COIL ROBUSTNESS AND FLEXIBILITY

- Plans for calculations in preparation for March PVR

ROBUSTNESS

"Robustness" reflects the ability of coils to support equilibria with a wide range of assumed internal profiles (pressure and current).

- Execution of planned XP's probably requires feedback on pre-programmed coil currents (or voltages). Since a correct prediction of plasma current and pressure profiles is unlikely for early experimental campaigns, pre-programmed waveforms will be approximate.

  If the assumed plasma profiles are not consistent with the assumed coil currents, do we obtain a configuration that is recoverable by feedback control?

ROBUSTNESS CALCULATIONS

1. In preparation for the PVR, we will repeat "robustness" calculations of the type presented in the Sept Project Mtg, but using updated coils:

   - Free-boundary VMEC will be run using fixed coil currents for a variety of assumed plasma profiles. β and I_p will also be varied for a chosen set of profiles. Overlays of the plasma boundary obtained by VMEC will be displayed to demonstrate robustness.
   - In separate calculations, the axisymmetric dipole field will be allowed to vary such that first wall constraint is always met. Physics properties will be monitored, but no optimization will be done (save the first wall constraint)

FLEXIBILITY

"Flexibility" reflects the ability of coils to produce changes in the plasma configuration which correspond to desired changes in physics properties.

- To date, we have compared the ability of modular and saddle coils to
  (a) Optimize the physics (β_{lim}^{kink}/QAS) for different profile choices.
  (b) Inflate/Deflate $\iota(s)$.
  (c) Increase/Decrease $\iota'(s)$.

- For the PVR we must show that the designated coilset has sufficient flexibility to meet the requirements of the physics program. Below, we enumerate elements of the physics program (taken from Mike Z's PVR Outline), together with numerical experiments to be performed which will demonstrate the ability of the coils to effect the program.

FLEXIBILITY CALCULATIONS

1. **Understand role of external transform & 3D shaping in disruptions**

   W7AS experiments reported at IAEA2000 showed stability does not depend on the magnitude of ι_{ext}, but requires avoidance of $\iota(1) = 0.5$. Since $\iota(1)$ is especially important (ι' to a lesser extent), we need the ability for NCSX to vary ι_{ext}/ι with fixed $\iota(s)$. The required flexibility experiments are similar to those reported at the Sept Project Mtg ("Type 1 ι-scan experiments") except we need to include runs with various I_p. Specifically:

   Using baseline profiles and low β (0%), decrease and increase $\iota(s)$ from the nominal profile by 3D shaping.

   Three runs can be same as 'Type 1 ι-scan, showing basic ι control:
   $I_p = 250$kA, $RB_t = 3.4$, $\beta = 0.0\%$, $\iota(0) = 0.40$, $\iota(1) = 0.65$ (essentially the baseline case)
   $I_p = 250$kA, $RB_t = 3.4$, $\beta = 0.0\%$, $\iota(0) = 0.20$, $\iota(1) = 0.45$
   $I_p = 250$kA, $RB_t = 3.4$, $\beta = 0.0\%$, $\iota(0) = 0.60$, $\iota(1) = 0.85$
   Two more cases will be run with reduced I_p (values TBD) for larger variation of ι_{ext}/ι.

2. **Understand role of kink- and ballooning modes on β-limit - tokamak-like vs. toroidally localized ballooning**

   First, we will identify two types of configuration - those whose β-limits are clearly limited by kinks (as opposed to ballooning modes) and those whose β-limits are clearly limited by ballooning modes (as opposed to kinks). Varying I_p should separate the two types of configuration (increasing I_p improves ballooning but deteriorates the kink). Data may already exist from Mike Z's optimization runs, allowing us to pick out the appropriate runs. Long-Poe's I_p vs β plots of kink/mercier/ballooning stability may also be helpful.

