Additional ac loss properties of REBCO superconducting two-strand parallel conductors

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Background

We have introduced the configuration of transposed parallel conductors for enhancing a current capacity of REBCO superconducting tapes.
The constituent strands need to be insulated and transposed for even uniform current sharing and low ac loss. In case the transposition point deviates from the midpoint (in length) which corresponds to the optimum one, shielding current, I, is induced to prevent the variation of the interlinkage magnetic flux. That results in an additional ac loss.

Objectives

Assuming that the I-V properties of REBCO superconducting tapes is expressed by using a n-value model, the additional ac loss properties of transposed two-strand parallel conductors composed REBCO tapes in the case that the transposition points deviate from the optimum ones are theoretically investigated.

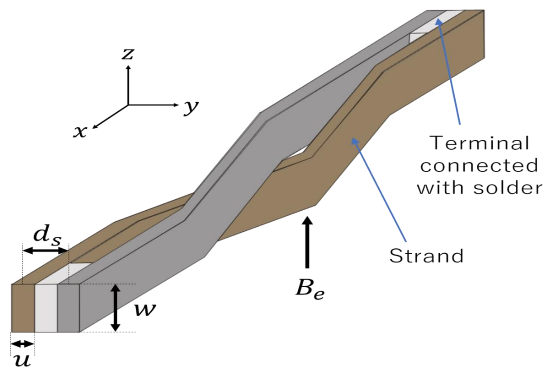
Conclusion

・The additional ac loss of parallel conductors is reduced by transposing the constituent tapes under the non-saturation condition. However, as n-value becomes smaller, the additional ac losses is enhanced.

・The smaller n-value, the larger additional ac loss even for the same deviation of the transposition point from the optimum one and the same magnetic field amplitude. The results suggest that, in the case that the parallel conductors are composed of REBCO tapes and, especially, they are used at high temperature where n-values of REBCO tapes is small, transposition should be made with high accuracy at the optimum points.

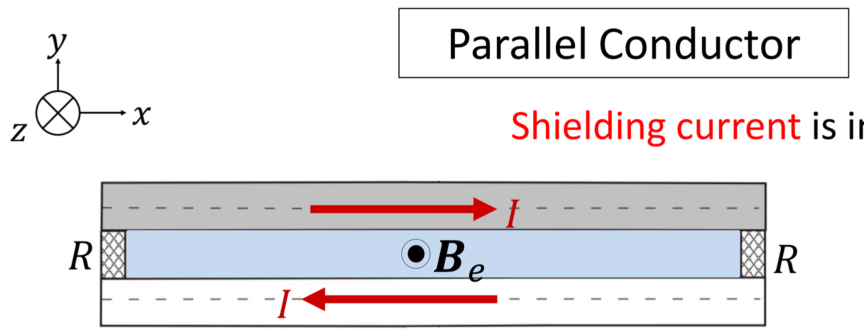
・In order to avoid an enhancement of additional ac loss, the n-value of tapes larger than around 10 should be secured and the deviation of the transposition point should be controlled less than several % in conductor length.

Additional AC Loss



Transposed parallel conductor

Parallel Conductor



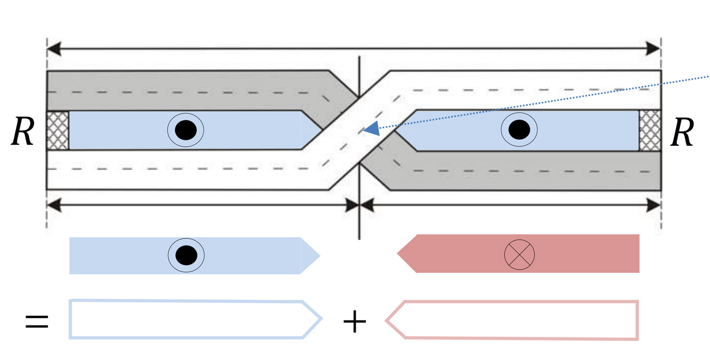
Shielding current is induced to prevent the variation of the interlinkage magnetic flux.

Leads to the production of an additional ac loss.

・The additional ac loss is the joule loss of the contact resistances at the both ends due to shielding current.

Transposed Parallel Conductor

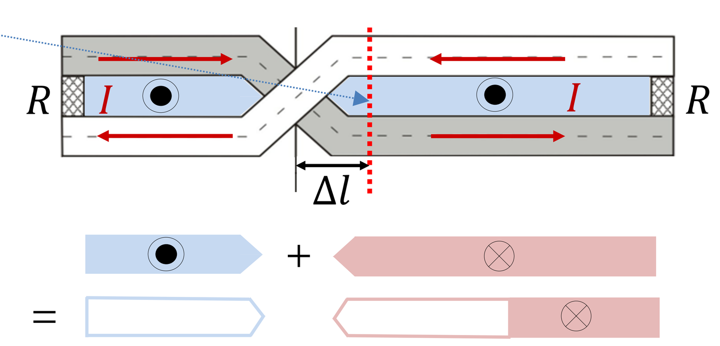
In case transposed at the optimum point.



