SEMINAIRE FRANCO-SUEDOIS 6-7/09/04

"NEW APPLICATIONS OF ELECTRON BEAM WELDING TO VERY LARGE PRECISION PARTS AND INDUSTRIAL PROSPECTS"

We will briefly introduce some basic principles of Electron Beam Welding technology before presenting two significant application to very large parts in main international projects, and conclude by examples of more usual industrial applications and equipment.

1. PRINCIPLES OF ELECTRONS BEAM WELDING (EBW)

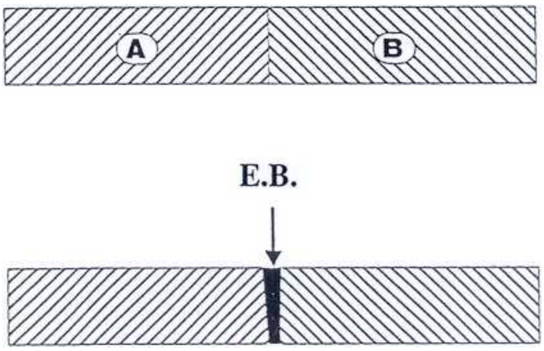
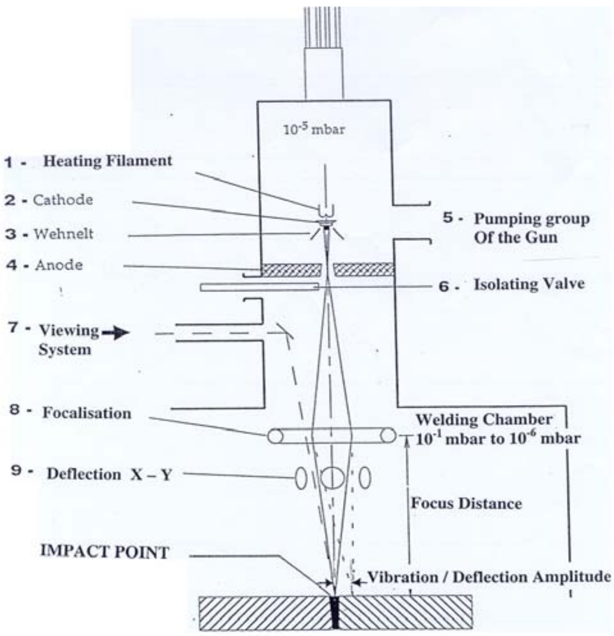


Fig. 1 : Principles of Electron beam welding

EBW process is a welding process by fusion using the kinetic energy conversion of the electrons into thermal energy when they enter in collision with the part to be welded.

Two machined parts are put together edge to edge; the electron beam melt the interface and forms a very narrow bead with almost parallel edges and limited deformations.

1.1. PRINCIPLE OF ELECTRON BEAM GUN



Electron Beam is produced by an EB gun operating under vacuum.

The electrons are extracted from a cathode, heated up to emission temperature.

They are accelerated by high voltage between cathode and anode.

2. INTRODUCTION TO ARIANE V EVOLUTION PROJECT

After qualification flight during year 1999 , ARIANE V launcher is able to transport 6.8 tons payload into geostationnary transfer orbit in dual-launch mode.
Each booster case, total length 25m and diameter 3 m roughly, is composed of 3 segments :
- The Forward segment S1 consists of a front dome and a short cylinder
- The central segment S2 consists of 3 cylinders each 3.4 m in length
- The rear segment consists of 3 cylinders each 3.4 m in length + a dome with a flange for the nozzle cone

