MT25

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Methods to Increase the Pumping Rate of Rotary HTS Flux-pump with Rotating HTS Tape to Charge the Field Coil of the Synchronous Motor.

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1. Introduction

- **This paper contains contents related to rotary HTS flux-pump to charge HTS field coil of synchronous motor operating in Pesistance Current Mode (PCM).**
- **The superconducting Synchronous motor that is operated as (PCM) can remove the direct connections by using flux-pump.**
- **The problem in charging is a slow charging speed, it causes the problem that the initial driving time of the superconducting rotating machine is very long.**
- **In order to test the charging characteristics under various conditions, prototype of rotary HTS flux-pump is fabricated.**
- **Various investigations were conducted to supplement the slow charging speed.**

2. Concept of Rotary HTS Flux-pump

1) Prototype of rotary HTS flux-pump

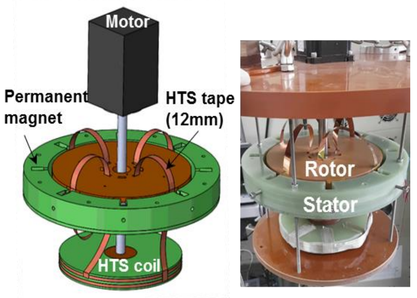


Fig. 1 Prototype of rotary HTS flux-pump

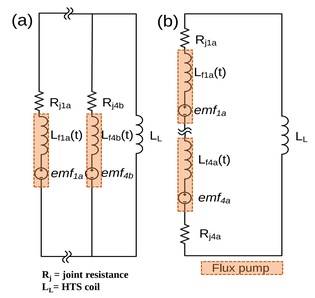


Fig. 2 Equivalent circuit diagram of parallel (a) and series (b) type flux-pumps

TABLE I
SPECIFICATIONS OF FABRICATED HTS FLUX-PUMP

PARAMETERS	HTS flux-pump
Flux-pump type	Rotating HTS tape type
HTS tape	SuNAM's copper stabilizer GdBCO wire Width: 12mm, Thickness: 0.22mm
HTS tape I_c	600A
Connection type	Series
Pumping points	4
Poles	4
HTS coil spec	Tape width : 4mm I_c : 116A Inductance : 1.1mH

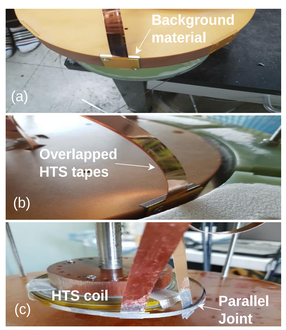
- ✓ HTS tape is wound toroidal shape. This is a devised method to increase the charging speed and saturation current by increasing the interlinkage magnetic flux to HTS tape in limited space.
- ✓ The permanent magnet used in the experiment was fabricated in a T-shape to focus magnetic field to HTS tape.

2) Concept of Experiments

Magnetic flux conservation law

$$LI + AB = constant$$

A : closed loop
B : magnetic flux density
L : self-inductance of the closed loop
I : current flowing in the closed loop



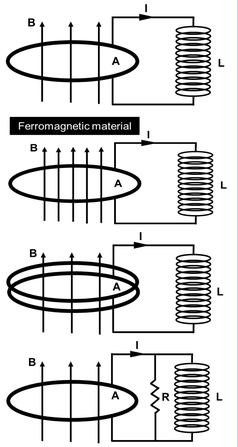


Fig. 3 The test setting of background material (a), overlapped HTS tapes (b) and parallel joint (c)

3) Equivalent Circuit

- **The first method, as shown in Fig. 3 (a), is to use an iron piece as the background material of the HTS tape to increase the amount of interlinkage magnetic flux to the HTS tape.**
- **Secondly, as shown in Fig. 3 (b), charging experiment was conducted by overlapping two HTS tapes. The magnetic flux is exerted on the overlapped HTS tape to interlinkage the two HTS tapes.**
- **Third, a parallel joint was constructed between the HTS tapes and the coil as shown in Fig. 3 (c).**

- ✓ Air gap between the permanent magnet and the HTS tape is fixed at 6 mm.
- ✓ The experiments were performed in a bath of liquid nitrogen at 77 K.

