manual

Miscellaneous.

contents

Code improvements

2.1 discretization of integrals

1. The plasma boundary, $\mathcal{S}$, does not change during the coil optimization, and so I expect it is computationally efficient to compute the surface integral on a fixed regular grid, e.g.

$$\int_{\mathcal{S}} ds \approx \sum_{j,k} \sqrt{g}_{j,k} \Delta\theta\Delta\zeta. \tag{1}$$

2. The benefit is that the $\sqrt{g}_{j,k}$, and the position on the surface, $\mathbf{x}_{j,k}$ need only be computed once.

3. The accuracy of the above expression can be improved. Second, or even third and fourth order accurate expressions should be used.

4. A similar point is true for the calculation of line integrals that appear in the Biot-Savart formula,

$$\int_{\mathcal{C}} dl \approx \sum_{i} dl_i \Delta t. \tag{2}$$

   Even though the geometry of the curve is changing, for each geometry it is required to determined $\mathcal{O}(N_\theta N_\zeta)$ evaluations of the magnetic field to compute the above surface integral and the derivatives of the magnetic field with respect to changes in the coil geometry. Precomputing the geometry of the coils and the differential line segment only once per coil geometry will reduce the computation, particularly so as the coils are described by a Fourier representation. The trigonometric coefficients need only be computed once.

5. The calculation of the length of each coil should also be discretized.

2.2 including constraint on enclosed toroidal flux

1. The toroidal flux through a surface bounded by a closed curve $\mathcal{C}$ is

$$\int_{\mathcal{C}} \mathbf{A} \cdot d\mathbf{l}, \tag{3}$$

2. This should be discretized consistently and also needs to be differentiated with respect to the coil geometry.

3. Constraining the enclosed toroidal flux will allow the coil currents to be varied (i.e. will eliminate the trivial solution).

2.3 including coil-self separation constraint

1. To ensure that each coil does not intersect itself, include an energy term similar to

$$\sum_{i,j\neq i} \frac{1}{|\mathbf{x}_i - \mathbf{x}_j|^{\alpha}} \tag{4}$$

2. This quantity needs to be differentiated with respect to the coil geometry.

2.4 including coil-coil separation constraint

1. To ensure the coils are separated, include an energy term similar to

$$\sum_{i,j\neq i} \int_{\mathcal{C}_i} \int_{\mathcal{C}_j} \frac{d\mathbf{l}_i d\mathbf{l}_j}{|\mathbf{x}_i - \mathbf{x}_j|^{\beta}} \tag{5}$$

2. This quantity needs to be differentiated with respect to the coil geometry.

2.5 including coil-plasma separation constraint

1. Similarly, to ensure the coils are separated from the plasma, include an energy term similar to

$$\sum_{i} \int_{\mathcal{C}_i} \int_{\mathcal{S}} \frac{dl_i ds}{|x_i - x_j|^{\gamma}} \tag{6}$$

2. This quantity needs to be differentiated with respect to the coil geometry.

2.6 appropriately normalize the energy functional

1. To better understand what numerical value of the associated weights, it is preferable that all quantities are normalized and dimensionless.

2.7 more efficient minimization algorithms

1. Our main task is to define an energy functional, $E\mathbf{x}$, which depends on the geometry of the coils, and to analytically construct the derivatives, $\nabla E(\mathbf{x})$.

2. Then, many numerical algorithms for (i) finding the minimum of E, or (ii) finding a zero of ∇E can be easily implemented.

2.8 additional constraints

1. Include additional constraint that each coil lies within its own segment (so that each coil can easily be removed for maintainence).

2.9 multiple plasma boundaries

1. We can include multiple plasma boundaries, if multiple currents can be given to each coil. This will allow us to perform many interesting coil-sensitivity studies, demonstrate 'flexibility', etc.