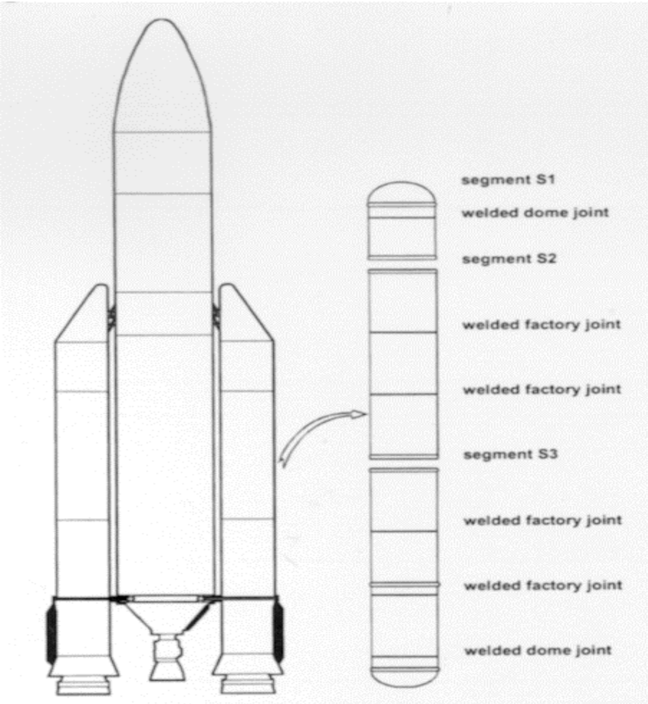


Fig. 2 :Schema of Ariane V connections to be replaced by welds

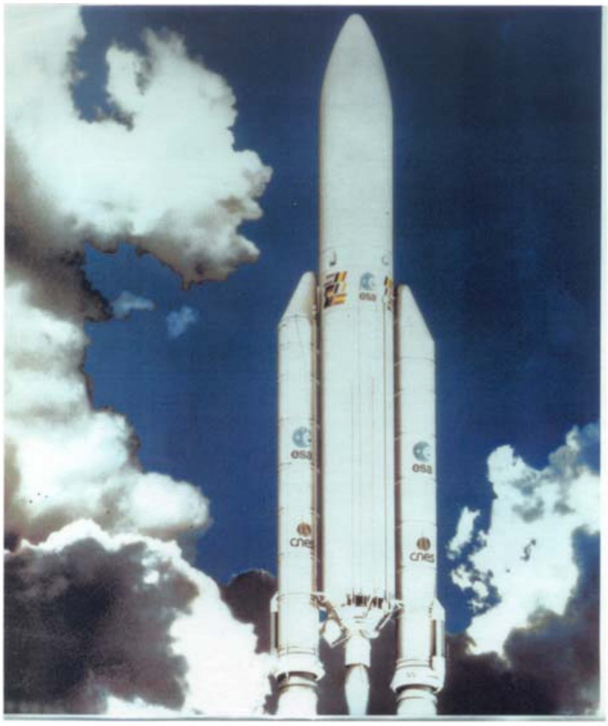


Fig. 3 :Picture of Ariane V

2.1. EVOLUTION FROM CLEVIS-TANG-CONNECTION TOWARDS WELDED CONNECTION

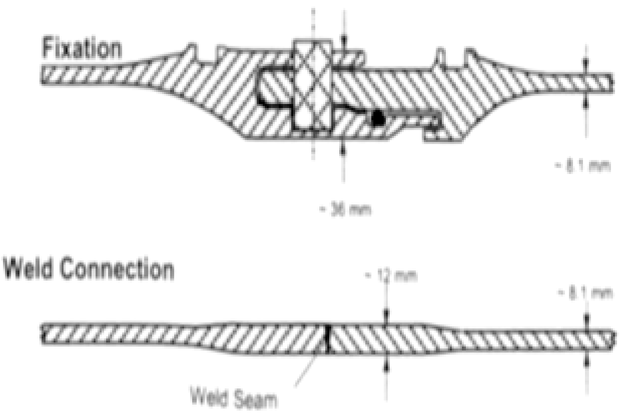


Fig. 4 :Geometry of factory connection with weld interface

The generic clevis-tang connection was designed with 180 bolts and one rubber O-ring for each connection, for total booster case weight 19.8 tons.

Advantages for evolution towards welded interface :

- Weight reduction of about 1.9 tons for each case (about 10% weight),
- Increase of payload capacity of about 150 kg,
- Easier machining,
- Increase of reliability by suppressing of rubber seal,
- Simplification of thermal insulation application,
- No more leak test needed.

2.2. BASE MATERIAL

Base material 48 CrMoNiV 4 10 (D6AC) is a low alloyed high strength steel.

Element	C	Si	Mn	P	S
Min.	0,45	0,15	0,60	-	-
Max.	0,50	0,30	0,90	0,010	0,001

Element	Cr	Mo	Ni	V
Min.	0,90	0,90	0,40	0,08
Max.	1,20	1,10	0,70	0,15

Fig. 5 :Characteristics of base material

The achieved properties in the base material after the above mentioned heat treatment are:

	measured single values	design values
♦ $R_{p0.2}$	≥ 1430 MPa	≥ 1300 MPa
♦ R_m	≥ 1560 MPa	≥ 1500 MPa
♦ K_{IC}	≥ 105 MPa√m	≥ 78 MPa√m (for cylinders)

2.3. WELDING

In a basic investigation program :
- TIG welding,
- A-TIG welding (with activating powder for deep penetration),
- Laser welding,
- Electron Beam welding.

