§6. Investigation of Advanced Superconducting Cable-in-Conduit Conductor

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A Cable-in-Conduit (CIC) conductor, which is made of many strands of less than 1 mm in diameter, is mainly used for a forced-cooled coil, because it has many advantages such as high stability, reduced AC loss and high mechanical strength. However, the cable is squeezed and compressed to about 60% in the conduit, and thereby the strands are slightly deviated from the original positions. These deviations cause different inductances among strands, and hence a current distribution in the conductor is no longer homogeneous during excitation. The imbalanced current can restrict the ramp rate of the current in a large coil, and also enhanced AC loss in large superconducting machines due to long decay time constants of loops between strands. It is very difficult to control the current distribution in cross section of the CIC conductor, because displacements of strands cannot be precisely estimated during compaction into the conduit.

We propose a new coaxial multi-layer type CIC conductor as shown in Fig. 1. The coaxial multilayer CIC conductor is composed of several layers wound on around the central tube for cooling, while each layer has its own pitch. Since all strands are tightly fixed by the winding, they cannot move during the fabrication. All strands in each layer have also the same performance and cannot deviate from the original positions during cable fabrication process. Consequently the strand arrangement can be kept as designed and controlled.

We derive generalized equation which describes layer current distribution as functions of cable parameters such as layer twist pitch, twist direction, layer radius and superconducting strands number (SC strands) and segregated copper strands (Cu strands), as following equation.

$$\frac{\mu_0}{2\pi}\left(\ln\frac{r_{k+1}}{r_k}\right)\sum_{i=1}^{k} I_i + \mu_0\left(\frac{1}{p_k}-\frac{1}{p_{k+1}}\right)\sum_{i=1}^{k}\pi r_i^2\frac{I_i}{p_i} + \mu_0\left(\frac{\pi r_k^2}{p_k}-\frac{\pi r_{k+1}^2}{p_{k+1}}\right)\sum_{i=k+1}^{n}\frac{I_i}{p_i} = 0 \quad (k=1,\cdots,n-1) \tag{1}$$

where I_i is layer current, μ_0 is permeability in vacuum, r_k is radius of k-th layer, p_k is twist pitch of k-th layer.

We apply the generalized equation to design a homogeneous current distribution in the CIC for a helical coil of Force Free Helical-type Fusion Reactor (FFHR), as folloes. We treat an arrangement that each layer is composed of almost 2 SC strands : 1 Cu strand, as shown in Fig. 2. The layers are numbered from the inner layer to outer layer which is restricted by the cable outer diameter of 38 mm. The twist pitch of inner most layer must be largest, and it is assumed to be restricted 500 mm in fabrication.

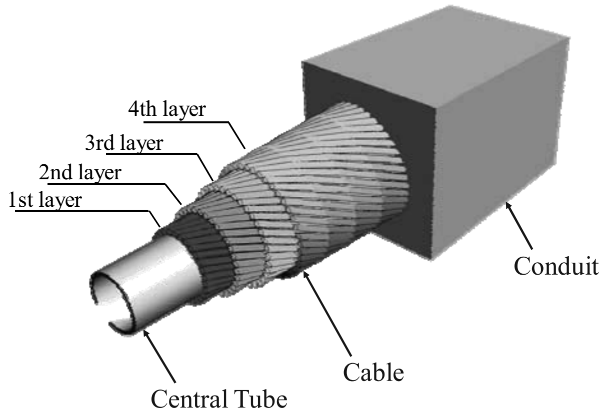

Fig. 1. Model of a coaxial multilayer type CIC.

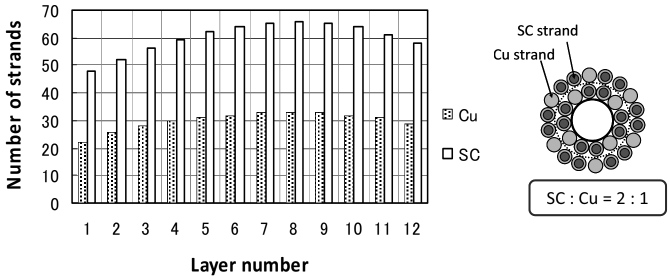

Fig. 2. Number of strands in case of SC:Cu = 2:1.

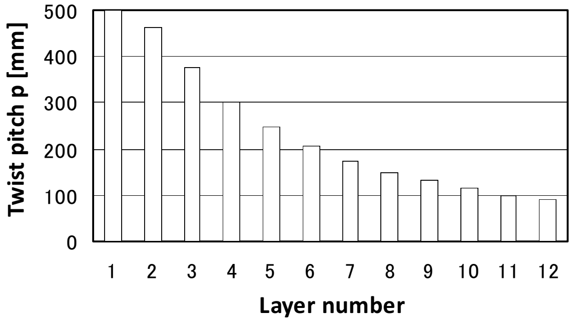

Fig. 3. Twist pitches of all layers in case of SC:Cu = 2:1.

We can obtain the strand numbers of all layers satisfying the homogeneous current distribution, as shown in Fig. 2. It is shown that each layer is composed of SC strands and Cu strands as the ratio 2:1. The number of strands increases from the inner layer, becomes maximum at the 8-th layer, and then gradually decreases at outer layers. Fig. 3 shows the results of all layer twist pitches. It is shown that twist pitches decrease monotonically with layer number. This stems from that since the first term in equation (1) is always positive, the summation of the second and third terms should be negative, and hence the twist pitch of outer layer should decrease. Consequently in the case that the outer layer twist pitch decrease rapidly compared with layer radius, the strand number of outer layer can decrease.

1) Hamajima, T., et.al. : IEEJ Trans. PE **129** (2009) 1299
2) Hamajima, T., et.al. : MT-21 4BP-24, China, 2009
3) Teshima, S., et.al. : IEEJ **ASC-09-21** (2009) 5