DEVELOPMENT OF A NEW RF FINGER CONCEPT FOR VACUUM BEAM LINE INTERCONNECTIONS

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Abstract

RF contact fingers are primarily used as a transition element to absorb the thermal expansion of vacuum chambers during bake-out and also to compensate for mechanical tolerances. They have to carry the beam image current to avoid the generation of Higher Order Modes and to reduce beam impedances. They are usually made out of copper beryllium thin sheets and are therefore very fragile and critical components. In this paper, a robust design based on a deformable finger concept is proposed. It allows the compensation of large longitudinal movements and also defaults such as transverse offset, twist or bending. The concept of this new RF fingers is first explained, then the design of the component is presented. The mechanical study based on a highly non-linear Finite Element model is shown as well as preliminary tests, including fatigue assessment, carried out on prototypes.

INTRODUCTION

Requirements for RF Fingers

RF fingers are a common component assuring the electrical continuity between adjacent vacuum chambers in high intensity beam accelerators. They are usually associated with an outer leak tight bellows and flanges to form a module. They have to assure this electrical function despite possible relative movements between the chambers. To not introduce large impedance, they are made out of copper alloy and can be coated as required.

Deformable RF Finger Concept

Usually RF fingers are based on a concept that decouples the two adjacent vacuum chambers by using a thin finger that can be considered as a beam, sliding on a copper piece. In this case, the contact force between the RF fingers and the copper piece is assured by a spring. This geometry is sensitive to buckling or large plastic deformation during thermal transients [1, 2] and loss of electrical contact.

In this paper, a new concept is presented and developed [3]. It is based on a flexible and deformable thin element that is attached or connected to the adjacent vacuum chambers. The mechanical movements required for the installation, commissioning or operation are compensated by the deformation of the fingers. The proposed geometry is similar to a bellows with convolutions to compensate the displacements but with additional longitudinal grooves to avoid circumferential compressive stresses and therefore local buckling (Fig. 1). In the operation configuration, the convolutions are stretched and almost straight to reduce the impedance. It allows also a smooth transition, without geometrical steps, between the fingers and the chambers.

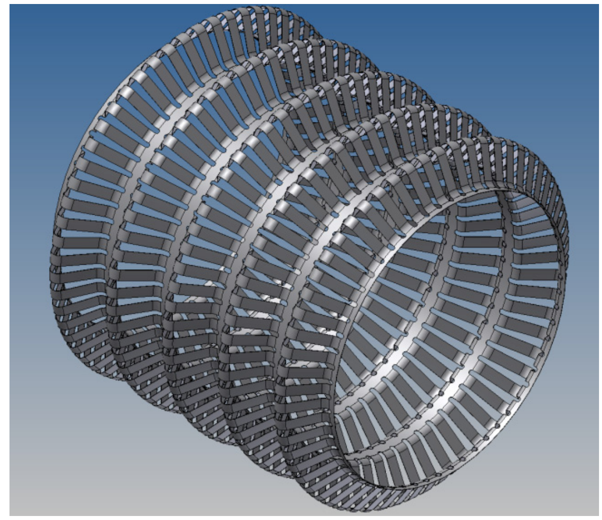

Figure 1: Deformable RF fingers in free configuration.

STUDY OF THE DEFORMABLE RF FINGERS

Design of the Deformable RF Finger

Preliminary tests with samples based on a single convolution have been carried out to assess the influence of the thickness on the global behaviour and the fatigue life of the deformable fingers. They have led to the choice of a copper beryllium alloy sheet of 0.1 mm thickness, in the half hard state. Basic mechanical properties have been measured by tensile tests at room temperature and at 150 °C. Results are presented in Table 1.

Table 1: CuBe Tensile Properties

Temperature [°C]	Young Modulus [GPa]	Yield stress [MPa]	Tensile strength [MPa]	Elongation A%
20	117	616	659	13.2
150	117	580	668	12.4

A height of 12.5 mm has been considered. This corresponds to a reasonable dimension to avoid interference between the RF fingers and the bellows end fittings. Then the geometrical parameters of the convolutions, namely the bending radius and the angle at free position, have been optimised by a Finite Element analysis. A half convolution has been considered. A 2D massive model has been used with the plane stress state assumption. An elastic-plastic model with a linear kinematic hardening has been used for the material. The hardening modulus has been estimated at 1000 MPa.

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Large displacements have been considered. It is assumed for impedance reasons that the operation configuration is defined by an angle α equal to 10 °. This corresponds to a half convolution length of L_{max} (Fig. 2).

