CURRENT LEADS

Application

The main purpose of a current lead is to act as feedthroughs between the power supply, working at room-temperature, and the superconducting coils of the magnets, which are placed inside the cryostat and operate at the temperature of the liquid helium (4.2 K or 1.9 K).

CECOM produced two kinds of current leads: the "conduction cooled" type, and the "HTS" type. Both type of leads were developed and designed at CERN for the LHC project. Further the development made at CERN, also DESY adopted the LHC conduction cooled design, adapting the interfaces to the specific requirements.

Conduction cooled current leads are installed into the main vacuum insulation of the cryostat. They can be divided mainly in the following sections:

- Warm edge
  - In-air side of the conductor
  - Insulating flange with electrical feedthroughs
- Conductor
  - Conductor rod with stainless steel envelope
  - Heat-sinks (conduction cooling)
- Cold edge
  - Edge of the conductor connected to the superconducting wires of the magnet

Another particular feature of the LHC conduction cooled current leads is the shape, since the bended shape of conductors must be adapted to the geometry of the cryostat and must fit into the available space.

HTS current leads can be divided mainly in the following sections:

- Normal conducting stage:
  - Top copper block
  - Insulation flange
  - Heat exchanger
- Intermediate copper block
- HTS stage
- LTS wires (Edge of the conductor connected to the superconducting wires of the magnet)

The device is insulated by a fiber-glass insulating envelop and the LTS stage is "Parylene® C" coated.

The helium tightness and the maintaining of mechanical and physical properties of all components after high thermal excursions are very important characteristics for all these devices.

Summary

1 References

These products were produced, tested and delivered by CECOM for CERN and for DESY.

2 CECOM activities

CECOM produced the following current leads:

- N. 100 conduction-cooled current leads (120A) for the dipole corrector magnets of LHC[1]
- N. 68 HTS current lead assemblies (13000A)[1]
- N. 10 HTS current lead assemblies (6000A)[1]
- N. 6 prototypes of conduction-cooled current leads (50A) for XFEL[2]

In all the above mentioned cases, CECOM carried out the following activities:

- Optimization of working cycles
- Manufacturing and shaping of components
- Application and management of all involved special technologies
- Final assembling, cleaning and testing

3 Materials and special treatments

Special materials have been used for the production of currents leads:

- Brass (Cu85-Zn15): conductor inner rod
- Copper plating (roughness R_a<3.6) : conductor external layer
- Polyimide Kapton®: electrical insulation for the connector
- Stainless steel (AISI 316L) pipes: tubular envelop of the connector
- PEEK™ (PolyEtherEtherKetone): insulation for flanges
- "Parylene® C" coating: improvement of electrical performances in humid/wet environment
- Nickel coating: used at the top of the conductor in order to prevent oxidations
- Vacuum soldering: applied for the soldering of superconducting material
- Vacuum brazing: applied for the assembling of 13000A current leads
- Electron-Beam-Welding: copper parts of the 13000A current leads
- Diffusion brazing: sub-assemblies for the 13000A current leads

[1] Large Hadron Collider: installed at CERN (European Organization for Nuclear Research)
[2] X-Ray Free-Electron Laser: installed at DESY (Deutsches Elektronen-Synchrotron)

4 Operation of the devices

The operating mode is different in the case of conduction-cooled leads and HTS leads
In the conduction-cooled leads the current flows through low resistance bars, which are maintained at the desired temperature by means of dedicated heat sink. In the HTS current lead assemblies, the conducting element is more complex, since it includes a warm part and an HTS part . Both parts are cooled by helium gas.

