A NEW RF SHIELDED BELLOWS FOR DAΦNE UPGRADE

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Abstract

A new Radio Frequency (RF) shielded bellows, using the technology of omega shaped strip of beryllium copper material, has been developed and tested on DAΦNE UPGRADE [1] [6] [7]. The RF omega shield is composed of many Be-Cu strips held by an external floating ring. Thermal power loss on strips can be easily extracted and dissipated allowing high beam current operation. Leakage of beam induced electromagnetic fields through the RF shield is almost suppressed. Twenty omega bellows were manufactured and installed in the DAΦNE storage rings and showed good performances up to 1.9A stored current.

MECHANICAL STRUCTURE

The new shielded bellows designed for the DAΦNE upgrade [2] has a circular cross section with a bore of 88 mm. The inner diameter of bellows convolutions is about 130 mm, the outer one is 160 mm while the length is about 50 mm. An RF shielding has been used to avoid the chamber discontinuity seen by the beam as shown in Fig. 1.

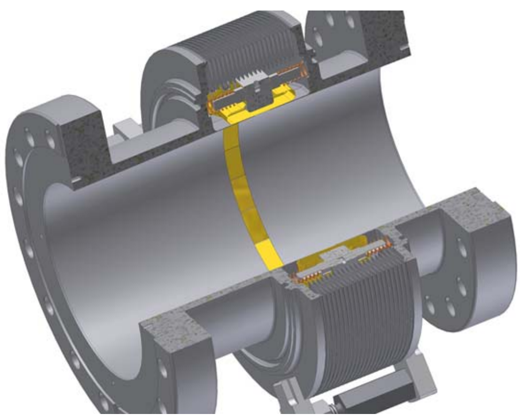

Figure 1: Section view of the RF shielded bellows (not cooled).

The shield is composed of 20 omega shaped Be-Cu alloy 25 strips of 0.15 mm thickness. The 20 formed strips are gold-coated with a thickness of 10µm and bolted on a thick aluminium annular ring. Two cylindrical AISI304 pipes are welded at the bellows ends and give continuity to the beam pipes except for the gap between them. The shape of the strips is preformed like an Ω. The aluminium ring supporting all the 20 omega strips is floating and centered on the gap by eight Be-Cu springs. The advantages of the RF-shield are the following:

(1) The RF shield has a high thermal strength due to the high thermal capacity of the annular supporting ring and cooling possibility shown in the next paragraph.

(2) There is a very small radial step (0.5 mm) on the inner surface of the beam duct.

(3) The RF shield can fit beam ducts with various cross sections.

(4) The axial stroke of the RF shield is structurally limited at ±7 mm.

(5) The maximum offset of the bellows is ±3 mm limited by strip detachment and bending angle is more than 50 mrad.

Table 1 summarizes the main parameters of the RF shielded bellows with shielding strips made of Be-Cu [3]. Fig. 1 shows an overall assembly view of the no cooled bellows. There are no specific devices to dissipate thermal power loss. In Fig. 2 there is a detailed view of the shielding and the centering system that pushes the sliding shielding always on the middle of the gap independently from the position or angle or radial offset of the external flanges.

Table 1: RF shielded bellows main parameters

	Be-Cu Strip
Axial Stroke	±7 mm
Radial Offset	±3 mm
Bend angle	50 mrad
Be-Cu strip thickness	0.15 mm
Minimum strip contact pressure	0.1 MPa

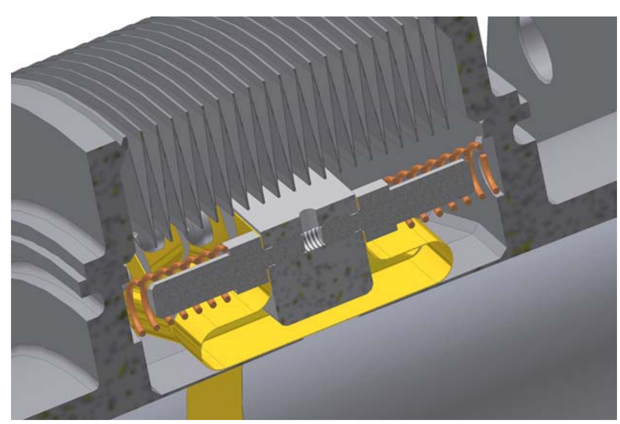

Figure 2: Detailed view of the RF shielding and centering system.

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Ω Strip Design

In order to obtain the maximum axial stroke and radial offset listed in table 1, a detailed study of the strips shape has been done. By means of finite element analysis the contact problem between the strip and the beam pipe was investigated. The optimization of the unloaded shape of the strip was performed in order to have the maximum contact pressure at the maximum radial offset and bending angle. After forming, the strip side facing the beam is planar and straight (see Fig. 3 (a)). Once the strip is bolted on the supporting annular ring it gets the required Ω shape like represented in Fig. 3 (b). In Fig. 3 (c) shows the assembling stage before bellows welding.

