Improving the SuperMagnet model; recent developments and future activities

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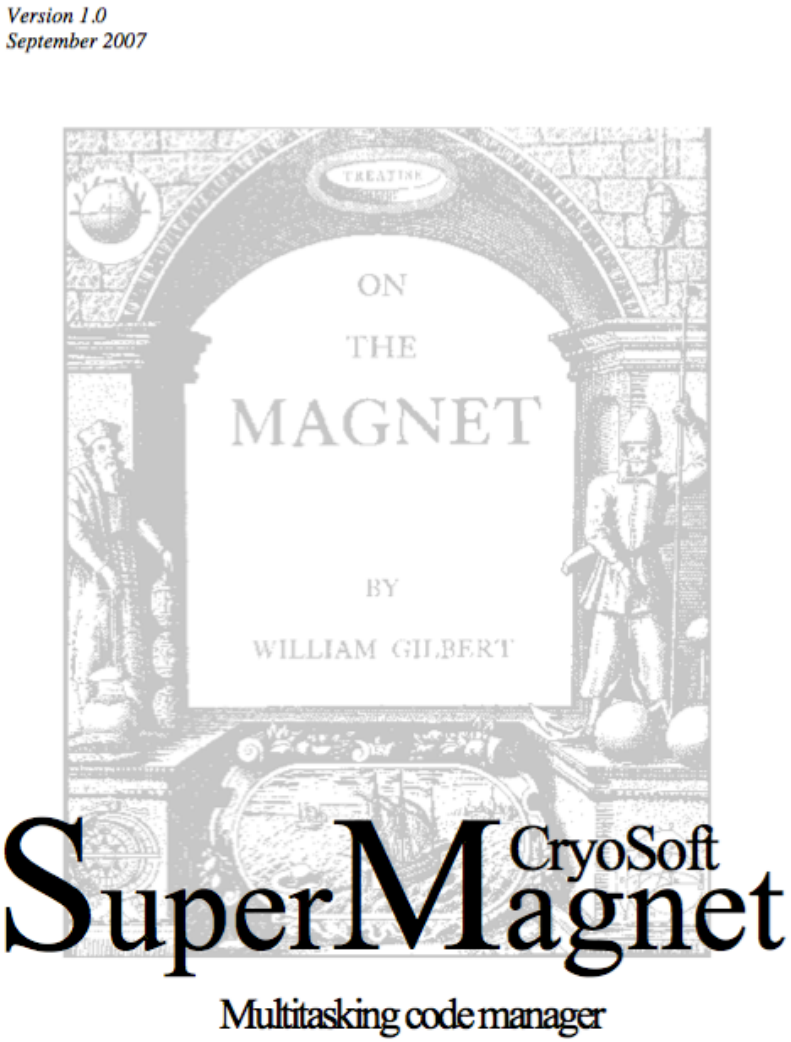
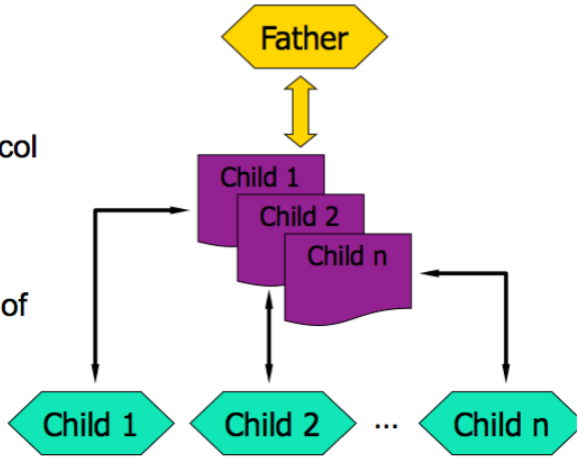
SuperMagnet model

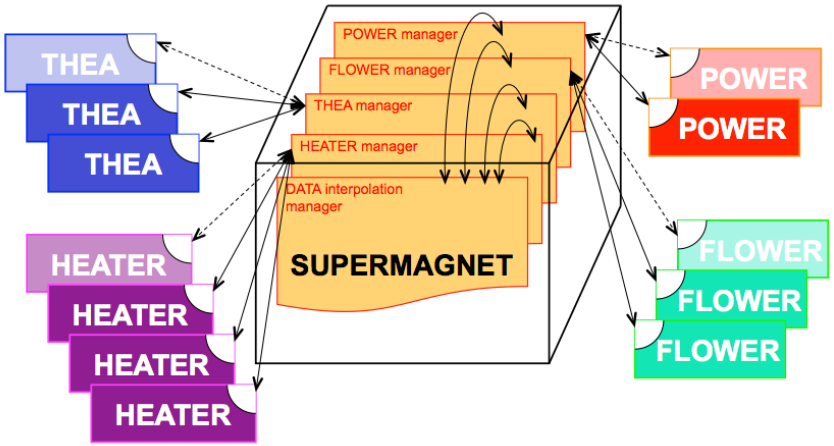


Concept

- Link independent simulation processes (children) through a communication protocol for data exchange
- A single master program (father) manages generation of each process, synchronization, and communication



Overall structure

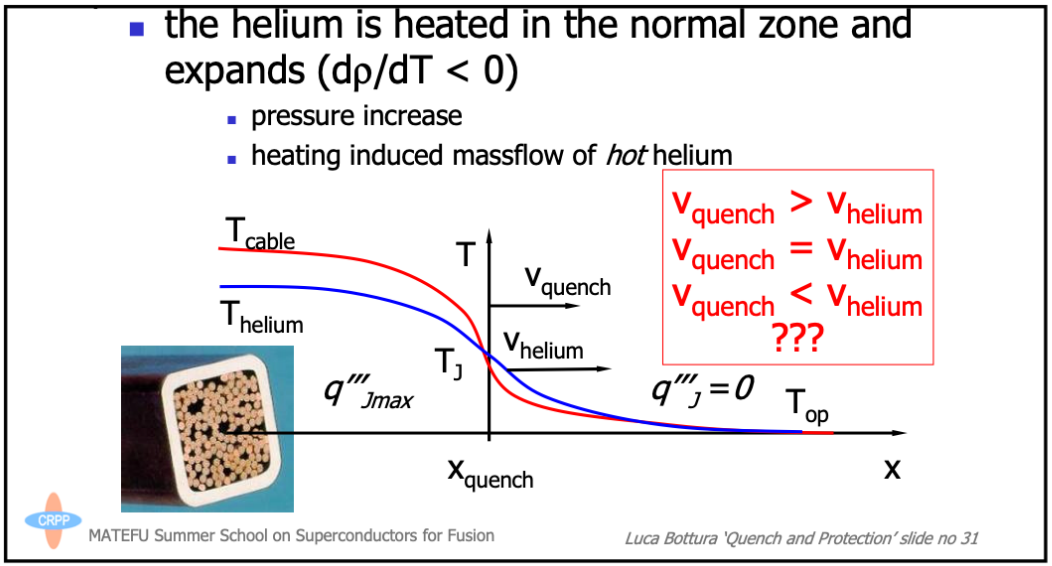


L. Bottura, SuperMagnet Benchmarking Close-out meeting, ITER-IO Cadarache , 15th May, 2012

Background (1/3)

✓ **Its basic idea is "binding" independent executables.**

➡ based on the specially developed codes, in particular, for the thermo-hydraulic behaviors in quench propagation…



$$\frac{\partial v_i}{\partial t} + v_i \frac{\partial v_i}{\partial x} + \frac{1}{\rho_i}\frac{\partial p_i}{\partial x} + 2\frac{f_i}{D_i} v_i |v_i| = 0$$

$$A_i \frac{\partial p_i}{\partial t} + A_i \rho_i c_i^2 \frac{\partial v_i}{\partial x} + A_i v_i \frac{\partial p_i}{\partial x} - 2A_i \phi_i \frac{f_i}{D_i} \rho_i v_i^2 |v_i| = \phi_i \dot{q}'_i + \phi_i \dot{q}'_{cf,i}$$

$$\rho_i C_i A_i \frac{\partial T_i}{\partial t} + \rho_i C_i A_i \phi T_i \frac{\partial v}{\partial x} + \rho_i C_i A_i v \frac{\partial T_i}{\partial x} - 2A_i \frac{f_i}{D_h} \rho_i v_i^2 |v_i|_i = \dot{q}'_i + \dot{q}'_{cf,i}$$

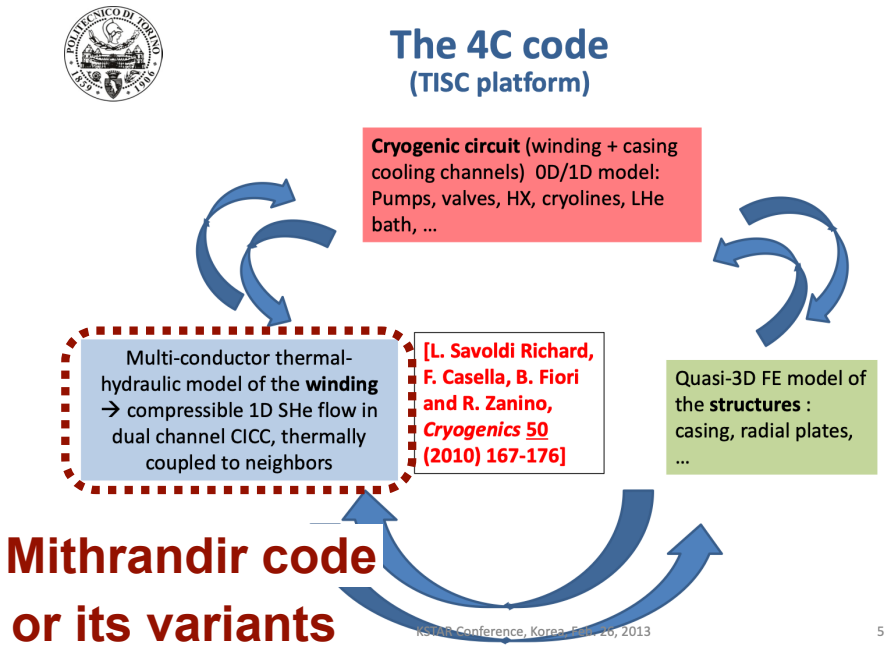
- **Hyperbolic PDE + Nonlinear diffusion-reaction wavefront**
- **Wide range of time scale + Steep frontend (needs fine mesh)**

Background (2/3)

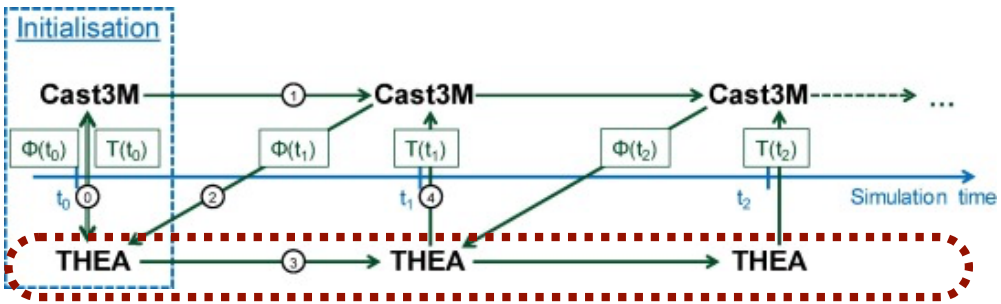
✓ **Its basic idea is "binding" independent executables.**

➡ based on the specially developed codes, in particular, for the thermo-hydraulic behaviors in quench propagation…

Like any other competing tool as a coupled simulation platform…



TACTICS
(*THEA-Cast3M-SimCryogenics*) model



THEA code

Key point : The <u>conductor model</u> makes it special.

The special features

✓ *Hyperbolic PDEs (fluid dynamics) without approximation*

➡ **No regular description for the <u>propagating discontinuity</u>**

: However, instability is suppressed by the artificial viscosity.

➡ **<u>Implicit time stepping</u> as the preferred option**

: The time steps should be large enough, e.g., for the time span to observe the recovery from quench.

➡ **<u>Linearization</u> for the implicit scheme**

: It is a concept to avoid iterations for the nonlinear solution.

The special features made issues

➡ **No regular description for the propagating discontinuity**

: The interfaces are vulnerable in case of rapid transient..

➡ **Implicit time stepping is preferred.**

: Its robustness is lost outside the individual code.

← The co-simulation models are unstable in practical..

➡ **Linearization for the implicit scheme.**

: Time stepping has to be minute in case of abrupt heat deposition..

