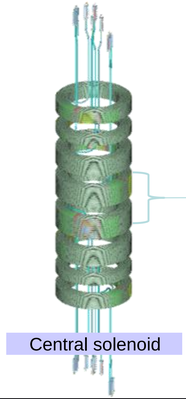
Effect of flow imbalance on the operational performance of the KSTAR PF1UL magnets

Hyun Jung Lee, Yong Chu, Kwang Pyo Kim, Kaprai Park, National Fusion Research Institute, Daejeon, Korea (Contact: yaeban@nfri.re.kr)

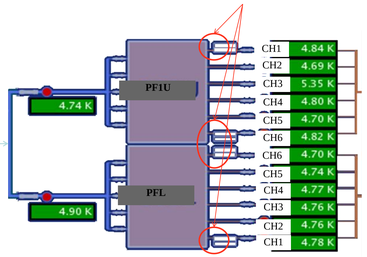
Abstract : A cryogenic circuit for large scaled superconducting device like a tokamak is installed quite complex. In the KSTAR tokamak, the five cryogenic circuits are managed for cooling of each compo-nents (Toroidal Field magnets, Poloidal Field magnets, structures current leads, thermal shield, bus-lines) independently. The cir-cuit for the Poloidal Field magnets branches into one hundred cooling channels. Five cryogenic valves are controlling the flow rates according to cooling channel length. The KSTAR PF1 upper and lower magnets have ten cooling channels parallel respectively. The pressure drop of the magnets is adjusted by cryogenic valve and is maintained by a supercritical helium circulator. The flow rate should be uniform among the cooling channels or magnets but the flow imbalance was observed during the flow test of magnet individually. The measured imbalance was around 10 % between KSTAR PF1 upper and lower. To investigate for effect of the flow imbalance on the magnet, the simple model of the PF1 upper and lower magnets has been developed using SUPER-MAGNET code. The maximum temperature trends are studied in details depending on the imbalance

1. PF1UL magnet system



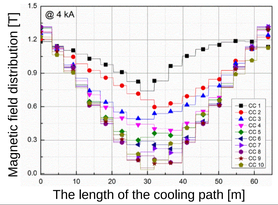
Central solenoid

Joint part which is mixed with joint helium
Therefore the temperature of the CH1, CH6 is cooled more

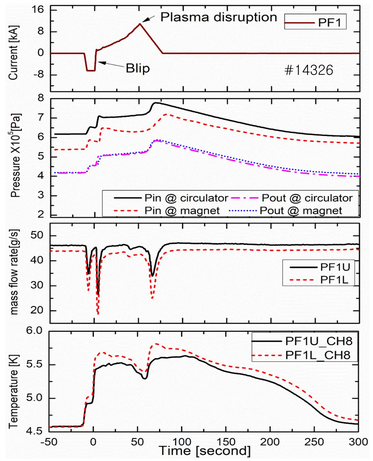


PF1 UL coil Cooling Scheme

Parameters	PF1
Superconductor	NB_3Sn
Jacket material	Incoloy908
Mean radius, R [mm]	570
CICC length [m]	663
Cooing channel length [mm]	64.5
Number of cooling channel [#]	10

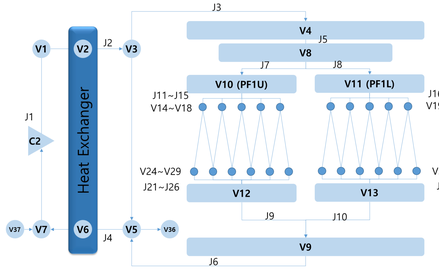


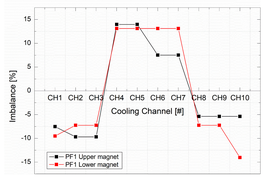
2. Operation trend

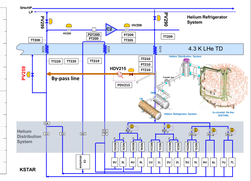


- The current on the PF1UL magnets, which consists of an electrically series circuit, is the same. The current is controlled by feedforward and feedback.
- The current supplied to -6.5kA with 2 kA/s and increased very slowly up to 11 kA after blip (from -6.5 kA to 1.5 kA with 4kA/s), and then the current decayed with 0.5 kA/s due to plasma disruption.
- The supply pressure is 6.3 bar at the circulator outlet and reduces to 5.4 bar in front of magnet. The outlet pressure is 4.3 bar .
- The supplied mass flow rate is 46.09 g/s and 44.89 g/s at the upper and lower magnets respectively.
- The differences is not so high but the flow reduction is quite different. The flow is drop up to the 18.63 g/s and 26.45 g/s in the PF1UL magnets respectively
- The maximum outlet temperature of the PF1 UL magnet is observed 5.60 K and 5.81 K at the CH5

