RFQ VACUUM BRAZING AT CERN

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Abstract

The aim of this paper is to describe the vacuum brazing procedure used at CERN for the brazing of Radio Frequency Quadrupole (RFQ). The RFQ is made of high precision machined OFE copper pieces assembled together. Vacuum brazing is one of the most promising techniques used to join the individual components leading to vacuum tightness and high precision alignment.

The RFQ modules brazed at CERN are made of four 100 or 120 cm long vanes (two major and two minor vanes). Our brazing procedure consists of two steps. The first step involves the brazing of the four vanes in a horizontal position. The second step consists of brazing the vacuum stainless steel flanges to the copper structure in a vertical position.

The paper describes the problems encountered with the alignment and the vacuum tightness. The difficulties related to the stress relaxation of the machined copper pieces during the brazing heat treatment are discussed. In addition, the solutions developed to improve the alignment of the brazed RFQ's are also presented.

INTRODUCTION

Since 1999 and 2002 respectively, CERN is involved in the vacuum brazing of the RFQ for the TRASCO (INFN-LNL) [1] and IPHI (CEA-Saclay) [2] projects. In both cases, the RFQ's are fabricated as six independent modules made of 4 vanes, two majors and two minors, machined from forged OFE copper (Fig. 1).

The vanes are vacuum brazed together, the brazing surfaces being localized between the major and the minor vanes. The brazing alloy, in wire form, is inserted into pre-machined grooves. The brazing surfaces are flat, without steps, in order to allow an accurate alignment of the vanes before brazing.

BRAZING PROCEDURE

While the 4-vanes vacuum brazed RFQ are generally brazed in a vertical position, we have proposed at CERN a two-step procedure where the vanes are initially assembled in a horizontal position. Consequently, the brazing surfaces are in a horizontal position and thus in an optimal configuration for a uniform distribution of the brazing material by capillary action. Before brazing, a precise alignment is made by using reference surfaces or an r.f. (bead pull) measurement (Fig. 2). The vanes are then blocked together by using OFE copper screws. These screws allow for a safe loading of the module into the horizontal furnace. At high temperature, the copper screws lose their mechanical resistance and thus cannot be a source of constraint. The plugs closing the cooling channels drilled from one side are also brazed at this stage.

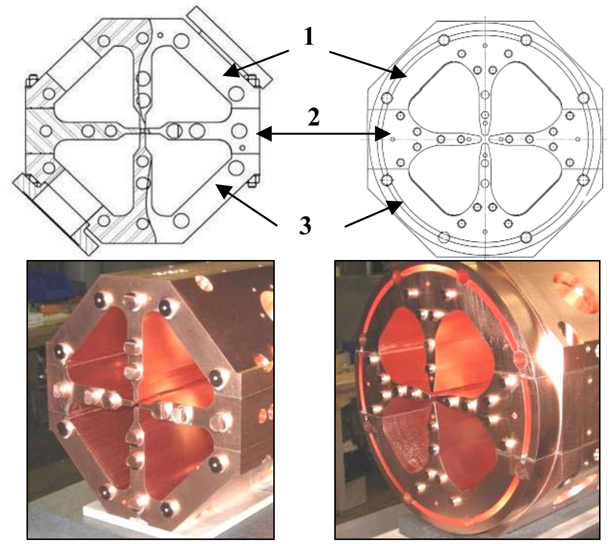

Figure 1: Transverse views of the TRASCO (left) and IPHI RFQ modules. 1 & 3 : major vanes, 2 : minor vanes.

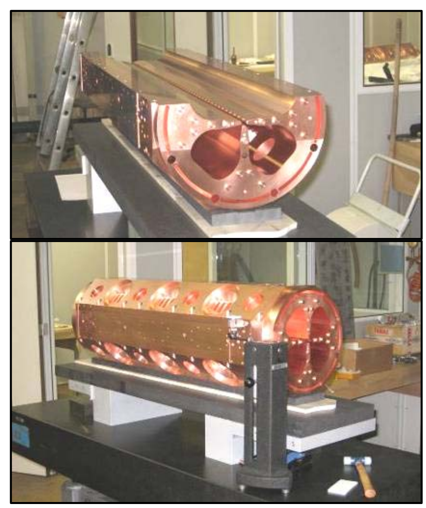

Figure 2: Assembly and alignment of a IPHI module before the first brazing step.

