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Effect of various pulse wave forms for pulse-type magnetic flux pump

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ABSTRACT

The excitation current of magnetic pole windings in magnetic flux pump needs to be generated by a control system. In this paper, the control system of pulse-type high temperature superconducting magnetic flux pump is discussed in detail. The control system consists of a control circuit and a drive circuit. A direct current power supply is the unique power supply of the drive circuit. The control circuit is powered by a computer through a USB interface of the computer. The control circuit receives commands from the computer and controls the drive circuit to generate different pulse waves. Each pulse wave generates a unique pulse-type traveling magnetic field and will pump magnetic flux into the superconducting loop. Experiments have been performed to examine the pumping effect of different pulse waves on both MgB_2 and Bi-2223 superconducting loops using the proposed control system, and the best pulse wave has been found. The experimental results show that the magnetic flux pump can compensate current decay up to 32.5 A for MgB_2 loop and 129 A for Bi-2223 loop. It indicates that the control system of the pulse-type magnetic flux pump is effective and feasible.

1. Introduction

High temperature superconductors (HTS) have low *n*-index that ranges from 10 to 14 [1]. The low *n*-index causes large index dissipation, which determines that HTS cannot work in persistent current mode [2]. This large problem obstructs the commercial application of HTS [3]. Two methods are proposed in order to solve this problem. One is to find high temperature superconducting materials with a high *n*-index. The other is to use magnetic flux pump (MFP) [4,5]. Many MFPs have already been proposed for superconducting magnets [6–10]. Recently a linear type magnetic flux pump (LMFP) has been presented as a current compensator for HTS magnet systems [4,11]. Though it can compensate current decay of a certain superconducting load, the current ripple is large and the power system is complex. We have presented a novel MFP with a higher compensating current level in Ref. [12]. The structure is also simpler, and only a DC power is needed for the excitation current supply of the novel MFP. This paper focuses on the design and implementation of the control system for the pulse-type magnetic flux pump.

2. System design

The structure of the MFP is shown in Fig. 1. A superconducting slice is inserted in the air gap between the upper and lower magnetic poles. The slice and superconducting load are connected by HTS tape to form a superconducting loop. A magnetic flux Φ_P is pumped into the loop after each pumping cycle. Seven magnetic poles are wrapped by eight copper coils interlacing with one another. The copper coils are numbered by 1–8 as shown in Fig. 1. A traveling magnetic field is generated by exciting the coils one by one. The excitation current of each coil is 1A. The exciting details will be discussed in the following Section 2.2.

The control system of the MFP consists of two parts: a control circuit and a drive circuit. They will be mentioned respectively as follows.

2.1. Control circuit

Fig. 2 shows the photograph of the control circuit. The core of the control circuit is a computer and a single-chip. The single-chip is programmed to monitor the temperature of the MFP and the superconducting slice, receive control commands from the computer, control the drive current of the MFP, and measure the current pumped into the superconducting loop. The single-chip communicates with the computer through a RS-232 interface. It transfers temperature data and Hall sensor value to the computer. The computer runs a Visual Basic (VB) program to save the data received from the single-chip and draws the temperature curves and the pumping current curves according to the data. Through the computer, the VB program also gives control commands to the single-chip through the RS-232 interface. The control commands include information about which pulse wave is used, what the pumping frequency is and how long the MFP works. Then the single-chip gives different control signals through the control cable to

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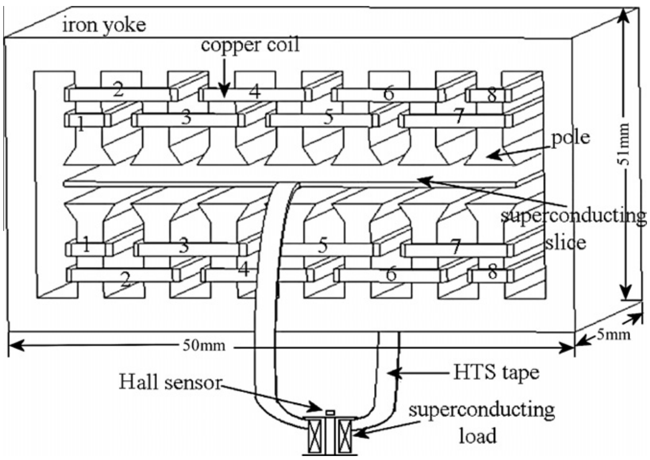

Fig. 1. Structure sketch of the MFP.

the drive circuit according to the command. The drive circuit controls the drive current flowing through the copper coils of the MFP. Finally a pulse wave is formed corresponding to the command.