Recent Progress

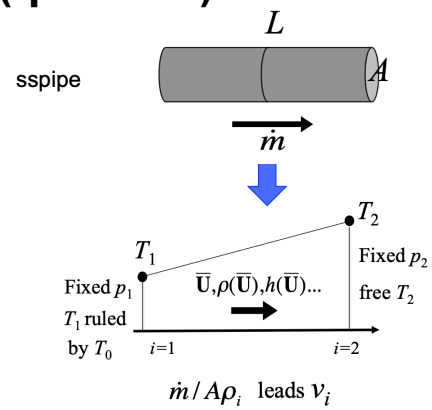
✳New BC in terms of the propagating discontinuity

$$[\mathbf{AU}]_i = \sum_j \mathbf{U}_j \int_0^L dx\, w_i\, \mathbf{a}(\overline{\mathbf{U}}) \frac{dw_j}{dx} \qquad (i \neq 1,\ \mathrm{n})$$

$$[\mathbf{AU}]_{i=1} = -\mathbf{a}^+(\overline{\mathbf{U}})\mathbf{U}_{1B} - \sum_j \mathbf{U}_j \int_0^L dx \left\{ \frac{dw_1}{dx} a^+(\overline{U}) w_j - w_1 a^-(\overline{U}) \frac{dw_j}{dx} \right\} \qquad (i = 1)$$

$$[\mathbf{AU}]_{i=\mathrm{n}} = \mathbf{a}^-(\overline{\mathbf{U}})\mathbf{U}_{\mathrm{n}B} - \sum_j \mathbf{U}_j \int_0^L dx \left\{ \frac{dw_{\mathrm{n}}}{dx} a^-(\overline{U}) w_j - w_{\mathrm{n}} a^+(\overline{U}) \frac{dw_j}{dx} \right\} \qquad (i = \mathrm{n})$$

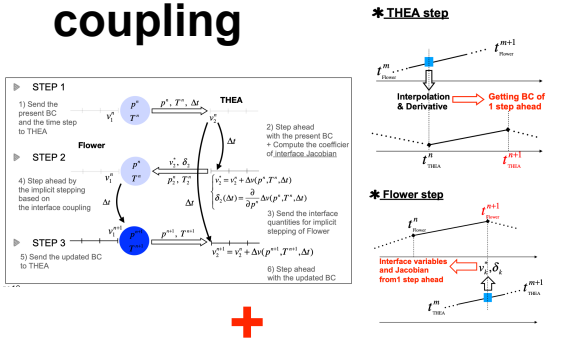
✳New steady state (quasi-1d) model



A single element of FEM

2017

✳Improved stability of THEA-FLOWER coupling

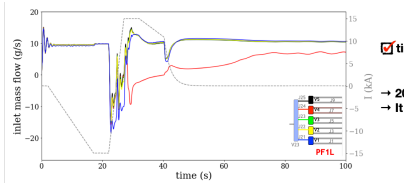


$$\begin{cases} [\mathbf{AU}]_{v,\,i=1} = \overline{v}\left(\frac{v_2 - v_1}{2}\right) + \frac{1}{\overline{\rho}}\left(\frac{p_2 - p_0^{(\mathrm{in})}}{2}\right) + \frac{\overline{v}}{\overline{\rho}\overline{c}}\left(\frac{p_1 - p_0^{(\mathrm{in})}}{2}\right) \\ [\mathbf{AU}]_{p,\,i=1} = \overline{\rho}\overline{c}^2\left(\frac{v_2 - v_1}{2}\right) + \overline{v}\left(\frac{p_2 - p_0^{(\mathrm{in})}}{2}\right) + \overline{c}\left(\frac{p_1 - p_0^{(\mathrm{in})}}{2}\right) \\ [\mathbf{AU}]_{T,\,i=1} = \overline{\rho\phi C_v T}\left(\frac{v_2 - v_1}{2}\right) + \overline{\rho C_v v}\left(\frac{T_2 + T_1}{2} - T_0^{(\mathrm{in})*}\right) + \frac{\overline{\phi C_v T}(\overline{c} - \overline{v})}{\overline{c}^2}\left(\frac{p_1 - p_0^{(\mathrm{in})*}}{2}\right) \end{cases}$$

Negligible

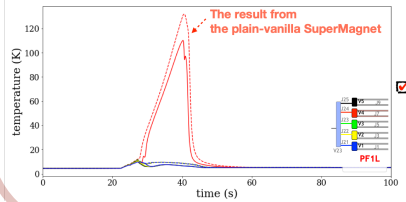
The boundary pressure follows the constraint in the speed of sound.

The boundary temperature follows the upwind constraint in the flow velocity.



☑time step : 10 ms (Flower)
10 μs ~ 5 ms (THEA)

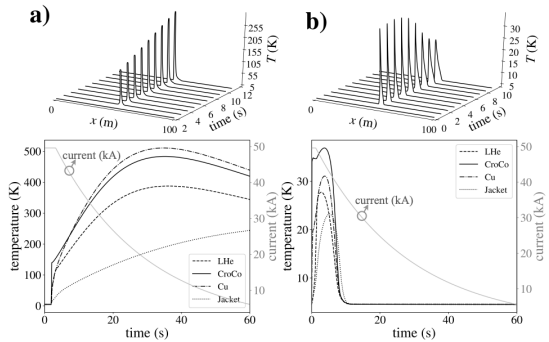
→ 20 times bigger time step
→ It takes less than 2 hours!

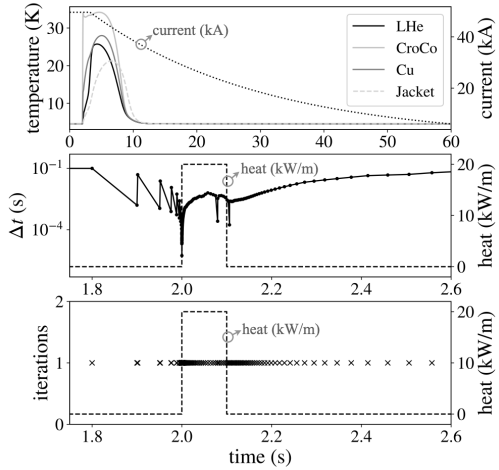


☑Eventually, accuracy issue is resolved during this study.

2019

✳Issue solved in adaptive time stepping



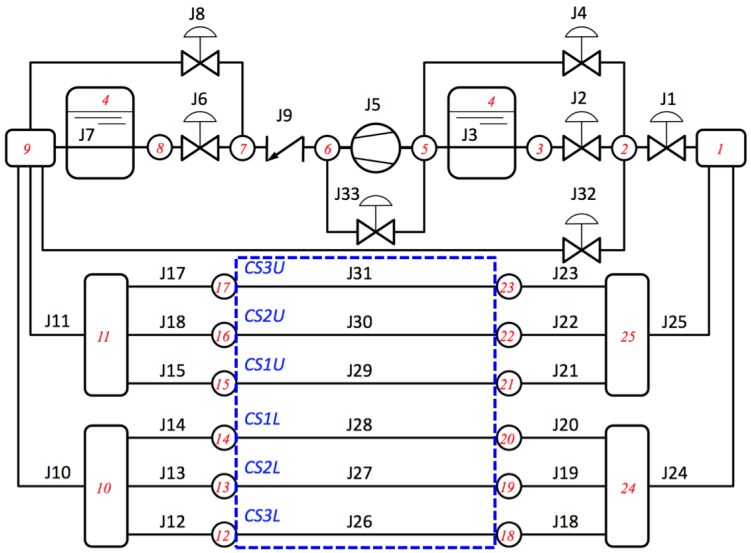


2021

#1. Steady state model (1/3)

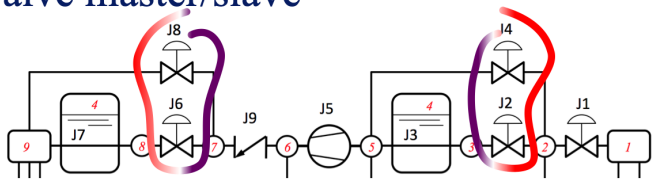
✓ *Steady state models are quite useful! For instance…*

Simplified CS model

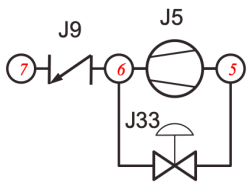


Each pipe represents 40 dual flow channels

Valve master/slave



Pump protection

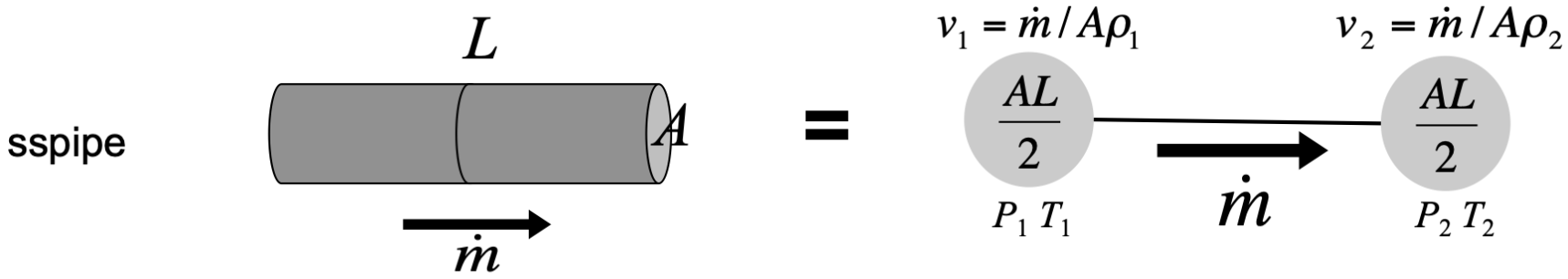


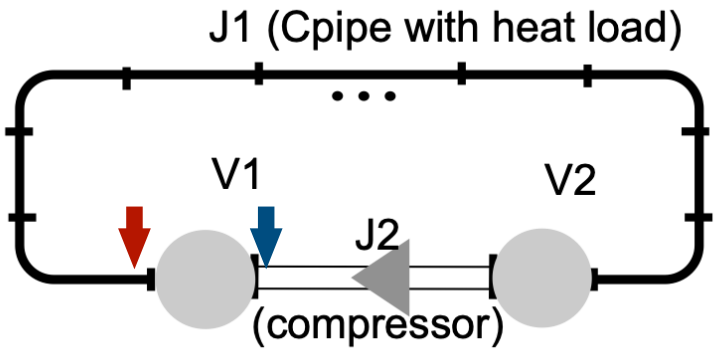
- **Simplification for the winding packs which are computationally heavy.**
- **Functional components : Valves, Pumps, etc..**

L. Bottura et al. "A Physics-based Simplified Model for the ITER Cooling Loop" CHATS-AS workshop, Bologna, Sep. 14-16, 2015

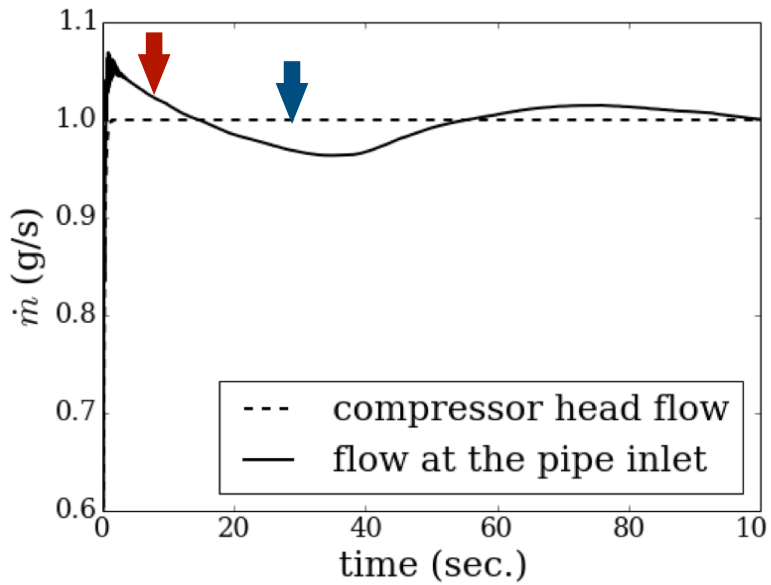
#1. Steady state model (2/3)

✓ *So, we have to remove the effect of volume nodes. Because..*





The pump is a steady-state component

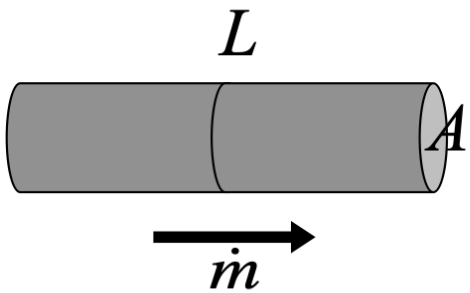


D. K. Oh and S. Oh, "Improved 1-d thermohydraulic network modeling for cryogenic circuits coupled to CICC models of fusion magnet system." Cryogenics 97 (2019): 133-143.