3. PF1 UL magnet circuit modeling







- Flow imbalance

$$\dot{m} = \rho \bar{v} A,$$

$$\Delta P = -f \frac{\rho \bar{v}^2}{2 D_h} L$$

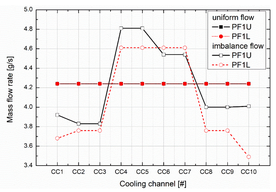
- AC losses

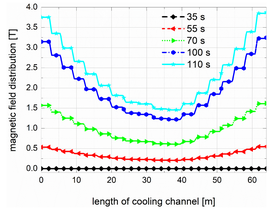
$$Q_{hys} \approx \frac{4}{3\pi} D_{eff} \int_{B_{min}}^{B_{max}} J_{c,sc}(B) dB \, A_{st} \; [J/m]$$

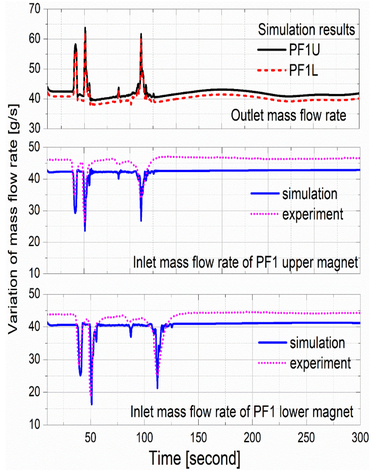
$$Q_{cop} \approx \frac{B_m^2 n \tau_{cp}}{\mu_0 \tau_m} A_{st} \quad [J/m]$$

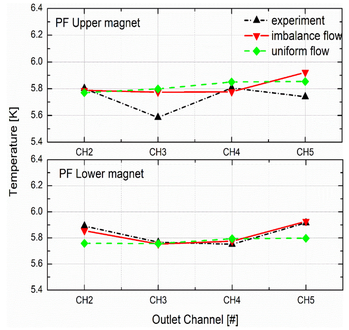
- The model takes into account twenty parallel cooling channels.
- For the calculation of the AC losses, the magnetic field distributions are calculated by ANSYS code and the results are applied to the each cooling channel.
- The one of causes of flow imbalance could be assumed the helium area in the CICC because the KSTAR PF conductor is continuous winding scheme in order not to be use the internal joint in the magnet.
- The flow imbalance study has been conducted according to change helium area from 94.91 mm2 to 124.31 mm2 (average helium area is 112.1 mm2). The calculated inlet mass flow rate depending on the helium area in the THEA code and the result are good agree with imbalance results.

4. Simulation results









- The flow imbalance results of the PF1 lower magnet are good agreement with experiment.
- In the CH5 of the lower magnet, the maximum temperature is 5.92K, 5.93K, 5.79K in case of experiment, imbalance flow, and uniform flow respectively. The temperature is higher 0.14 K versus the uniform flow.
- The inlet mass flow rates are 42.34 g/s and 40.68 g/s at the PF1upper and lower magnets respectively. The differences is 1.66 g/s between two magnets and that of the experiment is 1.2 g/s.
- The largest flow reduction occurs while plasma blip, and the values are 23.70 g/s, 16.36 g/s at the PF1 upper and lower magnets respectively. This value is reduced more by approximately 1 g/s compared to the difference of the initial flow values.

5. Conclusions

- The KSTAR PF1 UL magnets has the flow imbalance around 4 %.
- The cryogenic stability is investigated with the KSTAR PF1UL magnet circuit, which has been developed by the SUPERMAGNET code (THEA-Flower)
- Flow imbalance trends has been good implemented in the code.
- The mass flow rate and maximum temperature of PF1 lower magnet are good agree with the experiment data.
- The temperature rising on the CH5 of PF1 lower magnet is highest (5.93 K).
- Flow imbalance could be influenced on the magnet temperature.