A pressure drop model for helium flow in CIC Conductors based on porous media analogy

Zhicai Ma, Yuanwen Gao, Email: ywgao@lzu.edu.cn

College of Civil Engineering and Mechanics, Lanzhou University, Lanzhou, Gansu 730000, P.R. China

Introduction

- Cable-in-Conduit Conductors (CICCs) are being developed for use in large superconducting coils, such as tokamaks, stellators or high energy experimental devices.
- Pressure drop in CICCs cooled by a forced-flow of helium is one of the key parameters for the design of large superconducting magnet systems, which determines the heat removal capability and the thermal stability.
- In order to predict the pressure drop for a given mass flow, an analytical correlation between the mass flow and pressure drop needs to be established.

Theoretical model

The helium flow through channels in CICCs is laminar flow at low Reynolds number and turbulent flow at high Reynolds number. The flow channels are assumed to be a bundle of tortuous capillaries with a series of contracting and expanding sections. The total pressure drop in CICCs is the sum of the pressure drop caused by the viscous energy loss and the local energy.

Pressure drop caused by the viscous energy loss

\[
q = \frac{\pi \Delta P l}{128 L \mu} \Rightarrow \nabla \cdot \frac{q}{A} = \frac{\Delta P}{32 \mu} \frac{D_l}{l_0} \left( d = D_l, L = \tau l_0 \right)
\]

\[
\frac{\Delta P}{l_0} = \frac{32 \mu \tau}{D_l^3} \nabla \cdot \frac{\dot{m}}{D_l^2} \rho \nu \tau A_r
\]

where \( \tau = \frac{v}{\cos \theta}, \frac{\dot{m}}{A} = \rho \nu \tau, \mu = \rho \nu \) and \( A_r = D_l / \mu A_r \)

Pressure drop caused by the local energy loss

\[
\frac{\Delta P}{l_0} = \left( \frac{3}{2} - \frac{5}{2 \beta_1^2} + \frac{1}{\beta_1^4} \right) \frac{1}{2} \mu^2 \left( \frac{1}{2} \right)^2 \left( \frac{3}{2} - \frac{5}{2 \beta_1^2} + \frac{1}{\beta_1^4} \right) 2l_0^2 \rho \nu \tau A_r
\]

Total pressure drop

\[
\Delta P = \Delta P_{\text{viscous}} + \Delta P_{\text{local}} = \frac{32 \mu \tau}{D_l^3} \frac{\dot{m}}{D_l^2} \rho \nu \tau A_r + \frac{32 \nu \tau}{D_l^3} \rho \nu \tau A_r
\]

Results and Discussion

- The pressure drop predictions of the new model for PFCl-W and PFCl-NW conductor samples are in good agreement with the experimental data.

Conclusions

- An analytical model for predicting the pressure drop of CICCs is developed based on an analogy to porous media.
- An analytical model for predicting the friction factor of CICCs is also derived, the obtained expression is superior to the Katheder correlation at large Reynolds number.
- In the CICCs design, the cabling angle should be decreased, the void fraction should be increased. As the void fraction increases, the hydraulic diameter and the fluid area will also increase, so that the pressure drop will decrease for a given mass flow.