After brazing, both ends of the RFQ module are re-machined in order to fit perfectly the stainless steel end-flanges. These flanges are then brazed on to the module in a vertical position in a vertical furnace. The lateral flanges used for the pumping and piston tuner ports as well as the stainless steel cooling tubes are also brazed during this step (Fig. 3). The brazing alloys used are B-Ag68CuPd-807/810 (brazing temperature 825 °C) for the first step and B-Ag72Cu-780 (brazing temperature 790 °C) for the second step.

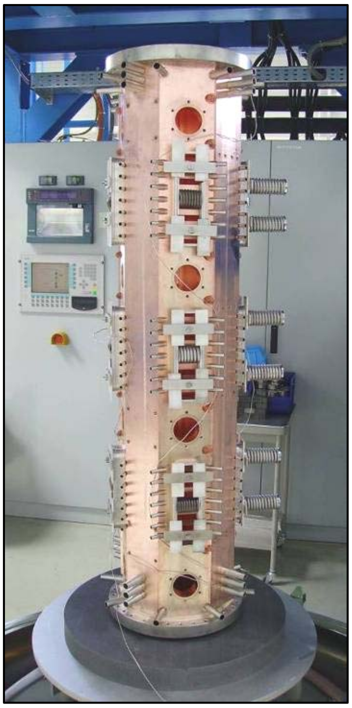

Figure 3: Second step brazing in vertical position of a RFQ (TRASCO) module.

POST BRAZING OBSERVATIONS

Vacuum Tightness

The first problem encountered has been for the TRASCO module #1 where significant leaks have been found on the vacuum flanges. This was the consequence of an unadapted mounting fixture and tolerances for these flanges having a delicate hippodrome shape. New flanges have been re-brazed after re-machining of the defective ones.

The vacuum leaks observed with the IPHI module #2 have been more serious. There, the cooling channels passing through the pumping port grids are drilled through the braze surfaces after the first brazing step. A deep groove is also machined at the same time on the front and rear surfaces in order to reduce the possible deformations due to the brazing of the end-flanges.

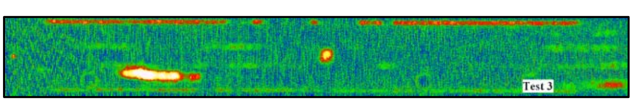

Figure 4:.Ultrasonic inspection of 500 x 50 mm test piece brazed with zero gap. The four brazing grooves are visible in addition to an unbrazed region. The central hole is for US calibration.

Our analysis is that these re-machining operations have created dangerous leaks between the cooling channels and the vacuum cavity. Several tests performed after this observation have shown effectively that in the case of large brazed areas with good surface finish and planity, some regions may not be perfectly wetted by the brazing alloy (Fig. 4). These regions are almost always localized in the center of the braze surfaces indicating that a re-machining through these regions may be problematic.

For the IPHI module #3, the front and rear grooves have been machined before the first brazing step and some grooves have been added around the drilled holes. This module has been brazed vacuum tight.

Alignment

The second type of problem encountered has been the displacement and deformation of the vanes after the first brazing step. For the TRASCO modules # 1 & 2, one has observed mainly a banana shape, with a maximum deformation of 200 microns and torsion. These displacements are clearly not a consequence of a gravity effect and thermal constraints during heating have been initially suspected.

For the IPHI module # 2, the major effect has been a longitudinal displacement (~ 80 microns) of one of the minor vanes. For the IPHI module # 3, Nimonic springs have been used in order to improve the longitudinal alignment during the first brazing (Fig. 5). Longitudinal displacements have been reduced to about 40 microns but important transverse displacements (more than 100 microns) have been observed for the minor vanes.

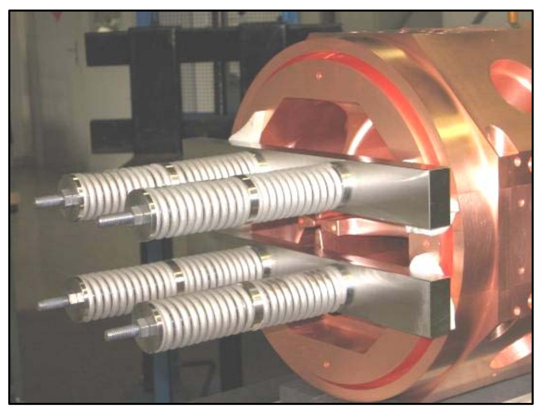

Figure 5: Nimonic springs used for the alignment during the first brazing step (IPHI module).