Optimum point

- I : Shielding current
- R : Contact resistance at the terminal
- B_e : external magnetic field
- u :Strand thickness
- w :Strand width
- d_S :Distance between the strands

In case the transposition point deviates from optimum one.



Interlinkage magnetic flux is canceled, and additional ac loss doesn't occur.

Interlinkage magnetic flux is not canceled, and additional ac loss occur.

Theory

Equivalent resistance is given by $R_{\mathrm{HTS}} = V_c \dfrac{I^{n-1}}{{I_c}^n}$

The interlinkage magnetic flux of the loop which is enclosed by the two tape is given by

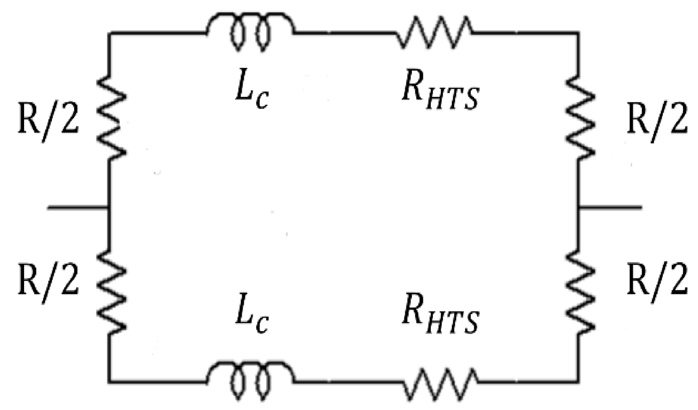
$$\Phi = \Phi_{B(x)} \sin \omega t + d_s \mu_0 \frac{k}{w} IL$$

Here, $\Phi_{B(x)} = d_s \left\{ \int_0^{\frac{L}{2}-\Delta L} B_m \,\mathrm{d}x + \int_{\frac{L}{2}-\Delta L}^{L} B_m \,\mathrm{d}x \right\}$

The circuit equation based on Faraday's law is given by $\dfrac{\mathrm{d}\Phi}{\mathrm{d}t} = -(2R + 2R_{\mathrm{HTS}})I$

By solving the circuit equation numerically, the shielding current can be evaluated.
Therefore, the additional ac loss due to forming a parallel conductor is calculated as

$$W = \int_0^{\frac{2\pi}{\omega}} \frac{2(R + R_{\mathrm{HTS}})I^2}{2uwL} \mathrm{d}t$$

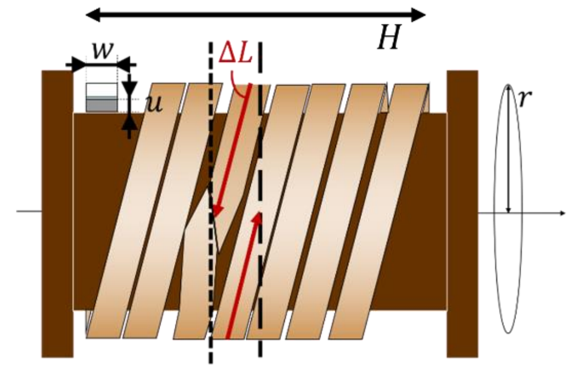


Equivalent circuit using n-value model

- L :Conductor length
- ΔL :Deviation from the optimum transposition point
- μ_0 :permeability of vacuum
- k :constant which depends on the arrangement of the strands
- R_{HTS} :Equivalent resistance
- L_c :Self inductance of strand

Results And Discussion

Using the obtained theoretical results, let us investigate the additional ac loss properties of transposed two-strand parallel conductors wound into the one-layer solenoid coil . Here it is assumed that the transposition point deviates from the optimum ones and the coil is exposed to external ac magnetic field in parallel to the coil axis. Here, the external ac magnetic field is spatially uniform.