#1. Steady state model (3/3)

✓ *So, we have to remove the effect of volume nodes.*

sspipe



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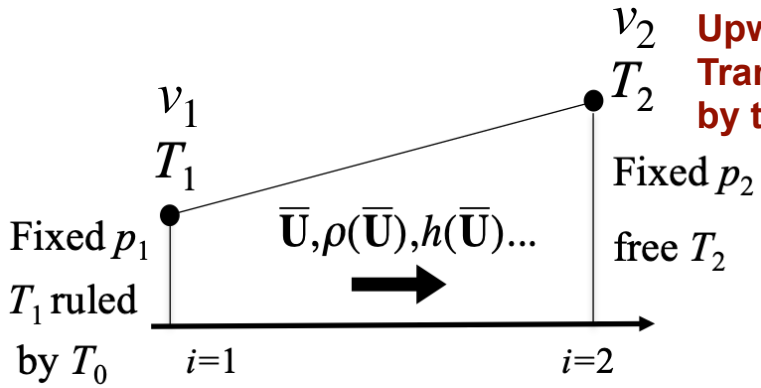
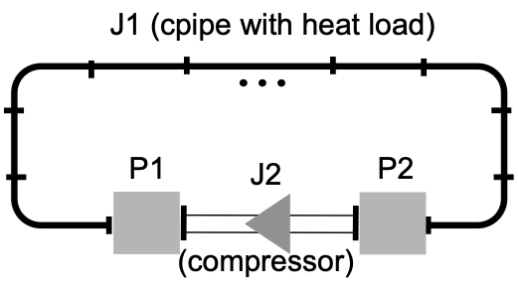
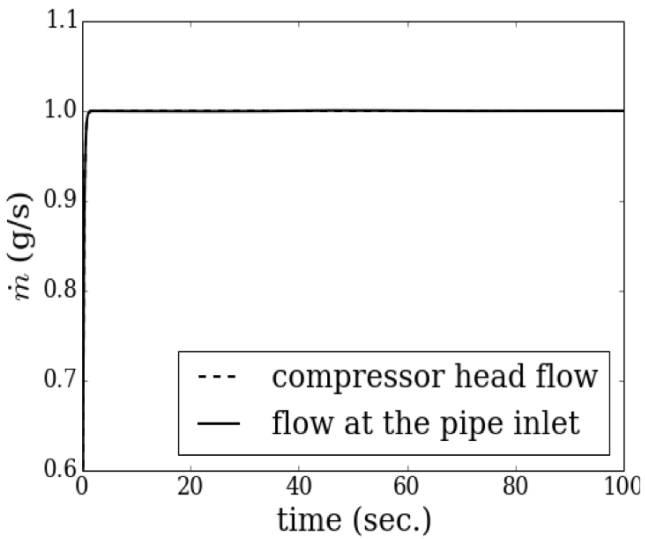


Upwind temperature Transferred by the mass flow

$$L\frac{dv_i}{dt} = \frac{\bar{c}}{2}\left(\frac{\dot{m}(p_1,p_2)}{A\rho_i} - v_i\right)$$

Delay of the sound wave (v-p) coupling





Note) New BC in terms of the characteristic waves

$$\begin{cases} \dfrac{\partial v}{\partial t} + v\dfrac{\partial v}{\partial x} + \dfrac{1}{\rho}\dfrac{\partial p}{\partial x} = -2f\dfrac{v|v|}{D_h} \\ \dfrac{\partial p}{\partial t} + \rho c^2\dfrac{\partial v}{\partial x} + v\dfrac{\partial p}{\partial x} = \phi(2\rho f\dfrac{v^2|v|}{D_h} + Q/A) \\ \rho C_v\dfrac{\partial T}{\partial t} + \rho C_v\phi T\dfrac{\partial v}{\partial x} + v\rho C_v\dfrac{\partial T}{\partial x} = 2\rho f\dfrac{v^2|v|}{D_h} + Q/A \end{cases}$$

an hyperbolic equation
(of real eigenvalues)
with dissipative source terms

$$\mathbf{m}\cdot\frac{\partial \mathbf{u}}{\partial t} + \mathbf{a}\cdot\frac{\partial \mathbf{u}}{\partial x} + \mathbf{s}\cdot\mathbf{u} = \mathbf{q}$$

$$\mathbf{m} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & \rho C_v \end{pmatrix}$$

$$\mathbf{a} = \begin{pmatrix} v & 1/\rho & 0 \\ \rho c^2 & v & 0 \\ \phi T\rho C_v & 0 & v\rho C_v \end{pmatrix} = \mathbf{m}\cdot\mathbf{X}\cdot\begin{pmatrix} v & 0 & 0 \\ 0 & v+c & 0 \\ 0 & 0 & v-c \end{pmatrix}\cdot\mathbf{X}^{-1}$$

inlet

$$\begin{cases} [\mathbf{AU}]_{v,i=1} = \bar{v}\left(\dfrac{v_2 - v_0^{(in)}}{2}\right) + \dfrac{1}{\bar{\rho}}\left(\dfrac{p_2 - p_0^{(in)}}{2}\right) + \bar{c}\left(\dfrac{v_1 - v_0^{(in)}}{2}\right) + \dfrac{\bar{v}}{\bar{\rho}\bar{c}}\left(\dfrac{p_1 - p_0^{(in)}}{2}\right) \\ [\mathbf{AU}]_{P,i=1} = \bar{\rho}\bar{c}^2\left(\dfrac{v_2 - v_0^{(in)}}{2}\right) + \bar{v}\left(\dfrac{p_2 - p_0^{(in)}}{2}\right) + \bar{\rho}\bar{c}\bar{v}\left(\dfrac{v_1 - v_0^{(in)}}{2}\right) + \bar{c}\left(\dfrac{p_1 - p_0^{(in)}}{2}\right) \\ [\mathbf{AU}]_{T,i=1} = \overline{\rho\phi C_v T}\left(\dfrac{v_2 - v_0^{(in)}}{2}\right) + \overline{\rho v C_v}\left(\dfrac{T_2 + T_1}{2} - T_0^{(in)*}\right) + \overline{\rho\phi C_v T v}/\bar{c}\left(\dfrac{v_1 - v_0^{(in)}}{2}\right) + \dfrac{\overline{\phi C_v T(\bar{c} - |\bar{v}|)}}{\bar{c}^2}\left(\dfrac{p_1 - p_0^{(in)}}{2}\right) \end{cases}$$

negligible

the sound wave
(v-p) interaction

The upwind term transferred
in the speed of mass flow

negligible

outlet

$$\begin{cases} [\mathbf{AU}]_{v,i=n} = \bar{v}\left(\dfrac{v_0^{(out)} - v_{n-1}}{2}\right) + \dfrac{1}{\bar{\rho}}\left(\dfrac{p_0^{(out)} - p_{n-1}}{2}\right) + \bar{c}\left(\dfrac{v_n - v_0^{(out)}}{2}\right) + \dfrac{\bar{v}}{\bar{\rho}\bar{c}}\left(\dfrac{p_n - p_0^{(out)}}{2}\right) \\ [\mathbf{AU}]_{p,i=n} = \bar{\rho}\bar{c}^2\left(\dfrac{v_0^{(out)} - v_{n-1}}{2}\right) + \bar{v}\left(\dfrac{p_0^{(out)} - p_{n-1}}{2}\right) + \bar{\rho}\bar{c}\bar{v}\left(\dfrac{v_n - v_0^{(out)}}{2}\right) + \bar{c}\left(\dfrac{p_n - p_0^{(out)}}{2}\right) \\ [\mathbf{AU}]_{T,i=n} = \overline{\rho\phi C_v T}\left(\dfrac{v_0^{(out)} - v_{n-1}}{2}\right) + \overline{\rho v C_v}\left(T_0^{(out)*} - \dfrac{T_{n-1} + T_n}{2}\right) + \overline{\rho\phi C_v T v}/\bar{c}\left(\dfrac{v_n - v_0^{(out)}}{2}\right) + \dfrac{\overline{\phi C_v T(\bar{c} - |\bar{v}|)}}{\bar{c}^2}\left(\dfrac{p_n - p_0^{(out)}}{2}\right) \end{cases}$$

$$v_0^{(in/out)}, p_0^{(in/out)}, T_0^{(in/out)}$$

(boundary values)

$$\mathbf{a}^+ = \frac{1}{2}\begin{pmatrix} c+v & (c+v)/\rho c & 0 \\ \rho c(c+v) & c+v & 0 \\ \rho C_v\phi T(1+\frac{v}{c}) & \frac{C_v\phi T}{c}(1-\frac{|v|}{c}) & (v+|v|)\rho C_v \end{pmatrix}$$

the matrix of positive eigenvalues

$$\mathbf{a}^- = \frac{1}{2}\begin{pmatrix} v-c & (c-v)/\rho c & 0 \\ \rho c(c-v) & v-c & 0 \\ \rho C_v\phi T(1-\frac{v}{c}) & \frac{C_v\phi T}{c}(\frac{|v|}{c}-1) & (v-|v|)\rho C_v \end{pmatrix}$$

the matrix of negative eigenvalues

D. K. Oh and S. Oh, "Improved 1-d thermohydraulic network modeling for cryogenic circuits coupled to CICC models of fusion magnet system." Cryogenics 97 (2019): 133-143.

Recent Progress

✳New BC in terms of the propagating discontinuity

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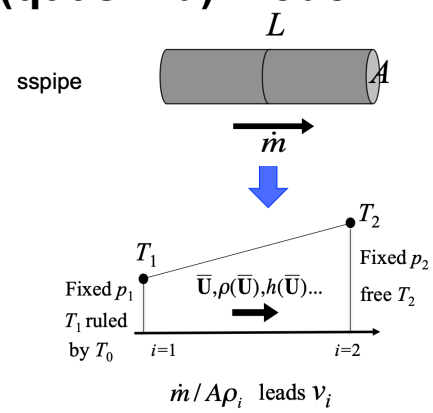
✳New steady state (quasi-1d) model



A single element of FEM

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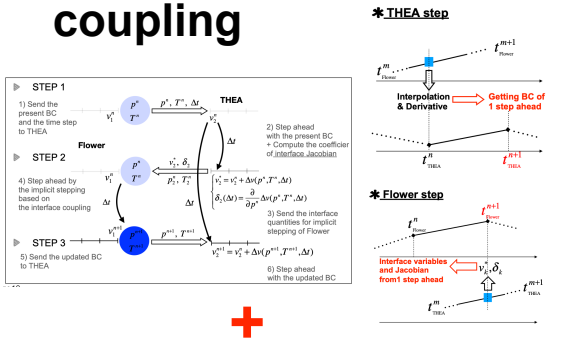
✳Improved stability of THEA-FLOWER coupling



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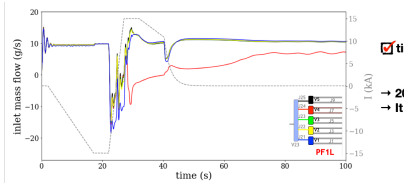

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10 μs ~ 5 ms (THEA)

→ 20 times bigger time step
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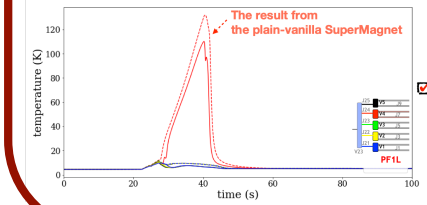

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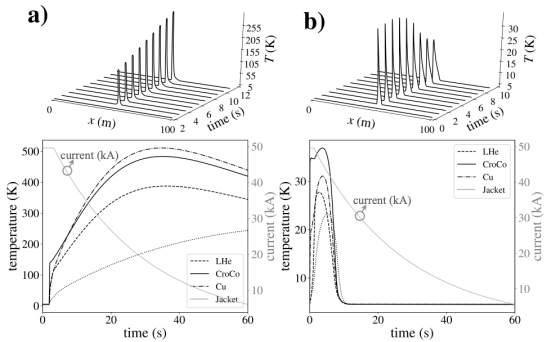
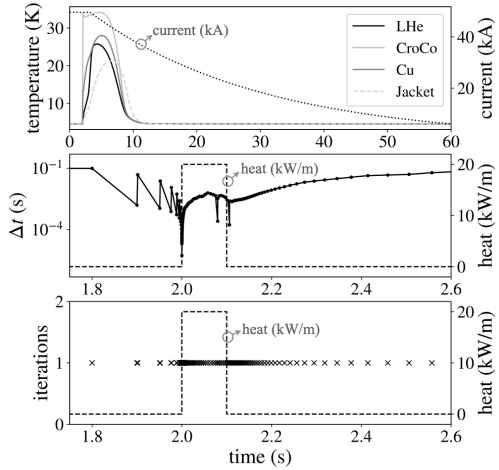
✳Issue solved in adaptive time stepping





2021

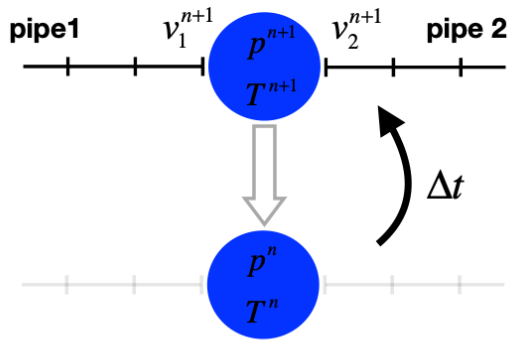
#2. Improved stability (1/4)

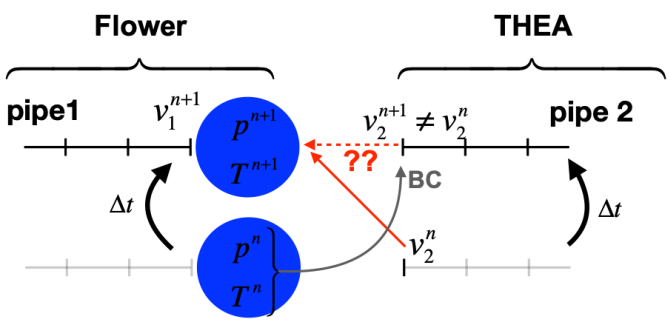
✓ *The loss of stability is intrinsic, if models use the "implicit stepping"*

