Status of vmec/extender-fields considering <β> and/or toroidal current for configurations

- standard
- high-iota
- high-mirror

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General remarks

- The equilibria have been calculated with VMEC.
- The calculations are taken from a collection of equilibria which has evolved during the two decades.
- The coil currents are generally not the ones used in experiments, scaling needs to be performed to relate beta-values or toroidal currents to experimental conditions.
- The files are stored on a fileserver (CIFS share):
  //share.ipp-hgw.mpg.de/mp/fieldline/geiger/w7x (linux)
  \\share.ipp-hgw.mpg.de\mp\fieldline\geiger\w7x (Windows)
  which can be mounted.
- The fileserver can also be assessed by the fieldlinetracer webservice:
  See http://webservices.ipp-hgw.mpg.de/docs/fieldlinetracer.html#Grid
- The different configurations are stored in folders named with the vmec-id of the corresponding configuration.
  - Subfolders in the configuration-folders contain beta- and tor. current-sequences
  - Example:
    ~/geiger/w7x/1000_1000_1000_1000_+0000_+0000/01/<fields>...

Standard configuration: 1000_1000_1000_1000_+0000_+0000

- subfolder 01
  - Note: coil currents used are I_1=...=I_5=15kA. In experiment 2.52T imply 12985A. Hence, to scale the toroidal current values to 2.52T, multiply them with 0.8656=12985/15000, i.e. a I_{tor}=10kA correspond to an value of 8657A at 2.52T.
  - The pressure profile is a simple one: p(s) ~ (1-s), s=norm. tor. flux $(\sim(r_{eff}/a_{eff})^2$
  - The current profile is a simple one: j(s) ~ s·(1-s)
  - Suffixes:
    - xdr-files are used for EMC3 and EMC3-lite
    - txt-files are used for webservice fieldlinetracer
  - There is a readme_standard describing the contents.
    - vacuum field: fieldn_altern181x181x96.w7x.1000_1000_1000_1000_+0000_+0000.01.00jh.xdr(txt)
    - at low beta (<β>≈0.16%) a toroidal current sequence from +20kA to -30kA (values not scaled!).
    - beta-scan without toroidal current up to <β>≈4.1% (01.20…)
      - Note: the “m” doesn't mean much, the appended “s” indicate that the underlying vmec-calculations had a different volume, “s” signifying a smaller volume and “ss” would be again smaller, etc..
        These volume studies are to check whether the underlying vmec-runs are appropriately sized.
- subfolder SCosSqSqrtS_01 (Sum of Cosines wrt Square root of “s”)
  - Particular current- and beta-study investigating the use of a new toroidal current density profile.
    - Beta-range limited: up to <β>≈0.65%
    - Toroidal currents also small up to 3kA.
  - Coil currents (I_1, …, I_5) chosen to be 13kA which is rather close to the experimental values of 12.985kA for 2.52T.
  - There are different current density profiles used for the same toroidal current specified by the suffix-labels cd01, cd02 etc.. For more details see readme.txt .

