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# Fabrication of NbTi Superconducting Joint by Electromagnetic Forming Method

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*Abstract*—**The electrical jointing of superconducting wires / tapes is a key issue for the construction of the scientific superconducting magnet that required high field stability, such as NMR, FTICR-MS and some inertial navigators. In this paper, the preliminary experiment of electromagnetic formed NbTi superconducting joint was done. The fabrication technique was researched by changing the parameters. The joint resistances were tested in liquid helium using coil current decay method. The contact resistance properties of the superconducting joint were investigated. The plastic deformation and the electrical contact characteristics of the NbTi superconducting joint were discussed. The results show that the electromagnetic formed NbTi superconducting joint has the excellent low-resistance property and good repeatability.**

***Keywords-electromagnetic forming; superconducting joint; NbTi; resistance***

## I. INTRODUCTION

The superconducting magnets for the scientific instruments, such as NMR, MRI, FTICR - MS and some inertial navigator scientific instrument have an extremely high requirement to the magnetic field stability [1,2]. Field stability of a magnet depends on the resistance in the coil circuit and inductance. To achieve satisfactory magnetic field stability in the system, the joints between magnet and its switch, and those between different sections of the magnet must be made with great care. The NbTi superconducting alloy multi-filament wire is the most widely used commercial superconductor. There are many exiting methods of fabricating NbTi superconducting joint, such as soldering [3], cold-pressing [4,5], diffusion welding [6], spot welding [7], ultrasonic welding [8], diffusion bonding and solder matrix replacement [9]. Among them, cold-pressing is comparatively convenience. However, the evidence of an oxide layer and residual Cu-rich particles at poorly bonded interfaces in the cold-pressing joint had been confirmed [10,11]. In order to enhance the electrical performance of cold-pressing joint, a new jointing method should be found to prevent the negative influence of the oxide film during jointing process.

The electromagnetic forming (EMF) technology is based on the Faraday's law of electromagnetic induction resulting in repulsive Lorentz body forces between two conductive bodies carrying opposed currents [12]. It has the advantages of high strain rates plastic deformation, self-cleaning surface, high bonding force, no-lubricant, contact-free, good repeatability and high production rate. The EMF technology is new for the superconducting jointing application. D. Schoerling manufactured $Nb_3Sn/Cu$ splices using EMF method for horizontal racetrack damping wiggler magnet [12]. But the superconductors in the joint haven't realized metallurgical bonding. Then it is very limited to promote of electrical interconnection property of the $Nb_3n$ joint in that work.

In this study, a superconducting joint fabrication technology for NbTi superconducting wire using EMF method is presented. The purpose of this research is to develop a novel efficient and repeatable fabrication technology.

## II. EXPERIMENTAL

### A. Electromagnetic Forming System

An EMF system mainly consists of a pulse power generator, an exchangeable tool coil, and the workpiece (joint) to be deformed [13]. The EMF equivalent discharge circuit is shown in Fig. 1. In this experiment, the EMF system has the ability of maximum accumulation energy of 20 kJ, initial operation voltage of 7.5 kV and discharge frequency of 40 kHz.

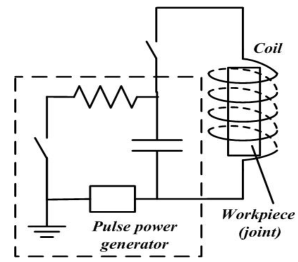


Figure 1. Equivalent discharge circuit.

### B. Joint Fabrication

All joints were prepared using the NbTi superconducting alloy round wire of 0.60 mm from Oxford Superconducting Technology. The joint assembly consists of the copper outer tube and the NbTi alloy inner column.

During jointing process, the filaments of the wires were put into the gap between the NbTi alloy inner column and the copper tube. Subsequently, the whole was placed into the hole of the exchangeable tool coil of EMF system. The pulse power

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generator of EMF system was charged, and then the energy was discharged quickly from the pulse power generator to the exchangeable tool coil. So, a temporarily varying magnetic field induced electrical currents in the copper tube and additionally exerted force (Lorentz force) to it. An induced Lorentz force caused the copper tube deforming and the NbTi filaments were embedded tightly in the composite tube to form a joint. Configuration of joint made by EMF method is shown in Fig. 2.

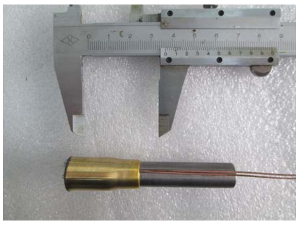

Figure 2. Configuration of joint made by EMF method.

### C. Testing Apparatus

The resistance of joint sample was measured by coil current decay method. The cryogenic Hall probe is from Lakeshore. The power supply of the magnet and transformer is a 200 Amp AMI Digital PS System. During testing, all of the parts are mounted on a stainless steel holder and then immersed in liquid helium at 4.2 K. The circuit is charged by transformer and operated in the persistent current mode. Then, the field decay rate is observed by the Hall sensor, located at the center of the NbTi wire ring, for several hours. The experimental data are collected and processed by LabVIEW software through a GPIB interface.

## III. Results and Disccussion

The joint resistance and critical induced current were tested using the coil current decay method under the 4.2 K temperature condition. The results are shown in Table 1. The stability of the critical current at 130 Amp indicates that the superconducting filaments were not harmed with the increasing of the electromagnetic force during EMF jointing procedure. The minimum joint resistance is $1.8\times10^{-13}$ Ω when the voltage is 7.0 kV. Too low or high voltage would both harm to the joint quality.

TABLE I. Testing Results of the Samples

| Sample | Initial Voltage | Critical Current | Resistance |
|---|---|---|---|
| 1 | 6.5 kV | 129.0 A | $6.4\times10^{-13}$ Ω |
| 2 | 6.8 kV | 127.5 A | $3.4\times10^{-13}$ Ω |
| 3 | 7.0 kV | 129.2 A | $1.8\times10^{-13}$ Ω |
| 4 | 7.2 kV | 128.1 A | $9.2\times10^{-13}$ Ω |

The solid welding process induced from electromagnetic pulse accelerating may be described in the plastic deformation dynamics. It could be seen that collision direction of the workpiece couple is not vertical but as an oblique impact with a slip angle, α, as shown in the Fig. 3. The collision impact is helpful to the jet being liked fluent. During the jointing, the jetting effect, a self-cleaning of the surfaces by ejecting a small surface layer, occurs. As a result, the EMF joint has the resistance value as low as the about 20% of the cold-pressing joint.

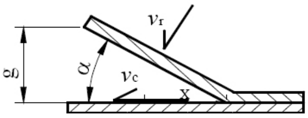


Figure 3. Schematic diagram of collision deformation.

## IV. Conclusions

The NbTi superconducting joint with electromagnetic formed method was manufactured successfully. The stability of the critical current indicates that the superconducting filaments were not harmed with the increasing of the electromagnetic force during EMF jointing procedure. However, too low or high voltage would both harm to the joint resistance performance. The collision impact of the EMF jointing process is helpful to the jet being liked fluent. Then the EMF surface has a better electrical jointing quality.

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