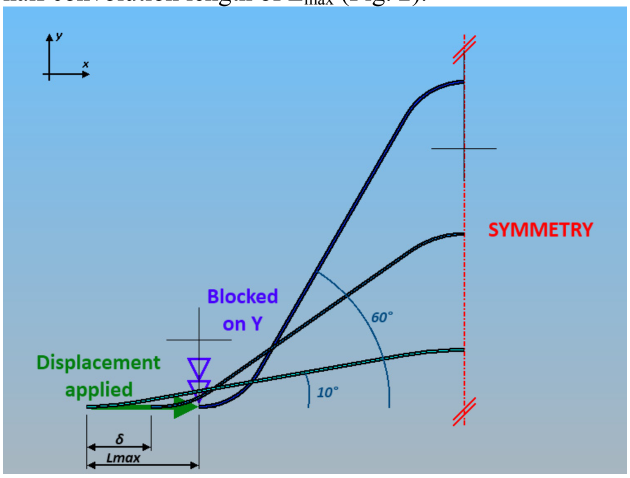

Figure 2: 2D model of an half convolution of the RF finger.

To define the bending radius, its influence on the fatigue life, driven by the accumulated plastic strain, $\Delta\varepsilon^{p}$ over a cycle, has been studied (Fig. 3). It is given by eq. 1, where $\underline{\underline{\dot{\varepsilon}}}^{p}$ stands for the plastic strain rate tensor.

$$\Delta\varepsilon^{p} = \int_{cycle} \sqrt{\frac{2}{3} \underline{\underline{\dot{\varepsilon}}}^{p} : \underline{\underline{\dot{\varepsilon}}}^{p}}\, d\tau \tag{1}$$

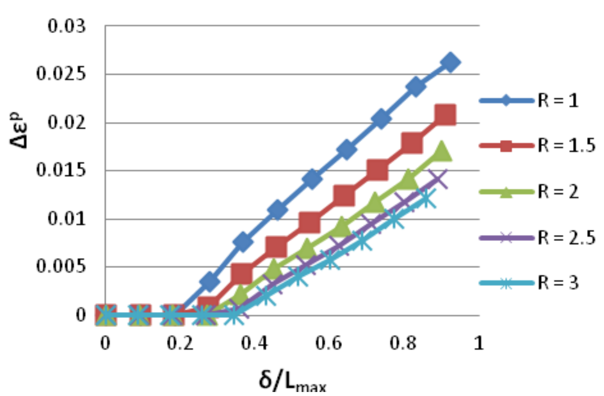

Figure 3: Influence of bending radius on the accumulated plastic strain.

It turns out that the plastic strain over a cycle is minimum for bending radius equal or higher than 2.5 mm. This value has been chosen as the baseline. The angle α in the free position has been determined to limit the compression stresses and compressive forces that could induce local or column buckling for RF fingers with several convolutions. It has been fixed at 60°.

The Fig. 4 shows the evolution of the angle and the axial force on an half a convolution as a function of the axial displacement. As expected, the force increases dramatically when the finger is almost straight and this represents the most critical aspect of this design. Over-extension has to be avoided. The nominal stroke defined by the two configurations, finger almost straight with an angle α and finger compressed in contact, is given in Table 2. The maximum possible extension is defined by the difference between the neutral fiber length and the convolution length in the free position. The margin obtained by the extension of the finger due to tensile force is not taken into account. The tolerance in tension per convolution, with respect to the nominal operation configuration, is shown in Table 2 as function of the operation configuration.

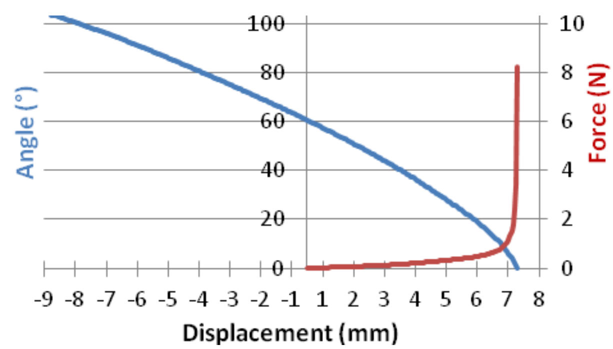

Figure 4: 2D model of an half convolution of the RF finger.

Table 2: Nominal Stroke and Acceptable Tolerance in Extension for One Convolution

	Nominal angle [°] 5	10	15	20
Nominal extension	13.1	12.4	11.6	10.9
Nominal compression [mm]	-16.5	-16.5	-16.5	-16.5
Tolerance in extension [mm]	0.28	0.94	1.64	2.39

Mechanical Behaviour of Flexible RF Finger

This new concept has been applied as an alternative for the replacement of a standard vacuum module installed in the LHC. The proposed concept has to be adapted to the existing design and space constraints. For this application, a deformable RF finger based on two convolutions could be used. From an RF point of view, the same width and ratio of RF fingers as the existing solution is used. The mechanical behaviour of the fingers from the free position to the operation configuration, i.e. with an extension of 24.7 mm, with or without misalignment has been studied. The Von Mises stresses after extension is shown in Fig. 5. Stress concentrations are localised in the root and the crest of the convolution where high bending occurs.

