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Technological aspects of construction molybdenum high gradient X-band standing wave accelerating structures

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Abstract

As known the SALAF Group activity is presently dedicated to set up an X-band, accelerating structure, using different materials and methods. In particular a three cells X-band standing wave structure has been realized entirely in molybdenum using high temperature brazing procedure. Here it will be reported the setup procedure of the second structure completely in molybdenum realized at LNF-INFN and technological problems met on this activity.

Introduction

The activity of testing high-gradient RF sections at 11.424 GHz for the next generation electron-positron linear collider is in progress in order to determine reasons of breakdown mechanisms which limit the high gradient performance.

Since the breakdown phenomena is an open problem, a dedicated research and development on this field has been launched within the linear-collider community. An useful trend in terms of DC breakdown study is underway at CERN in order to test candidate materials and surface preparation [1,2], even though it does not represent the real RF behavior.

In the framework of the collaboration with SLAC, KEK, INFN-LNF. in order to determine the maximum gradient possibilities for normal-conducting RF powered particle beam accelerator an intense technological activity is therefore dedicated to set up X-band, accelerating structures operating at 11.424 GHz, using different materials and methods [3,4,5,6,7]. Basically, the main fields under investigation are presently the following:

-high temperature brazing (800-1000) °C
-low temperature brazing (250-300) °C
-electroplating
-molybdenum sputtering on copper

In particular a three cells X-band standing wave structure at 11.424GHz has been realized entirely in molybdenum using a high temperature brazing procedure. Then, this section has been tested at high power at SLAC [8], too.

It is shown that the breakdown rate of the brazed Mo structure is higher than that of copper structure for same RF parameters. A structure internal inspection to understand the device behaviour is therefore necessary. Here we discuss the possible reasons that affect the molybdenum brazed section performance and related technological problems when constructing it.

Brazed section internal inspection

After being removed from high gradient test area, the structure was sectioned along the axis at SLAC klystron lab to allow for internal inspection [9]. The structure was first split into 2 pieces using EDM (Electrical Discharge Machining). One of the half pieces was split again. On the initial sectioning, one of the molybdenum “extension tubes” failed adjacent to the SST flange braze, as shown in figure 1. Note that the arrow shown in the image was observed by the machinist, not added during the cutting.

When one of the sections was cut again [also by EDM both flanges on one of the pieces (a 1/4 section of the whole) detached as shown in figure 2. It appears that in the case where the joint failed in the braze area (see figure 3), the molybdenum cylinder wall was thick enough to withstand the differential expansion forces but that the braze joint was not. In the case of the other end, the thinner molybdenum wall was insufficient to withstand the forces applied (see figure 4). On closer inspection we found that the joint was not completely filled with alloy which would result in uneven loading and increased/concentrated stress. We think that this increased stress between SST and molybdenum may have contributed to both failures. We speculate that during braze cycle, a large radial gap between SST flange and molybdenum appeared due to larger thermal expansion of the SST flange. This gap may have cause the non-uniform filling of the joint by the alloy.

A possible solution that may reduce stresses caused by difference of thermal expansions could make use of an additional flexible part (in this case a cylinder) between molybdenum structure and SST flange. This thin-wall cylinder could be made out of stainless steel, CuNi, or copper and it should be properly designed to accommodate stressed created during the brazing. The joint between this flexible cylinder and molybdenum could be made with a grove that locks outside diameter of the cylinder as shown on figure 5a. This joint has to be properly designed to have adequate clearance when the parts at heated during the brazing. The design should also take into account thermally induced forces between the locking grove and the cylinder. The joint can be strengthened by locking not only outside diameter of the flexible cylinder, but also its inside diameter as shown on figure 5b. This, for example could be done for the flexible cylinder with large diameter.

