREFORE, THE NEW COIL-SPECIFIC CALCULATIONS CAN BE DONE IN ADVANCE BEFORE STARTING GA ITERATIONS.

•FOR EACH CRITICAL MAGNETIC SURFACE (J) AND FOR EACH OF THE INITIALLY SPECIFIED COILS (K) OR FOR THE IDEAL SURFACE CURRENT DISTRIBUTION, THE FOURIER COEFFICIENTS, X_{MN}^{JK}, OF THE FIELD LINE DISPLACEMENT PER UNIT CURRENT ARE CALCULATED.

THE GA DETERMINES CURRENT IN THE REDUCED SET OF COILS. THE RESULTING FIELD LINE DISPLACEMENT FOURIER COEFFICIENTS ARE $\sum I_K X_{MN}^{JK}$, CALCULATED DURING EACH GA ITERATION.

ALGORITHM DIAGRAM



SUMMARY STATUS- CONCLUSION

•CODE WILL MAXIMIZE USE OF EXISTING MODULES, BOTH FROM NUMERICAL LIBRARIES AND FROM THE NCSX PROJECT.

•THERE ARE EXCELLENT OPTIMIZED SUBROUTINES FOR CUBIC SPLINE CALCULATIONS, E.G., THE IMSL LIBRARY.

•THE XERR CALCULATING CODE HAS BEEN USED ROUTINELY IN RECENT TIMES, AND HAS AT LEAST ONE COGNIZANT TECHNICAL PERSON. IT THEREFORE IS A GOOD CANDIDATE TO INITIALY EMPLOY FOR THE PURPOSE OF PRESERVING GOOD MAGNETIC SURFACES DURING COIL DESIGN

CODE IS BEING PUT TOGETHER AT PRESENT, AND MAY BE READY FOR ABSOLUTE INITIAL DEBUGGING TEST AT END OF THIS WEEK.

AFTER DEBUGGING IS COMPLETE, THERE SHOULD BE EXTENSIVE TESTING TO SEE HOW THE ALGORITHM BEHAVES IN COIL DESIGN.