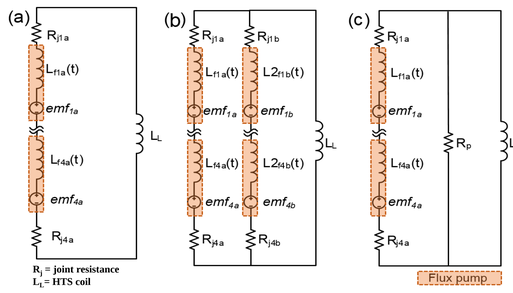


Fig. 4 Equivalent circuit diagram of different background materials (a), overlapped HTS tape (b) and parallel joint (c)

3. Experimental Results

1) Different background materials

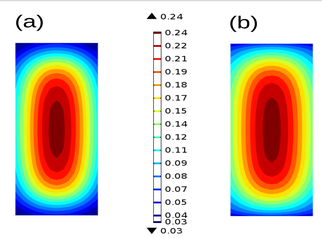


Fig. 5 Magnetic flux density on the HTS tape. (a) and (b) are bakelite and iron background, respectively. (6mm airgap)

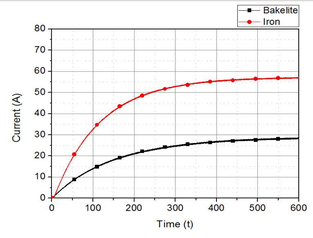


Fig. 6 Charging current of rotary HTS flux-pump with respect to different background materials.

- **Fig. 5 shows the FEM simulation results of magnetic flux density on the 12mm HTS tape when T-shape permanent is located on the center of the HTS tape.**
- **The saturation current is increased 200% from 29 A to 58 A.**
- **Bakelite and Iron background cases reached to charging time at 154 and 120 sec, respectively.**
- ✓ Relative permeability of bakelite is almost same with air, it can be seen as u_r=1
- ✓ Magnetic flux density is solved by the finite element software COMSOL.

2) Overlapped HTS tape

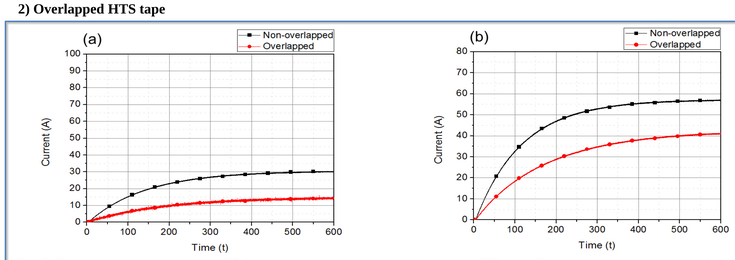


Fig. 7 Charging current of rotary HTS flux-pump with respect to overlapped HTS tape. The (a) and (b) are results of bakelite and iron background, respectively.

- **The saturation current is decreased from 30A to 14A, and charging time is increased from 140 sec to 169 sec.**
- **Unlike initial expectation, the results show that the saturation current and charging speed is rather decreased.**
- **It means that when the two HTS tapes is overlapped, the interlinkage magnetic flux is decreased, and screening current and travelling field affects to charging rate.**
- **Further research is needed to explain the affect by dynamics of travelling field on superconductors**
- ✓ Interlinkage magnetic flux density behind of the HTS tapes are 1867 G in single HTS tape, 1916 G in overlapped HTS tape.

3) Parallel joint

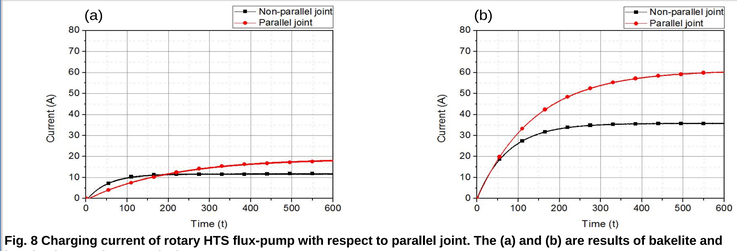


Fig. 8 Charging current of rotary HTS flux-pump with respect to parallel joint. The (a) and (b) are results of bakelite and iron background, respectively.

- **The saturation current is increased from 11 A to 19 A, and the charging time is increased from 52 sec to 208 sec.**
- **During the charging time, the current flows to parallel joint and HTS coil, and on the discharge time, the current flows to parallel joint.**
- **The charging speed is almost same, but saturation current is increased from 36 A to 61 A when the iron pieces are inserted as background materials.**
- **It means the enough magnetic flux and resistance of parallel joint can make the optimized charging condition.**
- ✓ Parallel joint can prevents that current of the HTS coil is consumed in flux-pump line when the quench is occurred on the flux pump line.

4. Conclusion

- **Background material that have high relative permeability for enhancing the interlinkage magnetic flux is an appropriate method to increase the amount of pumping rate.**
- **In the case of the method of overlapped HTS tape, saturation current and charging speed at HTS coil was rather reduced.**
- **We confirmed that the flux-pump was stably charged when configuring parallel joint. In discharging mode, the current is flows to parallel joint and flux-pump line not only flux-pump line, so the saturation current is increased and charging speed is decreased.**
- **The field coil of synchronous motor which we are studied will apply the above method based on results obtained from this experiment.**

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