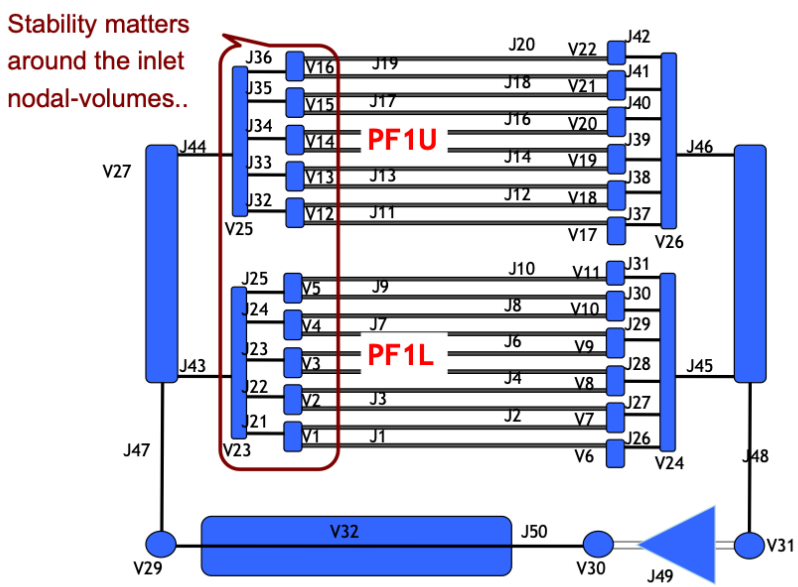
: Get <u>the future values</u> looking "backward"!

$$\begin{cases} p^{n+1} = p^n - \Delta t \sum_{i=1}^{2} v_i^{n+1} f_i\,(\mathrm{u}_{\mathrm{vol}}^n, \mathrm{u}_i^n) + \Delta t \phi^n \dot{q}^n / V \\ T^{n+1} = T^n - \Delta t \sum_{i=1}^{2} v_i^{n+1} g_i\,(\mathrm{u}_{\mathrm{vol}}^n, \mathrm{u}_i^n) + \Delta t \dot{q}^n / \rho^n C_{\mathrm{v}}^n V \end{cases}$$

Implicit stepping of volume
(Backward Euler)

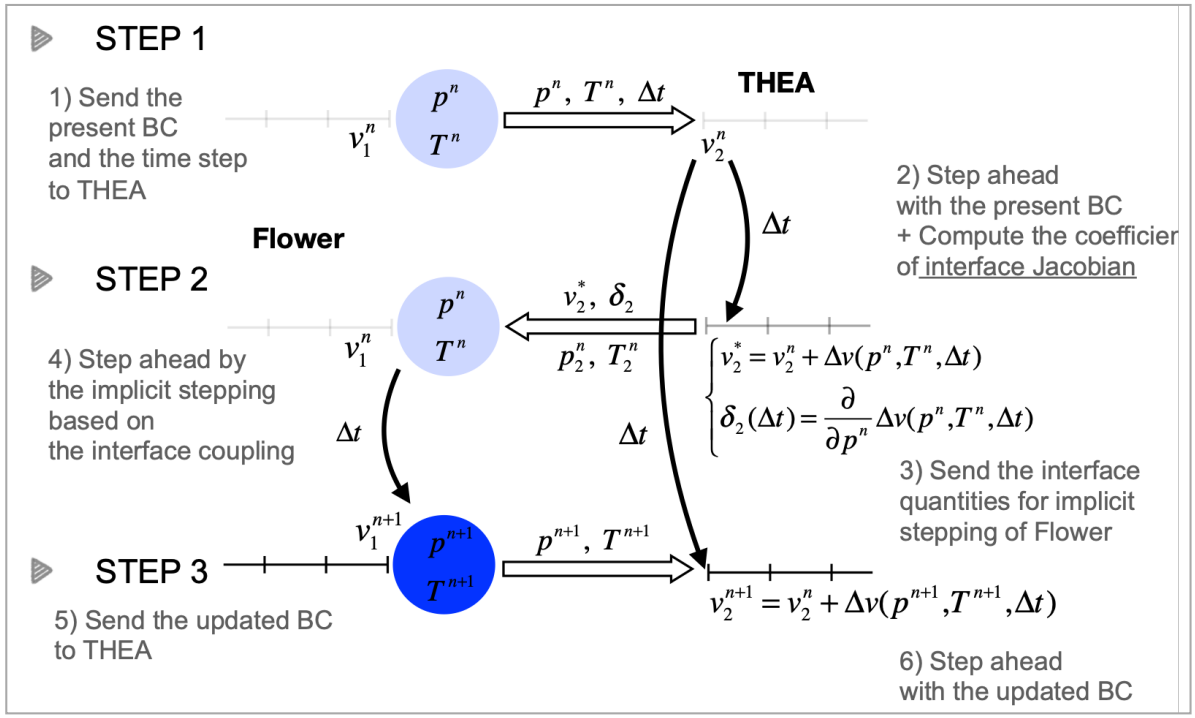




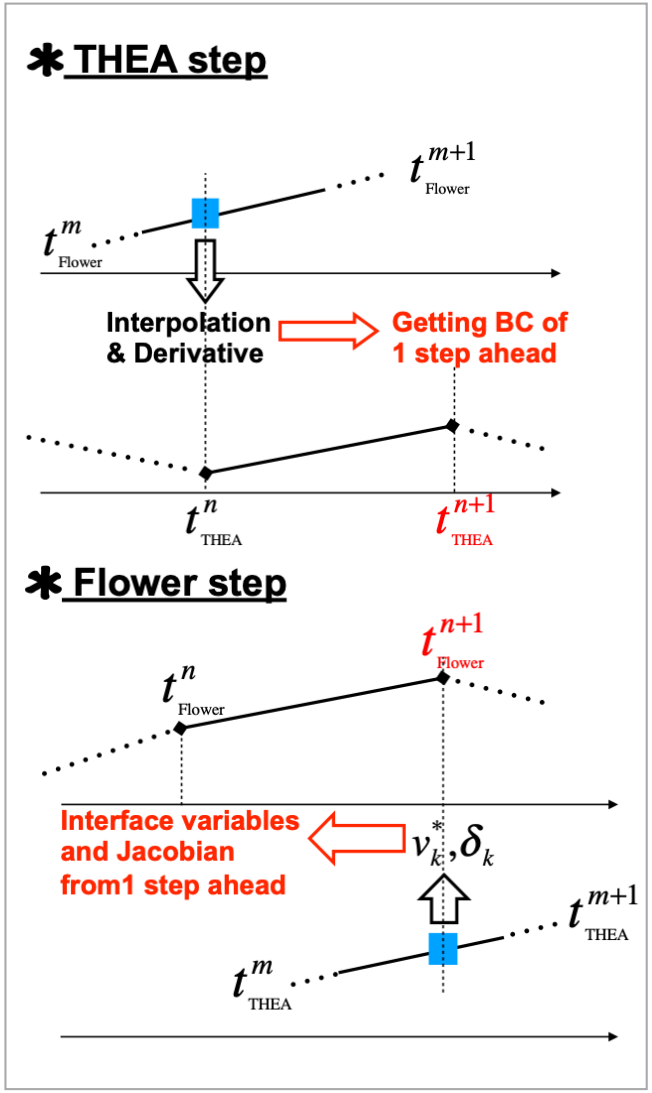


#2. Improved stability (2/4)

✓ *It is possible to improve the stability by means of ..*



Idea : implicit stepping using "interface Jacobian"

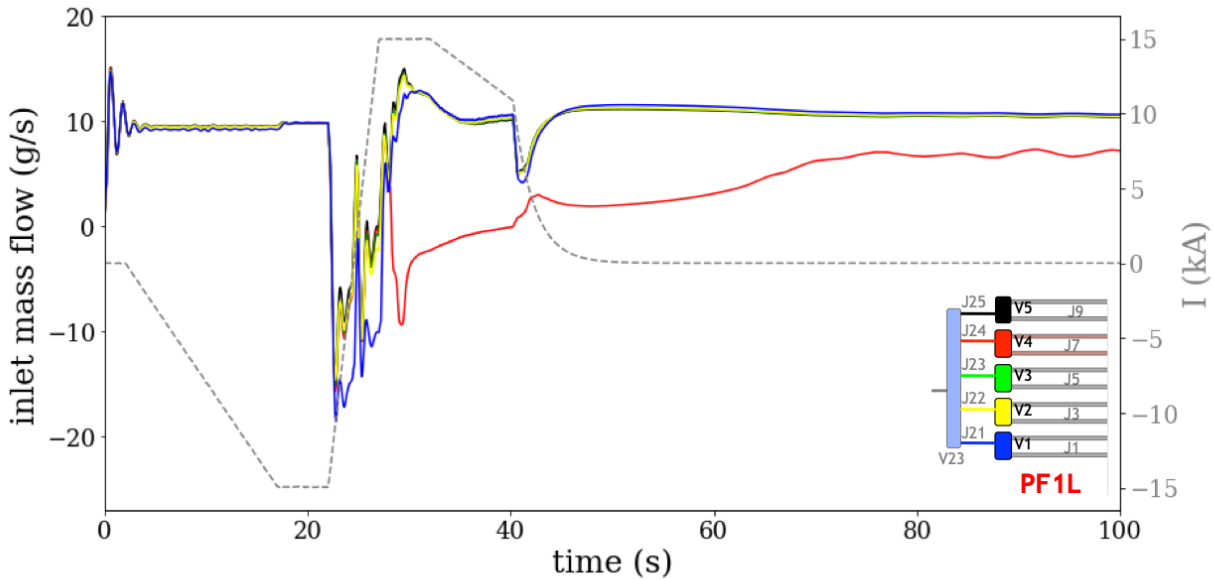


Actual implementation

D. K. Oh. "Coupled Simulation Model of CICC Components Integrated Into the Cooling Circuit." *IEEE Transactions on Applied Superconductivity* 29.5 (2019): 1-5

#2. Improved stability (3/4)

✓ *So, now..*



☑ **time step : 10 ms (Flower)**
10 μs ~ 5 ms (THEA)

→ 20 times bigger time step!
→ It takes less than 2 hours!

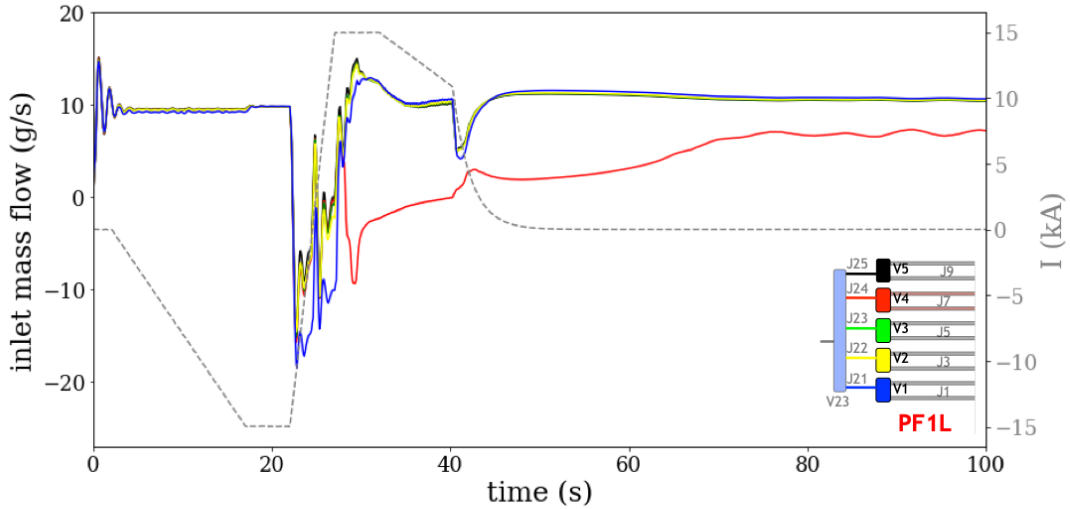
Jacobian-based Coupling Scheme Adopted to the Asynchronous Steps

+

Natural Boundary Constraining by Characteristic Decomposition

#2. Improved stability (4/4)