Parallel conductor wound into a one-layer coil

TABLE1

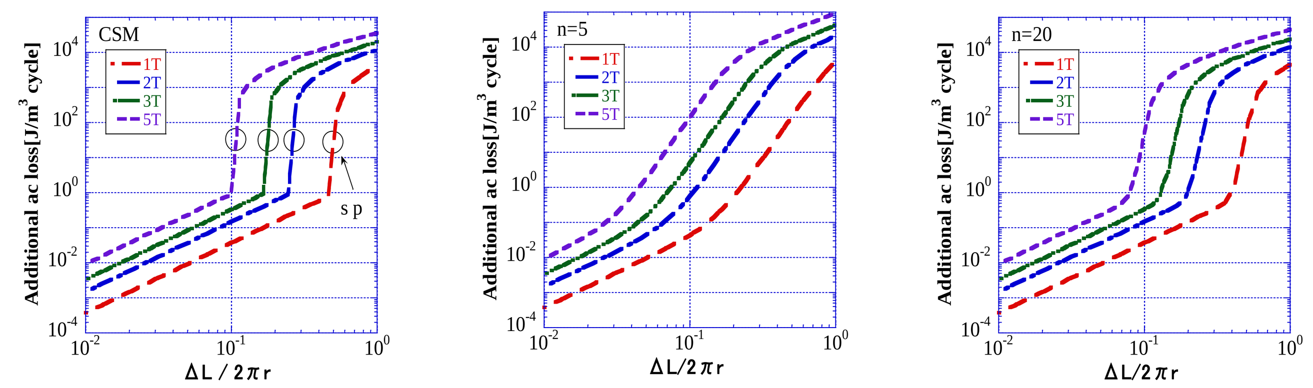
SOLENOID COIL PARAMETERS IN THE ASSUMED THEORETICAL ANALYSIS

Conductor length, L (m)	10.05
Diameter of a coil, r (mm)	40
Height of a coil, H (mm)	100
Number of turns	20
Contact resistance at the terminal, R (Ω)	1.4×10^{-8}
Strand thickness, u (mm)	0.2
Strand width, w (mm)	5
Distance between the strands, d_S (mm)	0.197
Critical current, I_C (A)	200
Frequency, f (Hz)	60

Critical State Model (n=∞)

・$I < I_C$ (Non-saturation condition)
$R_{\mathrm{HTS}} = 0$

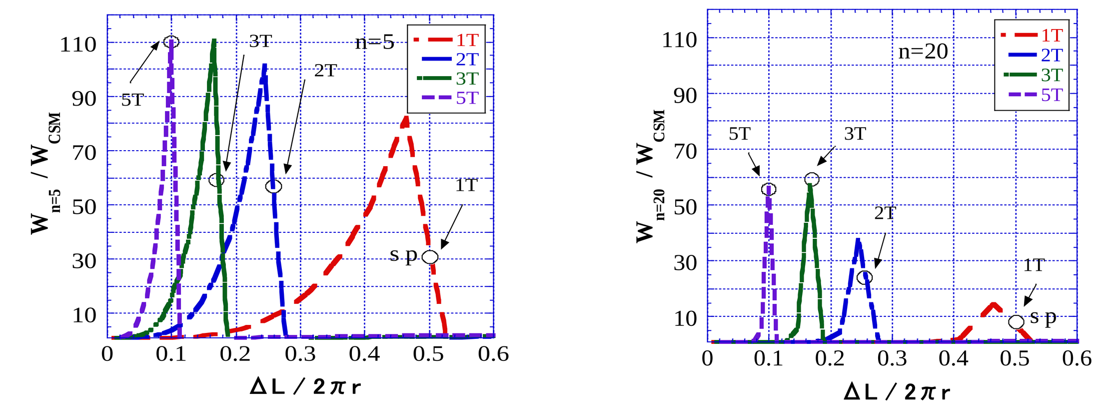
・$I = I_C$ (Saturation condition)
R_{HTS} = Flux-flow resistance



The calculated ΔL dependence of the additional ac loss based on the CSM with B_m as a parameter.

We can see that the additional ac losses abruptly increases when the induced shielding current reaches Ic. The induced shielding current increases in proportion to Bm and ΔL. So the ΔL corresponding to sp decreases witgh increasing Bm. Under the non-saturation condition, the additional ac loss is generated only at the contact resistance, while, under the saturation condition, magnetic flux flow resistance is produced and the additional ac loss drastically increases.

sp shows the boundary between the non-saturation and saturation conditions.



The dependences of the additional ac losses on the deviation length of the transposition point from the optimum one in the respective cases of n=5 and 20.

The vertical axis is normalized by the additional ac loss in the case of n=∞, WCSM. Here the parameter is a field amplitude, Bm. We can see that the additional ac loss could be several tens times larger than that in the case of n=∞ even in the case of n=20. The range of ΔL where the additional ac loss is much enhanced expands with decreasing n. And the ac loss enhancement is induced even for small ΔL when Bm becomes larger. However, if the deviation of the transposition point is controlled less than several % in conductor length, the additional ac loss is not so enhanced although the n-value of the tapes is requested to be larger than around 10.