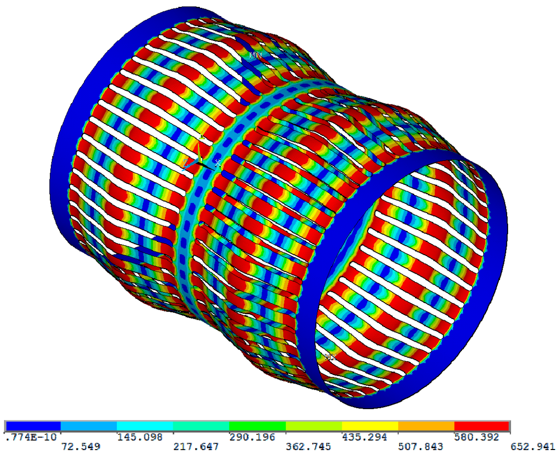

Figure 5: Von Mises stress field in extension.

Fatigue Tests

The empirical Manson Coffin equation is usually used to determine the low-cycle fatigue of metals. It reads:

$$N_f^{\beta}\Delta\varepsilon^{p} = C \qquad (2)$$

where N_f and $\Delta\varepsilon^{p}$ denote the number of cycles to rupture and the plastic strain range (or the accumulated plastic strain) over a cycle, respectively. β and C are two material constant. They can be found in the literature for torsional tests [4] and these values have been converted to an equivalent tensile test considering the accumulated plastic strain over a cycle. The two material parameters are equal to 0.3 and 0.18, respectively [4].

First fatigue tests have been carried out on non-rolled one convolution geometry (Fig. 6). The accumulated plastic strain over a cycle has been estimated by Finite Element simulations for different stroke applied during the tests. Results are presented in Fig. 7, representing the fatigue curve. Material parameters, β and C, have been evaluated to 0.36 and 0.09, respectively. The fatigue failure occurred at the crest of the convolution and the parts remained out of the aperture.

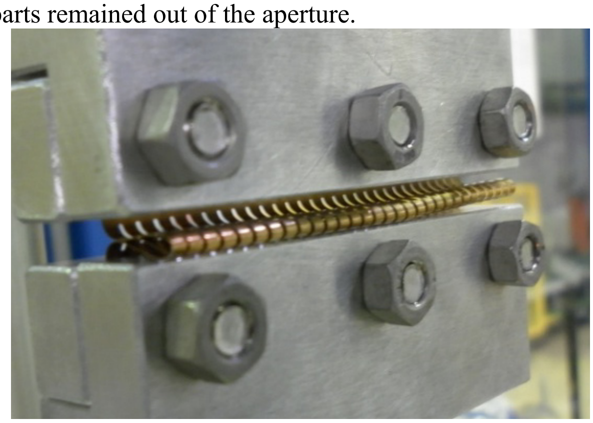

Figure 6: First fatigue tests on deformable RF fingers.

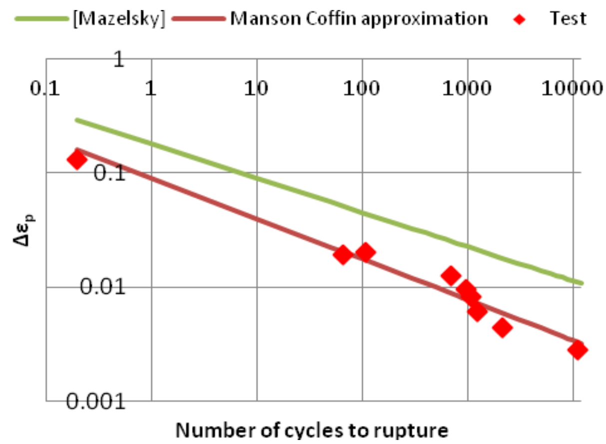

Figure 7: Fatigue curve for the deformable RF finger.

CONCLUSION

A new concept of RF fingers has been presented. It is based on a deformable thin structure, similar to a convolution that exhibits a robust behaviour. It is easily adapted to other geometrical configuration and can cope with significant misalignments or geometrical defects. This concept is also interesting from the RF point of view since it offers a smooth transition between the two adjacent vacuum chambers and avoid loss of electrical contact.

A short prototype that could be used for the LHC TAS module has been designed. It is being manufactured and will be tested. Further tests on rolled RF fingers are foreseen including fatigue tests at room temperature and at higher temperature and tests with misalignments.

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