✓ *So, now..*



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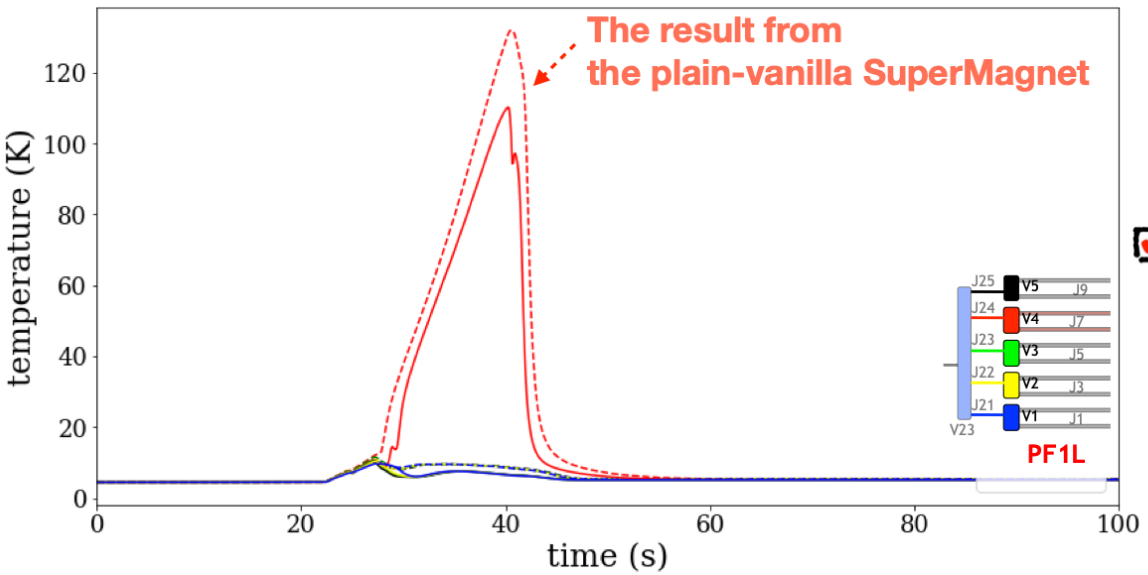
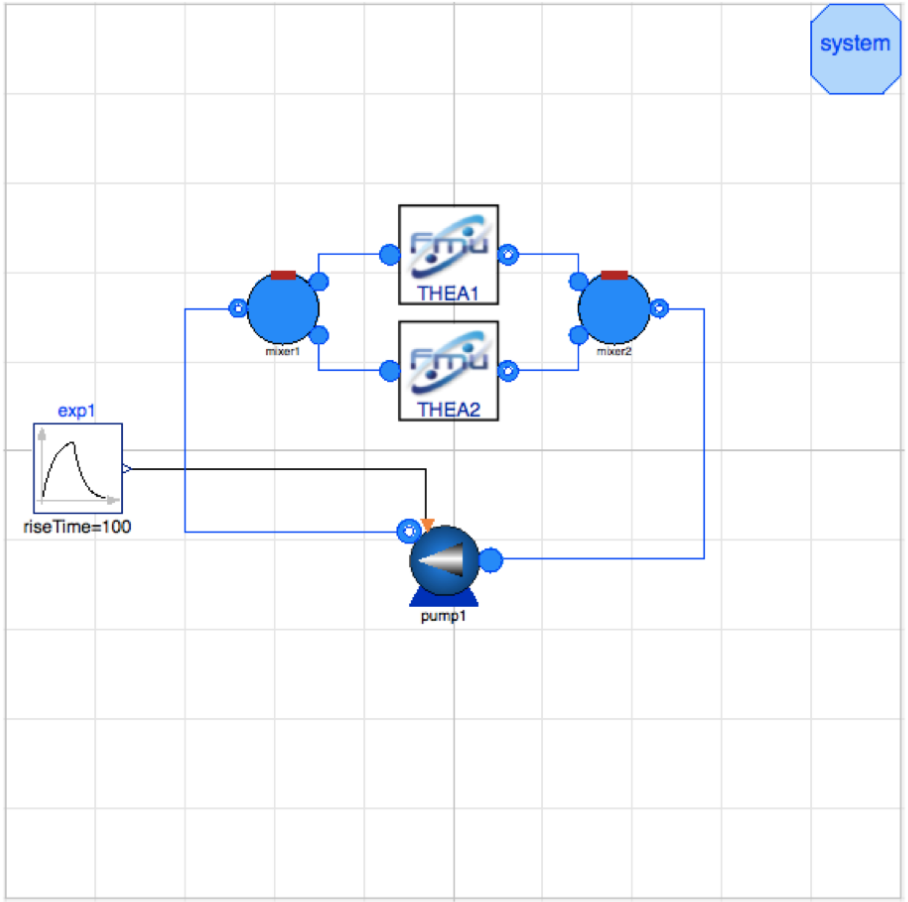


☑ Eventually, accuracy issue is resolved during this study.

D. K. Oh et al. "Numerical investigation of quench event in the innermost pair of the KSTAR central solenoids." CHATS-AS 2019, Szczecin, Jul. 9-12, 2019

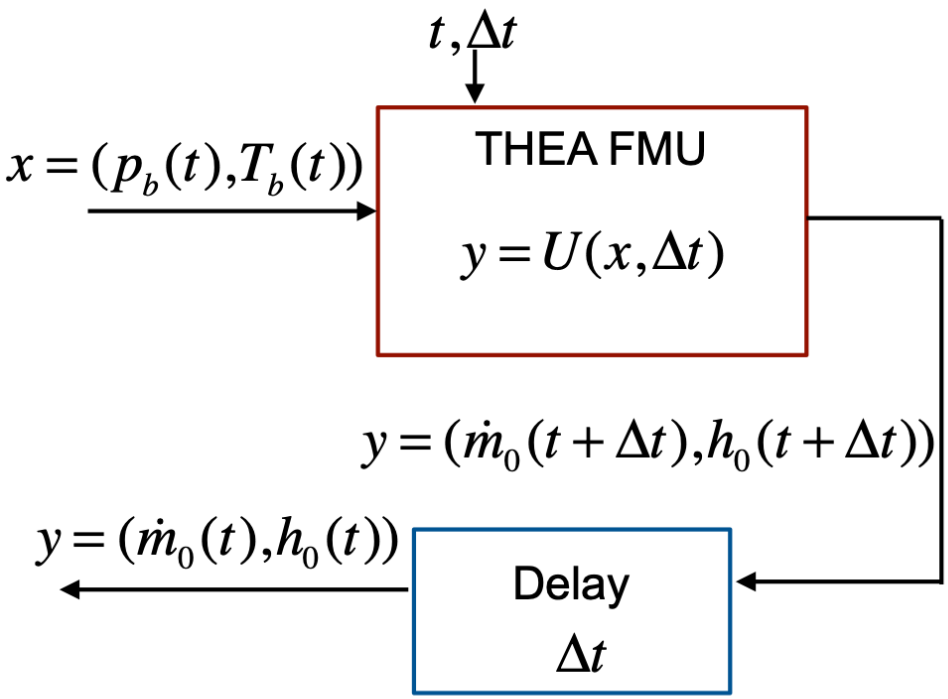
Note) This idea surely works in the other platforms..



$$\Delta t_{\text{modelica}} = 2.5 \times 10^{-3}$$

$$\Delta t_{\text{THEA}} = 10^{-5} \sim 5 \times 10^{-3}$$

i) The delay function is essential.



ii) The interface jacobian must be taken into account.

$$\dot{m} = \dot{m}_0 + \Delta t \; a \rho \delta \; \frac{dp}{dt}$$

```
infl.m_flow = delay(ret[1], commStepSize) + der(pi) * commStepSize *ret[5];
oufl.m_flow = delay(ret[2], commStepSize) + der(po) * commStepSize *ret[6];
infl.h_outflow = Medium.specificEnthalpy_pT(pi, delay(ret[3], commStepSize));
oufl.h_outflow = Medium.specificEnthalpy_pT(po, delay(ret[4], commStepSize));
```

Recent Progress

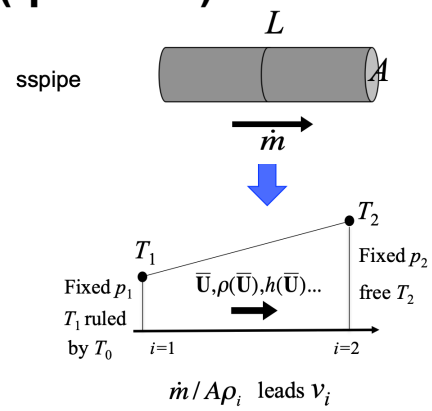
✳New BC in terms of the propagating discontinuity

$$[\mathbf{AU}]_i = \sum_j \mathbf{U}_j \int_0^L dx\, w_i\, \mathbf{a}(\overline{\mathbf{U}}) \frac{dw_j}{dx} \qquad (i \neq 1,\ \mathrm{n})$$

$$[\mathbf{AU}]_{i=1} = -\mathbf{a}^+(\overline{\mathbf{U}})\mathbf{U}_{1B} - \sum_j \mathbf{U}_j \int_0^L dx \left\{ \frac{dw_1}{dx} a^+(\overline{U}) w_j - w_1 a^-(\overline{U}) \frac{dw_j}{dx} \right\} \qquad (i = 1)$$

$$[\mathbf{AU}]_{i=\mathrm{n}} = \mathbf{a}^-(\overline{\mathbf{U}})\mathbf{U}_{\mathrm{n}B} - \sum_j \mathbf{U}_j \int_0^L dx \left\{ \frac{dw_{\mathrm{n}}}{dx} a^-(\overline{U}) w_j - w_{\mathrm{n}} a^+(\overline{U}) \frac{dw_j}{dx} \right\} \qquad (i = \mathrm{n})$$

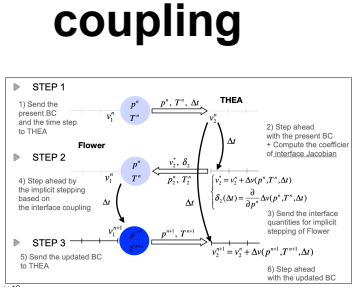
✳New steady state (quasi-1d) model

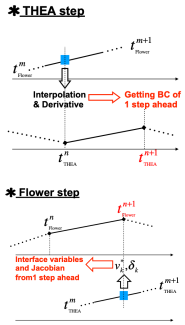


A single element of FEM

2017

✳Improved stability of THEA-FLOWER coupling





+

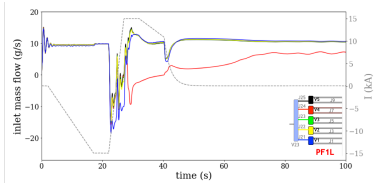
$$\begin{cases} [\mathbf{AU}]_{v,\,i=1} = \bar{v}\left(\frac{v_2 - v_1}{2}\right) + \frac{1}{\bar{\rho}}\left(\frac{p_2 - p_0^{(\mathrm{in})}}{2}\right) + \frac{\bar{v}}{\bar{\rho}\bar{c}}\left(\frac{p_1 - p_0^{(\mathrm{in})}}{2}\right) \\ [\mathbf{AU}]_{p,\,i=1} = \bar{\rho}\bar{c}^2\left(\frac{v_2 - v_1}{2}\right) + \bar{v}\left(\frac{p_2 - p_0^{(\mathrm{in})}}{2}\right) + \bar{c}\left(\frac{p_1 - p_0^{(\mathrm{in})}}{2}\right) \\ [\mathbf{AU}]_{T,\,i=1} = \overline{\rho C_v v}\left(\frac{v_2 - v_1}{2}\right) + \overline{\rho C_v v}\left(\frac{T_2 + T_1}{2} - T_0^{(\mathrm{in})*}\right) + \frac{\overline{\phi C_v T}(\bar{c} - \bar{v})}{\bar{c}^2}\left(\frac{p_1 - p_0^{(\mathrm{in})*}}{2}\right) \end{cases}$$

Negligible

The boundary pressure follows the constraint in the speed of sound.

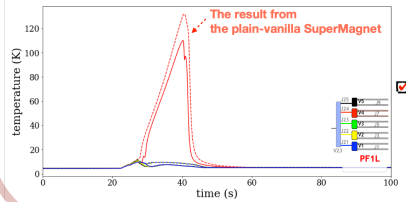
The boundary temperature follows the upwind constraint in the flow velocity.

=



☑time step : 10 ms (Flower)
10 μs ~ 5 ms (THEA)

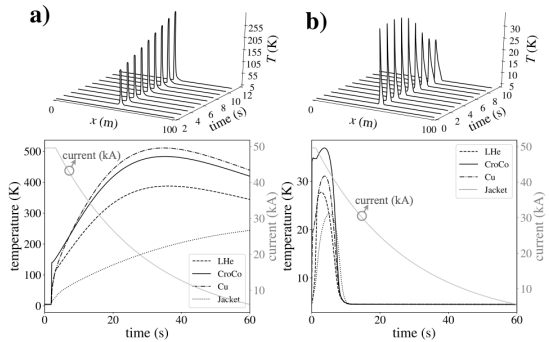
→ 20 times bigger time step
→ It takes less than 2 hours!

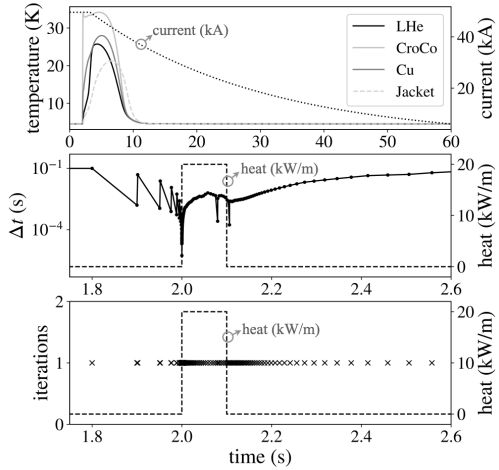


☑Eventually, accuracy issue is resolved during this study.

