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FEM ANALYSIS OF ULTRA-FLEX GASKET FOR **ILC** CAVITY FLANGES

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INTRODUCTION

In previous studies [1] we used Ultra-Flex gaskets [2] to replace the gasket in the flanges of TESLA cavity design. While advantageous for requiring a very low compression force and for being quite easy to clean, these gaskets have shown some weak points during thermal cycling that introduce local, sometimes non-permanent, leaks inside the vacuum volume. We believe the reason was a very low spring-back value (~ 50 μm) as resulted in the experimental leak-rate/load/compression plot for this kind of gasket (see Fig. 3).

We want to understand if this limitation can be removed by making moderate changes in the gasket geometry and for that reason we have developed an FEA model to simulate its behavior. In particular, we want to study the correlation between the torus diameter and the spring-back value. The results of this analysis are reported below.

1. GARLOCK ULTRA-FLEX GASKET

The Ultra-Flex gasket (cross section in Fig. 1) is a new kind of metallic o-ring developed by Garlock to replace the standard elastomer o-ring with the same advantage of the standard metallic o-ring (low permeability, high purity, low out-gassing, etc.) plus the advantage to properly seal the vacuum volume even with an applied lower load (90% less than the standard Helicoflex gasket).

The Ultra-Flex gasket is made of two materials (see Fig. 1), the inner ring gives it the elastic property and the soft external layer improves the sealing performance. In the Ultra-Flex gasket used in our previous tests, the inner ring is made of Inconel (X-750) and the soft jacket of aluminum (A5). This choice of materials makes it totally non-magnetic.

A special feature, called Delta, is made on the soft jacket to improve the seal tightness. The o-ring relies on the deformation of the material at the Delta under the compression to fill in the micro-surface irregularities, and this deformation of the soft material layer is plastic (permanent).

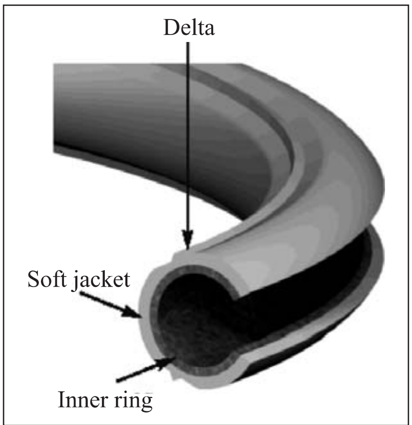

Fig. 1. Ultra-Flex gasket section

The dimensions and nominal properties (given from the company) of this Ultra-Flex gasket are as follows:

- internal diameter — 99.6 mm,
- external diameter —106.1 mm,
- torus diameter — 4.65 mm,
- seal contact circle diameter — 102.9 mm,
- working point Y_2 — 26 N/mm,
- sealing threshold Y_1 — 10 N/mm,
- optimum compression gap — 0.55 mm.

These dimensions were chosen to use this o-ring in the standard TESLA-style cavity flanges [3] without changing the groove dimensions.

For better understanding of the sealing behavior which is described below in this paper, a typical load/compression plot for a standard metal gasket is shown in Fig. 2.

Definition of terms:

- Y_0 = load on the compression curve above which the leak rate is at the required level.
- Y_2 = load required to reach optimum compression e_2.
- Y_1 = load on the decompression curve below which the leak rate exceeds the required level.
- e_2 = optimum compression.
- e_c = compression limit beyond which there is a risk of damaging the spring.

To check better the properties of this specific Ultra-Flex gasket, we asked the company to provide us also with an experimental plot that gives its characteristic values of these gaskets.

The experimental plot received is shown in Fig. 3, where the blue curve is the load compression relation-

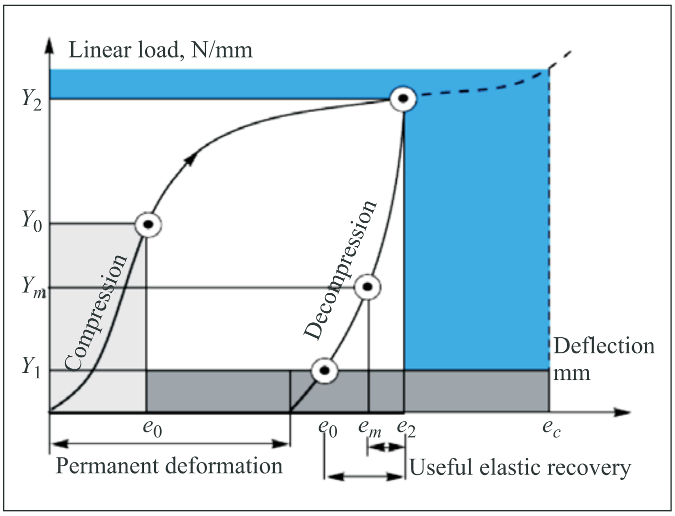

Fig. 2. Metallic gasket characteristic curve

ship and the red curve is the leakage compression relationship.