   - Once we have identified appropriate configurations we need to show they can be supported by coils as β is increased from well below to (well) above the β-limit. For the two values of β, the optimizer will target $\chi^2_{B_{mn}}$. The actual experiments would surely ask for the dependence of β_{lim} on ι_{edge}, shear, etc. Although Type 1 and Type 2 ι-scans could be done using these profiles there is no need to demonstrate Type 1 control, since this has been addressed in numerical experiment 1. above. However, we will vary the primary coil

currents to demonstrate Type 2 shear control using the kink limiting profile at some β (to be decided).

- In addition, we will demonstrate the use of L=3 secondary coils for effecting shear control (a) without the aid of the primary coils, and (b) allowing the primary coil currents to also vary. For the same targeted shear it will be interesting to compare the level of $\chi^2_{B_{mn}}$ achieved with and without the L=3 coils$\cdots\cdots$We should get a lower value because of the greater freedom. It will also be interesting to compare the final values of the primary coil currents after shear control with and without the L=3 coils. Their variation should be less. If correct, these two results would be arguments in favor of including secondary shear control coils. Long-Poe's interesting results showing magnetic island repair by decreasing the shear (eliminating rational surfaces from plasma and increasing the separation of rational surfaces) are a further argument for the secondary coils.

3. **Understand role of 3D shaping on vertical instability**

   Numerical calculations have shown that the $n = 0$ (vertical) family of modes is much more stable for QA stellarators than for tokamaks. Analytic calculations for large aspect ratio stellarators [Fu] have shown that sufficient external transform can stabilize the vertical mode. (Note: Furth originally proposed using external transform for stabilizing $n = 0$ in tokamaks $\cdots$ see Furth-Hartmann series of papers). The predicted external rotational transform needed for stability is $\iota_{ext}/\iota = \left[< \kappa >^2 - < \kappa >\right] / \left[< \kappa >^2 + 1\right]$.

   Since NCSX will PF coils capable of varying the average elongation (and triangularity), there will be a good opportunity to explore the role of 3D shaping on the vertical instability. We can demonstrate the ability of NCSX coils to produce configurations to explore an XP such as:

   - For some range of average elongation (say $< \kappa >= 1.5 - 2.5$), vary ι_{ext}/ι keeping ι_{edge} fixed. Correlate the onset of $n = 0$ modes with ι_{ext}/ι.
   - Simulations are similar to "1" above. I_p should be low to avoid large disruption loads. β can be zero (to avoid $n > 0$ modes). Two runs at different $< \kappa >$ will suffice. Variation of $< \delta >$ would be nice, if time permits.

4. **Test quasi-axisymmetric reduction of neocl. transport.**
   Understand induced flow-damping

   This should be done reasonably far below the β limit. We need to generate configurations (2) with different $\chi^2(B_{mn})$, same $\beta, I_p, \iota(s)$ (transport depends on $1/\iota^2$). Having same $\iota(s)$ important also to avoid confusion with possible effects of tearing modes, etc.

5. **Understand neoclassical-island stabilization using externally imposed islands**

   No point in doing this with primary coils.....Do with trim coils by demonstrating resonant B_n targeting ability on given flux surfaces.

   Also, see discussion at end of section 2.

6. **Other calculations**

   - Document dependence of QAS and Stability on profile shape, including I_p, β scans.
   - Ed Lazarus is doing rampup studies. However we should verify that if the "self-consistent" profile assumptions are not correct, we can still access the S3 states. So do at least one rampup with prescribed profiles quite different from the reference.

Additional Comments

- Mgrid files with coil currents in MA will be used

Some optimizer code modifications needed (Mike Z):

- Modify optimizer to always include $n = 0$ family with $n = 1$.
- Add many more initial conditions for ballooning calculations
- For modular flexibility we should try clamping the TF. In principle, the modular variation should be able to provide flexibility at fixed B_{tor} without the need for an auxiliary TF. The flexibility will be reduced, but to what extent?

- Priorities for calculations and division of labor to be made soon.