Have been checked for applicability.
With respect to the weld material properties, performance of the welding process and investments for serial production, the Electron Beam (EB)-welding in full vacuum chamber has been selected.

2.4. WELDING EQUIPMENT

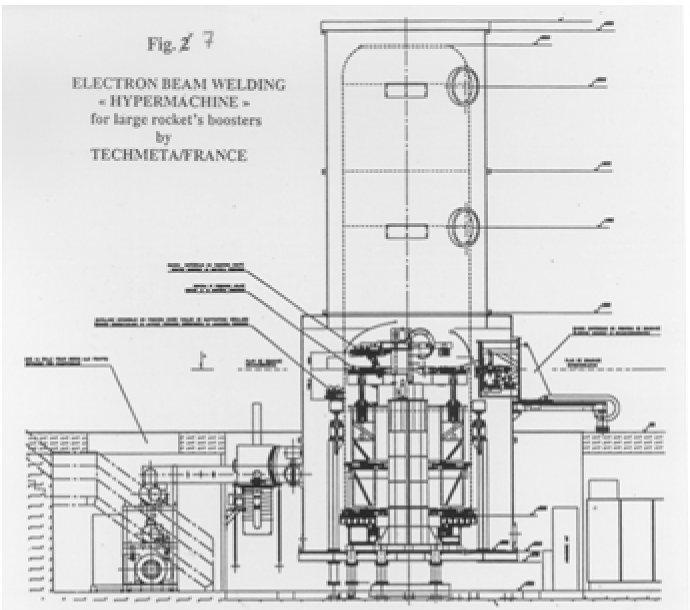


Fig. 6 :Cross-section of TECHMETA "hypermachine" in Augsburg -Diameter 5000 mm Height 15000 mm-

A

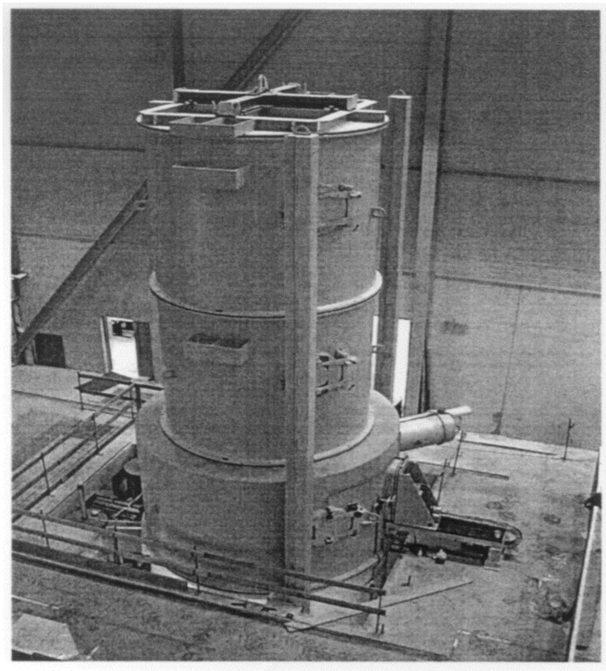


Fig. 7 :Picture of electron beam welding "hypermachine" for large rocket booster cases (during installation)

Dedicated huge welding machine was designed and manufactured by TECHMETA company in France.
This equipment has been delivered and fully tested at MAN TECHNOLOGY in Augsburg / Germany during year 2002.
The machine is schematically composed of following main elements

- Fixed base with all functional systems :
- External movable EB gun 20 kW/70kV,
- Vertical Internal carriage with EB gun 20kW/70kV,
- X Ray inspection system 4 KW/160kV,
- Pumping system with primary and secondary vacuum.

- Vacuum chamber modular elements :Those elements can be adapted in height to the height of the part, on each step of the works.
- Internal high precision clamping tooling system for positioning the parts in expanded position
- Handling system for displacement and stocking of the modular elements
- CNC system with data recording system

2.5. WELDING PROCEDURE

During welding the single parts are aligned with their vertical axes and fixed from inside by a clamping tool.
Following procedure has been selected :

a-From the outside :
- Discontinuous tacking pass (12x),
- Continuous tacking pass,
- Fusion pass and cosmetic pass on the face side.

b-From the inside :
- Cosmetic pass on the root side.
- X Ray inspection without removing the part.
- Tempering with a local heat treating equipment of about 40 mn.

