Current sharing properties of REBCO superconducting parallel conductors wound into a coil

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Introduction

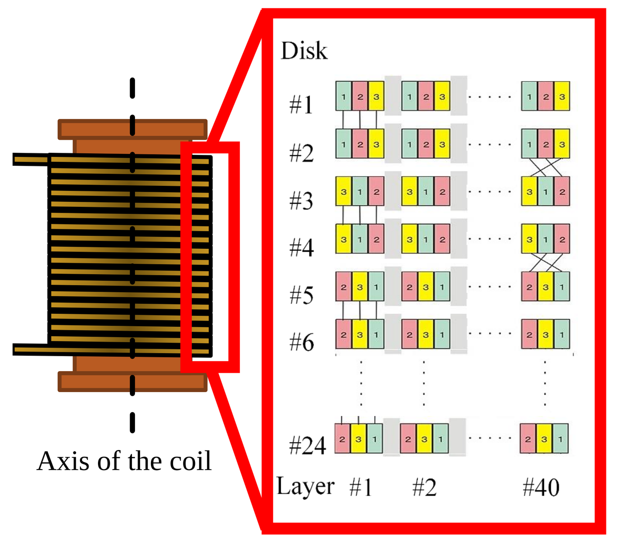
- Operating current of large-scale magnets need to be enhanced up to several kA to several tens kA in the view point of magnet protection.
- For AC applications, the current capacity of windings is determined due to the specifications of machines and devices (usually ranges from several hundreds A to several tens kA).
- We proposed the introduction of the configuration of parallel conductors for these reasons.
- Superconducting magnets for MRI need the uniformity in produced magnetic field within ppm order in time and space.
- To realize that, current sharing properties among tapes should be even.
- In this study, we have clarified the current-sharing properties taking account of the change of I_c due to the self-magnetic field of the three superconducting coils wound with parallel conductors.

Numerical simulation

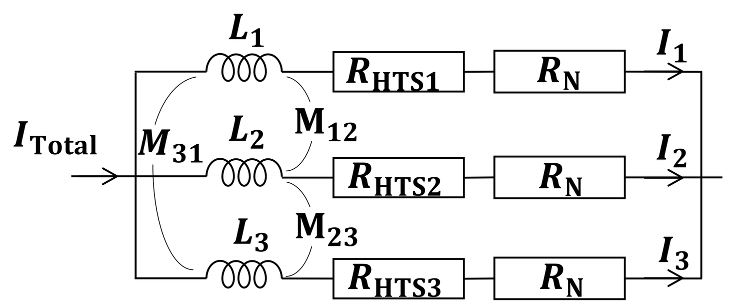
A Double pancake coil with a three-strand parallel conductor

- A three-strand parallel conductor composed of REBCO superconducting tapes was wound into a double pancake coil.
- Each tape of the double pancake coil is transposed and wound so that the inductance becomes equivalent. ($L_1 \approx L_2 \approx L_3$)

Unit of the optimum transposition pattern of the double pancake coil to realize uniform current sharing.

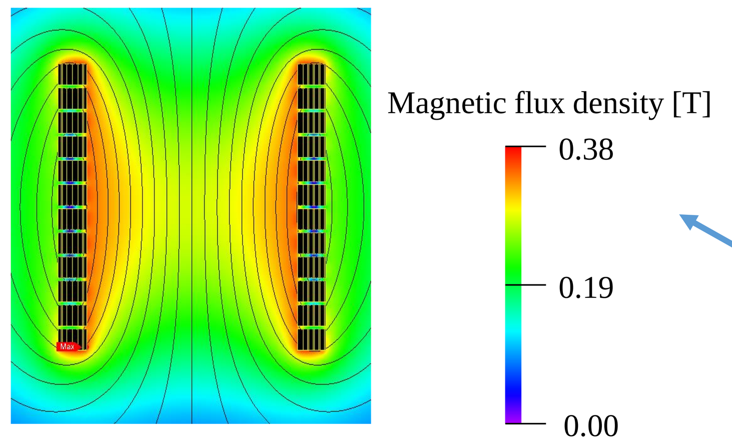


Circuit equation



$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} j\omega L_1 + R_N + R_{HTS1} & j\omega M_{12} & j\omega M_{13} \\ j\omega M_{21} & j\omega L_2 + R_N + R_{HTS2} & j\omega M_{23} \\ j\omega M_{31} & j\omega M_{32} & j\omega L_3 + R_N + R_{HTS3} \end{bmatrix}^{-1} \begin{bmatrix} V \\ V \\ V \end{bmatrix}$$

R_N : Contact resistance
R_{HTS} : Flux flow resistance



- In the magnetic field, the I_c of the REBCO tapes change at each turn of the coil.
- I_c depend on the converted perpendicular magnetic field $B_\perp(\theta)$.
- We conducted the numerical simulation considering magnetic field dependence of I_c.
- Variations of critical current under zero magnetic field I_{c0} and n-value to the parallel conductor also considered.

