DESIGN, MANUFACTURING AND INTEGRATION OF LHC CRYOSTAT COMPONENTS: AN EXAMPLE OF COLLABORATION BETWEEN CERN AND INDUSTRY

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Abstract

The components for the LHC cryostats and interconnections are supplied by European industry. The manufacturing, assembly and testing of these components in accordance with CERN technical specifications require a close collaboration and dedicated approach from the suppliers. This paper presents the different phases of design, manufacturing, testing and integration of four LHC cryostat components supplied by RIAL Vacuum (Parma, Italy), including 112 Insulation Vacuum Barriers (IVB), 482 Cold-mass Extension Tubes (CET), 121 cryostat vacuum vessel Jumper Elbows (JE) and 10800 Interconnection Sleeves (IS). The Quality Assurance Plan, which the four projects have in common, is outlined. The components are all leak-tight thin stainless steel assemblies (<10^{-8} mbar l/s), most of them operating at cryogenic temperature (2 K), however each having specific requirements. The particularities of each component are presented with respect to manufacturing, assembly and testing. These components are being integrated at CERN into the LHC cryostats and interconnections, thus validating the design and production quality. The major difficulties and improvements are discussed.

INTRODUCTION

Four types of components (mainly in stainless steel) for the LHC Short Straight Sections (SSS) have been manufactured by RIAL, Italy. The requirements of the CERN technical specification were the following:

1) IVB (Fig. 1). This component sectorises the insulation vacuum of the LHC machine cryostats each 214 m. It is designed to withstand the differential thermal contractions between cold-mass, vacuum vessel and cryogenic lines [1], [2]. This required thin bellows that provide leak-tight feed-throughs for cryogenic lines. The IVB is also designed for low conductive and radiative heat in-leak. The total supply is 112 units.

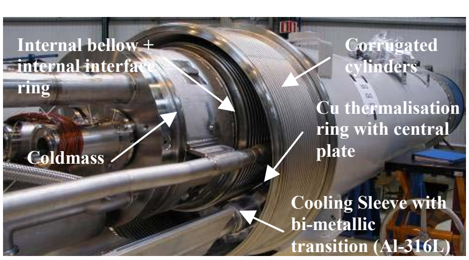

Figure 1: The Insulation Vacuum Barrier integrated into the Cryostat of a Short Straight Section.

2) CET (Fig. 2). This component is a leak-tight cryogenic extension of the coldmass operating at 2K and routing superconducting cables and instrumentation wires. It is a tubular welded construction with a flexible hose and four flange interfaces with a maximum working pressure of 2 MPa. The total supply is 482 units (of 2 types).

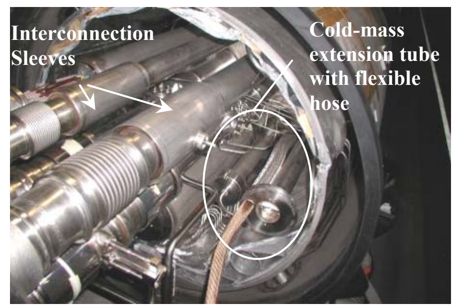

Figure 2: The integration of CET and IS.

3) JE (Fig. 3). This component is a leak-tight extension of the vacuum vessel of the SSS cryostat, housing cryogenic supply lines. It is a tubular elbow-shaped construction including two interfaces, one being a large forged flange that is the interface of the SSS to the cryogenic distribution line (QRL) which is connected in the tunnel. The total supply is 121 units (of 2 types).

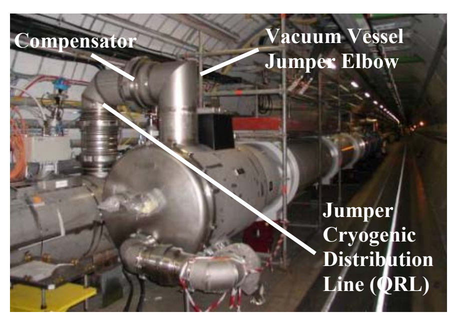

Figure 3: Vacuum Vessel Jumper Elbow welded to the compensator of the QRL.

4) IS (Fig. 2). This component is a leak-tight tubular sleeve that allows connecting the cryogenic tubing of two adjacent magnets by welding. The total supply is 10800 units (of 12 types).

INDUSTRIALISATION

The components were designed by CERN but the industrialisation was made by RIAL on the basis of CERN technical specifications.

