SLIDING FORCE MEASUREMENTS ON THE LHC RF CONTACT PLUG IN MODULES AT 15 K AND IN UHV

K.Artoos, M. Guinchard, T. Renaglia, CERN, Geneva, Switzerland

Abstract

Some sliding RF contacts mounted in the Plug In Modules in the LHC interconnects failed during a thermal cycle between 4.2 K and room temperature. Gold-coated copper-beryllium RF fingers buckled during the warm up of the machine, indicating that one or more parameters during operation (e.g. the friction coefficient under vacuum) could be different from what was used in the calculations. This report describes the measurement of the longitudinal forces acting on the sliding RF fingers at operating vacuum and temperatures.

INTRODUCTION

In the LHC beam vacuum interconnects, the low resistance electrical continuity between the beam screens is achieved with a set of gold-coated copper-beryllium RF contact fingers that slide on a rhodium-coated copper transition tube (figure 1). The contact is made sliding to allow for thermal expansion. The assembly of RF contact, bellows, beams screen transition pieces, cooling tubes, flanges and transition tubes is called Plug In Module (PIM) as it is inserted fully assembled with the beam screen in the cold bore tube.

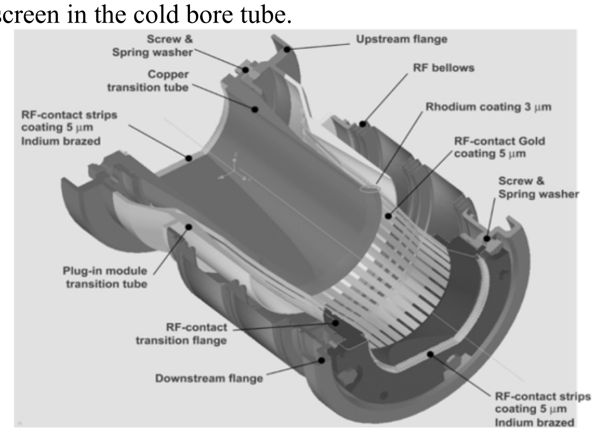

Figure 1: Layout of the LHC Plug In Module

The shape of the RF fingers that act as springs, the shape of the plug in module transition tube and the materials are selected to minimise the electrical impedance of the beam screen interconnect for the image currents.

After the warm-up of the first tested arc of the LHC, some buckled RF fingers were found. This is a serious problem as the RF fingers bent inwards, hence obstructing the beam. Several reasons for the buckling were proposed, one being the presence of excessive friction forces under the ultra high vacuum due to cold welding between the materials. Another possible reason was that during the production, the design shape of the RF fingers was modified to a shape with higher angles resulting in a higher contact force. This paper describes the measurements made to verify the proposed reasons.

MEASUREMENT SET-UP

The measurement set-up was built in order to have similar conditions as in a LHC PIM. The set-up is made of an UHV container that is put in a liquid helium bath at 4.2 K (figure 2). A PIM with removed bellow is placed vertically and the RF fingers are moved up and down between the rhodium-coated copper transition tube and the stainless steel PIM transition tube. The RF contact can be moved with a total range of 65 mm with a velocity that can be selected between 0.05 mm/min and 5 mm/min. The RF fingers are directly attached to a custom built force transducer that measures the sum of friction forces and the longitudinal component of the spring forces acting on the 30 RF fingers. The force transducer, based on strain gauges (HBM-LC11 glued with MM MB610) [1], is built and calibrated to work at 15 K and in UHV with a relative precision of ±5 % and a resolution of 0.05 N.

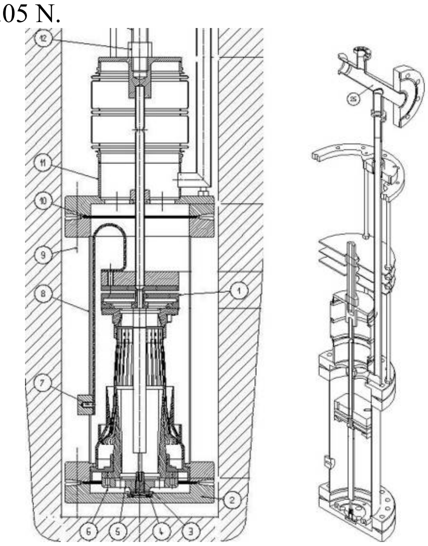

Figure 2: Measurement set-up

A precision linear conductive potentiometer (Pewatron LP-100FP-1-SW5) was conditioned to measure the displacement between the RF contact and the copper transition tube at 15 K and in UHV. The distance between the base of the RF contacts and the copper transition tube (called span) was measured with a precision of ±1 mm at the span of 93 mm with a resolution of 0.01 mm.

The parts in the vacuum are thermalised to have the RF fingers at a temperature of 15 K. The temperature is measured with two CERNOX thermometers positioned on the base of the RF fingers and copper transition tube.