We think that the joins between structure cells could be improved by removing a void created by two contact surfaces on the iris side of the cell. This void is clearly visible on figure 6. The void could contribute to gas contamination and gas load during structure brazing and operation. For example, if inner contact surface has a vacuum leak and larger-diameter contact surface is vacuum tight, than this may adversely effect structure operation but would be hard to detect using conventional vacuum leak detection. By removing second-larger-diameter contacting surface we can improve contact between surfaces and avoid the uneven-alloy-filling of the joint seen on zoomed part of figure 6.

We suggest a joint consisting of a single set of mating faces 1-3 mm wide between the body and iris. We may also use “nested” cells by creating a cylindrical step of ~1.5mm depth to lock the cells. The single mating surface will ensure contact at the cell-iris joint, would allow the cells to be made from much less material, and may significantly reduce the potential for contamination and virtual leaks. A multi-step braze sequence can be used to facilitate braze fillet control. In the noted design the first step would be a diffusion bond or an “alloy assisted” diffusion bond, if the body material and desired temperatures and pressures prevent direct bonding. Alloy assisted bonding uses temperature and pressure to create a bond between both sides of a filler (a thin “washer” in this case) and the base materials. If proper surface finishes, materials, temperatures, and pressures are used the resulting bond should be leak tight with a well “filled” joint. The joint can then be brazed traditionally with a lower temperature alloy to provide additional strength.

We think that for a case of copper-diffusion-bond and secondary braze the molybdenum can retain considerable hardness and strength. For example typical TZM (titanium zirconium molybdenum) molybdenum stress relieving schedule would run to 980 °C and a full re-crystallization schedule may run above 1180 °C for over an hour.

Bulk Molybdenum, three cells structure

The realization of second molybdenum brazed three-cell structure designed at LNF has been attempted. More details on the mechanical drawings and assembly will be given on a request.

Following the steps of the previous realization, the procedure began doing the machining of the structure components, three cells plus connections to the end CF flanges using a proper lathe and tools. Final machining of roughly 300 nm was obtained starting by a sintered Mo bar (figure 7).

Brazing procedure followed for the other molybdenum radio frequency structure has been applied. A film of electrodeposited copper has been applied to the joints surface in order to facilitate the operation.

This time during high temperature brazing sequence several problems were occurred. The following procedure was applied for each connection made between the pieces: brazed joints were removed from the vacuum oven, checked for vacuum leaks, and only if vacuum test gave positive results, the brazing procedure carried on.

Firstly, the external cells were brazed by using PalCusil 10 alloy (copper-based alloys are normally acceptable in the creation of relatively low resistance joints) with stainless steel flanges: the vacuum check gave positive results. After that the sequence continued with the brazing of the tuners; three cells, two tuners each one, means a total of six tuners. The braze of these pieces was performed in two steps.

Step 1: the first three tuners were joined using Palcusil 10.

Step 2: Once done, the other three tuners were brazed with Palcusil 5 in order to avoid problems with the previous joint done .

After that the entire structure was assembled and the final braze was attempted. To avoid problems related to previous brazed parts, Cusil was adopted because the brazing temperature is less than Palcusil.

Cusil was used to achieve the final structure, putting a thin layer of electrolytic copper placed at the joining surfaces.

After that, during vacuum check, a leak in the part of conjunction between the molybdenum and stainless steel was found. We tried to redo the braze to see if leak disappeared but without results. We tried to redo the brazing procedure alternating Cusil with Palcusil alloy but no improvements took place.

We also tried to make a new geometry of the joints surface to facilitate the brazing process, but again without results. In the figure 8 the assembled molybdenum structure is shown. Unfortunately the vacuum leak between the molybdenum and stainless steel right flange is again present.

The thermal treatments on the structure changed significantly the dimensions, especially in the conjunction area between molybdenum and stainless steel; in order to keep the initial dimensions the structure has been machined again and a new brazing process was attempted in order to close the vacuum leak at stainless steel flanges, but again without results.

Conclusions

The realization of second molybdenum X-band accelerating structure using brazing procedure has been described.