In this plot we see that the optimum linear load Y_2 is 28.5 N/mm. The minimum linear load Y_1 to obtain the requested leak-rate is 15 N/mm, and the optimum compression value E_2 is 4.1 mm.

These characteristic parameters for these Ultra-Flex gaskets are summarized in Table 1.

We define the value of the gasket spring-back as the difference between the optimum compression value and the minimum compression value (e_2–e_1); in Fig. 2 it is also called «useful elastic recovery».

From the experimental plot in Fig. 3 it is seen that in our gasket the spring-back is very low, about 0.05 mm, while for the standard Helicoflex gasket with a similar cross section this value is about 0.2 mm.

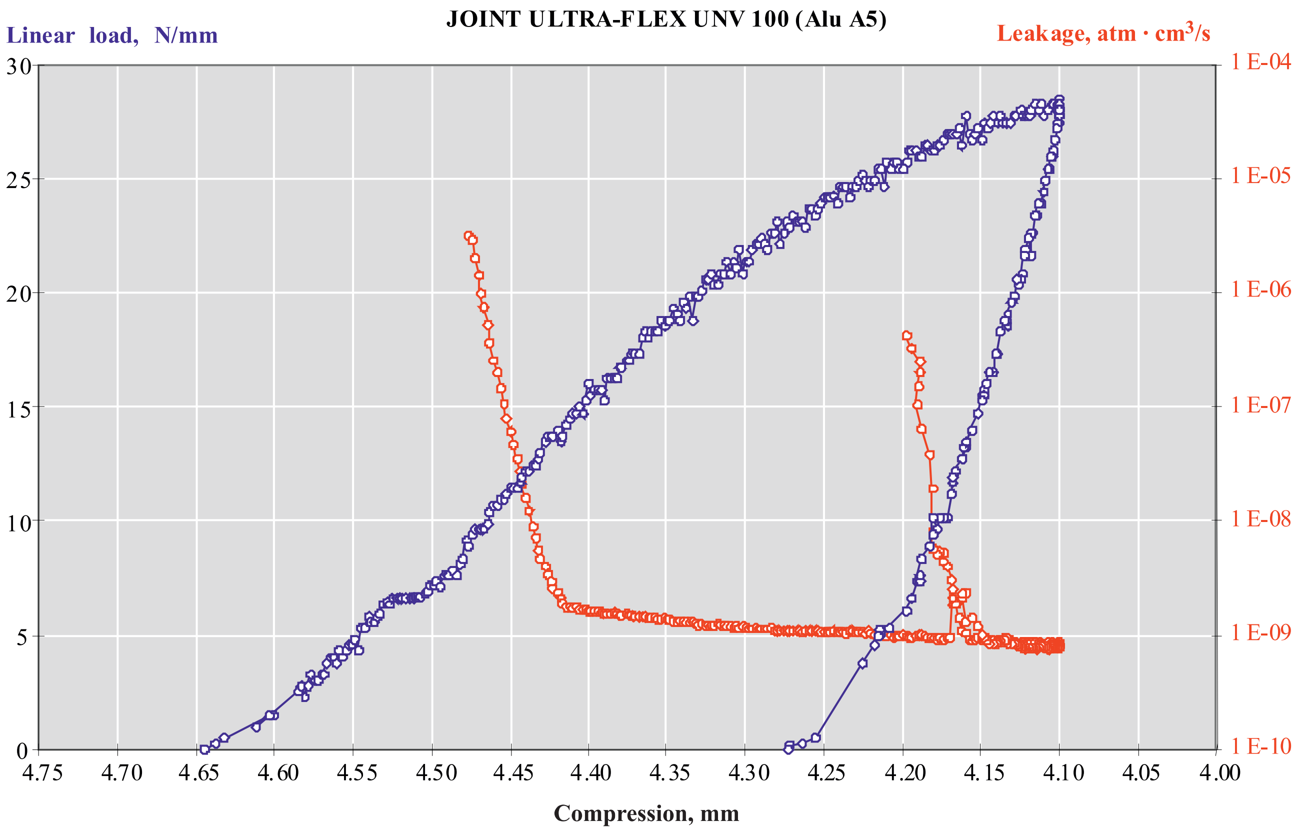

Fig. 3. Ultra-Flex experimental plot from Garlock

Table 1. Characteristic parameters for Ultra-Flex gaskets

Type	Y_0, N/mm	E_0, mm	Y_2, N/mm	e_2, mm	Y_1 (10–9), N/mm	e_1, mm
UNV 100	13	> 4.45	28.5	4.10	15	4.15

2. FEM ANALYSIS

The Finite Element Model (FEM) simulates two TESLA-style cavity flanges with the Ultra-Flex gasket in between. Figure 4 gives the dimensions of the grooves in the flanges (see Refs. [4, 5]).

The first goal of this analysis was to build a model which would describe as closely as possible the experimental data of the Ultra-Flex gaskets (see Fig. 3).

One of the key parameters in the analysis is the thickness of the gasket, but it is not in the company specification; therefore, we decided to measure it. Figure 5 shows photos of a section of the Ultra-Flex used in our tests. We can clearly see two layers of metal. We measured the thickness of each layer to be approximately 0.5 mm, with a camera connected to a CMM machine

