

5 Discussion

Based on the simulation results, the influence of current redistribution on the quench propagation velocity is discussed.

Figure 5.1 shows an example of current change and the element voltages of strands 1 and 2 for $\sigma_c = 2.5 \times 10^8$ S/m. The strand current was 387.5 A. At the element shown in the figure, the magnetic field at strand 2 is higher than that at strand 1. When the quench front reaches to this element, the voltage appears at the element of strand 2 first ($t = 5.78$ msec), since the quench margin of strand 2 is lower than strand 1 due to the higher magnetic field. Then the current escapes from strand 2 to strand 1, and the current of strand 1 increases, while the element of strand 1 is also heated up by the heat conduction from the preceding element of strand 1. Because of this heat conduction and the increase in current, the voltage appears at the element of strand 1 at $t = 5.84$ msec, and the voltage of strand 1 exceeds the voltage of strand 2 at $t = 5.86$ msec due to the current transfer from strand 2 to strand 1. Once the voltage of strand 1 exceeds that of strand 2, the current returns from strand 1 to strand 2 rapidly. In 0.06 msec ($t = 5.96$ msec), the voltages of strands 1 and 2 are almost balanced, and the rapid current change ceases. After this, the current changes slowly so that the current distribution depends on the resistance distribution due to magneto-resistance.

In such a current redistribution caused by the existence of the field gradient, the quench propagation velocity is influenced by the initial current transfer, which is the transfer from the higher field region to the lower field region. From Eq. (4.19), when the current exceeds the critical current, the superconducting state becomes the normal state. The critical current decreases with increasing temperature as shown in Fig. 4.3.

Let define a quench margin as $1 - (I_{strand}/I_{c,strand})$. If the current does not transfer from the higher field region to the lower field region, the temperature of the lower field region

increases owing to only the heat conduction along the strand. Since $I_{c,strand}$ decreases with the increase of the temperature, the quench margin decreases, and the lower field region becomes the normal state when $I_{c,strand}(T)$ equals I_{strand} .

If the current can transfer from the neighboring strand, because of the decrease of $I_{c,strand}(T)$ and the increase of I_{strand} , the element becomes the normal state in the time shorter than that without the current transfer.

In this mechanism, the faster current transfer is preferable in order to increase the quench propagation velocity. The time constant of the current transfer depends on the electrical contact conductance.

Figure 5.2 shows an example of current change and the element voltages of strands 1 and 2 for the low electrical contact conductance, $\sigma_c = 2.5 \times 10^5$ S/m. The strand current was 387.5 A. As can be seen in this figure, the little current transferred in the time span between the take-off times of the element voltages of strands 1 and 2, from 6.41 to 6.5 msec. This indicates that the time constant of the current transfer is very large.

In the low electrical contact conductance range, the reason why the time constant becomes large is that the region of the current redistribution spreads, as shown in Fig. 4.15. The spreading of the current redistribution region is equivalent to the enlargement of the effective loop size. Therefore the effective inductance of the loop of the circuit becomes large, and the time constant of the current redistribution also becomes large. Since the current transfer is small because of the large time constant, the quench margin decrease owing to mainly the heat conduction from the previous element, and the quench propagation velocity does not increase.

Figure 5.3 shows the maximum current change of strand 1 and the quench propagation velocity for the strand current of 387.5 A as a function of electrical contact conductance between strands. As can be seen in this figure, there is a strong correlation between the quench propagation velocity and the maximum current change.

In the low contact conductance region, the current changes and the quench propagation velocities decrease with the decrease of the electrical contact conductance, since the time constant of the current transfer becomes large with the decrease of the conductance.

In the high contact conductance region above $\sigma_c = 2.5 \times 10^9$ S/m, the current changes and the quench propagation velocities stay at constant values. The reason for this is that the element length is finite. From Eq. (4.30), the region of the current redistribution decreases with the increase of the electrical contact conductance. If the region of the current redistribution is sufficiently smaller than the element length, the effective loop becomes the loop of one element, and the time constant is defined only by the element conductance and the inductance of the loop. Therefore, in the calculation with the finite element length, the quench propagation velocity in the high contact conductance region is independent of the contact conductance.

If the element length is infinitesimally short, as the electrical contact conductance increases, the time constant of current transfer keeps decreasing. Therefore the quench propagation velocities keep increasing with the contact conductance. Finally, at $\sigma_c = \infty$, it seems that the quench propagation velocity becomes the velocity when all the cable is exposed to the field of B_{max} . For example, the quench propagation velocity at B_{max} and 387.5 A was 41.8 m/s.

In the cable tests, the average quench propagation velocities in high contact cable were almost the same as those in original cable in the current range below 3000 A, and the average velocities in high contact cable above 3000 A were lower than those in original cable. These results are different from the expectation described above. The most likely reason for this discrepancy is the influence of the polyimide tape. While the polyimide tape was wrapped by machine for original cable, it was wrapped by hand for high contact cable and low contact cable. Since the cooling condition for the cable wrapped with polyimide tape by hand was better than that for the cable wrapped with polyimide tape by machine, it seems that the quench propagation velocities in the cable wrapped with polyimide tape by hand decreased.

