§3. 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 into the conduit by about 60%, 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 investigated a coaxial multi-layer type CIC conductor as shown in Fig. 1(a), then in this paper, we propose a HTS coaxial type CIC conductor as shown in Fig. 1(b). 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 HTS tapes are tightly fixed by the winding, they cannot move during the fabrication. All tapes in each layer have also the same performance and cannot deviate from the original positions during cable fabrication process. Consequently the tape arrangement can be kept as designed and controlled.

We derive a generalized equation which describes layer current distribution as functions of cable parameters such as layer twist pitch, twist direction, layer radius and HTS tape number, as following equation[1-3].

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

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 equation to design a homogeneous current distribution in the CIC for a helical coil of Force Free Helical-type Fusion Reactor (FFHR) and ITER coil[3]. Since recent progress of critical current of YBCO tape with 4 mm in width and 0.2 mm in thickness shows the critical current is about 150 A at 4.2 K and 13 T parallel in c-axis, an operation current is assumed to be 100 A at 13 T. The

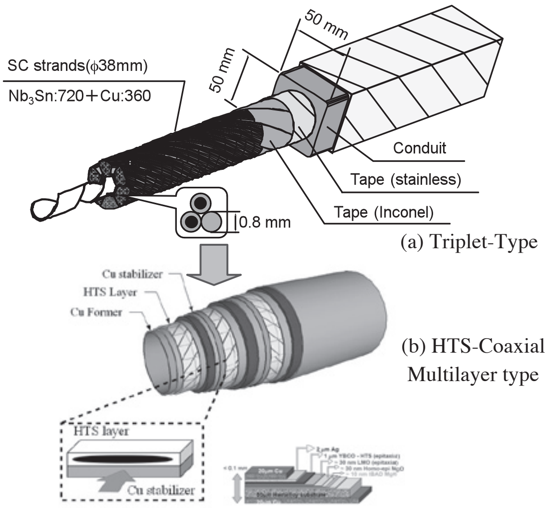

Fig. 1 Triplet & coaxial multi-layer type CICs

homogeneous current distribution is obtained, when 20 layers are wound by many HTS tapes with proper twist pitches as shown in Fig. 2 and 3. It is found that the tape number of mid-layer becomes large, because tape twist pitch becomes small according to layer number and circumference becomes large according to radii. Since the YBCO tapes are composed of Hasteloy which is more than 600 MPa in mechanical strength, it is suitable for fusion coils against large electromagnetic force.

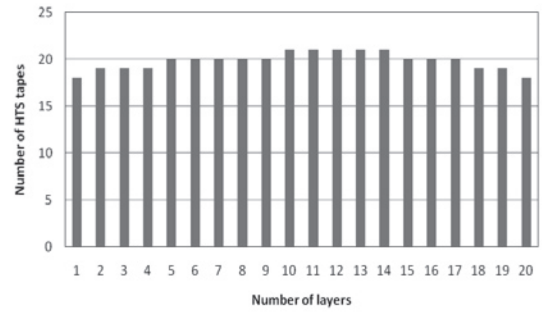

Fig. 2 HTS tape numbers of layer.

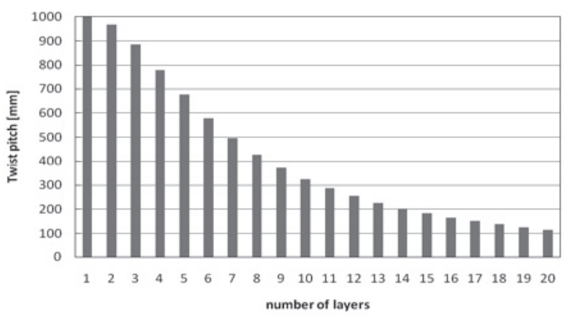

Fig. 3 HTS tape layer pitch.

1) Hamajima, T., et.al. : IEEJ Trans. PE **129** (2009) 1299
2) Teshima, S., et.al. : IEEJ **ASC-09-21** (2009) 5
3) T. Hamajima, et. al., IEEE Transactions on Applied Superconductivity, **20** (2010) 560-563