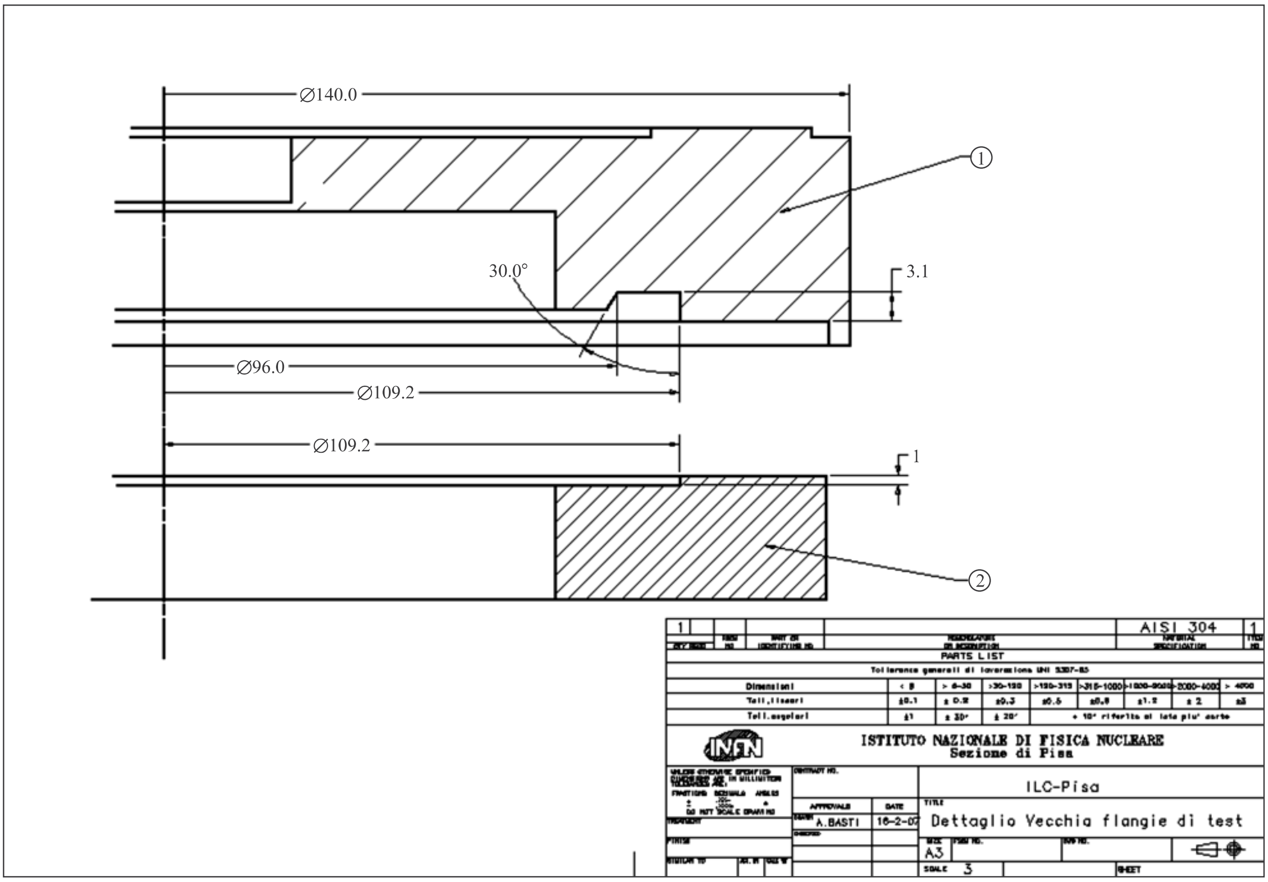

Fig. 4. Details of flange groove dimensions

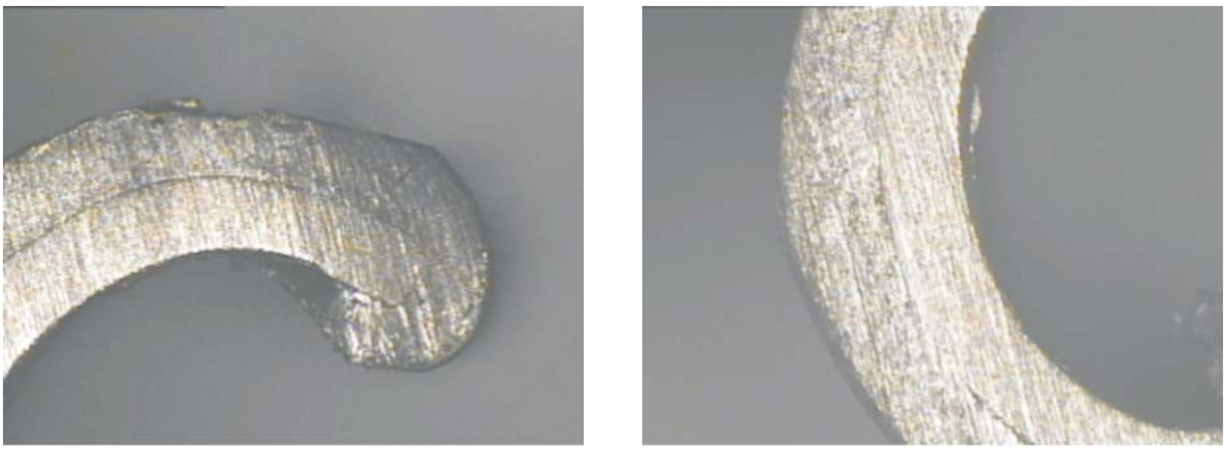

Fig. 5. An Ultra-Flex gasket section

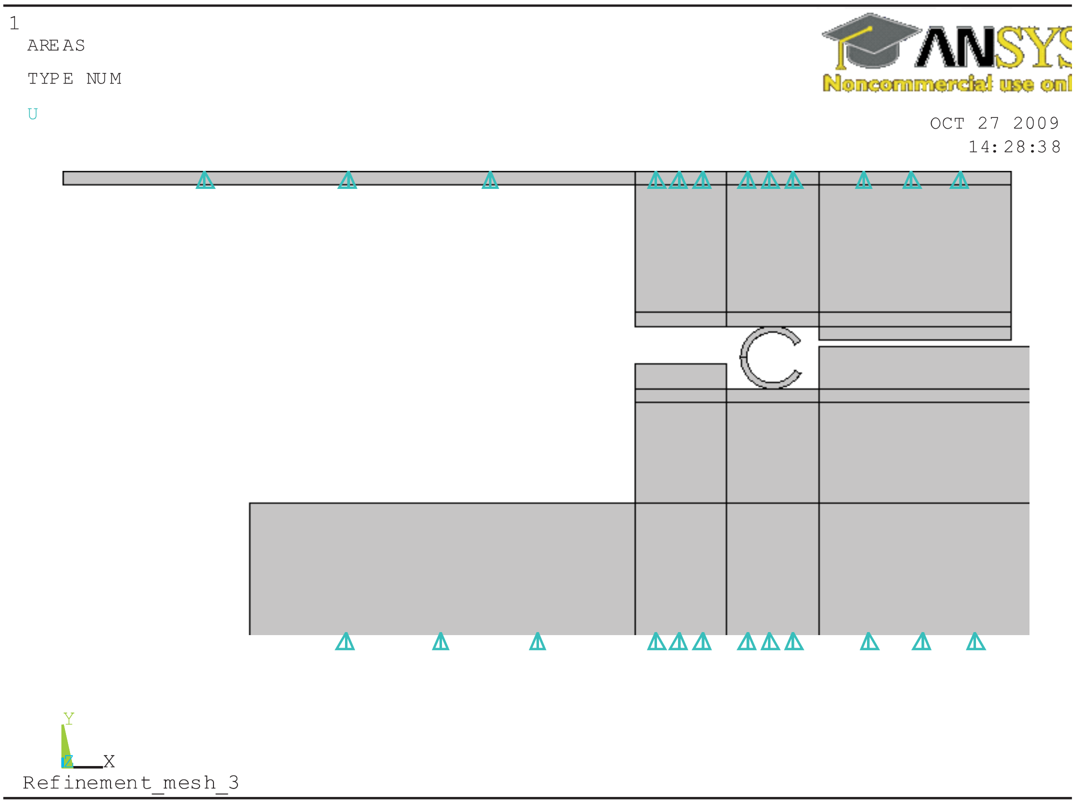

Fig. 6. FEA model and boundary conditions

(with an optical lens APO-5 from Mitutoyo, magnification 5×).

It is not easy to simulate the behavior of the gasket made of two layers since we do not know exactly the interconnection (interchange of the stress) between the two materials. For that reason to simplify the FEM analysis, we decided to consider only the Inconel layer and we modeled only it. We need also to take into account that the elasticity of Inconel is much higher than that of aluminum, about 300 GPa versus 70 GPa.

The simulation was done by using an ANSYS two-dimensional model consisting of two flanges made of stainless steel and the Ultra-Flex gasket in between as described above.

In the flanges the dimensions of the grooves are made in such a way that when we obtain the contact between two flanges, the optimum compression value of the o-ring (e_2 in Table 1) is reached.

We developed a two-dimensional axially symmetric model, shown in Fig. 6, using the axial symmetry with respect to the vertical axis (Y axis).

In the analysis we fixed the top flange and applied displacements to the bottom flange to reach the contact between them outside the groove for the gasket. The model was developed by means of PLANE82 elements.

Type TARGE169 and CONTA175 contact elements were used to create contact pairs between the flanges and the Ultra-Flex gasket.

In the model we used the free quadrilateral mesh and the refined mesh in the contact areas.

The detail of the FEA model with the contact elements is shown in Fig. 7. The friction coefficient for the contact pairs used in the simulation was 0.2.

To take into account the plasticity of the materials, a bilinear relationship between stress and strain for each

Table 2. The material properties

Material	Yield stress at 0.2% offset, MPa	Tensile strength ultimate, MPa	Elongation at break, %
SS – (Flanges)	382	939	40
Inconel X-750 – (Gasket)	700	1110	22

