

High Quality Splices of Superconductors

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Important developments have been made in the technology over the last 50 years for the large-scale applications of superconductivity in terms of field strength, scale, field volume, and stored energy. The use of superconductors allows production of high field magnets. The magnets for NMR and MRI generally require superconducting splices. (Splice: a join consisting of two ropes, cables, etc).

Reasons to prepare splices in NMR and MRI magnets:

- connection to power supply
- joining the preprepared superconducting units

Thus, the splicing technology is very important in developing applied products and expanding the practical applications. To prepare splices is crucial from point of quality of the superconducting circuits: to ascertain superconducting quality of the splices is not an easy task.

By applying the explosive welding technique high quality superconducting splices with sub $n\Omega$ electrical resistance can be prepared. The limit of practical application of this technique is the quantity of the high explosive. As the quantity is defined by the critical thickness of the high explosives, crucial point of the technology is the reduction of the applicable commercial high explosives.

Keywords: superconductivity, explosive welding, splices.

1. Introduction

Important developments have been made in the technology over the last 50 years for the large-scale applications of superconductivity in terms of field strength, scale, field volume, and stored energy. The development of new conductors has increased their capabilities to withstand high current densities and large mechanical forces and stresses. The use of superconductors allows production of high field magnets. The magnets for NMR and MRI generally require superconducting splices.

Reasons to prepare splices in NMR and MRI magnets:

- connection to power supply
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Thus, the splicing technology is very important in developing applied products and expanding the practical applications.

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Main requirements regarding the superconducting splices:

- 1) Mechanically and electrically sound (low sub $\text{n}\Omega$ electrical resistance)
- 2) Compact – space many times is an issue
- 3) Use of tooling easy to multiply

Based on our preliminary experiments [1], the explosive welding technique could satisfy all the criteria above for making high quality splice joints.

Generally the explosive welding technologies represent a new paradigm in the field of production of knowledge-based more components materials: high quality joining of the materials can be carried out directly, by high speed, high energy shock waves. These shock waves can be created by high explosives. The high explosives are chemical systems, produced in different forms as powder, plastic or detonating cords. During the chemical reactions of these systems high pressure gases are created resulting high energy shock waves.

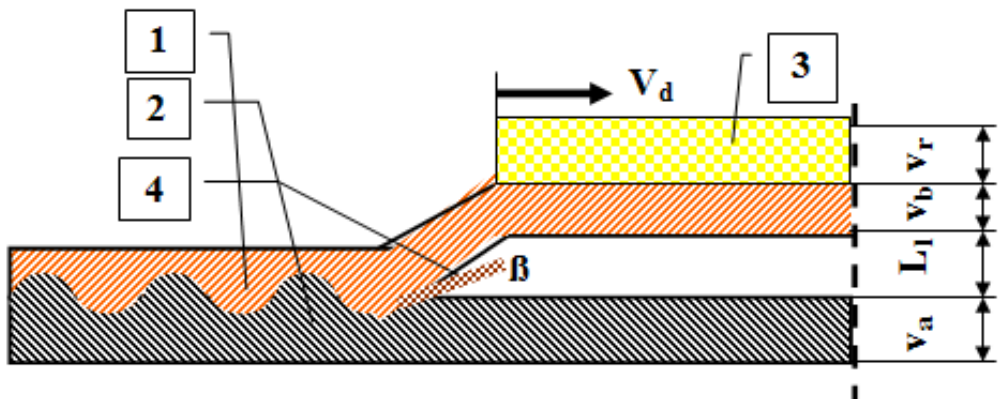


Fig. 1. More components materials prepared by explosive welding

2. Experimental

2.1. Principle of the explosive welding

Explosive welding is a solid state process in which controlled explosive detonations force two or more metals together at high pressures, resulting a high quality metallurgical bond between the colliding surfaces (Fig.2. and Fig.3.).



1 – Metal1 to be welded, 2 – Metal2 to be welded, 3 – high explosive, 4 – jet: melted metal at the collision point containing the materials of Metal1 and Metal2

Fig. 2. The principle of the explosive welding



Fig.3. Bonding zone of the explosively welded NbTi (superconductor) sheet and copper sheet

2.2. Concept of preparation of superconducting splices

- Two copper stabilized NbTi superconducting cable pieces will be cold welded together using the explosive welding technique.
- Angle cuts are prepared at the ends of the cables to be bonded
- NbTi superconducting foil is placed in between the two cable pieces at the location where the cut has been made (Fig.4).

