§7. Development of a New Conductor Controlled the Twist Angle to Improve the Performance of LTS Coils

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The development of SMES to protect from momentary voltage drops is conducted. In this SMES, conduction-cooled low temperature superconducting (LTS) pulse coils are used. The conduction-cooled prototype coil was fabricated and tested. The coil was wound by new design method for coils, in which the twist angles around the axis of the conductor were controlled according to the coil shape. The test results on the coil showed that the coil has high performances [1]. In this coil, however, there are some problems, for example, the winding conductor is not optimized, and the special winding machine and the winding technique of high level are needed. The purpose of this study is to develop the new conductor, in order to fabricate without using special winding machine the low cost coil with both low loss and high stability. For this purpose, we have proposed the new conductors which were low cost NbTi/Cu multifilamentary tapes with high aspect ratio cross-section. These conductors were obtained by cold rolling process from normal multifilamentary wires with the single matrix of cooper. Therefore, the conductors are expected to have following advantages: (1) Ac loss in the conductor under changing transverse magnetic fields oriented to parallel to the flat face of the conductor is reduced. (2) The stability increases because the matrix of the conductor is cooper and the surface cooling is possible. (3) The cost is reduced, because the tape can be fabricated by simple fabrication process. We have already fabricated test conductors and experimentally showed that the conductors have high performances [2]. As the next step, we fabricated the practical scale conductors with large current capacities, and measured their electromagnetic properties.

The parameters of the original round wire are as follows: The diameter of the wire is 2.0 mm. The cooper ratio is 2.4. The diameter of filaments is 26 μm. On the conductors, which were after rolling, the twists due to filament twisting were observed. When the coil is wound, the twists of the conductor would be problem. Therefore, we prepared three samples which were performed in different process to straighten. The sample MP was performed the mechanical process. The sample AN was performed the annealing. The sample MP-AN was performed the mechanical process and then annealed. The parameters of samples are shown in Table I.

Firstly, critical currents I_c of these samples were measured. I_c of the samples was 1105 A under 7 T of transverse magnetic fields in directions parallel (Edge-on, EO) to the flat face of the conductor. Secondly, magnetizations were measured under transverse magnetic fields in EO direction. The applied magnetic fields were changing magnetic fields of 0.2 T in amplitude, which were superposed on the bias magnetic fields of 6 T, 7 T, and 8 T. The magnetization curves, *M-H* curves, were measured by pick-up coil method. The samples were wound into single-layered solenoidal coils of 47 mm in diameter. The effective filament diameters d_{eff} are normalized ΔM, which were gotten from measured *M-H* curves, by J_c. d_{eff} is 13.5 μm @ 7T. This value is half of 26 μm, which is the filament diameter in the round wire. It is indicated that hysteresis losses in our conductor decrease in half in spite of increase in critical current by rolling process. Finally, coupling losses were measured by pick-up coil method. Measuring conditions were as follows: The measurements were carried out in liquid helium, at 4.2 K. The applied magnetic fields were the ac ripple magnetic fields of 0.1-1.6 mT in amplitudes, which were superposed on the bias magnetic field of 0.5 T. The magnetic fields applied to the samples in EO direction. The coupling time-constants of each sample, which are obtained from measured their coupling loss properties, are listed in Table II. The coupling time-constants are given by dividing measured coupling losses by $\mu_0 H_m^2 \pi\omega$, where H_m, μ_0 and ω are amplitude of applied magnetic fields, permeability of vacuum and angular frequency, respectively. $A^*\tau$ of the sample MP was 0.6 ms. Even in the sample AN and MP-AN in which annealing were performed and RRR of copper increased, $A^*\tau$ of these samples were 1.8 – 1.9 ms. These values are very low. It is found that our conductors are very low loss. In the annealed samples, the experimental value is in good agreement with the theoretical one. In contrast, the experimental value is two times as large as the theoretical value, in the no-annealed sample MP with low RRR. The causes are considered that the difference of resistivity of cooper in the core, filamentary bundle, and the outer region were produced by the rolling process.

On the practical scale conductor with large current capacities, the critical current, magnetization, coupling losses were measured. These results showed that our conductors are adequate as a candidate of the conductor for the low cost coil with both low loss and high stability.

References
[1] T. Mito, et al.: IEEE Trans. Appl. Supercond., 16 (2006) 608
[2]F. Sumiyoshi, et al., to be published IEEE Trans. Appl. Supercond.

Table I Parameters of the samples

Sample	dimension	aspect ratio	RRR
MP	$0.61\text{mm}^t \times 4.77\text{mm}^w$	8	42
AN			288
MP-AN			284

Table II Coupling loss time-constants for EO-fields

Sample	Coupling loss-time constant $A^*\tau$ [ms]		
	Experiment	Theory	Experiment/Theory
MP	0.6	0.27	2.22
AN	1.82	1.82	1
MP-AN	1.88	1.79	1.05