2019

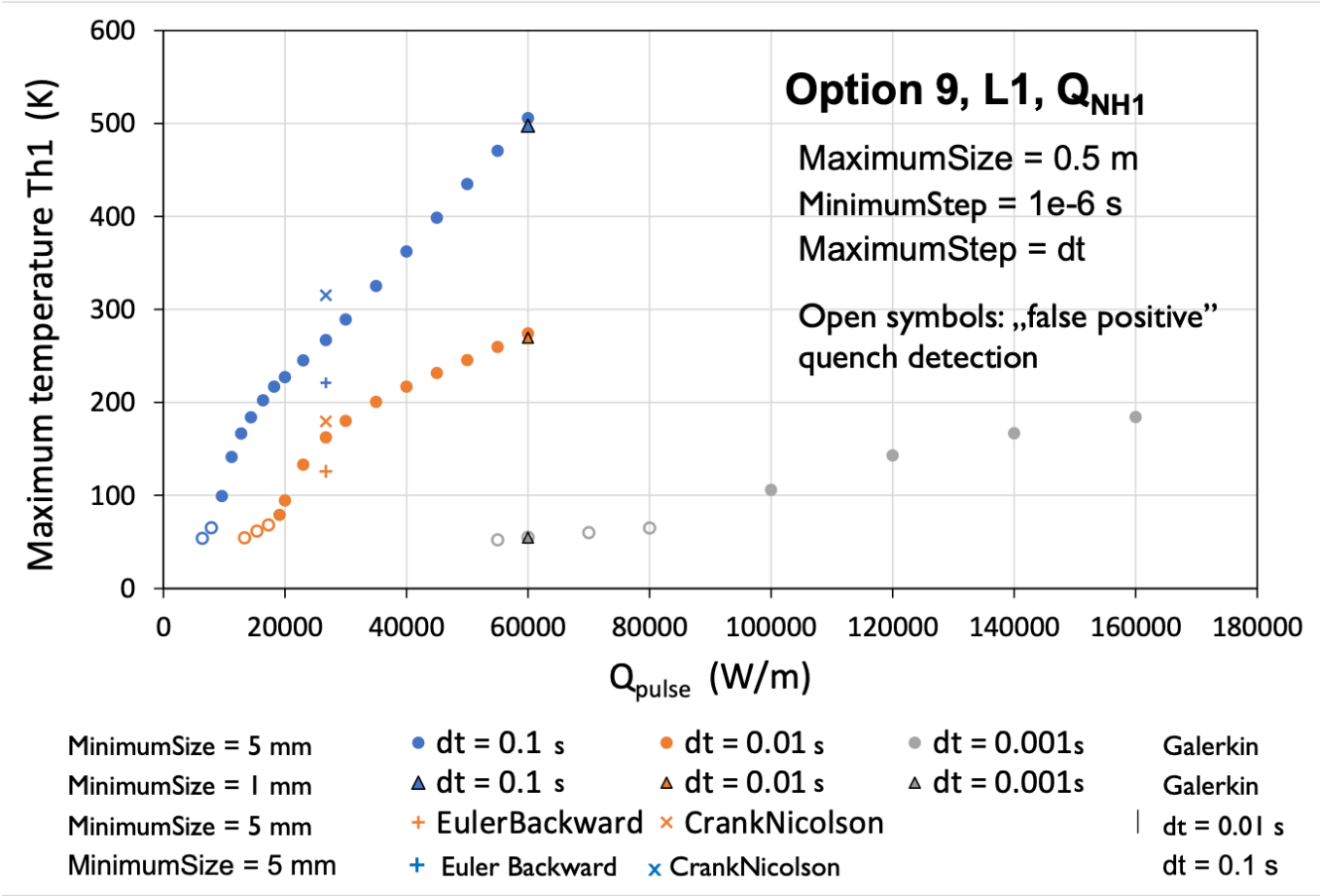
✳Issue solved in adaptive time stepping

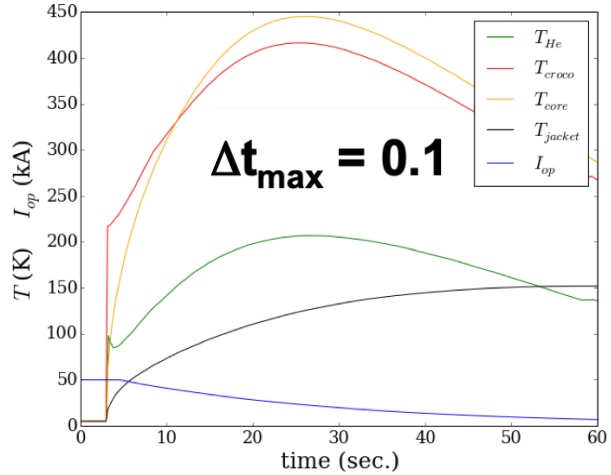


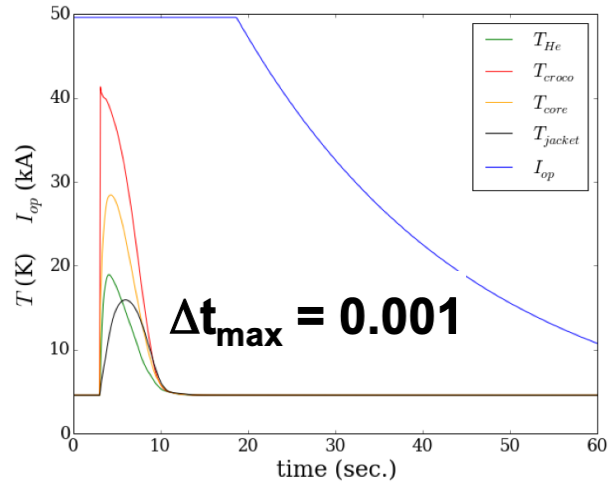


2021

#3. Issue of adaptive time stepping (1/3)





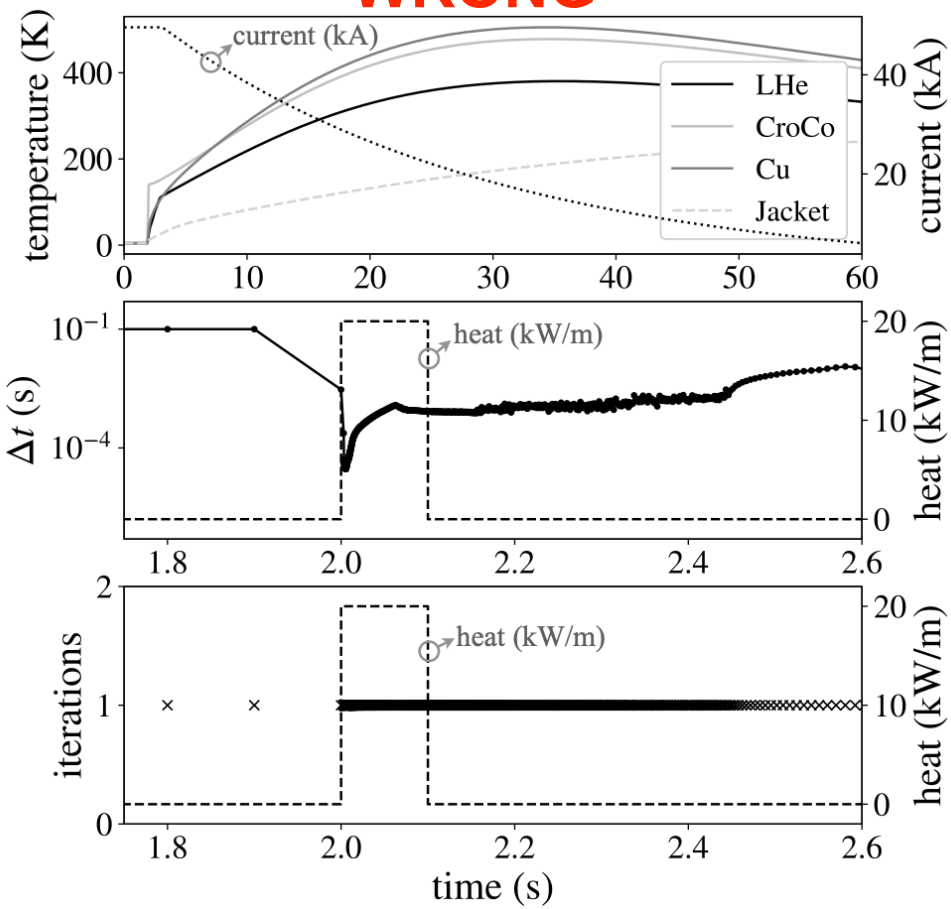


M. Lewandowska et al. "Thermal-hydraulic Analysis of the HTS Demo TF Coil"
CHATS-AS workshop, Sendai, Dec. 10-12, 2017

#3. Issue of adaptive time stepping (2/3)

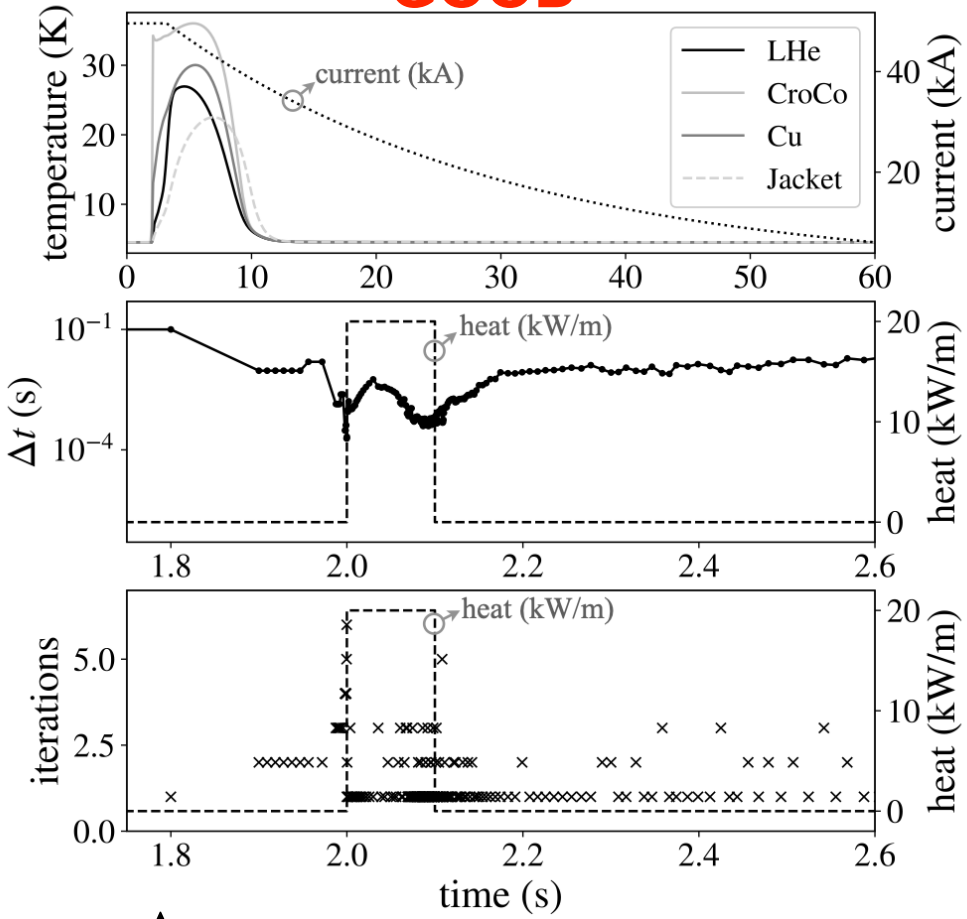
✓ *It is practically impossible without iteration!*

WRONG



Δt = 0.005 ~ 0.1, TOL = 1.0×10^{-4}, without iteration

GOOD



Δt = 0.005 ~ 0.1, TOL = 1.0×10^{-3}, with iteration

D. K. Oh et al. "Adaptive Time Stepping in Quench Simulation for Superconducting Magnets" Cryogenics, in review, 2021

#3. Issue of adaptive time stepping (3/3)

✓ *So, we propose a new non-iterative control scheme*

Algorithm : update Δt ⇨ evaluate the solution of $t_n+\Delta t$

//get the heat load vector at $t_n+\Delta t$, and update the error indicator

1 **update** ERR $\leftarrow$ $\max\left(\left|\Delta t \frac{Q_i(t_n+\Delta t)}{\rho_i^n C_{vi}^n T_i^n} - \frac{\Delta T_i}{T_i}\right|\right)$

A new error indicator taking into account the heat load

//update Δt with respect to TOL

2 **if** ERR $\neq$ TOL, **update** $\Delta t \leftarrow a\left(\frac{\text{TOL}}{\text{ERR}+\varepsilon}\right)^p \Delta t$

//if shrinking Δt,
//set the limit for ratcheting

3 **if** ERR > TOL,
update $t_{lim} \leftarrow t_n + \Delta t$

//if growing Δt and exceeding the limit,
//ratchet by the limit, and unset the limit