4.1 Overview of the "conduction-cooled" current leads

Each conductor element is a brass bar, copper plated and insulated from the outer stainless steel pipe by means of kapton® (Fig. 1).
The main phases of the manufacturing process of every conductor bar are:

- Galvanic treatment of the brass rod: copper plating
- Machining of the copper plated surface, in order to achieve the required shape.
- Insertion of the copper plated rod into the Kapton® insulator
- Insertion of the insulated conductor into the stainless steel envelop

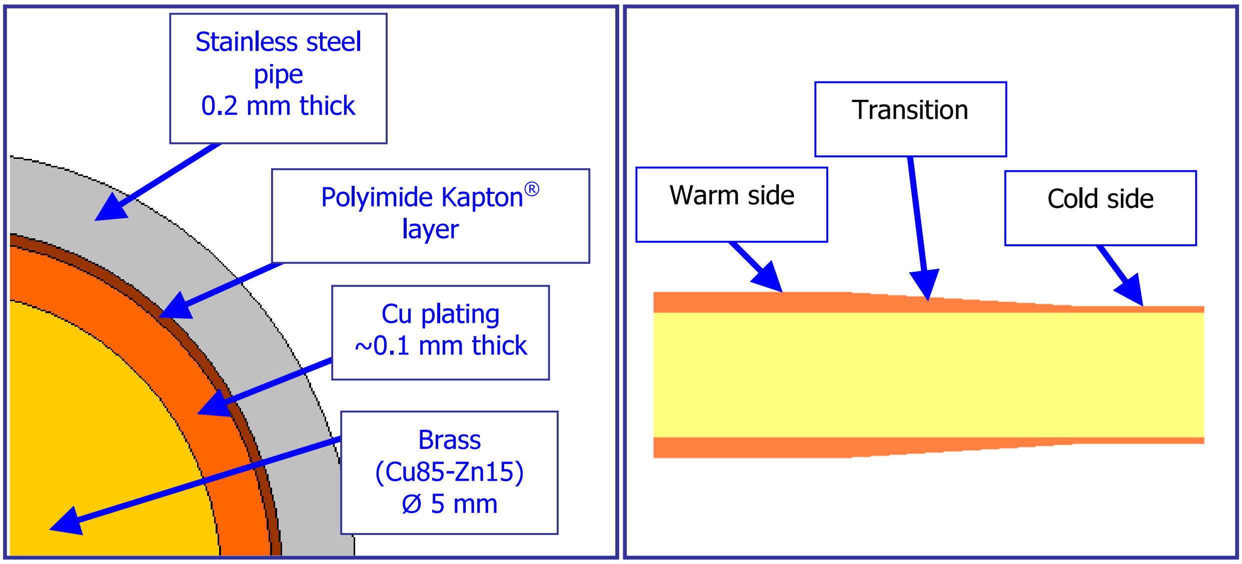


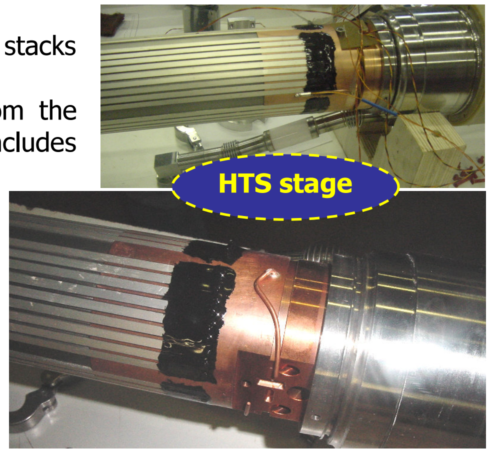
Fig. 1: Scheme of the conduction bar (conduction-cooled current leads)

The copper plating is performed along the whole length of the conductor brass rod. The thickness and the roughness of the copper plated layer are than adjusted by machining the conductor rod (lathe machine with suitable machining tools are used). Depending on the application, the final dimensions could be obtained also without additional machining.

The obtained conductor rod is inserted in two layers of Kapton®, and then into a stainless steel (AISI 316L) pipe. The Kapton® layers guarantee the electrical insulation between the conductor bar and the stainless steel envelop.

4.2 Overview of the "HTS" current leads

The LTS (Low Temperature Superconducting) wires, connected to the superconducting coil of the magnet, are located at the end of the bottom copper block. The bottom copper block is immerged in liquid helium, at a temperature of 4.5 K, and the superconducting element is self-cooled by means of the Helium vapour.