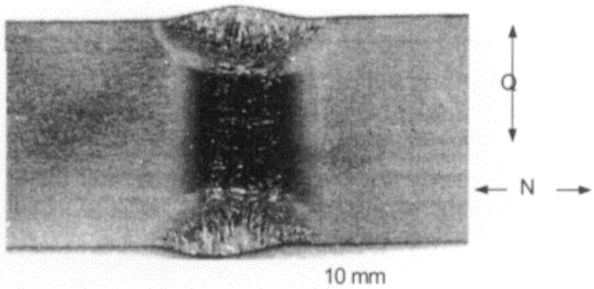


Fig. 8 :Macrograph of the weld cross-section

2.6. QUALIFICATION STEPS

During qualification procedure, integral tensile test samples of size 12 x 40 mm have been tested.
The rupture of the most of these samples was in the base material far away from the weld.
Because the stress distribution of a tensile sample is different to that in a pressure vessel, a further qualification concept has been developed first in sub-scale burst tests, and then in full scale.

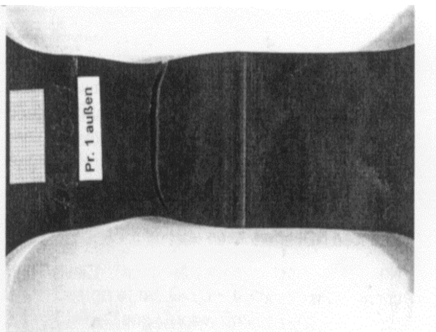


Fig. 9 :Ruptured integral tensile test sample / cross-section 12x40 mm

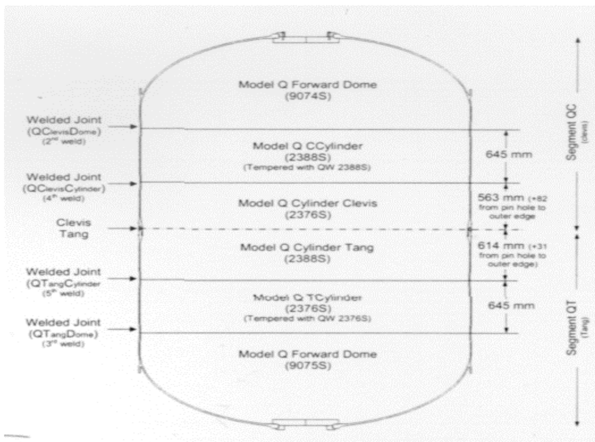


Fig. 10 :Full-scale pressure vessel Model Q

2.7. SERIAL QUALITY CONTROL

Welded Samples
In the series production, 3 different types of samples have to be welded to guarantee the weld quality as reproducibly as possible.

Data Recording
The data recording system of the machine can record in a high frequency during welding following parameters :
- Beam current,
- Beam voltage,
- Welding speed,
- Focus current,
- Vacuum level in chamber,

- Vacuum level in operating gun,
- Position of the rotating table.

2.8. REPAIR PROCEDURE

For welding cost-intensive work pieces, a qualified repair procedure is absolutely required.

- EB and TIG process have been qualified for repairing.
- The full production process has been qualified for starting serial production of EB welded booster cases.

2.9. THE MANUFACTURING OF EB WELDED BOOSTER CASES HAS BEEN QUALIFIED AND THE EQUIPMENT IS READY FOR STARTING INDUSTRIAL PRODUCTION

3. CONTINUOUS REINFORCEMENT OF SUPER-CONDUCTOR FOR THE "CMS" EXPERIMENT AT CERN LAB IN GENEVE

This second example concerns continuous welding of Al 6082 reinforcement profiles at both sides of a super-conductor extruded in a pure Aluminium section.
Pure Aluminium has been selected for its electrical and thermal properties. Its reinforcement by Aluminium alloy profiles with high mechanical properties is necessary to allow to encoil the Super-conductor with precision in coils of a diameter about 6 000 mm, needed to constitute the huge solenoid designed for the experiment.
Super-conductivity properties are destroyed by an exposure at 400 °C during 2 minutes.
The very high energy concentration of EB allowed to select parameters combining full penetration of the 22 mm to be welded with a thin geometry of the bead allowing to maintain melted zone as far as possible from the super-conductor, and a high welding speed reducing at the minimum the exposure time to heat.