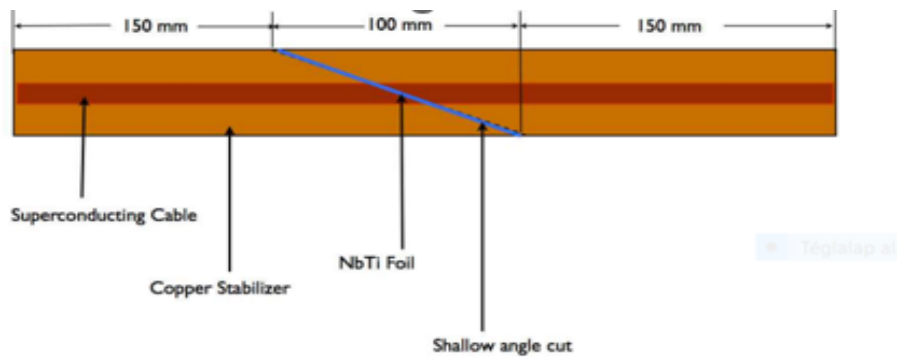


Fig.4. Concept of preparation of superconducting splices

2.3. Realization of the concept

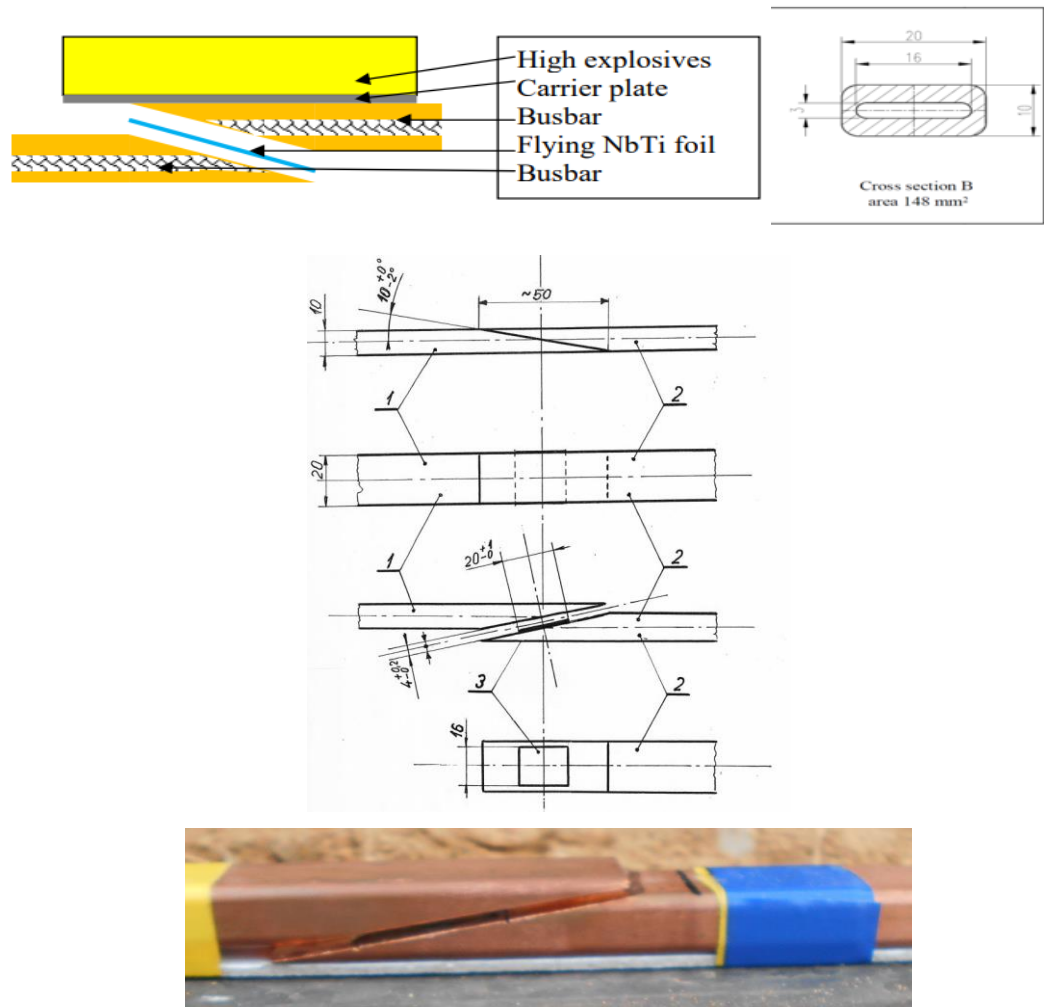


Fig. 5. Arrangement of the superconductors to be spliced (bonded)

The container of the high explosive (cartoon box) was positioned above the overlapped end sections. The explosive welding was carried out in the explosive chamber (Fig.6.).