Quality assurance plan and traceability

RIAL is qualified according to ISO 9001, as required by CERN technical specifications. This qualification certifies a quality system where responsibilities, processes and tasks are clearly identified. In addition, Quality Assurance Plans (QAP) were established focusing on the reliability of special processes such as the manufacturing cycle, non-conformity handling, releasing of components and on the important requirement of traceability at each stage of procurement, manufacturing and testing. The large amount of ensuing data has been organised in databases, most of them able to generate automatically test reports. The required information was uploaded, via Internet, to CERN's specific databases.

Raw Material procurement

Since the – often thin walled – components are used for cryogenic and vacuum applications, CERN imposed rather stringent requirements for the stainless steel to be used in terms of chemical composition (low content of C, P and S), grain size (<40µm) and inclusion content (max. class 1 according to ASTM E45-97e1 method D) [3]. Availability of stainless steel fully complying with these requirements was limited. Where large quantities were involved for the LHC, CERN procured the raw material in advance and supplied industries. RIAL however did most of the procurement of materials themselves. This meant buying small quantities in European stocks, leading to a complex handling of quality records and data traceability. This difficult exercise allowed RIAL to improve its competence in material characterisation and to identify potential procurement sources for future projects. In some cases the initial material specifications had to be discussed. The aluminium foreseen for the bi-metallic transition (IVB), chosen for its thermal conductivity, had to be changed to obtain a leak-tight friction weld between aluminium and stainless steel. The proposal coming from the industry was verified at CERN Cryolab to be suitable [4].

Vacuum integrity and welding of cryogenic lines

In vacuum technology, where 100% penetrated welds are requested, TIG welding is certainly one of the most delicate operations. But it becomes even more critical for cryogenic components where thin walls (in compensating bellows) are involved. Welders and welding procedures were qualified according to Euro norms (EN287-1 and EN288-3) and the welding defects had to remain within the tightest criteria of welding class B (EN25817). Often the joint design was very particular leading to special qualifications with welding joints according to reality. In some cases, norms defining welding imperfections were not properly applicable and therefore acceptance criteria were defined in good co-operation. An inspection plan was established to evaluate the quality of the welds and brazing (visual, X-ray, ultrasonic or macro-graphic inspection). Residual deformation after welding has been controlled using special welding jigs (Fig. 4). The definition of the right welding parameters was the result of a joint collaboration between CERN experts and RIAL's welders. Single pass penetrating welds on 3mm material thickness could be achieved, by choosing the right shielding gas composition (5%H_2, 20%He, 75% Ar).

Figure 4: Welding tooling used to minimise deformation.

Tests

To ensure that the components comply with the technical specification, several final tests are carried out such as dimensional controls and helium leak-testing (in some cases after pressure testing and cycles of thermal shocks at 77K). Intermediate tests are made "in process", to keep under control and to validate manufacturing activities. CERN quality inspectors were regularly visiting RIAL to witness manufacturing and testing activities. Test tools have been designed to combine pressure and leak testing without disassembling the component. During the design stage attention has been paid to the roughness of the sealing surfaces. The problem of He-pollution of the elastomer seals has been faced by baking them out and replacing them regularly to reach the required sensitivity. The leak test diagrams are attached to each component and available in the CERN Electronic Data Management System (EDMS) guaranteeing full traceability during the exploitation of LHC.

INTEGRATION OF COMPONENTS

The integration of the components in the SSS at CERN was an important step to validate CERN's design and RIAL's manufacturing quality. The assembly of a pre-series of components was set as a contractual milestone. A production review was organised in order to give feedback to RIAL and possibly improve the design and the manufacturing cycle before launching the series production. Some examples will be given in the following, stressing the paramount importance of this feedback process and underlining the need for flexibility and cooperation from the industrial partners.

During final leak-testing (at 25 bar) of the SSS at CERN, leaks appeared on the flexible hose of the CET housing superconducting cables, resulting in difficult and lengthy repair activities. The weak point was identified in the design of the flexible hose (not specified by CERN but chosen as an "off-the-shelf" component), being the single weld that melted together bellows, braid, end-piece and ring.

Therefore the design of the flexible hose was changed imposing a leak-tight weld between bellows and end-piece and a structural weld between braid, ring and end-piece (Fig. 5). This allowed a better control of the welding parameters with good Argon protection from inside (corrosion was seen in some cases) and no sharp edges in the last convolution that could eventually cause damage to the superconducting cables. A new supplier of the hoses was selected and a pressurised leak-test with 25 bar helium inside the flexible hose was imposed.