The LTS wires are vacuum soldered to the superconducting stacks of the HTS (High Temperature Superconducting) stage.
An intermediate copper block separates the HTS stage from the heat exchanger, which ends on the top copper block, that includes the room temperature connection to the current supplier).
Helium gas at a temperature of 20K is injected in the region of the HTS stage, and the rising path of the helium gas is forced within the heat exchanger, in order to guarantee the correct thermal distribution along the length of the conducting elements.
The heat exchanger is contained in a vacuum jacket, that ends on the insulating flange, which is vacuum brazed to the top copper block.

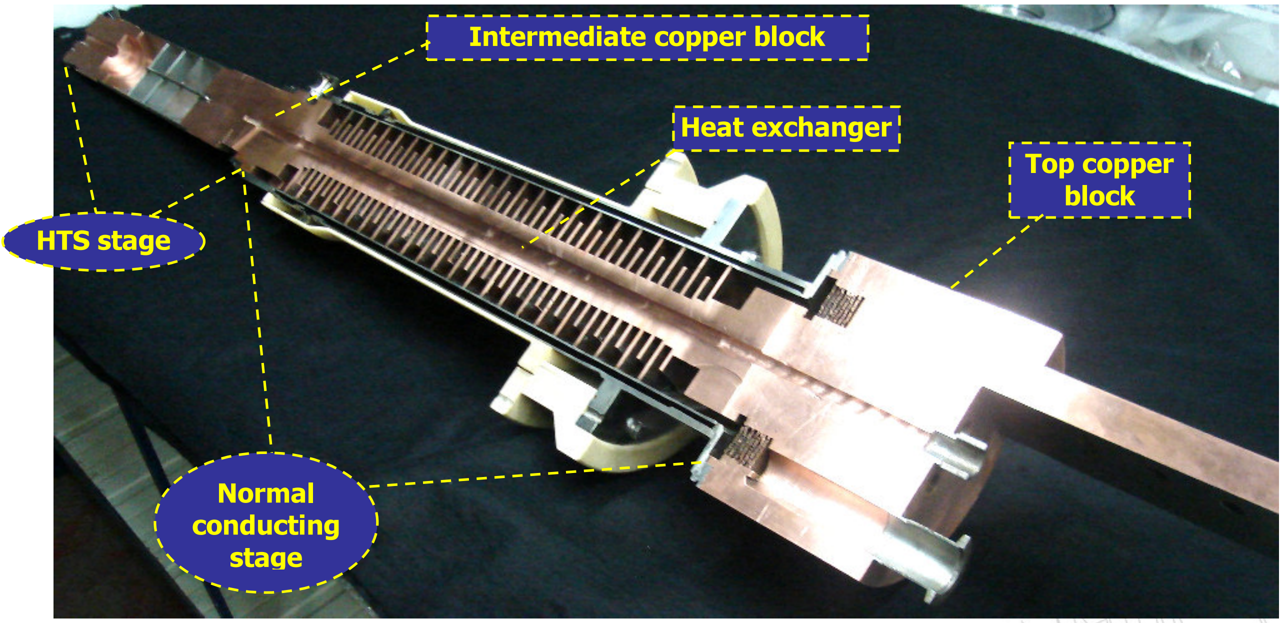


Fig. 2: Description of the 13000A current lead

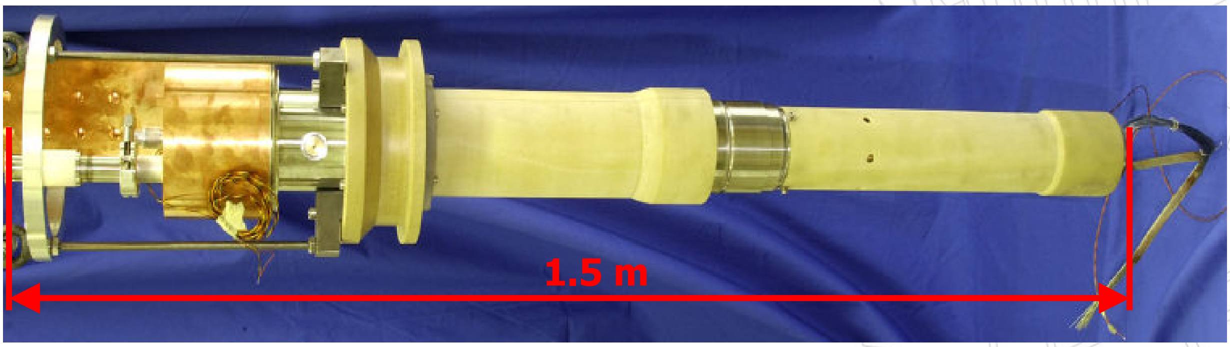


Fig. 3: 13000A current lead assembly

5 Mechanical tasks and involved technologies

The assembling of Current Leads has lots of critical points that can affect the good final result of the assembling. The involved mechanical details and technologies are different for conduction cooled leads and for HTS assemblies, but in both cases represent a technical challenge in the fields of high precision machining, technical experience, ultra-high-vacuum knowledge and skills, special processes and management capability.
The production process is characterized by several critical steps, related to used materials, special treatments, machining, shaping and welding. Also the stringent technical requirements related to the application plays a crucial role for design, production and test.

The most relevant tasks will be summarized in the following sections.

5.1 Copper plating

This part of the production process must be carried out with extreme care and with an accurate control of intermediate steps. For this reason we always took special care in controlling this step.
The copper plating applied for the CERN 120A leads was carried out by an Italian galvanic company.