Self-magnetic field distribution in a pancake coil wound with a three-strand parallel conductor.

Parameters of the REBCO tapes and the double pancake coil

REBCO tape Substrate Buffer layer Superconducting layer Critical current under zero magnetic field, I_{c0}	10 mm wide, 0.1 mm thick Hastelloy (90μm) CeO_2, $LaMnO_3$, MgO, Y_2O_3, $Gd_2Zr_2O_7$(1μm) REBCO(1μm) approximately 300 A
Coil Inner diameter Outer diameter Height Number of turns Number of pancakes	Double pancake coil 120 mm 184 mm 240 mm 40 turns / single-pancake 12 double-pancake

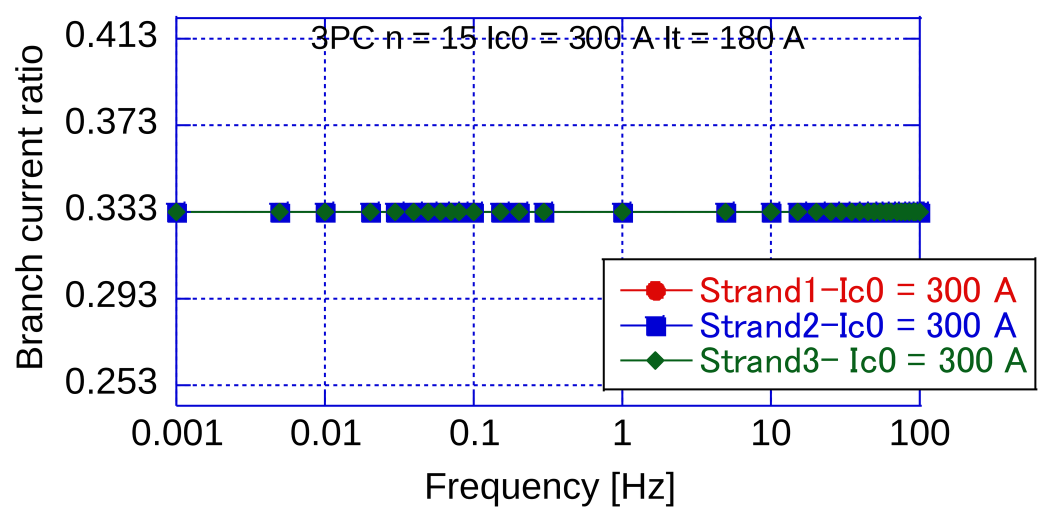
The center magnetic field of the coil is 0.5T
Total transport current I_t =180 A

Conclusion

- If transposition is correctly performed, and I_{c0} and n-value of each tape are equal, the current-sharing properties become substantially uniform.
- At the low frequency regions below 1 Hz, Non-uniform current occurs due to the variation of the I_{c0} and n-value.
- At the high frequency regions over 1 Hz, current-sharing properties converged even if there are variations in I_{c0} and n-value.
- In AC applications such as motors and transformers, uniform current-sharing properties can achieve with transposing tapes and composing parallel conductors.