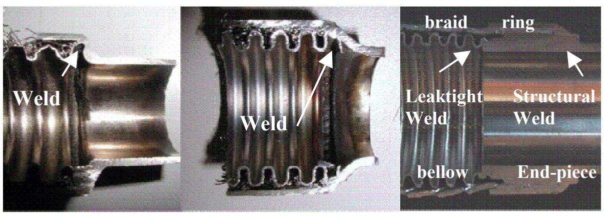

Figure 5: Three types of joints for the flexible hose. From left to right: pre-series , intermediate and final design.

A leak was also found in the material of several flanges of the CET which had a very tight specification for inclusion content. Macroscopic analysis showed a defect, an irregular X-shape of 1 x 0.3mm, passing through the thickness of the flange and containing non-metallic products (O, Al, Mg, Ca), see Fig. 6 [5]. The cause was

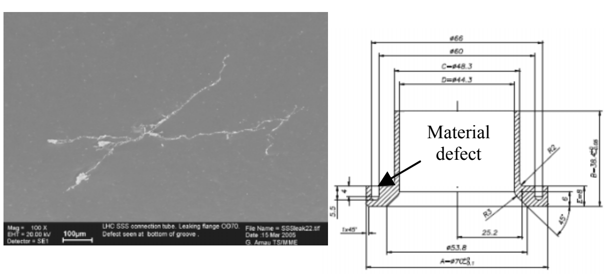

Figure 6: X-shape material defect (left) and localisation of the material defect in the flange (right).

a macro-inclusion in the extremity of the raw material bar that normally should have been removed by the material supplier. The inclusion elongated during the extrusion of the final round bar. On CERN side this lead to a reflection whether refining of the steel (such as electro slag remelting) should be imposed to the raw material supplier. Thanks to the material traceability system of RIAL, it was possible to identify all CET's with flanges from the suspicious material heat. Part of them were checked by an eddy current method and a minimum quantity of CET's with affected but tested flanges was used to keep the SSS assembly going. In parallel, RIAL changed immediately the material heat and replaced flanges on 27 items.

During the integration of the first IVB, a leak was found between the weld of the Internal Interface Ring (IIR) and internal bellows (0.4mm), possibly induced by the weld done at CERN between IIR and cold-mass which is nearby. This has led to an improvement of the delicate welding process between IIR and internal bellows. The key issue was to keep the welding lips together, which in this case was realised by increasing significantly the number of tack-welds.

The integration of the JE and IS at CERN went without major problems. The main difficulty was to achieve the dimensions with tight tolerances according to specification. For the JE, a tool was made to position the jumper elbow in order to have the flange interface within the tolerances required for the connection to the QRL in the tunnel (Fig. 3). The orbital welding tooling foreseen to weld the flange of the JE to the compensator of the QRL is being modified due to ovalisation of the compensator. For the IS, a significant improvement with respect to the ovalisation of the tube extremities was achieved by changing the manufacturing process from pressing to a cold rolled forming process.

CONCLUSION

Deliveries by RIAL of most of the components have come to an end. Approximately 330 CET's, 50 IVB's and 50 JE's have been integrated into a SSS and 2500 interconnection sleeves have been interconnected in the tunnel. During pre-series manufacturing and integration at CERN, there has been an intensive collaboration where knowledge transfer took place. With a flexible and reactive attitude this led to the improvement of design, manufacturing process and testing and allowed minimising the number of non-conformities. RIAL made a giant leap in quality assurance for vacuum and cryogenic equipment which is now part of a well-settled working culture. A partnership with industry, more than a simple contractual framework, was the key to the success in such a complex project.

REFERENCES

[1] V.Parma et al. "The insulation vacuum barrier for the Large Hadron Collider (LHC) Magnet Cryostats", ICEC18, Bombay, India, 2000.

[2] L. Nielsen, V. Parma, M. Canetti and F. Gangini, "Industrialisation of the Insulation vacuum barrier for the Large Hadron Collider (LHC) magnet cryostats", EVC'03, Berlin, June 2003.

[3] CERN Materials Technical Specification (SPL-PS), No 525 - Ed.3 - 02.08.1999, Unpublished.

[4] J.M. Rieubland, L. Dufay "Mesure de delta T sur un thermalisation des barrières a vide pur le LHC", CERN Cryolab Note-5-03, 2003. Unpublished.

[5] G. Arnau, S. Sgobba, Investigation report origin of a leak in connection tube LHCQQAIS004-RI000019 assembled to a LHC Main Quadrupole, EDMS nr 575358.