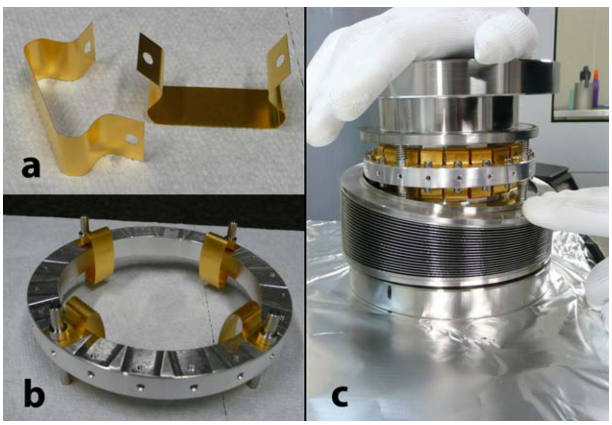

Figure 3: View of gold coated strip (a), supporting annular ring (b), RF shielded bellows assembly (c).

Ω Cooled Strips Shield

As shown in the next paragraph, the power dissipated on each strip is negligible in the case of DAΦNE and so no cooling is required. However for high energy accelerators, where the power loss on the strips is higher, a cooling system on the supporting annular ring is foreseen. The uncooled shielded bellows was modified as shown in Fig. 4. The bellows convolutions were split in two halves and an external cooling serpentine was set around the annular supporting ring. The mechanical performances are the same of the uncooled one while the thermal behaviour was improved.

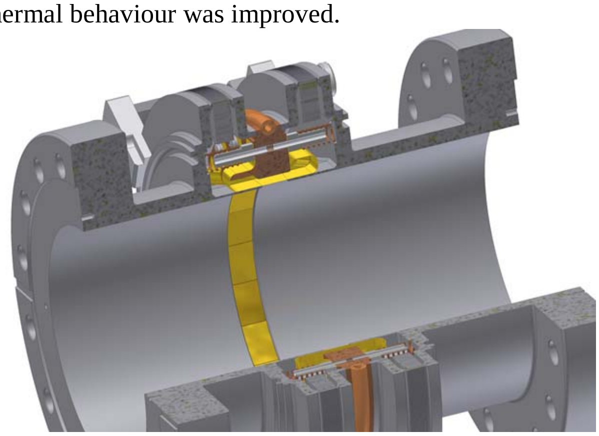

Figure 4: Pictorial view of the RF shielded cooled bellows.

A detailed view of the cooled shielding is shown in Fig. 5. The external serpentine is brazed on the outer skin of the supporting annular ring and it is TIG welded to the two lateral AISI304 flanges.

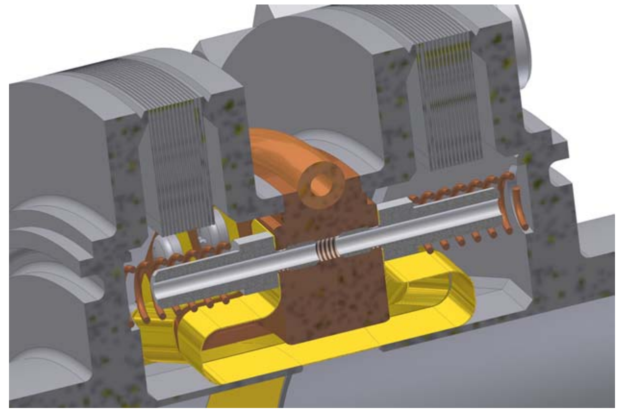

Figure 5: Detailed view of the RF cooled shielding.

BEAM IMPEDANCE AND POWER LOSS

The effects of the electromagnetic interaction between the bellows and the beam have been studied with the HFSS code [4] [5]. The geometry used in the simulations is a thin slice of the bellows (9 degrees since the shield is composed of 20 strips) with a conductor placed along the axis of the structure. Adopting the same principle of the wire method for impedance measurements, the current flowing through the central conductor simulates the beam current. The distribution of the fields generated at 1 GHz by the beam in the bellows is shown in Fig. 6. The scale of the representation is logarithmic and the plot shows that the intensity of the fields in the volume outside the shielding is very weak .The simulations have covered the frequency range from DC to 6 GHz: no HOMs have been found and even at the highest frequency the shields come out to work properly reducing the field intensity by several orders of magnitude.