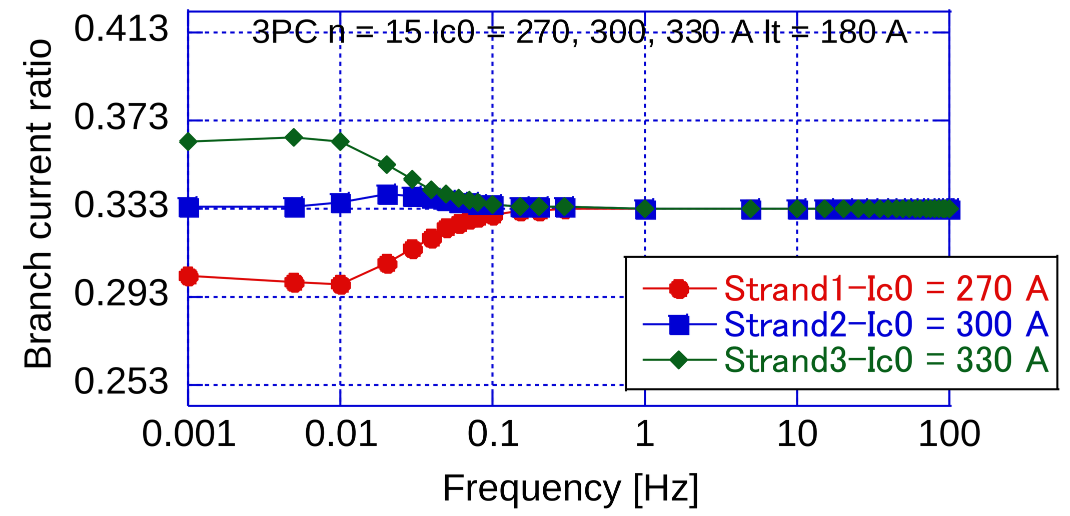
Simulation result

No dispersion
I_{c0} = 300 A, n = 15



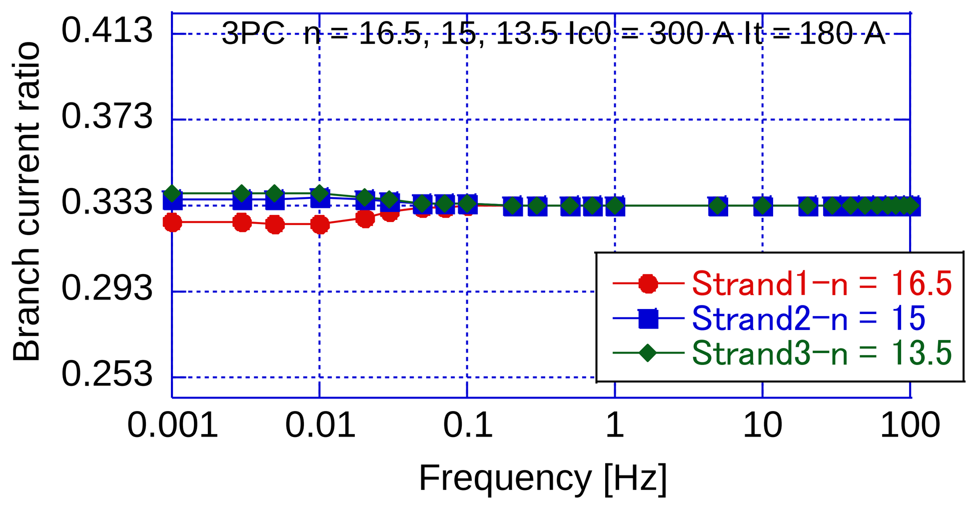
This graph indicates the optimum transposition is performed.

Dispersion in I_{c0}
I_{c0} = 270, 300, 330 A (±10%), n = 15



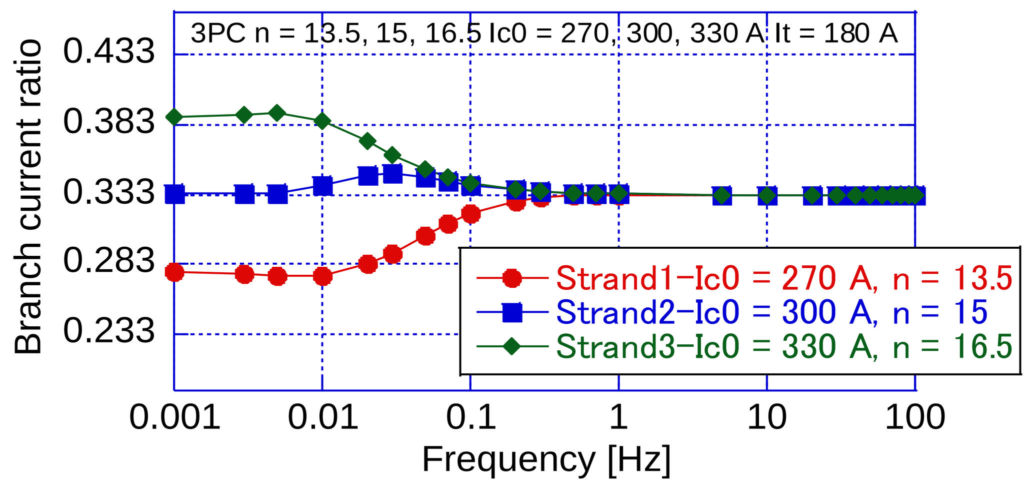
I_{c0} variations cause the non-uniform current.

Dispersion in n-value
I_{c0} = 300 A, n = 16.5, 15, 13.5 (±10%)



n-value variations also cause the non-uniform current.

Dispersion in both of I_{c0} and n-value
I_{c0} = 270, 300, 330 A (±10%) ,
n = 13.5, 15, 16.5 (±10%)



With I_{c0} and n-value variations, the non-uniform current became more serious.