EXPERIMENTAL AND THEORETICAL ANALYSIS OF THE TESLA-LIKE SRF CAVITY FLANGES*

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Abstract

In view of the future large SC accelerator, an improvement of the reliability and cost reduction of the SRF cavities cold flanges is required. In this paper, a critical analysis of the TESLA-like cold connection flanges at room and at cryogenic temperature is presented. This analysis is based on experimental characterization of the mechanical properties of the joint and of the leak rates during the sealing process. A FE model, that agrees with the experimental data, is also presented. This model is being used for the optimization of the present SRF flanges and the development of new cold connections.

INTRODUCTION

An analysis of main ancillaries of SRF cavities is going on to highlight possible criticalities for future large accelerator facilities, like ILC (International Linear Collider). Among the main ancillaries [1], flange connections play a crucial role and an improvement of the sealing reliability, a reduction of their cost, a decrease in assembling time and a shortening of the junction dimensions are some of the key points to take into account. As a matter of fact, tests on different type of joints, at room and at cryogenic temperature, have been performed by several laboratories [2-5]. A research activity, mainly focalized on a critical analysis of the TESLA-like beamline connection flanges, is going on at LASA since 2005 [6]. The development of a Finite Element Model (FEM) and its experimental validation are presented in this paper, together with the analysis of the seal generation and joint behavior in different temperature conditions. The good agreement, between the developed FE model analysis and the experimental results, opens new strategies for the study of new reliable connection solutions. In particular, the success of the FE model will allow to develop improved seals by optimizing important parameters, such as the compression force, the groove and seal geometry and the gasket material.

In the following sections, after a brief description of the experimental set-up and of the FE model, a critical review of the obtained results is presented as well as future developments.

MECHANICAL MEASUREMENTS

Compression tests on gaskets

To understand the sealing behavior and to obtain the necessary parameters for the validation of the numerical model, several tests on diamond shaped gaskets have been performed, both manually and using a compression testing machine (Instron). These tests were carried out both at room and LN_2 temperature using two flanges machined following the TESLA specifications. As far as concern the gaskets, two aluminum alloys, typically used at the TESLA Test Facility (TTF), were tested: Al5754 and Al6060. Furthermore, the manual compression tests have been performed adopting the standard torquing procedure used at TTF, with 12 M8-A4 bolts and washers and CuNiSil nuts.

The most important results obtained are here summarized:

- evaluation of the gasket squashing as a function of the compression force and of the gasket alloy;
- analysis of the seal after several compression tests (loading/unloading cycles);
- experimental relation between compression force and bolts tightening torque considering the effect of friction, reported in Fig. 1 (f is the friction coefficient);
- understanding of the sealing process and evaluation of the lowest load necessary for a tight seal.

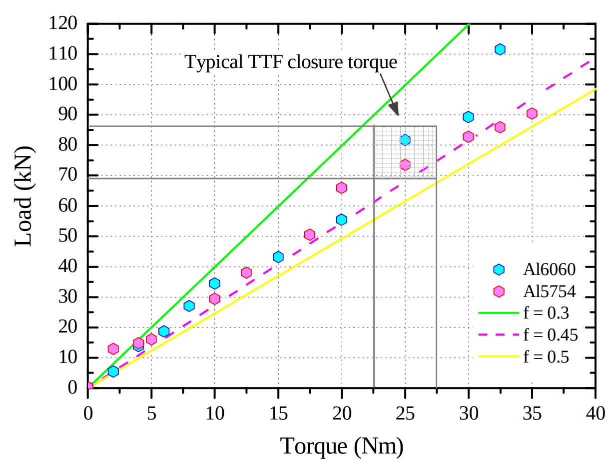

Fig. 1: experimental relation between torque and compression force (A4 bolts, CuNiSil nuts). The typical TTF torques and corresponding experimental loads are highlighted in the gray box.

Material characterization of Al alloys

In order to numerically simulate the behavior of the connection, the mechanical characteristics of the two aluminum alloys have been evaluated by tensile tests performed at Politecnico di Milano, while for the stainless steel and NbTi flanges the nominal material characteristics have been assumed. The obtained results for the gasket alloys are reported in Table 1.

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Table 1: material characteristics from tensile tests. E_y and E_t are the elastic and hardening modulus, f_y and f_t are respectively the yield and the tensile strength.

