§16. A Problem on Current Imbalance in Insulated Multi-Stranded Superconducting Conductor

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We have been investigating the current imbalance problem comparing the calculated result obtained by the measurement of inductance distribution in multi-strand superconducting cable conductor using high accuracy LCR meter and the measured actual current distribution in it . So far, the measurement of inductance and that of actual current had been carried out at 1kHz and at few Hz, respectively. As a result, the experimental result did not agree well with the calculated one in the region of more than 0.5Hz. Furthermore, we could not obtain the enough experimental results more than 1 Hz because of the lack of the capacity of AC power supply [1].

Therefore, we have made the larger diameter superconducting coil using a insulated nine-strands (3×3) superconducting cable conductor. For each strand a shunt resistor (60-80 $\mu\Omega$) is attached in order to measure the current in each strand. And, the relation between the calculated results and the experimental ones are investigated [2]. The larger diameter coil has larger inductance. So, it is expected that the behavior of current distribution pattern will shift to lower frequency range compared with that of the lower diameter one. And, the inductance measurement technique has been improved by using GP-IB cables instead of twist-pairs between a LCR meter and a personal computer, and the measurement frequency was set at 100Hz, which is 1/10 of the former experiments. However, due to the experimental restriction, the measured inductances have to include those of the current lead connecting the power source and the coil. So, the obtained magnetic coupling factors should be thought to be smaller than the actual net values. Fig.1 shows the inductance distribution of the 2-stage stranded cable conductor at 4.2K. The dispersion of the inductances is lower than 0.3%. And the coupling factor between strands in the same first cable is 0.997 and others are 0.9956. However, the actual magnetic coupling factor can estimate higher values because of the existence of the inductance of current lead. Fig.2 shows the frequency characteristics of current distributions in the conductor, where marks such as ■, ●, ▲, are the experimental values and others are the calculated ones. From these figures, it is recognized that the frequency region can be divided roughly to three regions. That is, the first is the one lower than 0.01Hz in which the resistance is dominant, the second is the one higher than 10Hz in which the inductance is dominant, and the third is the intermediate region between the resistive and the inductive regions. According to our experiment, the current behavior is very dynamic in the intermediate region.

In the inductance measurement, the extra inductance of the current lead has been included. Therefore, we are going to measure the inductance of current lead more precisely and to re-calculate the current distribution using newly obtained higher magnetic coupling factors. According to our preliminary measurement, the self- and mutual-inductance of the current leads are about 10 μH and 5 μH respectively. Fig.3 shows one of the calculated results, where the coupling factor between strands in the same first stage cable is set to 0.9996, and others are 0.9980.

From the experimental and theoretical results, it is found that the magnetic coupling factor is the sensitive parameter to the current imbalance problem, especially when the coil size becomes larger, its values are very closely to unity. Therefore, conductors for larger scale application may have to be designed to have lower magnetic coupling factor.

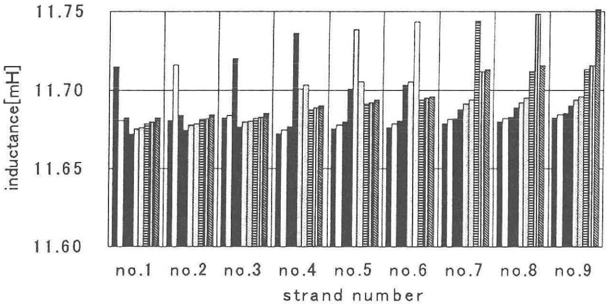

Fig.1. Inductance distributions of the test coil.

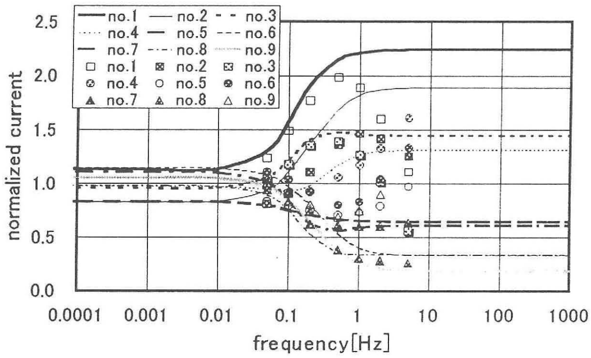

Fig.2. AC test result.

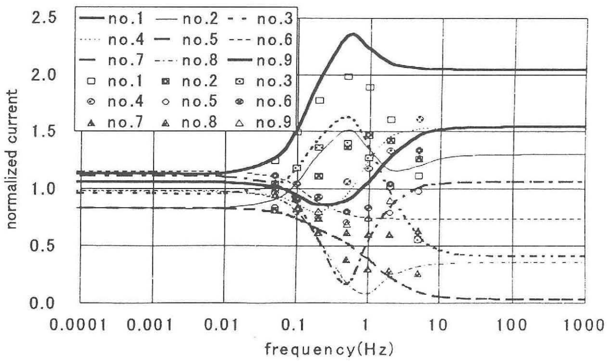

Fig.3. Re-calculation result of AC operation.

Reference

1) T.Ishigohka, A.Ninomiya, et al, IEEE Trans. on Appl. Supercon. Vol.10, No.1, pp1216-1219, 2000.
2) A.Ninomiya, T.Ishigohka, et al, IEEE Trans. on Appl. Supercon., Vol.11, No.1, pp1466-1469,2001.