The first structure realized at LNF following the same procedure gave good results [1] .This time several problems were occurred. Thermal treatments on the structure changed significantly its dimension, especially in the conjunction area between molybdenum and stainless steel; the deformations unfortunately are stochastic and no repeatable, and this could be due to the nature of the material (sintered metal). If so, the future of the bulk Mo structures is linked to the possibility to find on the market the proper Molybdenum. Obviously other ways (with low stress on Mo) can be tested for the connections. For example:1) Tin brazing procedure or 2) Electron beam welding.

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Figure captions:

Fig 1 Moly structure was split up into 2 pieces using EDM.

Fig 2 When one of the sections was cut again (also by EDM) both flanges on one of the pieces (a 1/4 section of the whole) detached as shown

Fig 3 Highlight of joint failed in the right side of figure 2.

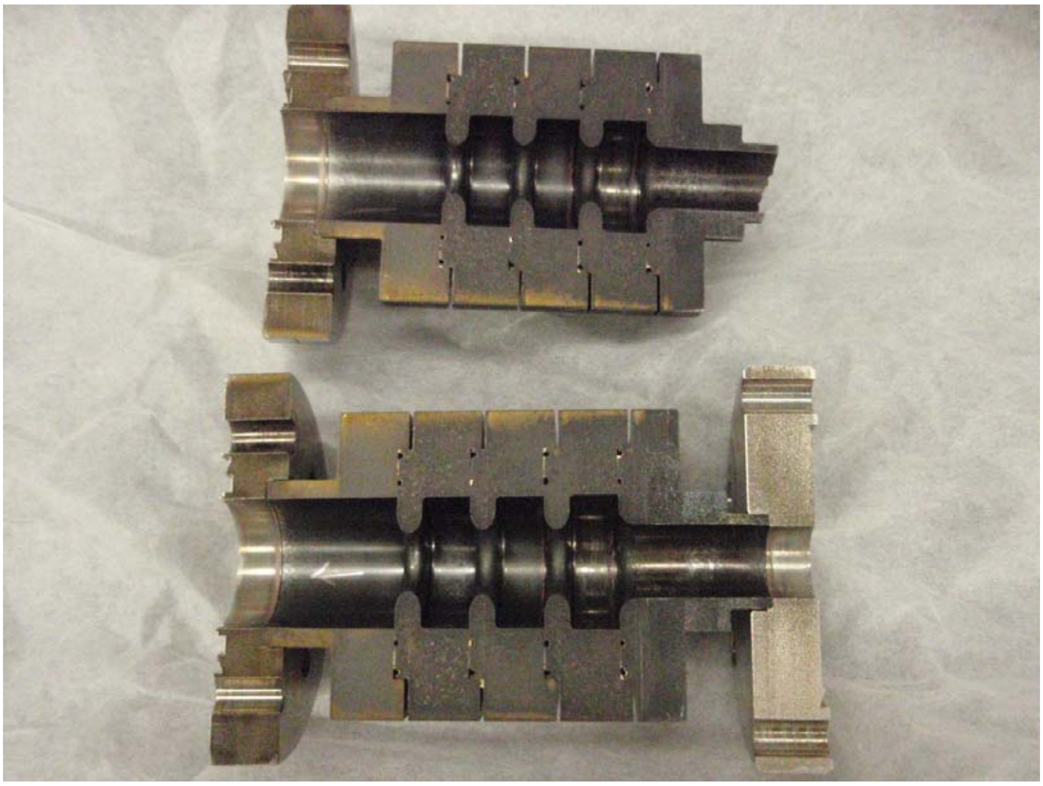
Fig 4 Highlight of molybdenum “extension tubes” failed adjacent to the SST flange in the left side of figure 2.

Fig 5 Possible joint designs between molybdenum and a flexible cylinder: a) locking outside diameter of the flexible cylinder; b) locking both inside and outside diameters of the flexible cylinder.

Fig 6 The image highlights a body/iris joint typical of moly structure.

Fig 7 Components of moly structure, three cells plus connections to the end CF flanges

Fig 8 The assembled molybdenum structure.



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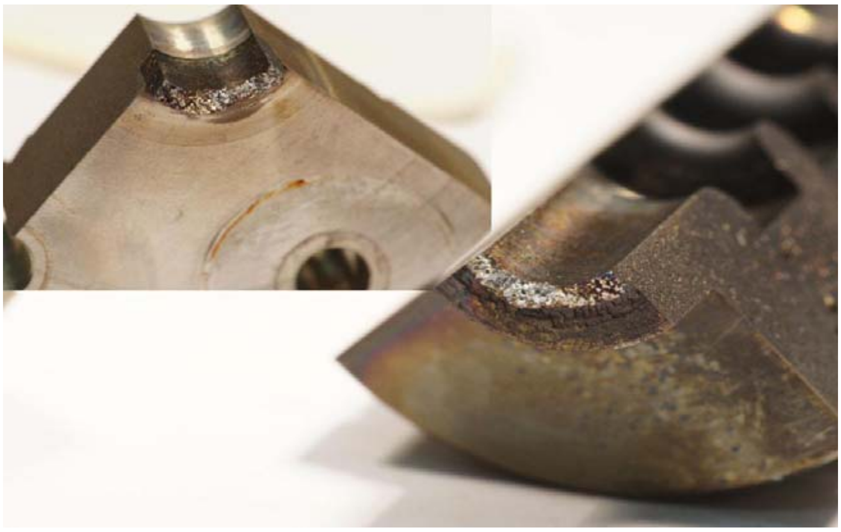

Fig 4 Highlight of molybdenum “extension tubes” failed adjacent to the SST flange in the left side of figure 2.

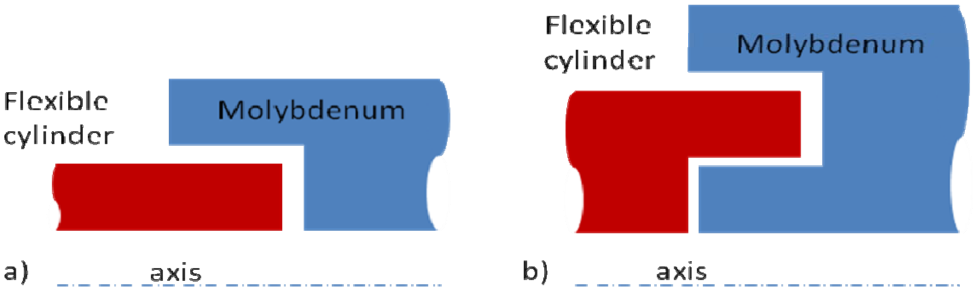

Fig 5 Possible joint designs between molybdenum and a flexible cylinder: a) locking outside diameter of the flexible cylinder; b) locking both inside and outside diameters of the flexible cylinder.