Afterwards, for the production of the DESY 50A leads, we have set up the complete equipment for executing the copper plating in our facility. This allowed us to have the complete control of every step of the production, also monitoring the intermediate results during the copper deposition.
Our equipment is studied in order to carry out the copper plating of more than one bar in the same galvanic bath.

The most important aspects involved with this process are:

- <u>Providing the good quality of the copper deposited layer:</u>
  - Bubbles and picks must be avoided, since they damage the kapton tubes during the bending of the leads. This damage would lead to electrical problems, not recoverable after the bending of the assembled parts. Also the low roughness of the deposited layer is important at this purpose. With our galvanic equipment we can achieve the required roughness.
  - The copper plating must be symmetric and homogeneous, in order to guarantee the correct electrical behaviour and to obtain the tapered shape in the middle of the leads. The application of the method for obtaining this tapered section is very critical, in particular in the transition regions between the conical shape and the adjacent straight parts. We studied and applied a solution to optimise this process. Without this optimisation, cracks of the deposited copper could occur in this region during the bending: this would cause not repairable electrical problems after the bending of the leads.
- <u>Check of the deposited copper layer:</u>
  - After the copper plating it is very important to carry out specific tests of the parts in order to control the adherence of the deposited copper for each lead. We have included these tests in our production procedure.
- <u>RRR measurement:</u>
  - The RRR measurement is an important measurement for the qualification of production processes and used materials.

