Platform on integrated design of fusion reactors

Yuichi OGAWA
The University of Tokyo

Acknowledgements: Dr. M. Nakamura and Mr. Y. Miyoshi
DEMO Reactor Design

DEMO would be the last integrated R&D device, just after experimental reactor ITER, and before the 1st generation commercial reactors.

We will required to design several versions of DEMO Reactors, according to changes of

[ Mission, Objectives and Role of DEMO ]

@ Technical reasons: i.e., R&D results
  ➔ Critical path, critical issues

@ Public acceptance and/or socio-economic aspect
  Fast track (early realization)
  Construction cost
  Economically attractive (COE)
History of Experimental Reactor ITER

CDA
(R=6m)
Double null

EDA
(R=8.2m)
single null
Q=\infty

FEAT
(R=6.2m)
single null
Q=10
Variations of DEMO/Commercial reactors

13T(Nb3Sn)
  - R=5m
    - A=3
      - 4
      - 5
  - 7m
    - A=3
      - 4
      - 5
  - 9m
    - A=3
      - 4
      - 5

16T(Nb3Al)
  - R=5.5m
    - A=3
      - 4
      - 5
  - 6.5m
    - A=3
      - 4
      - 5

>20T(HTS)
  - 7.5m
    - A=3
      - 4
      - 5

ARIES-AT
11.5T, 5.2m, A=4

PPCS-AB
13T, 8.6m, A=3

Slim-CS
16T, R=5.5m, A=2.6

DEMO-CREST
16T, R=7.3m, A=3.4
Steady state or pulsed
• Need to resolve technology gap for SS operation
• Pulsed operation with several hours: feasible in operation technology, but its concerns are reactor size and material fatigue

Aspect ratio
• Connected to controllable elongation, triangularity, also dependence on $b_N$
  (direct and indirect (through elongation))

Single or double null
• Need more information on physical advantages on DN and compatibility from point of view of engineering

CS flux
• Connected to reactor size
• For small CS flux, a roadmap needed for experimental verification

Magnet technology
• $\text{Nb}_3\text{Sn}$, $\text{Nb}_3\text{Al}$ or high temperature superconductor?

Maintenance scheme
• Closely related with DEMO concept but insufficient knowledge on maintenance and remote handling

CD system
• How to proceed set of CD schemes

Controllability
• Sensors/actuators available in DEMO
• Selection criterion on operation regimes

Possibility of variable power production
• Staged approach to DEMO
• Flexibility in power production and impact to BoP
Procedure of reactor design

Crude design by an system code

c.f. Demo-CREST analysis by FUSAC code

Detailed reactor design
- Equilibrium (2D coil position and current)
- Plasma transport (operation scenario)
- Current drive
- MHD stability
- Divertor
- Neutron transport (blanket, shielding)
- Thermal-hydraulics
- Mechanical structure
- Tritium
- Maintenance scenario

Finalize fusion reactor design

e.g. ITER

Detailed component design
With engineering companies

Iterations
Issue and motivation

Crude design by an system code

c.f. Demo-CREST analysis by FUSAC code

Detailed reactor design
- Equilibrium (2D coil position and current)
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- Maintenance scenario

These two steps are **off-line**.

**Iteration** between several components are required.

**Making design activities time-consuming**

**Reactor design changes** according to progress in physics and engineering, and politics.

**Motivation**

If these steps are **integrated**, the design will be **quick and efficient**.
Our purpose

• Goal
  – Integrate sophisticated design activities
  – Self-consistent design and cross check between each component
    • quick and efficient

• What to do
  – Develop a framework on an integrated system design code

• Expected benefit
  – "On-line" reactor design

Bridge the gap between crude system design and detailed reactor component design

Automatic iteration and cross-check for self-consistent design
Platform of the integrated system design code

System code FUSAC

Plasma parameters
  Power balance
    TF coil design
    CS coil design
    radial build
    structure weight
    Cost estimation
    Disposal

constants
inputs

interface

Power balance
  constants
  inputs

1-D ➔ 2-D/3-D

detailed plasma analysis modules
  equilibrium
  current drive
  MHD stability

detailed engineering analysis modules
  TF coil
  Shielding

detailed economics analysis modules
  cost
  disposal

Disposal

System code FUSAC

Plasma parameters
  Power balance
    TF coil design
    CS coil design
    radial build
    structure weight
    Cost estimation
    Disposal
Guideline of the code development

@ General philosophy
  * Integration of existing, authorized calculation codes into the system analysis code FUSAC.
  * Modification of these codes is as little as possible.

@ Problems
  * Different parameter names for the same physical parameters (e.g., plasma major radius ; $R_p, R_0, \ldots$)
  * same names for subroutine and common in different programs

@ Environment of the computer tools
  * Fortran 95/90
  * Module-packaging
  * “Private/Public” statements
  * prohibit to use common
program main
    use constants
    use inputs
    use variables
    use fusac
    use tosca
    use outputs

    call read_inputs
    call fusac_plasma(...) call fusac_TFcoil(...) call fusac_CScoil(...) call fusac_radialbuild(...) call fusac_PFcoil(...) call fusac_structure(...) call fusac_cost(...) call fusac_disposal(...) call go_tosca(...) call outputs
end program main

module tosca
    use constants
c    private
    public go_tosca
contains
    subroutine go_tosca(a,b,c,...)
        real(8), intent(in) :: a,b
        real(8), intent(out) :: c, ...
call sub1_tosca
call sub2_tosca
...
end subroutine go_tosca
subroutine sub1_tosca
...
end subroutine sub1_tosca
subroutine sub2_tosca
...
end subroutine sub2_tosca
...
end module tosca

'go_tosca' can be called in external programs

Execute TOSCA
Isolated from any external programs

The 2D equilibrium by TOSCA
Graphic output from system analysis code

- Elevation and plane figure of plasma, TF coil, CS coil
- Profile of Neutron wall load on the first wall in the poloidal direction.

Figs. examples of output figures (ITER case)
Automatic Optimization of PF coil positions and currents

@Given parameters
Rp, a, Δ, Hmax
κ, δ
b = κ a, c = δ a

@ category of PF coils
* Divertor coil
  X-point, κ δ
* Vertical field coil
  Opening of port
* 3rd coil
  , κ δ
Optimization of 3rd coil position

![Graph showing Triangularity (δ) and Elongation (κ) as functions of the major radius of the 3rd PF coil.](image_url)

Future plan and Perspective

@ Plasma (Heavy codes are independently developed.)
  * MHD stability
  * Non-inductive current drive
  * Core plasma transport
  * Divertor design

@ TF coil (e.g., Nishio code)
  * Characteristics and basic data for each S.C. materials (Nb3Sn, Nb3Al, HTC)
  * Mechanical design (ANSYS code?)

@ Blanket design
  * Various combinations between breeder (solid, liquid, molten salt), material (ferrite, Vanadium, SiC) and coolant (water, helium, liquid,..).
  * Detailed designs and parameterization (or sets of database)
    for typical combinations (e.g., TBM cases) might be feasible.
  * Neutronics (MCNP + CAD/CAM)

@ maintenance scenario
  * prepare several concepts / options

⇒ This platform will be useful and applicable for other concepts (helical, laser,..)