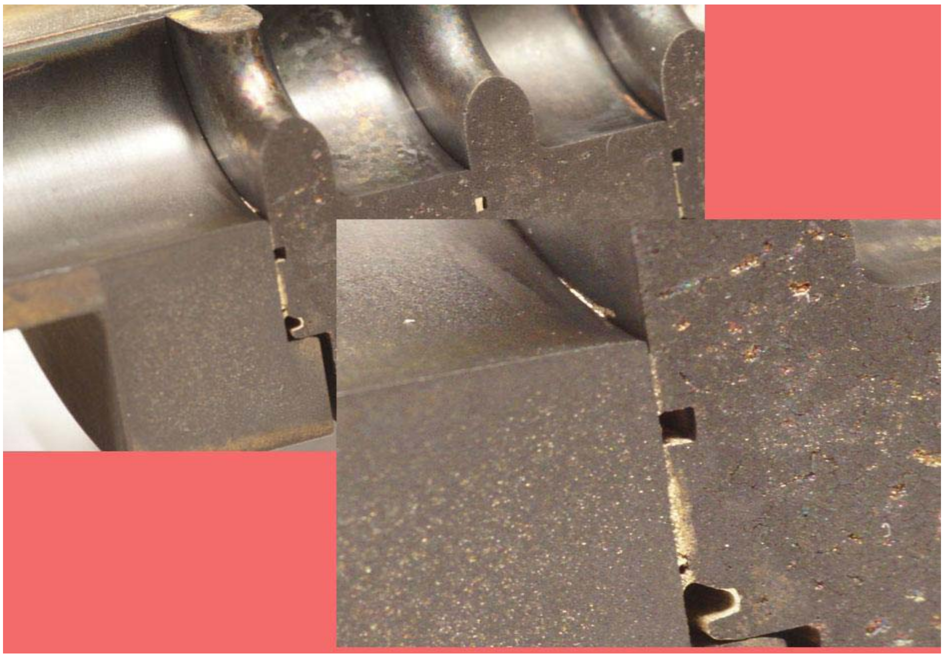

Fig.6 The image highlights a body/iris joint typical of moly structure.

Fig 7 Components of moly structure, three cells plus connections to the end CF flanges

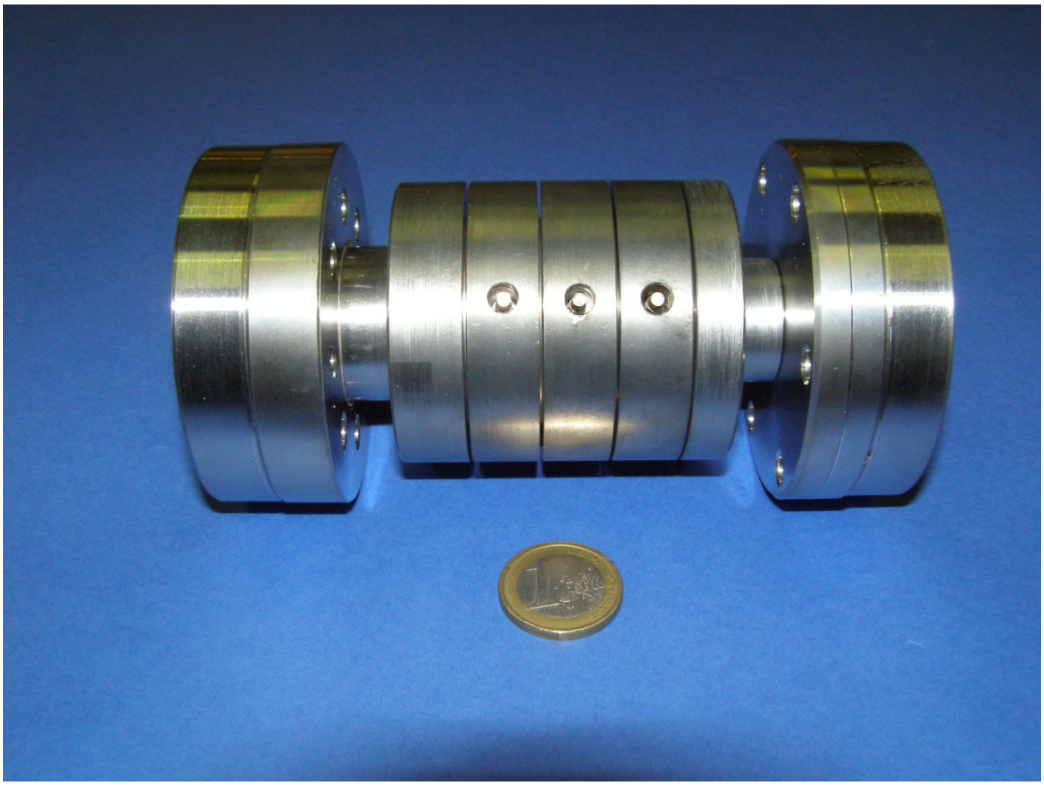

Fig. 8 The assembled molybdenum structure.