Alloy	E_y (MPa)	f_y (MPa)	E_t (MPa)	f_t (MPa)
Al6060	66551	198.1	545	229.2
Al5754	71175	199.7	320	243.6

FE MODEL AND ANALYSIS

The model

An axisymmetric model has been develop to describe the geometry of the flange connection. Material and geometrical non linearity have been considered.

The model consists of 1787 plane elements, 82 target elements and 237 contact elements for a total of 5822 nodes (see Fig. 2).

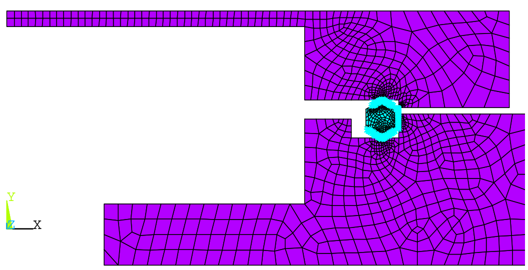

Fig. 2: finite element model of the connection. In violet, the upper and lower flanges and in light blue the gasket.

Results

The experimental and numerical results are compared in Fig. 3 for the two aluminum alloys respectively.

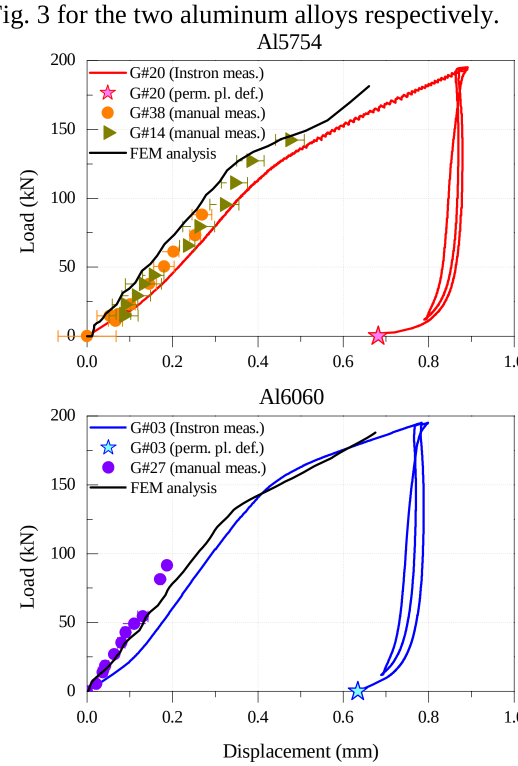

Fig. 3: flange compression curves for the two different aluminum alloys.

In the plots, we show the FE results and the experimental data measured both manually and with the compression machine. The star markers indicate the permanent plastic deformation of the gasket after the compression tests. The good agreement between the simulated and measured data confirms that the numerical model describes well the behavior of the connection. A further information obtained from the tests is the pressure acting on the gasket surface, defined as the ratio of the total compression force and the gasket flattened surface. These values are reported, as a function of the compression force, in Fig. 4 and there compared with the data obtained by the numerical analysis. The agreement is good also in this case, except for low loads, probably due to a too large mesh in the FE calculation and to the difficulties in measuring the small flattening.

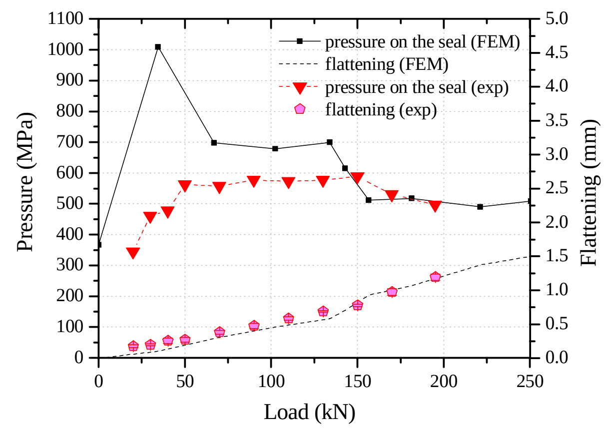

Fig 4: flattening and pressure on the Al5754 seal.

VACUUM LEAK TESTS

The characterization of the connection has been completed performing several vacuum leak tests to study the onset of a leak-tight sealing (leak rate lower than $1 \cdot 10^{-9}$ mbar·l/s and pressure on the gasket constant [7]).