2.10 include non-zero $\mathbf{B}\cdot\mathbf{n}$ on plasma boundary

1. We should not depend explicitly on VMEC or BNORM, but we can simply include another Fourier series in the `plasma.boundary` input file that describes the normal field on the plasma boundary produced by the plasma currents.

2.11 maintain flexibility

1. Please keep in mind that I want to use this code for knotatron optimization; so, keep the code very flexible.

2. For efficiency, we can include field-periodicit constraints, stellarator-symmetric constraints, etc., but I want to do this in a way that is very flexible. For example, in each `.op.coil.xxx` file, we can include an integer that identifies each coils stellarator-symmetric pair.

Applications

3.1 whatever you can imagine

1. Your imagination and creativity is just as good (if not better) than anybody elses.

3.2 reconstruct existing experiments

1. Modular LHD, helical LHD, . .

2. NCSX,

3. W7-X,

4. error field sensitivity,

3.3 Uniqueness of solution, importance of "initial guess"

Code documentation, Echidna interface

4.1 in-source, online documentation

1. Keep the code well documented. Describe all input variables. Update the LaTeX documents in each subroutine, and this LaTeX source will later be easily incorporated into your future publications.

2. We can create a "mirror" website similar to my own on your website. Please make this site well linked and informative.

3. This will make the code easier for us to use!

4.2 Echidna interface

1. Keep the Echidna interface easy to use.

2. Additional capabilities should be included, such as (i) automatically generate an `mgrid` file after completion of `xknotopt`, and automatically run `xglass` to construct a Poincaré plot with additional diagnostics (e.g. calculate rotational-transform on magnetic axis); (ii) implement capability to automatically strengthen or weaken the various constraint "weights"; . .

3. Improve and include additional graphics. Presently, the representation of the plasma surface looks terrible! We will need better figures when it is time to publish.

3. This will make the code easier for us to use!

4.3 CAD and the 3D printer

1. Using Computer Aided Design and the 3D printer, we can create physical models of the stellarators that we design. This will be very useful to promote our research.

2. Also, for knotatrons it is difficult to visualize the different configurations on the screen, and I will need 3D objects to bette understand how coils can be constructed for a given knotted configuration.

3. Please download CAD software and construct STL files for 3D printer.

Developing problems and solutions

1. Differential flow gets stuck at somewhere.
   Description: I found that with certain inputfiles, like using a circular torus plasma model with 10 initial coils ($R_0 = 3.0, r = 1.0$) and making weight_bnorm = 1.0, weight_tflux = 1.0, target_tflux = 1.0 without normalizing weights. The differential flow method would get stuck at $\tau = 2.9$ and keep callling cost functions without any outputs. When turning on the weights normalization, it worked till tauend. The same situation happened on w7x case.
   Guess: With certain sets of weights and cost functions, the differential flow would fail to find solution for current "time".
   solution:

2. E04LBF crash and non-positive-definite Hessian matrix.
   Description: The least-square minimization routine NAG:E04LBF crashed after several iterations, like 102 iterations, and then displayed the error *" xknotopt:23405 terminated with signal 11 at PC=2b2892891ba1 SP=7fff16ecddc0. Backtrace: "*. And also during runing E04LBF, the roytine warns Hessian matrix is not positive definite. I may have to contruct psudo-inverse of the jacobian matrix.
   Guess:
   solution:

3. Better constraints about equal arclength and coil-coil separation.
   Description: Right now, equal arclength constraint was included in equarcl. It seems working in single constraint differential flow but when coupling with other constraints, it seems not working. I still need more tests. But first of all, I should figure out whether this constraint applies our case. It's derived from surface problems (and with stellarator symmetry) . As to coil-coil separation, using electric potential would lead coils compressing into a point or putting a coil inside another coil. I have to find a more robust way, maybe about coil forces.
   Guess:
   solution:

4. Specify the positive angle, both toroidal and poloidal. And also the positive current direction.
   Description:
   Guess:
   solution: