§4. Hydraulic Characteristics of Cable-in-Conduit Conductors for LHD Poloidal Coil

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Poloidal field coils for LHD consist of Nb-Ti cable-in-conduit conductors. The first cool-down of LHD started in February of 1998, and the LHD experienced the cool-down three times up to the present time. Pressure drops of the conductors and coils have been measured during inspections at room temperature, cool-down, steady state and warm-up.

The hydraulic characteristics have been investigated by means of the Darcy friction factor. The relationship between the pressure loss (ΔP) and the friction factor (λ) can be expressed as

$$\Delta P = \lambda(L / D_h)(\rho V^2 / 2) \qquad (1)$$

where L is the length of the flow path, D_h the hydraulic diameter, ρ the density of fluid and V the average velocity. The friction factor depends on roughness and the Reynolds number (Re_h). The feature of laminar flow is

$$\lambda Re_h = \text{Constant}, \qquad (2)$$

and the constant, called a laminar friction constant, is different for different geometries. For circular pipes, the constant is 64 according to the Hagen-Poiseuille equation.

Figure 1 shows the friction factors of the OV conductors for Reynolds numbers between 1 and 20 in the manufacturing process at room temperature. The factors were found to lie below the line of the Hagen-Poiseuille equations. Figure 2 shows the laminar friction constants for three types of coils, OV, IS and IV. For each coil, the mean values were confirmed to be constant. Furthermore, the variations showed the same levels, and an abnormality did not appear. Such an inspection is considered to be valid for manufacturing process of cable-in-conduit conductors.

In the cool-down and warm-up, the Reynolds number varied between 10 and 300 depending on the mass flow rate and the viscosity. For the steady state, the Reynolds number increased to 3000 because the helium became supercritical and its density became comparable to that of liquid. The friction factors of the OV coils in operation were compared with those of the short samples. The results are shown in Fig. 3. The open circles and triangles indicate the factors for the upper and lower coils respectively. All data in three operational periods are plotted on the figure. The experimental results showed that the characteristics did not change for all operational periods and agreed well with those of the short samples indicated by closed circles. This suggested that no obstruction existed in the coils. The comparison with short samples is considered to be valid for detection of chokes.

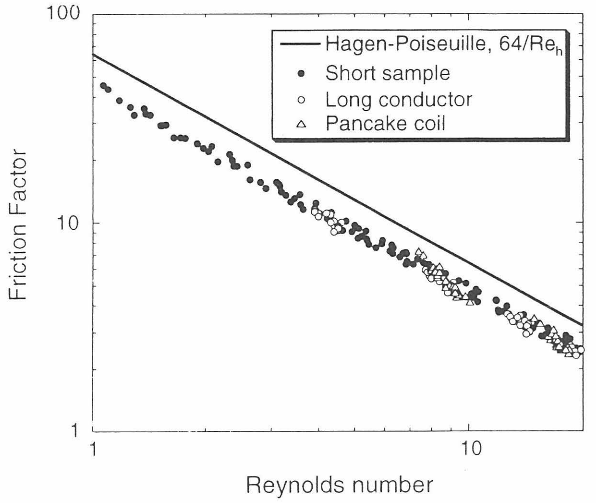

Fig. 1. Friction factors at low Reynolds numbers.

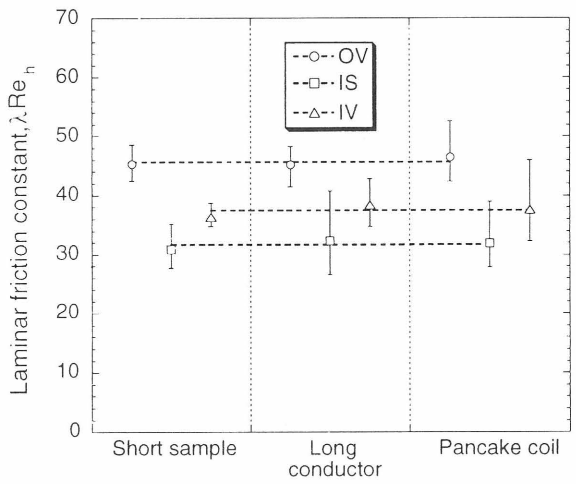

Fig. 2. Laminar friction constants of the LHD coils in the manufacturing process.

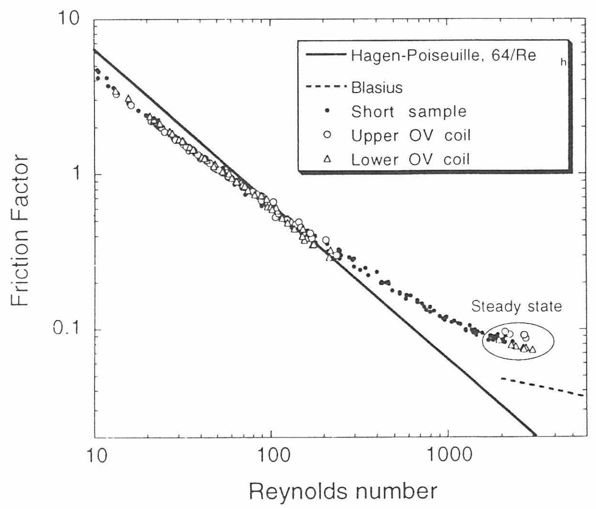

Fig. 3. Friction factors in cooling operation.