Fig. 6. Welding in the explosive chamber

2.4. Morphological analyse of the splice sample

The explosive welding experiments with copper stabilized busbars were controlled by morphologically.

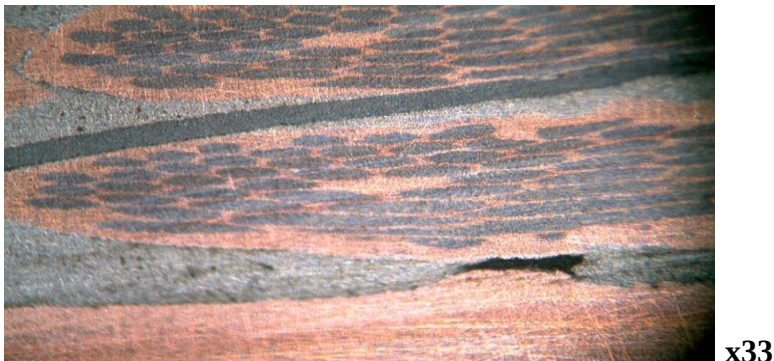


Fig.7. Microscopy of the bonded section

According to the morphological analyse metallic bond was created between the Rutherford cables in the two busbars and the superconducting foil. These samples were not suitable for cold tests—to control the resistance of the bond of the two superconductor section at low temperature.

2.5. Preparation samples for cold test measurements.

Possible way to test the bond between the Rutherford cables and superconducting foils the measurement of the current decay constant in test loops with known inductance.

Principle of the measurement is described in details in the literature [2-5].

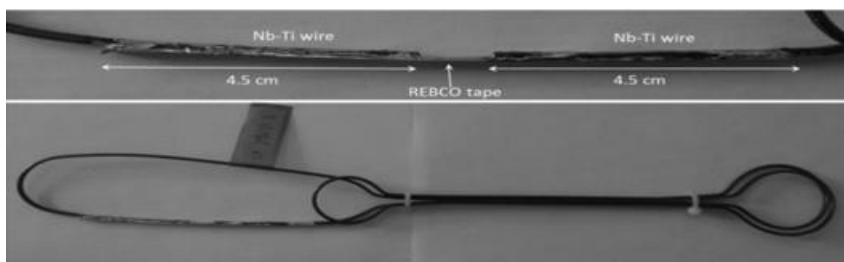


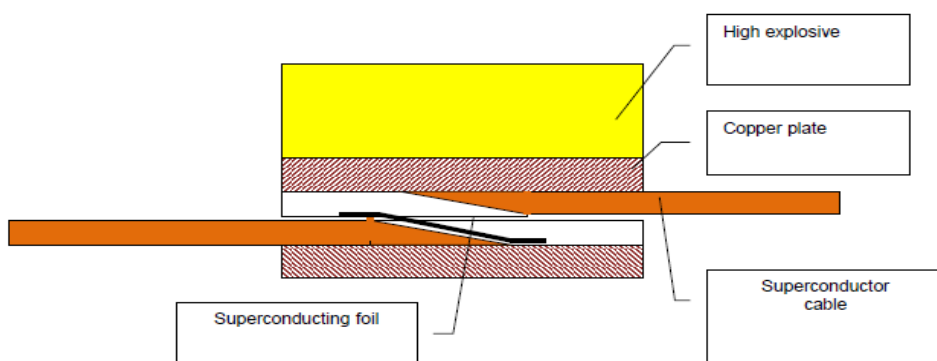
Fig.8. Principle of the measurement of the current decay constant in test loops

Test loops can be easily produced out of ductile Nb-Ti superconducting wires and cables. Our partner (TE-MS/CERN) prepared test samples for splicing (Fig.9.).



Fig.9. 1,39 m long cable samples for preparation of splice joint with copper sleeves

Splicing array for preparing test loops is shown in Fig.10., the explosive welding experiments were carried out in the explosive chamber (Fig.6.)



Superconducting cable: NbTi 2,17mm*1,45mm

Copper plate(sleeve): CuE 50mm*35mm*4mm

Superconducting foil NbTi 20mm*1,45mm*0,15mm

High explosive: Permon 55 g

Fig.10. Splicing array for preparing test loops



Fig.11. Explosively spliced superconductor test loops

3. Cold test of the superconductor test loops

The principle of the cold tests is illustrated in Fig.12. (according to Point 2.5.) and the test results are shown in Fig.13. The method applied for qualify the quality of the splices is based in making the splice in a loop of cable, inducing a current in it and measuring its decay time constant.