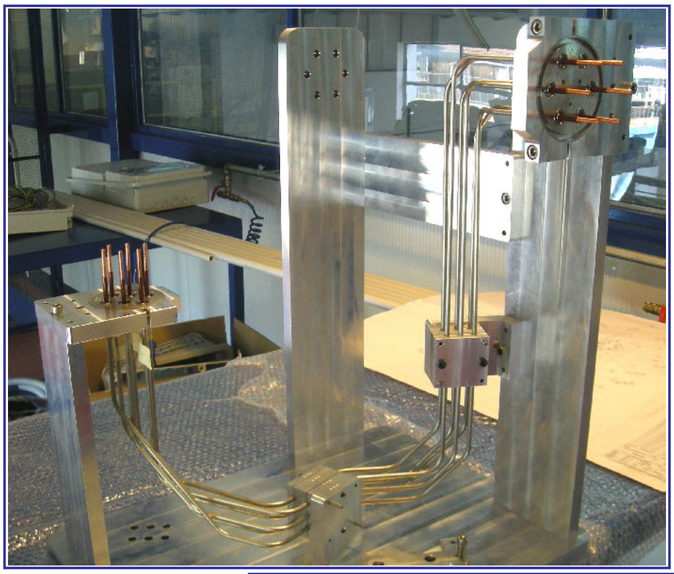
5.2 Bending

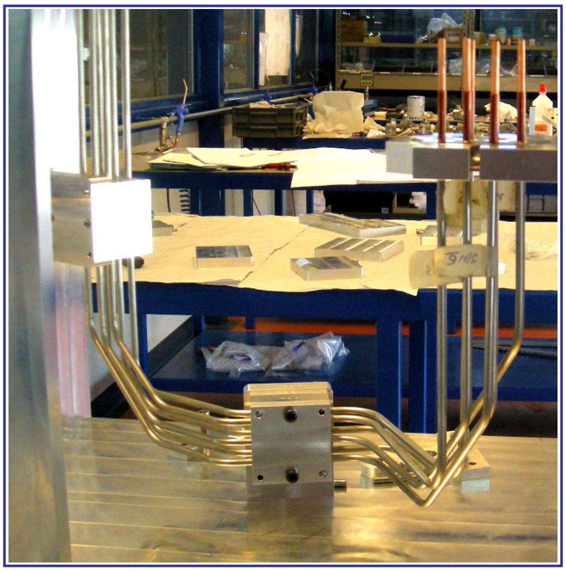
This process is involved with the construction of the conduction-cooled current leads.

Each Current lead is composed of several leads that are bent at special shapes:

- CERN 120A assemblies: 5 leads for each assembly, bent in 2D shape.
- DESY 50A assemblies : 6 leads for each assembly, bent in 3D shape

The bending was executed manually with a specific tooling.: In particular it is very important to check the parts during the bending to avoid unwanted narrowing along the bent radius, thus damaging the tubes and leading to leaks or cracks on the kapton layer.
For this reason we dedicated specialized technicians to this delicate operation, and we developed dedicated bending tools.
The tools allow also to execute the final dimensional control for the positioning of the leads assemblies: the reference points of the installation position are replicated on the tool, in order to allow the simulation of the final installation. According to our experiences (both for CERN and DESY projects), this is the most reliable method for the dimensional check.





5.3 Welding

The welding is a critical step of production. For this reason, in order to guarantee the leak tightness of each component, the following items were applied:

- Qualification of each welding before starting the production.
- Optimization of the assembling and bending process in order to limit the risk of leakage after the bending of the leads.
- Intermediate control of each welding step along the whole process.

The welding of the flange on the leads is delicate because it is performed near kapton tube which is close to the stainless steel. In case the kapton would be spoiled during the welding, a not recoverable damage to the part would occur, thus causing the rejection of the component. We studied and built a dedicated tool, aimed at avoiding the burning of the kapton tube.
Also the welding process was set up carefully at this purpose:

- The welding procedure was optimized, in order to minimize the heating of delicate parts.
- Special TIG torches are used, in order to access the welding regions, without causing damages to the product.

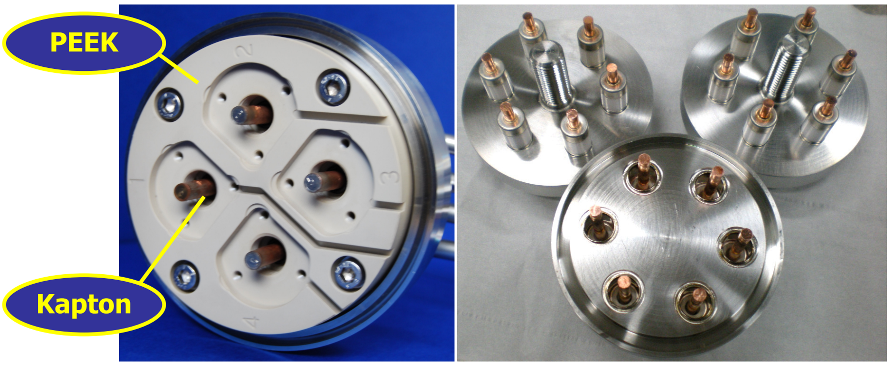


Fig. 4: TIG welding of the conductor elements to the warm flange

For the production of the 13000A HTS current lead assembly, also the Electron-Beam Welding process was involved: the base of the heat exchanger for helium vapour is composed of two OFHC-copper parts, that are joined by means of a full-penetrating EB-welding. A section of a dedicated sample is shown in Fig. 5.