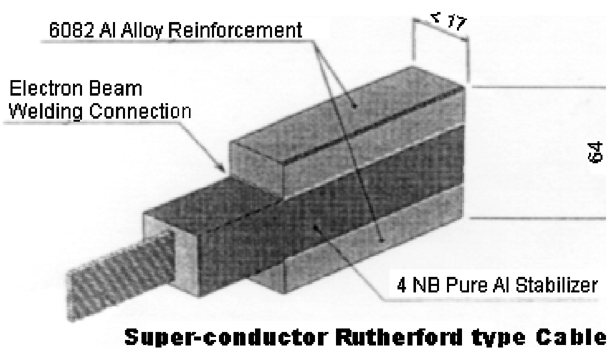


Fig. 11 : Schema of reinforced super-conductor

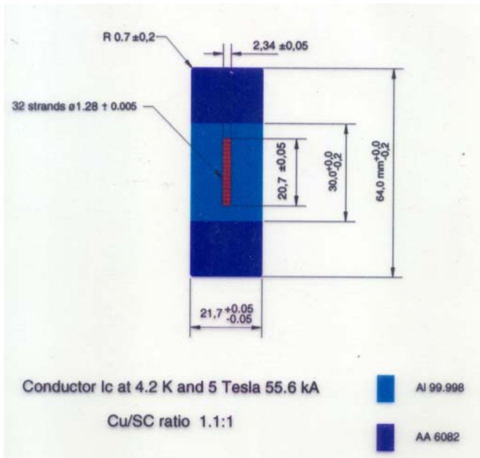


Fig. 12 : Cross-section reinforced super-conductor

3.1. PRESENTATION OF THE "CMS EXPERIMENT"

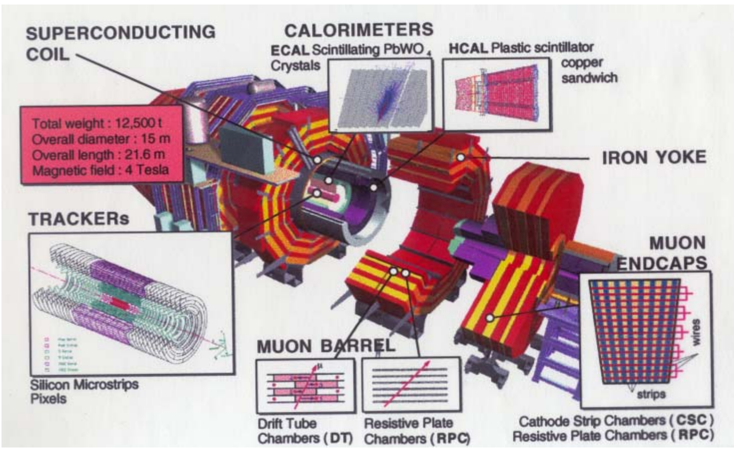


Fig. 13 :General view of the "CMS"

The “CMS” experiment will take place in the new ring installed at 80 meter depth underground at the French-Swiss border in Geneva, in view to verify the existence of particles named “Muons” according to theoretical calculation.

3.2. WELDING EQUIPMENT

Since more than 30 years, TECHMETA developed air-vacuum-air EB welding lines for different applications in multi-metallic strips. Based on this experience, a new world single equipment was designed and manufactured for CERN account, and the 52 km continuous welded assembly of super-conductor was achieved at TECHMETA workshop.

The machine is schematically composed of following main elements:

- Pay-off station for the 3 basic profiles
- Uncambering/planning units
- Cleaning system
- Continuous air-vacuum-air EB welding unit
- Cooling system
- Ultra Sonic inspection unit
- 4 faces Machining unit
- Cleaning unit
- Laser dimensional inspection unit
- Driving unit
- Encoiler