High-iota configuration: 1000_1000_1000_1000_-0690_-0690

- subfolder 01
  - Note: coil currents used are I_1=...=I_5=14814.81A & IA=IB=-10222.22A which corresponds to 2.6313T. However, in this folder is **only a beta-scan**.
  - The pressure profile is a simple one: p(s)~(1-s), s=norm. tor. flux $(\sim(r_{eff}/a_{eff})^2$
  - Suffixes:
    - xdr-files are used for EMC3 and EMC3-lite
    - txt-files are used for webservice fieldlinetracer
  - There is a readme-file: readme.01.txt describing the contents.
    - beta-scan without toroidal current up to <β>≈4.3% (01.20s)
      - Note: the appended “s” indicate that the underlying vmec-calculations had a different volume, “s” signifying a smaller volume.
- subfolder 02
  - Note: coil currents used are I_1=...=I_5=14188A & IA=IB=-9790A which corresponds to 2.52T (**only a beta-scan**).
  - The pressure profile is a more peaked one (peaking factor 3) : p(s)~$(1-s)^2$, s=norm. tor. flux $(\sim(r_{eff}/a_{eff})^2$
  - There is a readme-file: readme.02.txt describing the contents.
    - beta-scan without toroidal current up to <β>≈1.35% (02.09(ss))
      - Note: the appended “s” indicate that the underlying vmec-calculations had a different volume, “s” signifying a smaller volume.
      - Calculations with the suffix l8ns148 are based on extended volume calculations and should not be used for divertor investigations.
- subfolder 16
  - Note: coil currents used are I_1=...=I_5=14800A & IA=IB=-10212A which corresponds to 2.6287T. In experiment 2.52T imply 14188A. Hence, to scale the toroidal current values to 2.52T, multiply them with 0.9586=14188/14800, i.e. a I_{tor}=10kA correspond to an value of 9586A at 2.52T.
  - The pressure profile is a more peaked one (peaking factor 2) : p(s)~(1-s), s=norm. tor. flux $(\sim(r_{eff}/a_{eff})^2$
  - There is a readme-file: readme.16.txt describing the contents.
    - beta-scan without toroidal current up to <β>≈2.5% (16.120_…))
    - toroidal current scan between -20kA and 20kA in steps of 5kA. The calculations with negative currents had not been adapted particularly since there confinement volume increases and they evolve to limiter configurations.
      - The current density profile is the most simplest one: a constant (current density), i.e. j(s) ~j_0
      - Note: the volumes of the calculations with positive currents (iota-increasing) had been adapted in order to not be too large.

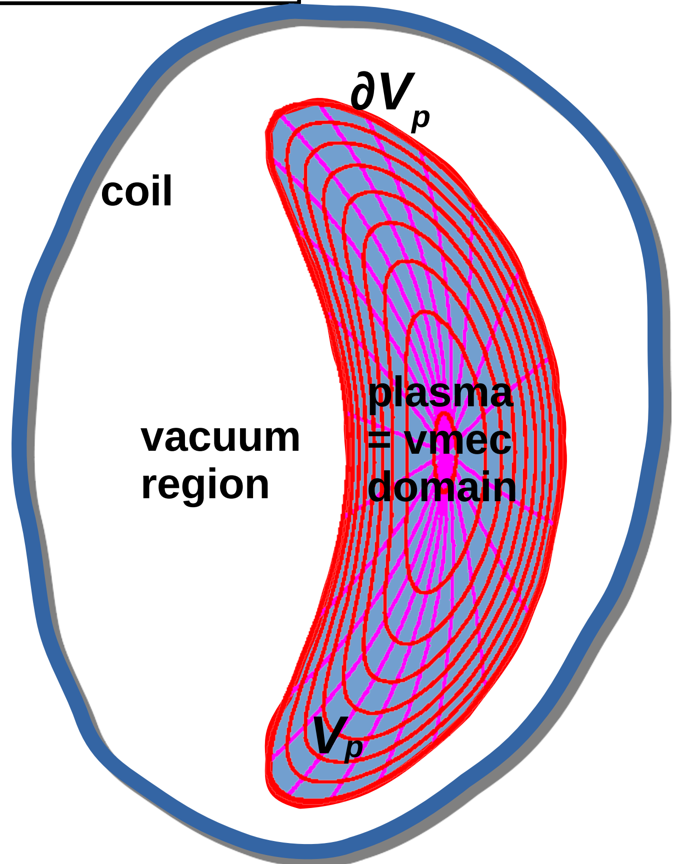
High-mirror configuration: 0972_0926_0880_0852_+0000_+0000