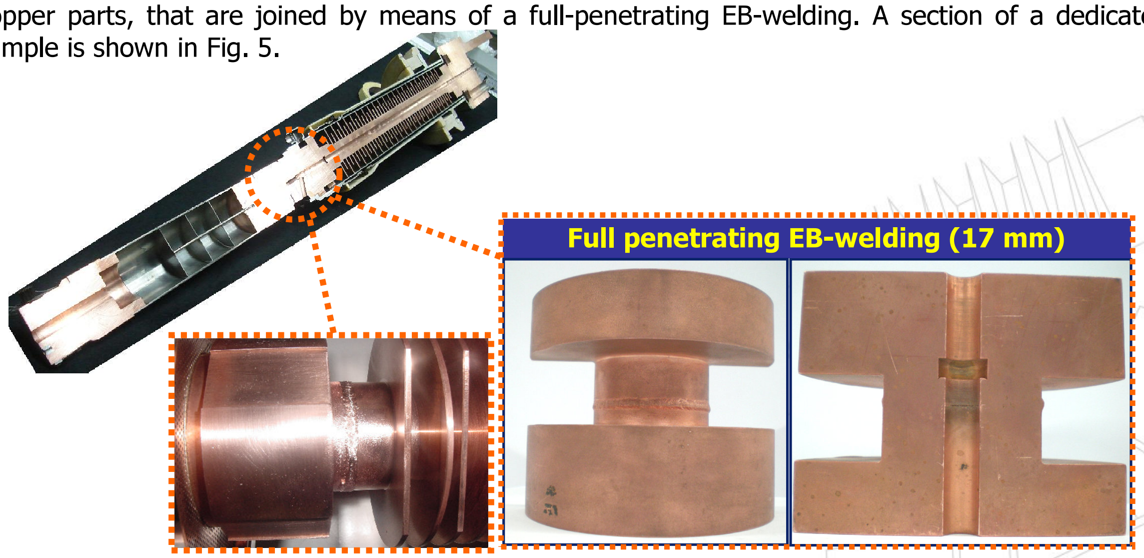


Fig. 5: EB-welded intermediate copper block

5.4 Vacuum soldering and "Parylene® C" coating

The vacuum soldering process was applied for welding the superconducting wires to the superconducting stacks (Fig. 6). This process was chosen in order to minimize the thermal stress to the superconducting parts, also guaranteeing the homogeneous distribution of the temperature during the process.

This process is very critical, due to the extremely delicate handling of the assembled parts. For this reason we designed and produced a dedicated vacuum oven, that was used for the vacuum soldering of all assemblies.