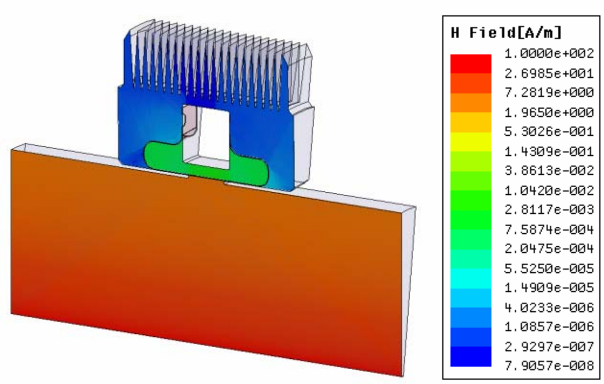

Figure 6: H field excited by the beam in the shielded bellows.

The coupling impedance of the device has been calculated by the following formula, generally used with the wire method in the case of small impedances:

$$Z_c = -2Z_0 \ln(S_{21})$$

where Z_0 is the characteristic impedance of the coaxial line composed of the wire and the beam pipe and S_{21} is the transmission coefficient of the scattering matrix between these two coaxial ports. The obtained values of coupling impedance are plotted in Fig. 7 up to the cut-off frequency of the first high order mode of propagation in the coaxial line. For a more accurate result, the plot has been divided into three different sweeps obtained from the meshes generated at three different frequencies.

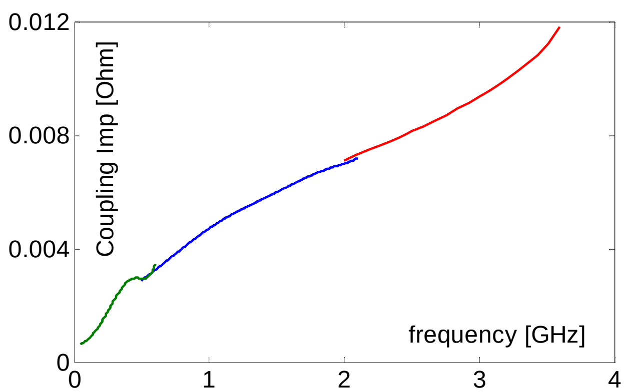

Figure 7: Beam coupling impedance obtained from simulations.

The power released by the beam to the bellows structure can be estimated from the calculated coupling impedance as:

$$P_b = \frac{1}{2}\sum_n Z_c(f_n) I_n^{\,2}$$

where I_n is the n-th line of the beam current spectrum in which the roll-off factor, due to the finite bunch length, must be included. Assuming a total beam current of 2 A, an r.m.s. bunch length 15 mm and all buckets filled, the power loss is 400 mW for the entire bellows. It is also important to evaluate the power dissipation in each Cu-Be strip in the shield because they are relatively thin and their heating could be a problem. This evaluation starts from the calculation of the tangential component, on the strip surface, of the magnetic field induced by the beam. This quantity (H_t) is plotted on the surface of two adjacent half strips in Fig. 8. H_t is concentrated in the region of the strip facing the beam, in the gap between the two aluminium rigid cylinders. Calling *g* the length of this gap and *w* its width and observing that H_t is almost constant along the longitudinal coordinate, the power dissipated in a single strip is evaluated from the formula:

$$P_{strip} = \frac{1}{2} g \left(\int_{-w/2}^{w/2} (H_t / I_b)^2 \, dw \right) \sum_n R_S(f_n) I_n^{\,2}$$

where H_t has been normalized to the beam current I_b and R_S is the Cu-Be surface resistivity.

With the same parameters for the beam of the previous calculation, the power loss in each strip comes out to be only about 0.5 mW.

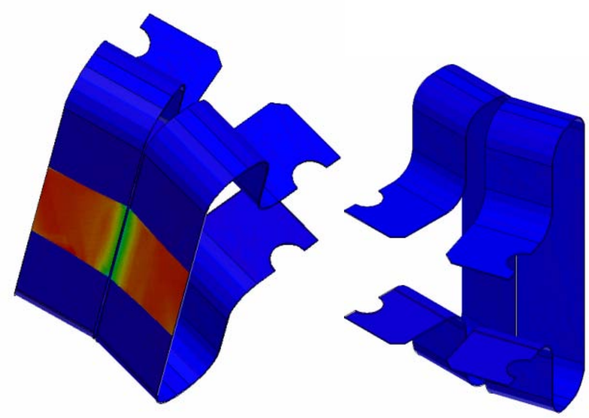

Figure 8: Tangential magnetic field (current distribution) on the strip surfaces.

CONCLUSIONS

Twenty RF shielded bellows without cooling system, were manufactured and installed on the DAΦNE storage rings showing good performances up to 1.9A. Improvements for high current accelerators are foreseen (see Fig. 4), and a prototype of the cooled type is under construction. Due to its large elasticity this solution is suitable for devices where large movement of the vacuum chamber are required. There are no limitations on the cross section shape of the beam pipe.

REFERENCES

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