4 **if** ERR < TOL **and** $t_{lim} < t_n + \Delta t$,
update $\Delta t \leftarrow (t_{lim} - t_n)/2$, $t_{lim} \leftarrow \infty$

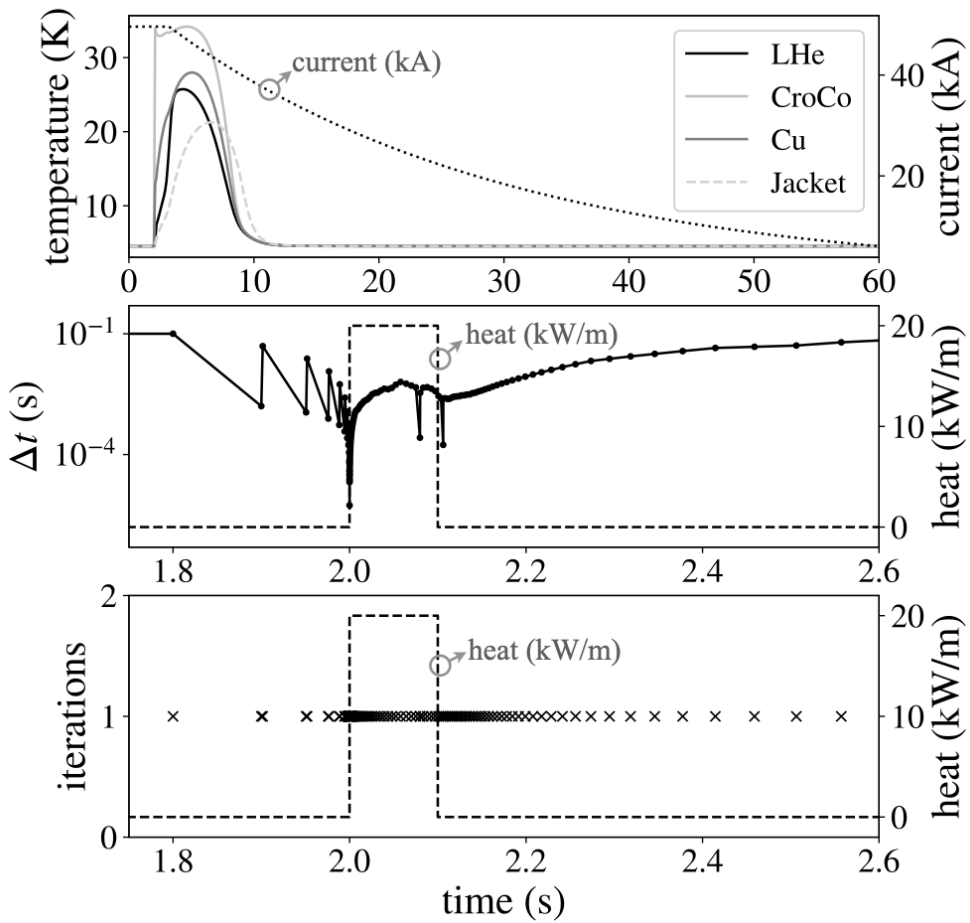
Ratchet action to avoid overshoot after decreasing the time step by crossing the heat pulse edge

//set the upper and lower limits of Δt

5 **update** $\Delta t \leftarrow \min(\max(\Delta t_{min}, \Delta t), \Delta t_{max})$

// evaluate the next step

6 **evaluate** the PDE step



D. K. Oh et al. "Adaptive Time Stepping in Quench Simulation for Superconducting Magnets" Cryogenics, in review, 2021

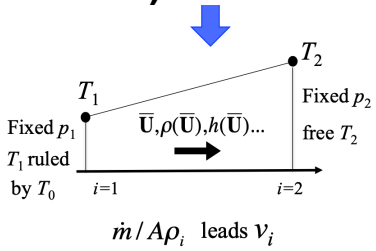
Perspective for the next..

D5-1

Chats 2021 Applied Superconductivity

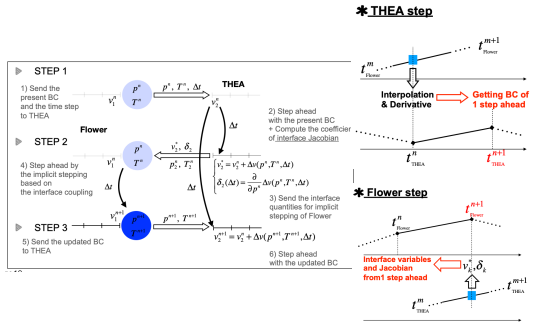
✳New decomposed BC

✳New steady state (quasi-1d) model

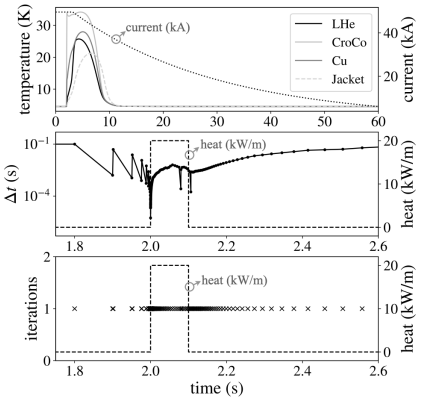


A single element of FEM

✳Improved stability of the SuperMagnet model



✳Issue solved In adaptive time stepping



✳Component-wise Modulation

An FMU is built, as a pilot

✳Versatile Connection

MPI or ZeroMQ?

As a practice, the Windows version is tested.

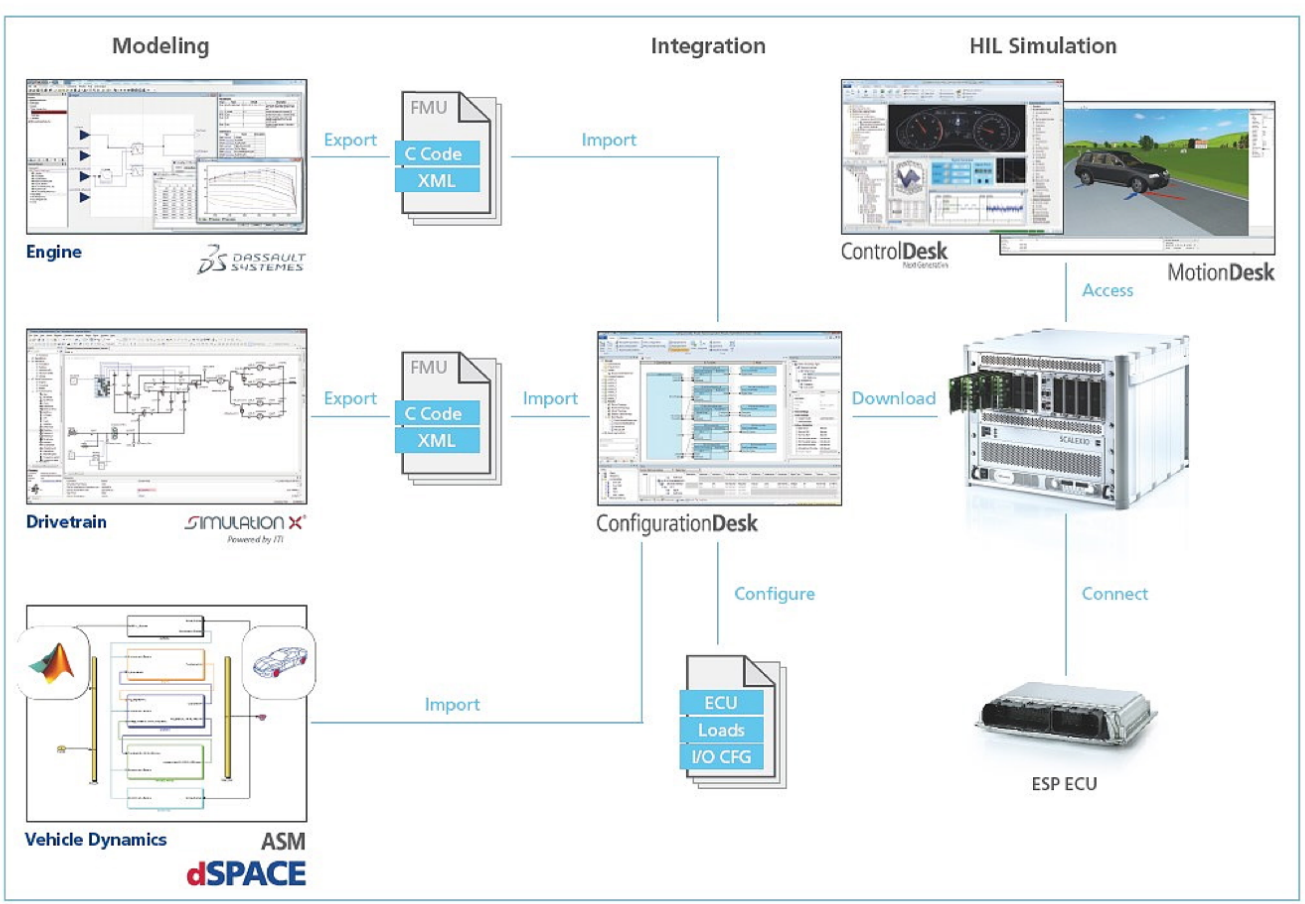
✳Usability

GUI or other utilities

Pythonization is the most tangible now..

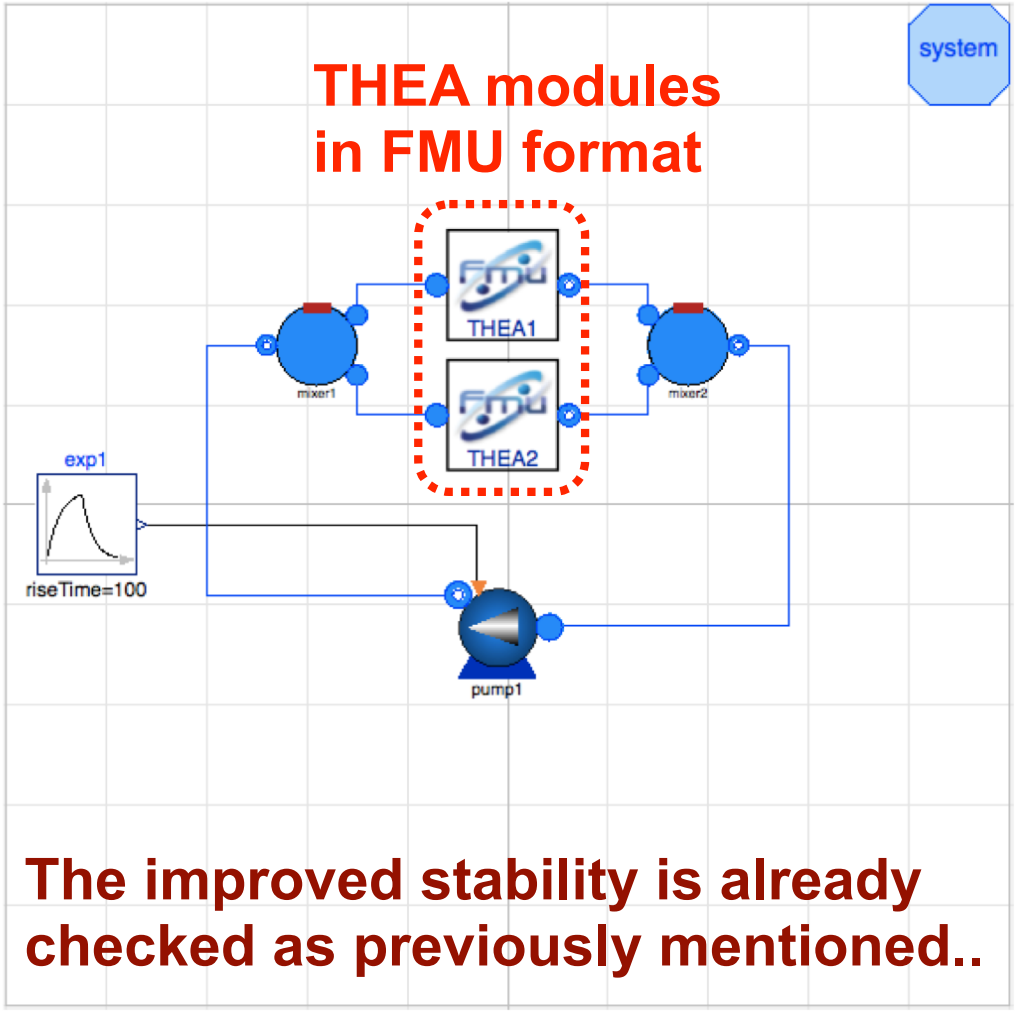
FMI as a standard interface (1/2)

- **Actively supported for an industrial standard**
- **Developed in a part of Modelica Association –** Linköping Univ. Sweden
- **Interoperable with commercial packages – ANSYS, Simulink etc.**
- **Wrapping compiled C or Fortran code with interface description in XML**