A Hall sensor is used to measure the magnetic field B generated by the current I flowing through the load superconducting coil (Fig. 1). Thus

$$B = \beta I \tag{1}$$

where β is the coefficient between B and I. The coefficient can be considered as a constant for a certain load. The Hall sensor value V_{Hall} is

$$V_{Hall} = \alpha B \tag{2}$$

where α is Hall coefficient. So

$$I = \frac{V_{Hall}}{\alpha\beta} = aV_{Hall} \tag{3}$$

where a is a coefficient calibrated by a measurement. Three copper-constantan thermocouples are used to measure the temperature of the MFP and the superconducting slice relative to the second stage of the GM cryocooler, respectively.

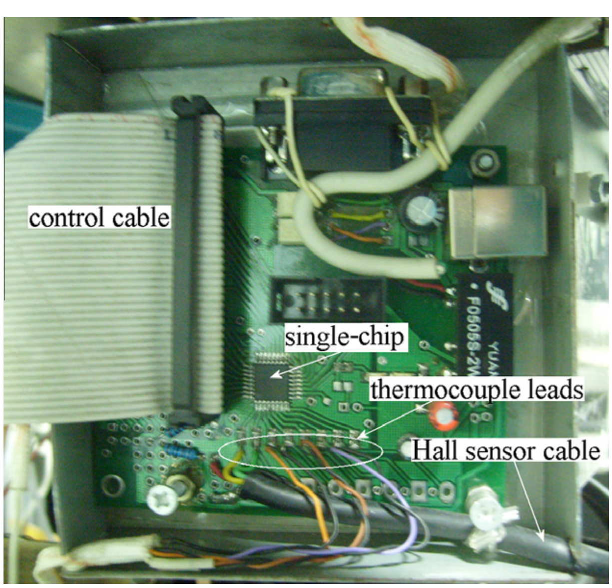

Fig. 2. Photograph of the control circuit.

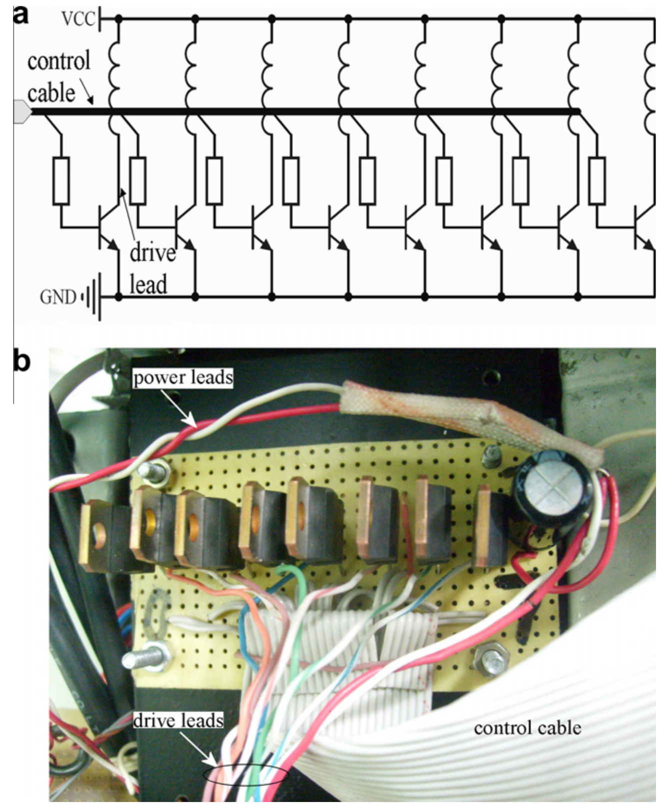

Fig. 3. Drive circuit. (a) Circuit schematic diagram. (b) Photograph of the drive circuit.

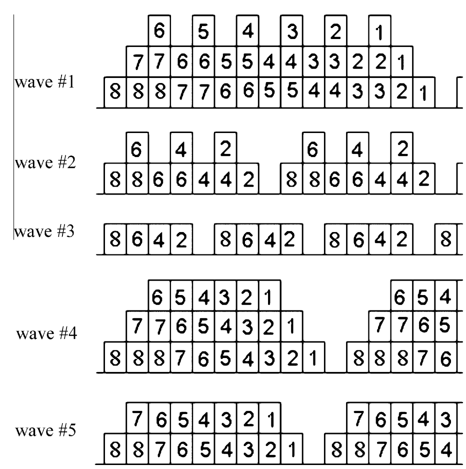

Fig. 4. Sketch of different pulse waves.

2.2. Drive circuit

The drive circuit excites the copper coils of the MFP to generate moving magnetic fields. Fig. 3 shows the circuit schematic diagram and photograph of the drive circuit.

Inductors in Fig. 3a represent the copper coils of the MFP. One lead of the copper coils is connected to the positive power line (i.e. VCC in Fig. 3a). The drive leads join the collector terminals of the transistors and the other lead of the copper coils respectively. The base terminals are joined with the single-chip by the control cable and resistors. The emitter terminals are connected directly to the cathode (i.e. GND in Fig. 3b) of the power leads. The power supply is a DC regulated power supply.