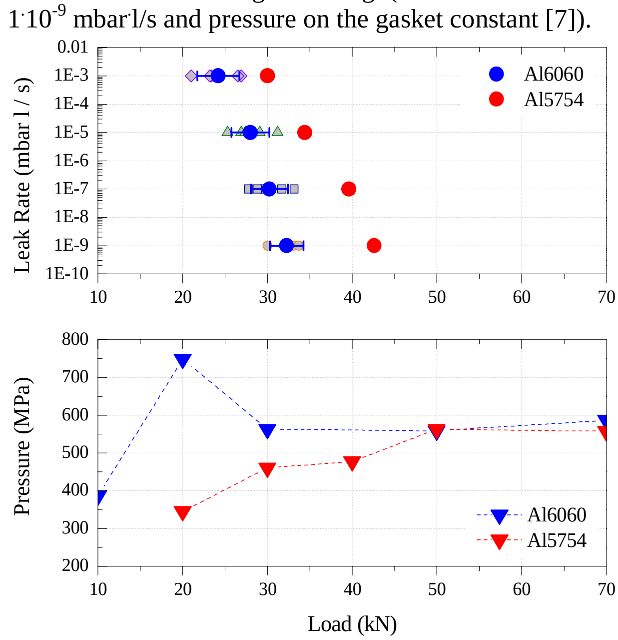

Fig. 5: leak rate and pressure on the gasket vs. load.

The results show that the two gaskets behave in a similar way, with the only exception of the load necessary to generate the seal, higher for the Al5754 alloy. The leak rate is reported in the upper plot of Fig. 5, while the estimated pressure is reported in the lower one.

COLD TEMPERATURE EFFECTS

Influence of temperature: a simple analytical model

In order to describe the temperature influences, a spring model has been developed, based on simple considerations and on the experimental results shown before. The model is sketched in Fig. 6 and it is based on the following assumptions:

- the bending of flanges is negligible;
- the elastic deformations of flanges are negligible;
- the bolts behave in linear elastic way (Hooke's elastic law);
- the connection is in thermal equilibrium, therefore the transient phase is not considered or the dynamic effects can be considered as quasi-static (low temperature gradient).

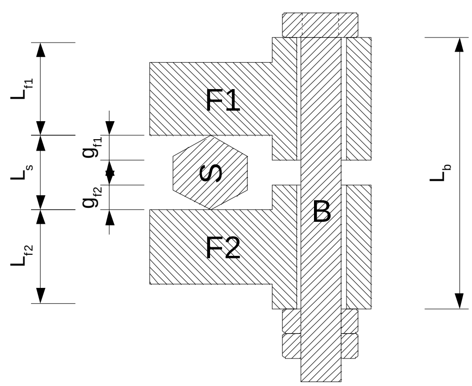

Fig. 6: simple model for the analysis of thermal effects.

For sake of space, the description of the model can not be reported here, but we can state that, after the first thermal cycle from room to LHe temperature and back, the load variation on the gasket remains restricted to about 11 kN [6]. This value, for the typical TTF tighten torques (Fig. 1), does not compromise the quality of the seal as shown in Fig. 5.

Thermal cycle tests

At the end of our study we stressed one joint with 20 thermal cycles between room and LN_2 temperature. The joint, closed with a tightening torque of 25 Nm, was directly sink in liquid nitrogen and let to cool for 10 minutes. Every time the joint was leak checked both at cryogenic and at room temperature. The connection performed well and the measured leak rate was always less than $1 \cdot 10^{-10}$ mbar·l/s.

In order to evaluate the criticality of the tightening procedure, a last test was performed on a joint applying a lower torque, near to the one necessary for the leak-tight seal generation. We observed that a joint bolted with a 12 Nm torque (about one half of the typical one used for the TTF beamline flanges) remain leak tight also after one thermal cycle in LN_2.

CONCLUSION

The experimental tests performed on a TESLA-like connection and the developed finite element model have been briefly described. The behavior of the joint has been well reproduced by FE model and the sealing mechanism has been also experimentally studied to obtain a correlation between the compressive force and the vacuum leak rate.

The TESLA flange connection has shown good performances. Nevertheless, we identified some drawbacks that should be removed, in view of a large use of this kind of connection as foreseen for ILC. The most important are:

- the tightening procedure, in "clean room" conditions, is complicate and time consuming;
- the use of bolts or stud bolts require an important longitudinal clearance that reduce the machine filling factor;
- the high number of bolts increase the probability to make mistakes in the tightening procedure.

ACKNOWLEDGEMENTS

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