THERMAL TREATMENT EFFECTS

For the TRASCO modules # 1 & 2, the vanes have been heat treated at 250 ºC after rough machining. This temperature has been chosen primarily to retain some of the mechanical properties of the OFE copper before final machining.

For the IPHI modules, the first treatments performed at 250 ºC have shown significant deformations. Subsequently, it has been decided to perform a full annealing at 600 ºC after rough machining for the all vanes.

Owing to the deformations and movements observed after the first brazing step, the annealing before final machining is now considered to be insufficient. Effectively, the heat treatment at 800 ºC of a major IPHI vane after final machining has shown a significant deformation of the brazing surfaces (~ 100 microns) (Fig. 6). Two successive treatments performed on the same vane produced practically the same deformations showing that these deformations are due to the relaxation of constraints induced during the final machining.

These relaxation effects occurring during the first brazing step can explain a major part of the deformations and movements observed.

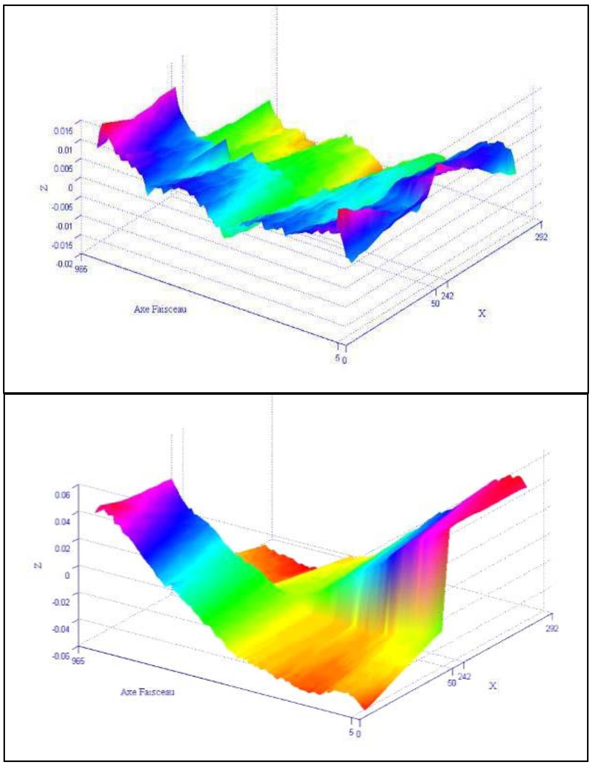

Figure 6: Evolution of planity of the braze surfaces for a major IPHI vane after final machining before (top) and after (bottom) heat treatment at 800 ºC. The dimensions are in mm, for the drawing, the left and right braze surfaces, X axis, are represented side by side.

This has subsequently been confirmed following the first brazing of the TRASCO modules # 3 & 4. For these modules, a heat treatment of the vanes after rough machining has been performed at 600 ºC in place of 250 ºC. The constraints induced during final machining of the TRASCO vanes seem to be more limited and substantially reduced displacements (~ 20 microns) after the first brazing of these two modules have been observed.

These results show that a full annealing of the copper is certainly required before the final machining of the RFQ vanes. However, depending of the machining conditions, the final machining itself can introduce new constraints which are a source of relaxation movements during brazing.

CONCLUSIONS

A two step vacuum brazing procedure has been used at CERN for the assembly of the RFQ modules for the TRASCO and IPHI projects. The results obtained by using alternatively a horizontal and a vertical furnace have demonstrated the validity of the procedure which will be used for the future Linac 4 RFQ.

Our observations have shown that the main difficulties are related to the relaxation movements during the first brazing step as a consequence of the constraints induced during the final machining.

ACKNOWLEDGMENTS

This work is the result of a continuous and fruitful collaboration with the following persons: A. Pisent, A. Palmieri, M. Comunian (INFN-LNL), P.Y. Beauvais, M. Painchault, B. Pottin (CEA-Saclay), P. Bourquin, J.P. Bacher, Th. Callamand, J. Carosone, J.M. Geisser, M. Malabaila, D. Pugnat, C. Rossi, S. Sgobba, A. Vacca (CERN).

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