- subfolder 01
  - Note: coil currents used are I_1=14400A, I_2=14000A, I_3=13333.33A, I_4=12666.67A, I_5=12266.67A, I_A=I_B= 0A which corresponds to 2.743T on axis at φ=0°. The folder currently contains **only a beta-scan**.
  - The pressure profile is a simple one: p(s)~(1-s), s=norm. tor. flux $(\sim(r_{eff}/a_{eff})^2$
  - Suffixes:
    - xdr-files are used for EMC3 and EMC3-lite
    - txt-files are used for webservice fieldlinetracer
  - There is a readme-file: readme.high-mirror.01 describing the contents.
    - beta-scan without toroidal current up to <β>≈5.3% (01.24a)
  - Reminder: the assumption in generating the vmec-extender fields is, for these particular ones, a low-beta assumption. The larger the beta-values the less reliable the generated fields are.
- subfolder 02n
  - Note: coil currents are the same as for the cases in subfolder 01. The folder currently contains **only a beta-scan**.
  - The pressure profile is a more peaked one (peaking factor 3) : $p(s)\sim(1-s)^2$, s=norm. tor. flux $(\sim(r_{eff}/a_{eff})^2$
  - There is a readme-file: readme.high-mirror.02n describing the contents.
    - beta-scan without toroidal current up to <β>≈1.7% (02n.12)
- subfolder 04
  - Note: coil currents are the same as for the cases in subfolder 01.
  - The pressure profile is a similar to that of 01 (peaking factor ca 2) : $p(s)\sim(1-s)\cdot(1-s^4)$, s=norm. tor. flux $(\sim(r_{eff}/a_{eff})^2$
    The second part in the pressure profile lets the pressure gradient vanish at the boundary (s=1).
  - There is a readme-file: readme.high-mirror.04 describing the contents.
    - beta-values range up to <β>≈2.5% (04.1214ss)
    - the toroidal currents are between -20kA and +20kA (not scaled to 2.52T!)
      - current density profile is s·(1-s)

Equilibrium fields for divertor studies

MHD-equilibrium => VMEC

- assumes existence of flux surfaces
  - no separatrix structure, no islands
- based on energy minimization
  - small field components forming separatrix in low-shear configurations poorly resolved
- robust calculations
- easy profile handling
- field only inside VMEC-calculation domain



EXTENDER to complete field outside of **VMEC**

- use of virtual casing principle
  - outside VMEC-domain field of plasma currents
  - inside VMEC-domain field of coil currents
- combination VMEC-solution, EXTENDER-fields and field of coils (Biot-Savart) enables fields everywhere
- different combinations possible:

origin of fields	$\vec{x} \in V_p$	$\vec{x} \notin V_p$
vmec	$\vec{B}_{vmec}$	none
Biot-Savart	$\vec{B}_{BS}$	$\vec{B}_{BS}$
extender	$\vec{B}_\sigma \rightarrow \vec{B}_{coil}$	$\vec{B}_\sigma = -\vec{B}_{pl}$

traditional
(VMEC-solution + extended field)

$$\vec{B}(\vec{x}) = \begin{cases} \vec{B}_{vmec} & \vec{x} \in V_p \\ \vec{B}_{BS} - \vec{B}_\sigma & \vec{x} \notin V_p \cup \partial V_p \end{cases}$$

alternative combination
(proposed by Andreas Werner)

$$\vec{B}(\vec{x}) = \begin{cases} \vec{B}_{BS} + \vec{B}_{vmec} - \vec{B}_\sigma & \vec{x} \in V_p \\ \vec{B}_{BS} - \vec{B}_\sigma & \vec{x} \notin V_p \cup \partial V_p \end{cases}$$

Fields: properties & interpretation

Traditional field combination

- consistent MHD-equilibrium inside VMEC-domain
- flux surfaces up to VMEC-boundary
- result of fieldline tracing around VMEC-boundary depends on grid of field for calculation
  - rectangular cyl. grid ("discretization error" at boundary → div(***B***)- issue)
  - flux surface like grid extension to outside (better properties, numerically more complex)

New field combination - no guarantee of good flux surfaces

- relation between field and VMEC flux surfaces broken
- not a self-consistent equilibrium field in VMEC-domain
- may be interpreted a "*first-order correction*" of the VMEC-assumption of nested flux surfaces
- better div(***B***)-properties at boundary for rectangular cyl. grids

Reasons for deviations

- EXTENDER vac. field inside VMEC-domain differs from Biot-Savart-field
  - assumption of nested flux surfaces (internal islands excluded!)
  - finite Fourier representation
  - numerical resolution of energy minimization (?)
  - Vac. islands in a configuration not seen by VMEC-vacuum calculation

Effects & Advantages

- VMEC allows easy profile handling (=> net-tor. currents)
- good flux surface region of new fields differ from VMEC-region due to
  - different separatrix
    - boundary island size due to β
    - different boundary-ι_b due to net-toroidal currents
  - may be used to adjust VMEC-volume more easily
- Internal flux surface topology may differ from VMEC assumption
  - rational ι-values may lead to island formation