A vacuum measurement directly at cold in the UHV volume was not available. A turbo molecular pump pumped the UHV volume for several days before (without bake out) and during the cool down. The temperature difference during and after the cool down, between the RF contacts and the UHV container in contact with the liquid helium bath provided significant cryo-pumping. The vacuum measured at the exit of the pumping tube from the cryostat was 5E-7 mbar. The vacuum inside the UHV volume is estimated to be 2 orders of magnitude higher.

MEASUREMENTS

Tests were performed on three PIM of the type that failed in the tunnel (SSS-MB). The first tested set PIM1 had nominal RF fingers. PIM2 had a shape bent back from a shape with larger angles. Finally, PIM3 had a shape with larger angles that resulted in higher contact forces.

Longitudinal forces over the nominal span

The RF fingers were moved in two directions between the position at warm after installation (span 48 mm) and the nominal position after cool down to 15 K (span 82.5 mm) at a velocity of 1 mm/min.

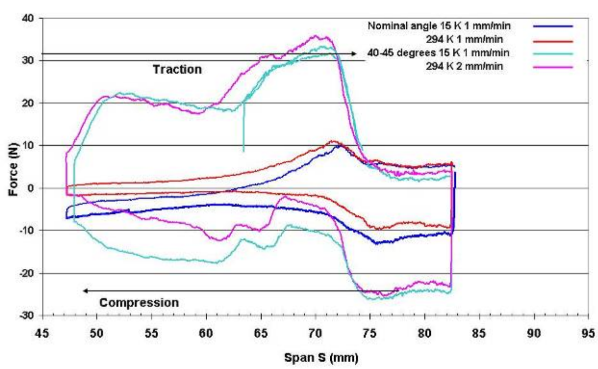

Figure 3: Longitudinal force over the nominal span

As mentioned before, the measured force is the sum of friction forces and the longitudinal component of the spring forces of the 30 RF fingers. Between span 48 and 72 mm, the RF fingers are bent to follow the shape of the PIM transition tube and the measured force increases until the tip of the RF fingers pass over the narrowest position at span 72 mm. The longitudinal component of the spring force is also measured without moving the contact and remains in the same direction when the movement is inversed. The curves on figure 3 are hence not symmetric around the zero. The measured forces can also remain compressive even when the RF fingers are moved in the direction of traction, as e.g. between span 48 and 60 mm where the copper transition tube opens the RF fingers at their base. Moreover, movement will change the shape of the RF finger and the friction force will hence depend on the direction of the movement. The longitudinal forces are significantly higher for the RF fingers with larger angle. The differences between measurements made at room temperature and 15 K are relatively small. A 20 % increase was measured at span 82.5 mm (nominal cold position) from room temperature to 15 K for the fingers with nominal angle and 10 % increase for the fingers with large angle. This increase is mostly due to the increase of Young modulus, resulting in a higher contact force.

Longitudinal compression at cold

At 15 K, the extended RF contact will operate between the nominal cold position at 82.5 mm and the maximum extended position at 92.5 mm. In this region, the fingers are the most sensitive to buckling. The RF fingers were moved to positions in this critical span and then left for a time without moving (several hours to a maximum time of 72 hours) to allow for eventual cold welding. The time scale needed for junctions to form between metallic surfaces is of the order of minutes [2]. During the first minutes, after stopping the movement, some slow release of longitudinal force was observed. This release is probably due to the spring force of the RF fingers, elastically deformed during the movement, which releases in the friction contact. After the hours of idle time, the RF fingers were moved in the compression direction, hence simulating the start of a warm up, at a velocity selected between 0.05 and 1 mm/min. The compressive force increased first with only little movement (built up of spring force in the RF fingers), until the maximum static friction is reached and the contact starts sliding (figure 4).

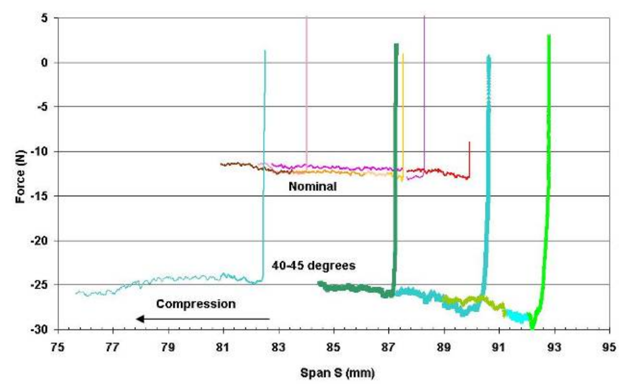

Figure 4: Static compressive forces where the fingers start sliding

Given the very low velocity of the movement (quasi static) and the fact that the measured force is the sum of the forces on 30 fingers, there is no visible difference between the static and the dynamic friction force. There is also no significant influence from the velocity for movements below 1 mm/min.

The static longitudinal force is two times higher for the PIM with RF fingers with a larger angle. For spans between 82.5 mm and 93 mm, the shape of the fingers is very different (figure 5). While the nominal fingers are practically straight over the span, the fingers with a larger angle bend inwards and exert a longitudinal compressive spring force and the sliding becomes less stable between 87 and 93 mm span.