As described in the previous chapter, especially in the high contact conductance range, the heat conduction between strands cannot be neglected. In this case, J_{NBT_i} in Eq. (4.19) increases owing to the current transfer, and the critical current decreases simultaneously because of the heat conduction. Since the heat and current transfer simultaneously, the lower field strand becomes the normal state in the time slightly shorter

than the time without heat conduction. Therefore, the maximum current change decreases as shown in Fig. 4.18, and the quench propagation velocity increases slightly. For example, as shown in Fig. 4.18, the quench propagation velocities at $h_{const} = 0$ W/mK, 100 W/mK and 500 W/mK, are 38.81 m/s, 39.31 m/s and 39.32 m/s, respectively.

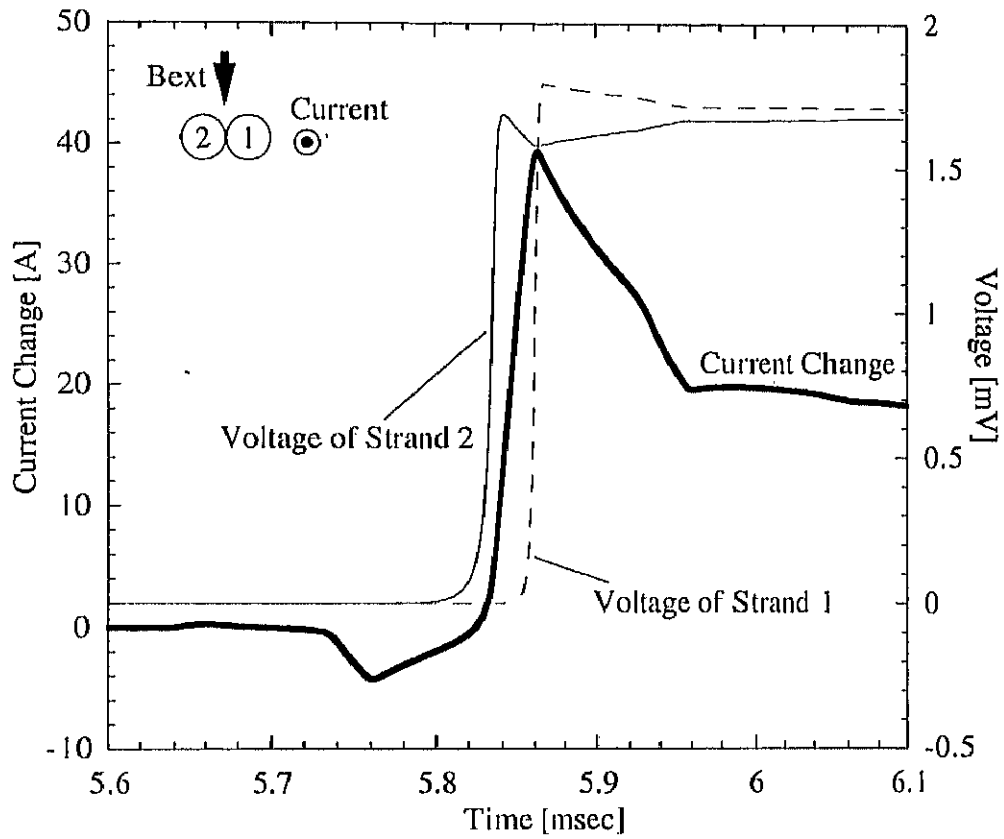


Fig. 5.1: Current change of strand 1 and element voltages of strands 1 and 2 at $\sigma_c = 2.5 \times 10^8$ S/m and the strand current of 387.5 A.