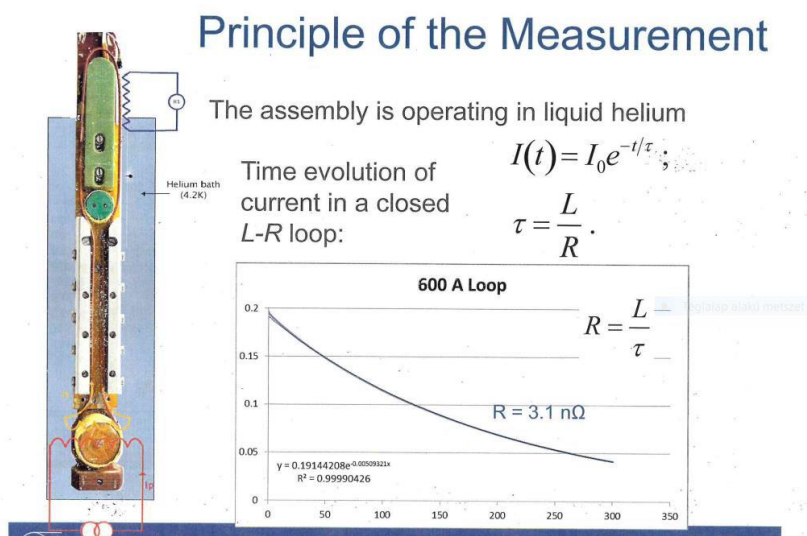


Fig.12. Principle of the cold tests

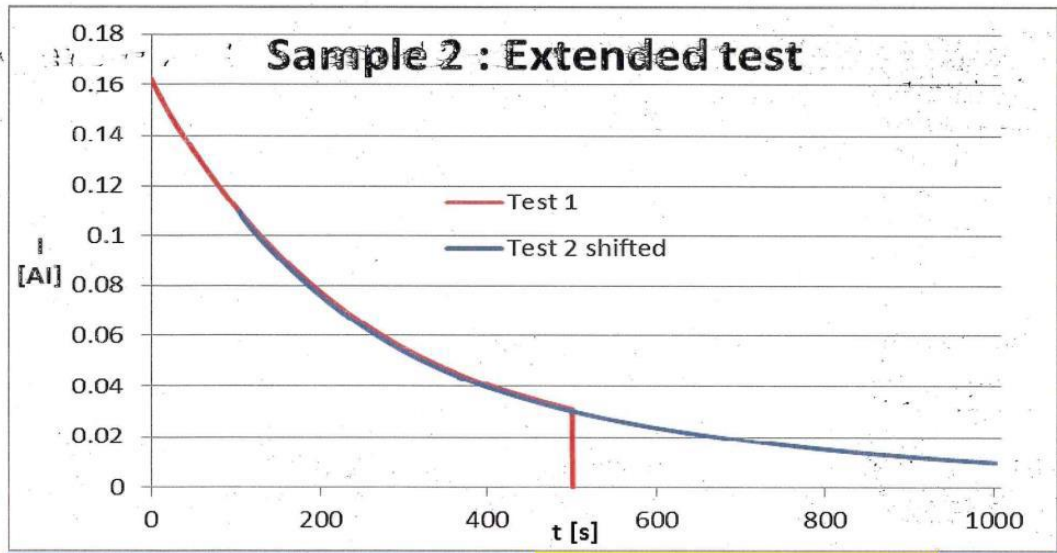


Fig.13.: Result of the cold test of the explosively welded superconducting splices
The electrical resistance of superconducting cable splices is in the $10^{-9} \Omega$ range.

4. Conclusions

- By applying the properly calculated and directed shock waves on a carefully designed experimental arrangement it is possible to weld superconducting wire ends creating high quality (subnanohm) splices in laboratory conditions
- For practical application of the technology in real conditions and circumstances the energy source – the high explosive – should be analysed. The high explosives are chemical systems. The chemical reactions of these systems can be initiated by electrical pulses. Each high explosive composition has its own characteristic „critical diameter or thickness” what is needed to create the perfect chemical reaction resulting a great quantity of gases producing the shock waves.
- Explosive material selection is of outmost importance, as critical diameter of the explosive will impose a minimal size constraint. By decreasing the critical diameter the splice size can be decreased. Performing of further systematic R&D work is needed to achieve practical application of this technique.

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