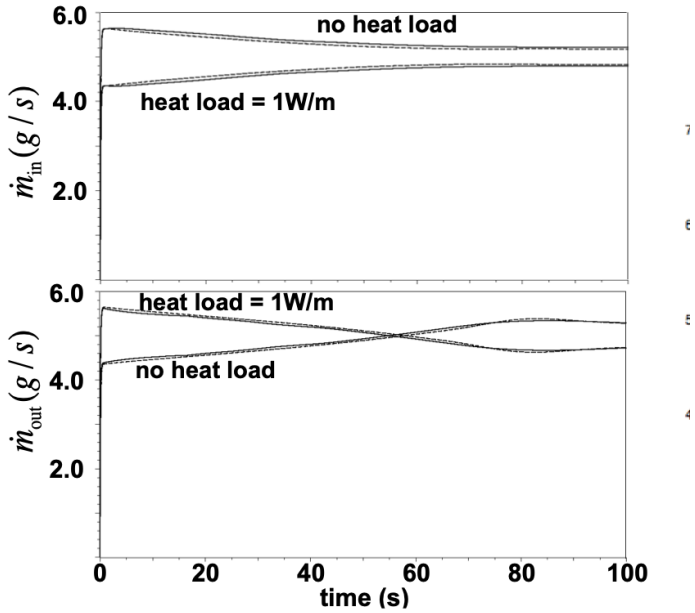


✳ **Modelica is a meta-language to generate simulation code (in C) from the equation (ODE, DAE) based codes…**

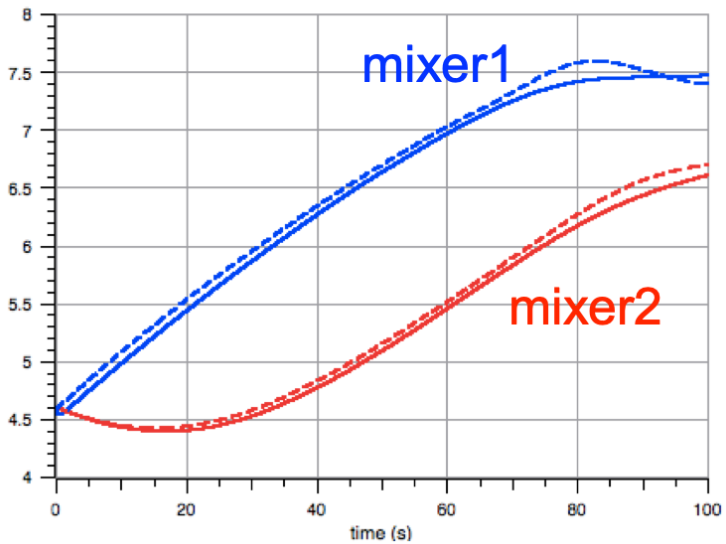
FMI as a standard interface (2/2)



the mass flows at the terminals



The temperature



Connectivity of SuperMagnet (1/2)

✓ *The SuperMagnet model has a room to be extended..*

➡ **Process-based design**

: Submodules are independent executables.

➡ **UNIX native interprocess communication (pipe) and process control (signal)**

: So, we just examined a possibility of other systems;
MS Windows version is attempted replacing the signals with Windows Event Objects.

➡ **<u>Socket based communication is considerable in the near future</u>**

: Actually, I'm have 0MQ (ZeroMR) in my mind..

Connectivity of SuperMagnet (2/2)

Chats 2021 iter cea
Applied Superconductivity

x86_x64 Cross Tools Command Prompt for VS 2019

```
D:\SUPERMAGNET\xample\supermagnet\code_2.0\thea-flower>supermagnet
 Enter input file name
SM.input
 FLOWER Enter input file name
 FLOWER Check data as read from input/storage ...
 ... done
 THEA Enter input file name
 THEA Check data as read from input/storage ...
 ... done
 FLOWER Set initial conditions ...
 THEA Set initial conditions ...
 ... done
 ... done
 before sorting, matrix size           8
 after compacting, matrix size           8
 FLOWER Time :     2.000E-03   Step :  2.000E-03   Time/Tend :   0.00200
 THEA   Time :     1.000E-06   Step :  1.000E-06   Time/Tend :   0.00000
 THEA   Time :     2.000E-06   Step :  1.000E-06   Time/Tend :   0.00000
 THEA   Time :     3.500E-06   Step :  1.500E-06   Time/Tend :   0.00000
 THEA   Time :     5.750E-06   Step :  2.250E-06   Time/Tend :   0.00001
 THEA   Time :     9.125E-06   Step :  3.375E-06   Time/Tend :   0.00001
 THEA   Time :     1.419E-05   Step :  5.063E-06   Time/Tend :   0.00001
 THEA   Time :     2.178E-05   Step :  7.594E-06   Time/Tend :   0.00002
 THEA   Time :     3.317E-05   Step :  1.139E-05   Time/Tend :   0.00003
 THEA   Time :     5.026E-05   Step :  1.709E-05   Time/Tend :   0.00005
 THEA   Time :     7.589E-05   Step :  2.563E-05   Time/Tend :   0.00008
 THEA   Time :     1.143E-04   Step :  3.844E-05   Time/Tend :   0.00011
 THEA   Time :     1.720E-04   Step :  5.767E-05   Time/Tend :   0.00017
 THEA   Time :     2.585E-04   Step :  8.650E-05   Time/Tend :   0.00026
 THEA   Time :     3.882E-04   Step :  1.297E-04   Time/Tend :   0.00039
 THEA   Time :     5.829E-04   Step :  1.946E-04   Time/Tend :   0.00058
 THEA   Time :     8.748E-04   Step :  2.919E-04   Time/Tend :   0.00087
 THEA   Time :     1.313E-03   Step :  4.379E-04   Time/Tend :   0.00131
 THEA   Time :     1.970E-03   Step :  6.568E-04   Time/Tend :   0.00197
 THEA   Time :     2.955E-03   Step :  9.853E-04   Time/Tend :   0.00295
 FLOWER Time :     4.000E-03   Step :  2.000E-03   Time/Tend :   0.00400
 THEA   Time :     4.433E-03   Step :  1.478E-03   Time/Tend :   0.00443
 FLOWER Time :     6.000E-03   Step :  2.000E-03   Time/Tend :   0.00600
 THEA   Time :     6.650E-03   Step :  2.217E-03   Time/Tend :   0.00665
 FLOWER Time :     8.000E-03   Step :  2.000E-03   Time/Tend :   0.00800
 THEA   Time :     9.975E-03   Step :  3.325E-03   Time/Tend :   0.00997
 FLOWER Time :     1.000E-02   Step :  2.000E-03   Time/Tend :   0.01000
 THEA   Time :     1.496E-02   Step :  4.988E-03   Time/Tend :   0.01496
 FLOWER Time :     1.200E-02   Step :  2.000E-03   Time/Tend :   0.01200
 FLOWER Time :     1.400E-02   Step :  2.000E-03   Time/Tend :   0.01400
 FLOWER Time :     1.600E-02   Step :  2.000E-03   Time/Tend :   0.01600
 THEA   Time :     1.996E-02   Step :  5.000E-03   Time/Tend :   0.01996
 FLOWER Time :     1.800E-02   Step :  2.000E-03   Time/Tend :   0.01800
 FLOWER Time :     2.000E-02   Step :  2.000E-03   Time/Tend :   0.02000
 THEA   Time :     2.496E-02   Step :  5.000E-03   Time/Tend :   0.02496
 FLOWER Time :     2.200E-02   Step :  2.000E-03   Time/Tend :   0.02200
 FLOWER Time :     2.400E-02   Step :  2.000E-03   Time/Tend :   0.02400
 FLOWER Time :     2.600E-02   Step :  2.000E-03   Time/Tend :   0.02600
 THEA   Time :     2.996E-02   Step :  5.000E-03   Time/Tend :   0.02996
 FLOWER Time :     2.800E-02   Step :  2.000E-03   Time/Tend :   0.02800
 FLOWER Time :     3.000E-02   Step :  2.000E-03   Time/Tend :   0.03000
 THEA   Time :     3.496E-02   Step :  5.000E-03   Time/Tend :   0.03496
 FLOWER Time :     3.200E-02   Step :  2.000E-03   Time/Tend :   0.03200
 FLOWER Time :     3.400E-02   Step :  2.000E-03   Time/Tend :   0.03400
```

You are watching the SuperMagnet code running in MS Windows 10.

KFE

Pythonization (1/1)

✓ *For the libraries and the post processing…*

pycryolib.make (/.00/home1/spinhalf/

파일(F) 편집(E) 보기(V) 검색(S) 도구(T) 문서(D)

pycryolib.make

```
include ${CRYOSOFT}/etc/arch.conf
include ${CRYOSOFT}/etc/fs.conf

# FORTRAN to Python wrapper
F2PY=f2py
FORTRAN=gfortran

# targets for this makefile

BUILDDIR=${PYLIB}

pycryolib: cryosoft.so hotinput.so theadata.so flowerdata.so

##########################################################################

cryosoft.so : ${ZERODEEUSER}zerodeeu.f ${MODELUSR}KSTARPFlib.f\
              ${FLUIDS}fluids.f ${FLUIDSHE}he_tables.f \
              ${FLUIDSHE}he_perfect.f ${FLUIDSN2}n2_tables.f ${FLUIDS}pfun.f \
              ${LIB}miscellanea.a ${LIB}geometry.a ${LIB}algebra.a ${LIB}
system.a \
          ${SOLIDS}solids.f ${SOLIDS}alprop.f ${SOLIDS}cnprop.f \
              ${SOLIDS}cuprop.f ${SOLIDS}epprop.f ${SOLIDS}geprop.f \
              ${SOLIDS}nbsnprop.f ${SOLIDS}nbtiprop.f ${SOLIDS}ncolprop.f \
              ${SOLIDS}nconprop.f ${SOLIDS}pbsnprop.f ${SOLIDS}plprop.f \
              ${SOLIDS}ssprop.f ${SOLIDS}tiprop.f ${SOLIDS}al6063prop.f \
              ${SOLIDS}agprop.f ${SOLIDS}bscco2212prop.f  \
              ${SOLIDS}mnprop.f ${SOLIDS}cmprop.f
    mkdir -p ${PYLIB}
    cat ${SOLIDS}solids.f ${SOLIDS}alprop.f ${SOLIDS}cnprop.f \
```

메이크파일 | 탭 너비: 8 | 16행, 1열

material libraries

hotinit.py (/.00/home1/spinhalf/Work/GPUhotspot/KSTARGPhotspot) - gedit

파일(F) 편집(E) 보기(V) 검색(S) 도구(T) 문서(D) 도움말(H)

hotinit.py

```
def _cpnbti( self, T, B, Iop):
    Jop = abs(Iop)/self.Asc
    Tcs = cryosoft.tcsnti(B, Jop, self.Tc0m, self.Bc20m, self.C0)
    Tc = cryosoft.tcnbti( B, self.Tc0m, self.Bc20m)
    Tc0 = cryosoft.tcnbti( 0.0, self.Tc0m, self.Bc20m)
    return cryosoft.cpnbti(T, B, Tcs, Tc)

def _cpnbsn( self, T, B, Iop):
    Jop=abs(Iop)/self.Asc
    Tcs = cryosoft.tcsnsn( B,
    Tc = cryosoft.tcnbsn( B, s
    Tc0 = cryosoft.tcnbsn( 0.0
    return cryosoft.cpnbsn( T,
```

Flower post processing

Untitled

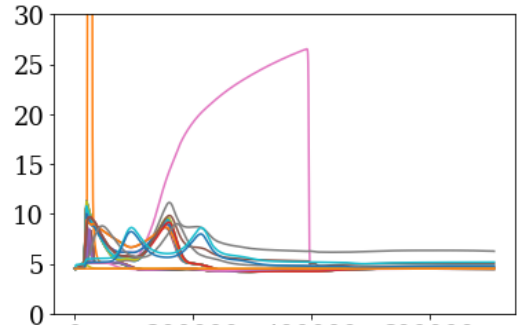
file:///.00/home1/spinhalf/Desktop/Untitled%20(1).html

```
In [8]: from KSTARTHData import flowerdata as fl

In [9]: fl.initflowerdata('PF1UL.store')

In [10]: nt_max = fl.alltimes.ntimes
         nvol = fl.f_comm.nvolme
         rectime = fl.alltimes.rectime
         time = []
         tvol = []
         for i in range(nt_max):
             t = rectime[i]
             fl.getflowerdata(t)
             tvol.append(copy(fl.f_comm.tvolme[:nvol]))
             time.append(t)
         tvol = array(tvol)

In [11]: plot(time, tvol[:,:])
         ylim((0, 30))
         fl.closeflowerdata()
```



The Fortran codes are exported as Python classes almost without modification.

Conclusion

➡ Improvements are done taking into account **the peculiar design** of the thermal-hydraulic model.

: It's a brute-force modification so that we expect <u>regular code work for a stable version</u> - it depends on the agreement and plan.

➡ The **special features** commonly belong to the other tools (4C & TACTICS).

: A benchmark activity is recommendable based on discussions for improvement.

➡ There are some important items for the future development.

: **<u>Versatile connectivity</u>** (in the consideration for parallel computing), **<u>Modulization</u>** (in FMU format or any other standard), and **<u>Usability</u>** (Pythonization, GUI, etc)