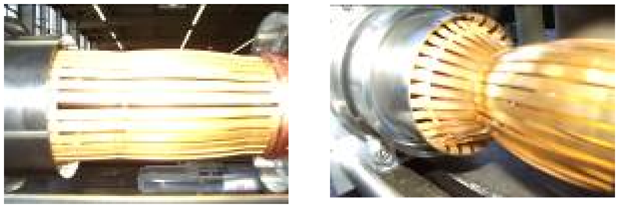

Figure 5: Shape of the RF fingers at critical span for nominal and large angle

Cold welding and "sticking" fingers

On the three tested PIM, 45 tests were carried out. After each stop or change of direction enough idle time was left to allow for cold welding. During 23 tests, the RF contact was left without moving for several hours in the range of the critical span. From the entire measurement campaign only one event can be interpreted as a finger that "sticks" under compression inside the critical span. The test 1_compression6 was measured with PIM1 with nominal RF fingers after an idle time of 72 hours (figure 6). The force increased about 2 N before it started sliding at the force level seen before. This is the level of force that can be expected from one or two fingers that stick. The contact force per finger is about 0.5 N. This test was repeated several times with long idle time but no other similar events were observed and not a single finger buckled. With the timescale for bonding of metallic surfaces under vacuum around a minute [2] and the number of tests carried out, one can conclude that there is only a small probability for cold welds to occur.

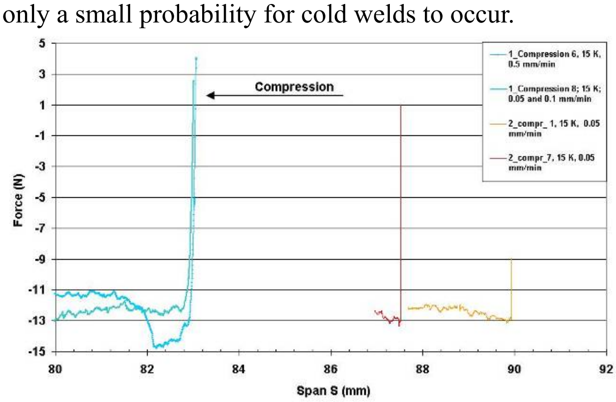

Figure 6: A single "sticking" RF finger

Comparison with calculations

The friction coefficient can not be deduced directly from the measurements as the contact force is not measured. A finite element model was however built [3] and forces in the critical span were calculated at 15 K for different friction coefficients. The level of forces measured corresponds to equivalent friction coefficients around 0.4.

Geometry problem for PIM with large angles

A structural problem was observed for the PIM with RF fingers bent at a larger angle. For a span between 88 and 93 mm, the fingers are bending inwards and there is not enough space for the 30 fingers. The fingers touch each other and some fingers are pushed more inward (figure 7). The contact forces and hence longitudinal forces on such fingers are higher, increasing the chance for buckling. On a mock-up it was observed visually that those fingers slide more irregularly.

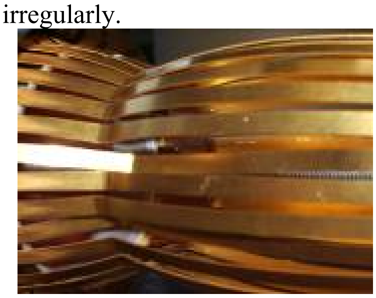

Figure 7: Geometry problem for PIM with higher angle

CONCLUSIONS

The measurement set-up discussed in this paper allowed measuring the longitudinal forces acting on the LHC Plug In Module RF fingers with the same conditions as in the LHC machine and with the required resolution. The forces measured on the RF fingers with nominal geometry were low. For the RF fingers with higher angles the forces were about twice as high. For both cases the equivalent friction coefficients can be considered low for metallic contacts under vacuum. There were only very few indications of fingers that stick over a short distance. There were no indications of cold welds for the three tested plug in modules and none of the fingers buckled

The friction becomes however less stable at the end of the available span for the RF fingers that were pre-bent at higher angles. In the range between 88 mm and 93 mm some of the fingers touch each other and fingers are moved more inwards. Those fingers have a higher chance of buckling.

Acknowledgements

The authors wish to thank the CERN cryo-lab (AT/CRG) for the efficient support to obtain the low temperature and UHV conditions during the tests.

REFERENCES

[1] K.Artoos et al., Performance of strain gauges in super fluid helium, variation of apparent strain and k-factor, CERN technical note EST-ESI/97-1, Geneva, 1997

[2] R.Budakian et al., Time scale for cold welding and the origins of stick slip friction, Physics Department University of California, Los Angeles, March 2002

[3] D.Ramos, Modelling of the RF-shield Sliding Contact Fingers for the LHC Cryogenic Beam Vacuum Interconnects Using Implicit and Explicit Finite Element Formulations, TUPD035, EPAC08, Genoa, June 2008