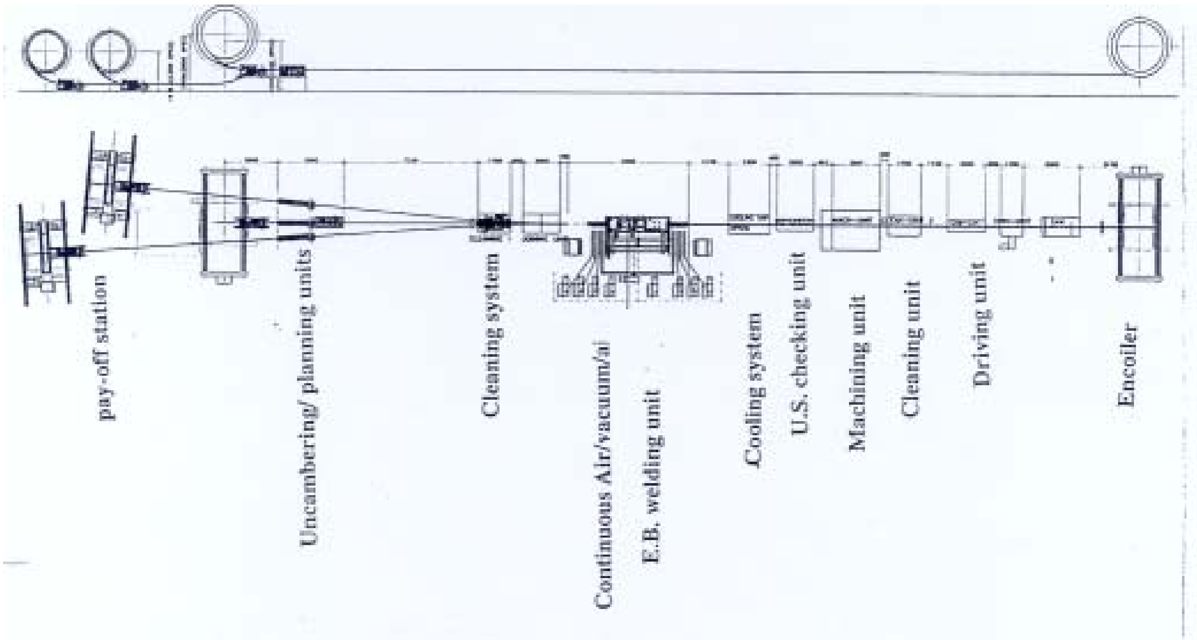


Fig. 14 :Schema of the 60000 mm length air-vaccum-Air EB welding line

3.3. PRODUCTION OF 52 km SUPER-CONDUCTOR

During year 2002/2003, the whole needed length of 52 km reinforced Super-Conductor was manufactured, on line and off line inspected, and delivered to Italy for encoiling in final magnetic coil to be installed in the international CERN LAB in GENEVE.

4. MORE USUAL INDUSTRIAL APPLICATIONS

These two huge projects are spectacular aspects of the EB technology that is applied in various industrial fields. Figures 16 to 18 are showing some examples of bead shapes and EB welded industrial parts.

Figures 19 to 21 are showing some types of usual EBW machines.

SINGLE PASS EB WELDING

Fig. 15 : 200 mm in Aluminim

Fig. 16 : 110 mm in Steel

EB WELDED INDUCTRIAL PART

Fig. 17 : Copper part (Electrical connection)

Fig. 18 : Cross-section reinforced super-conductor

Fig. 19 :Medium size universal EBW machine

Fig. 20 :Small size universal EBW machine

Fig. 21 :Double gun high productivity EBW machine for automotive parts

5. CONCLUSION

The two projects are showing the progress authorised by application of EB technology to very large components in huge international programs.
Design offices of the industries dedicated to defence, automotive, space, aeronautics, as well as research laboratories, are more and more confronted with the need to manufacture precision parts in specific alloys as Titanium or Aluminium Alloys, high strength steel, refractory metals, etc…
EB technology can bring an industrial solution combining high energetic performances with almost no distortion in protected surroundings under vacuum. The fully automated process allows full data recording to establish high level Quality Assurance procedures and further statistical analysis.

By courtesy of MAN TECNOLOGY for information and figures concerning ARIANE V booster cases (for more details please refer to "Welding and brazing in Aerospace Industry" Vorträge des Internationalen Symposium in Berlin-Schönefeld on 12th and 14th May 2004 , genehmigte Übersetzung aus dem DVS-Berichte Band 229 "Schweißen und Löten im Luft- und Raumfahrzeugbau" des DVS-Verlages, Düsseldorf).
By courtesy of CERN for information and figures concerning CERN project. (fore more details, please refer to "Bindungsprüfung an elektronenstrahlgeschweissten Hochstrom-Supraleiterkabeln" CERN publication Genève.)