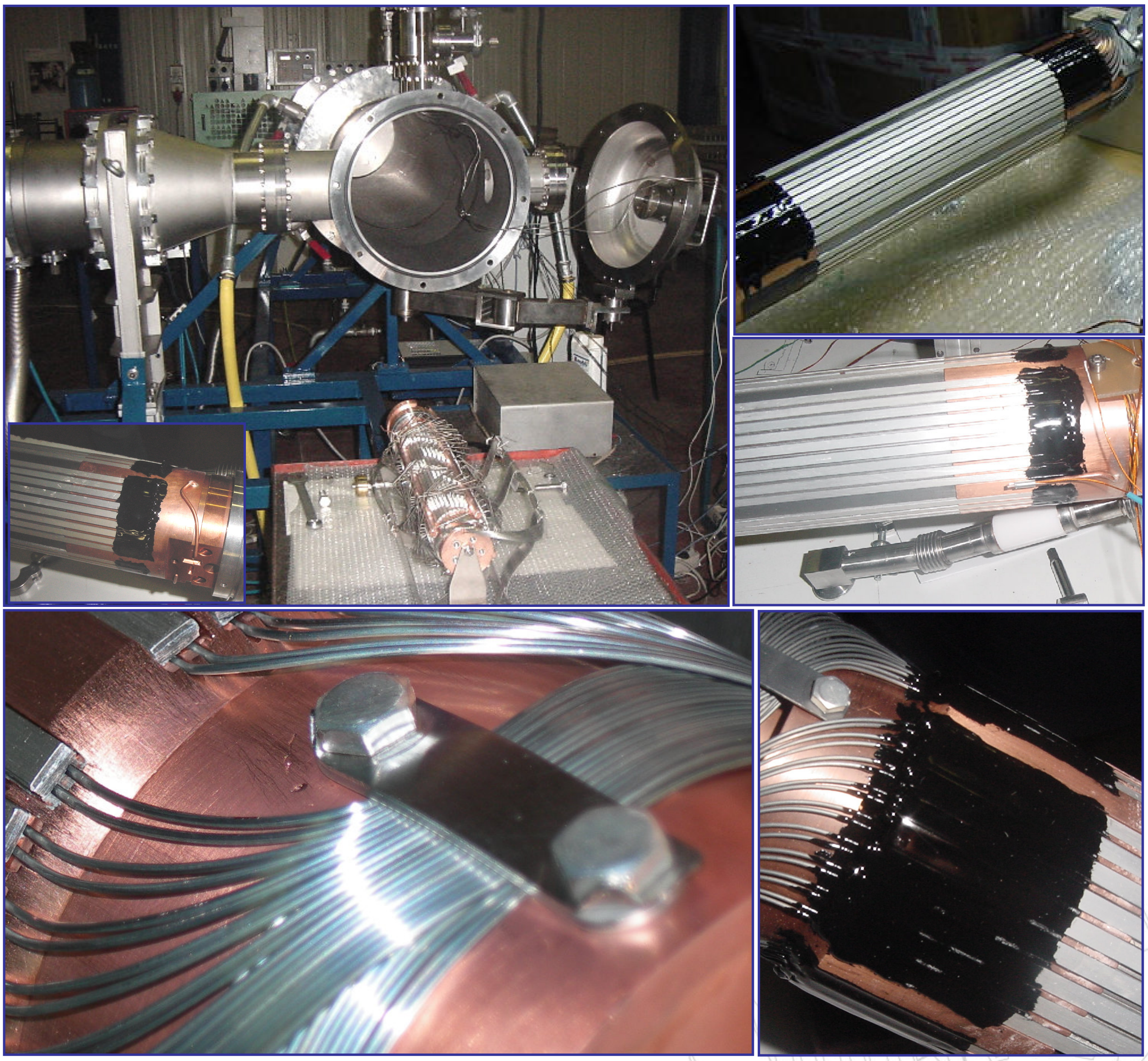


Fig. 6: Vacuum soldering: CECOM oven and soldered parts

The alloy used for the vacuum soldering contains silver, and the cryogenic liquid helium could penetrate the silver matrix. In order to avoid this unwanted effect, "Parylene® C" coating was applied on the superconducting stage. The "Parylene® C" coating is carried out by means of vacuum impregnation at room temperature.

5.5 Leak test

In order to avoid unexpected leakages on the final parts, the following tests are performed:

- Several intermediate leak tests (during assembling and welding).
- Check of each lead before proceeding with the final welding on the flanges.

Due to the geometry and to the low vacuum conductance of the bended leads, in case of leakages, it could be very difficult to identify the exact position of the leak. We optimized the leak test procedure accordingly.

The leak test is carried out in our clean room (class 1.000), with environmental control of particulate contamination and controlled temperature and humidity. Every weld is checked.

Fig. 7: Leak test of the conduction-cooled current leads

5.6 Pressure and electrical tests

The equipment for these tests is described below:

- Pressure Tests: Dedicated connection, with pressure regulator, for the pressurization with Nitrogen - grade 6 (up to 20 barG), followed by the Helium leak test (up to 1×10^{-10} mbar·l/s).
- Electrical Tests: MegaOhmMeter "FLUKE 1550B", for measuring the electrical resistance while High Voltage is applied. This is very important for this product: in case of eventual imperfections on the deposited copper or small cracks in the kapton layer, discharges could occur at High voltage even if short circuits are not detected with a standard multimeter. Our procedure for executing this test is the result of the cooperation with CERN for the 120A Current Leads production.