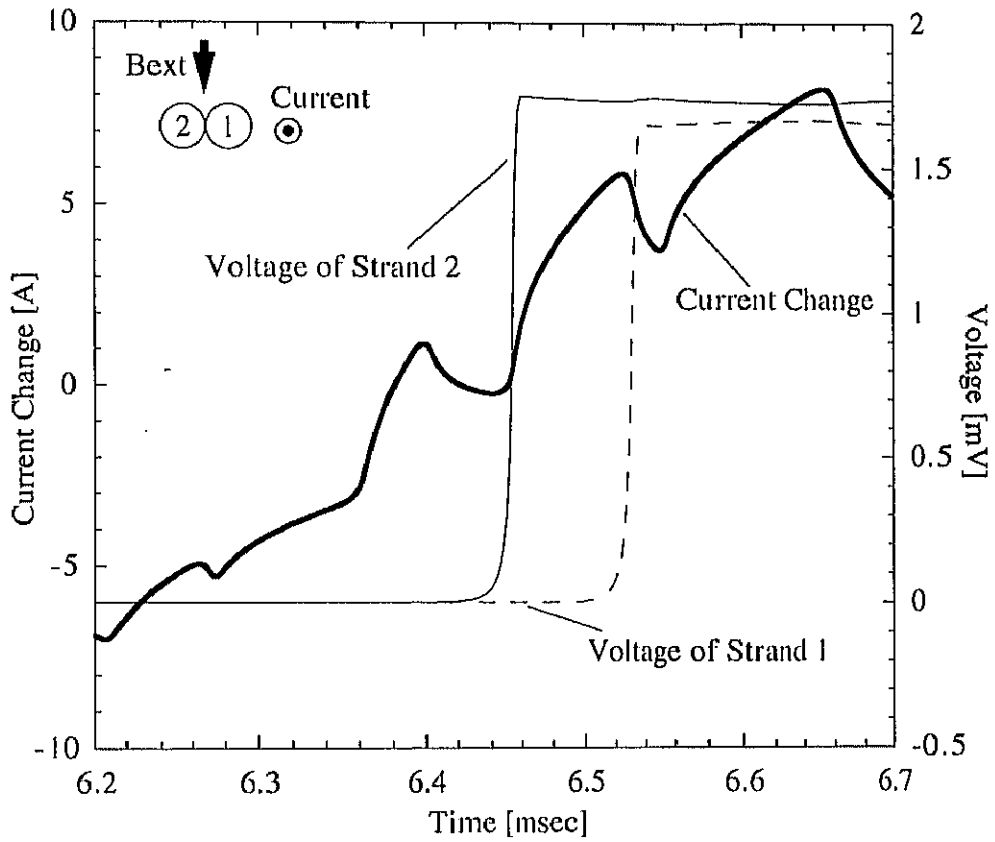


Fig. 5.2: Current change of strand 1 and element voltages of strands 1 and 2 at $\sigma_c = 2.5 \times 10^5$ S/m and the strand current of 387.5 A.

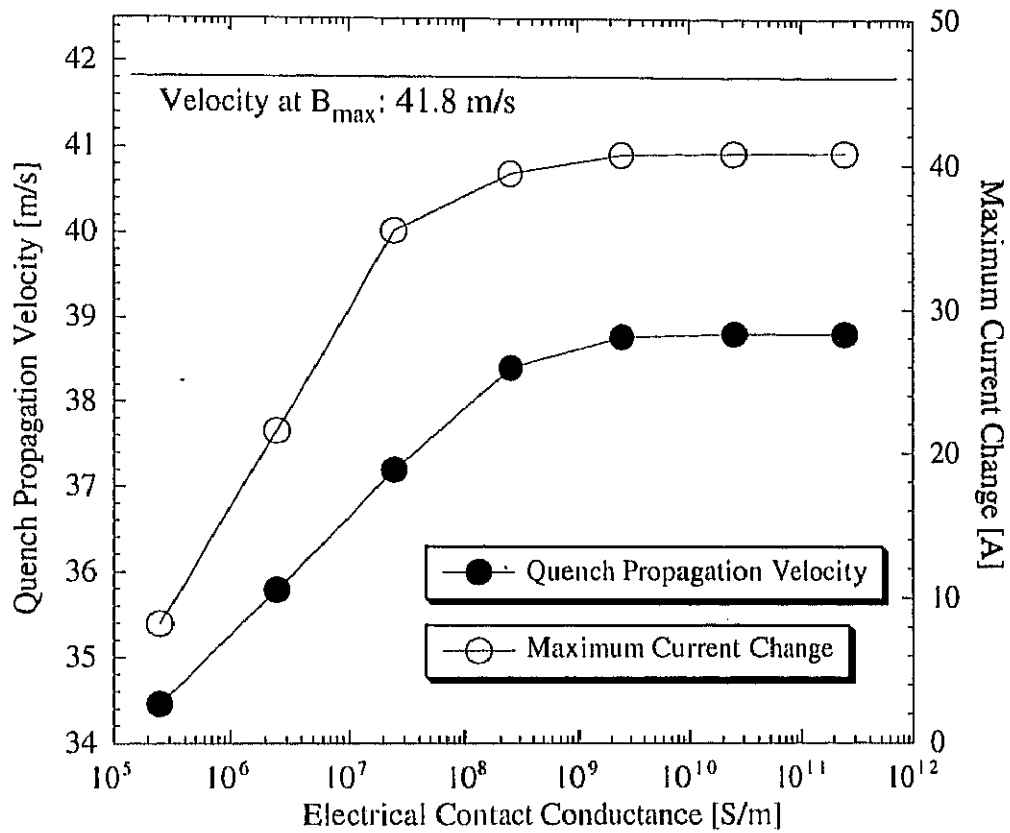


Fig. 5.3: Maximum current change of strand 1 and the quench propagation velocity at the strand current of 387.5 A as a function of the electrical contact conductance between strands.