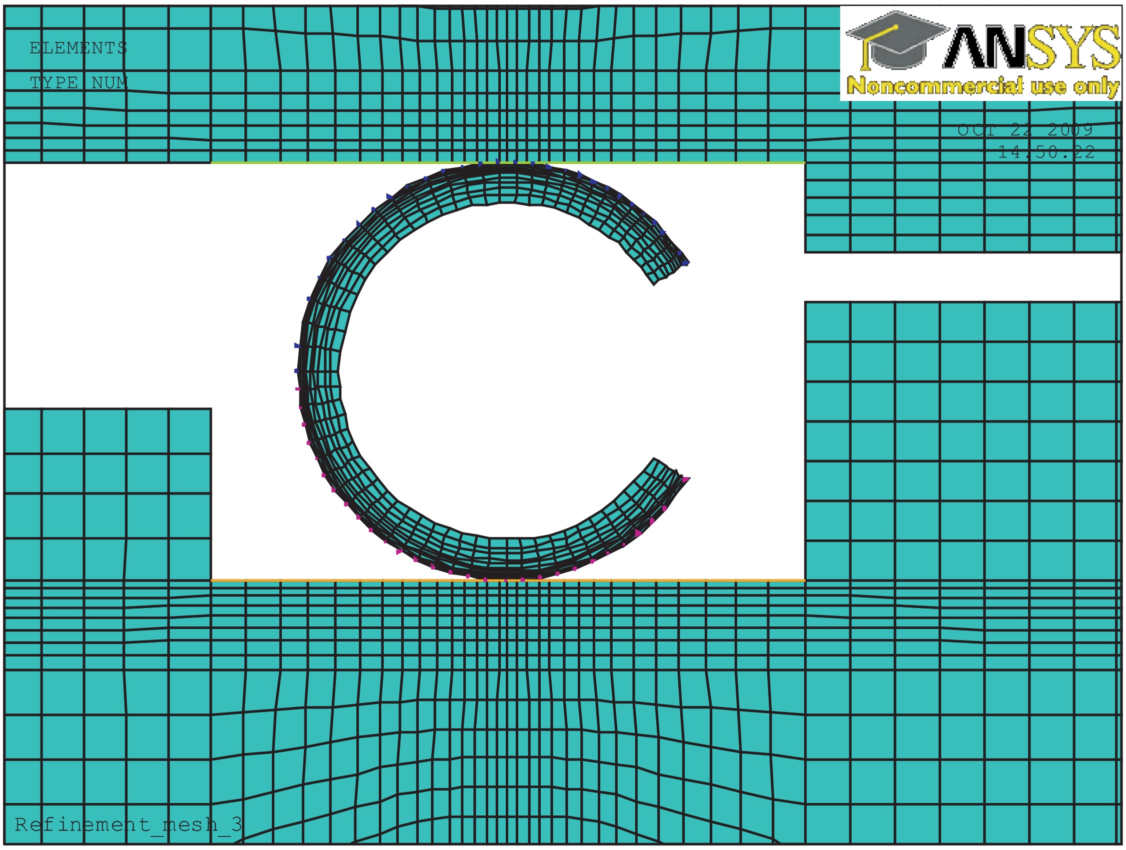

Fig. 7. Detail of the FEA model with the contact elements

element material was introduced within the simulation code using the properties reported in Table 2.

To reach the maximum compression value, roughly 4.1 mm, we used the displacement of the bottom flange in the *Y* direction equal to 0.55 mm to close the gap between the flanges.

We used a multiple substep load, and Fig. 8 shows the first result of our analysis. In particular, the plot shows the dependence of the applied linear load (*Y*) on the current vertical size of the torus (*X*) during the compression/decompression process. At the initial moment this vertical size is equal to the nominal diameter of the

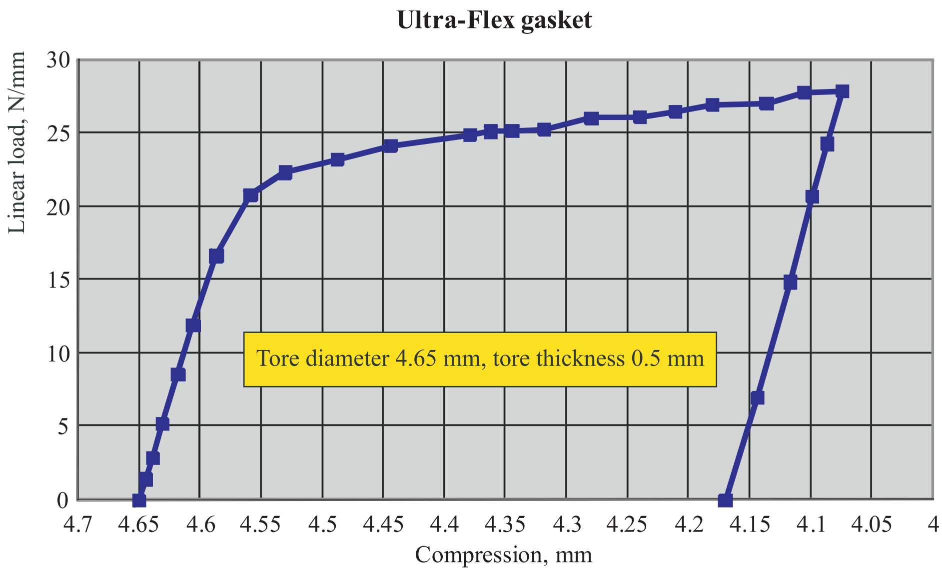

Fig. 8. The linear load versus the current vertical size of the torus during the compression/decompression process obtained with our FEA model

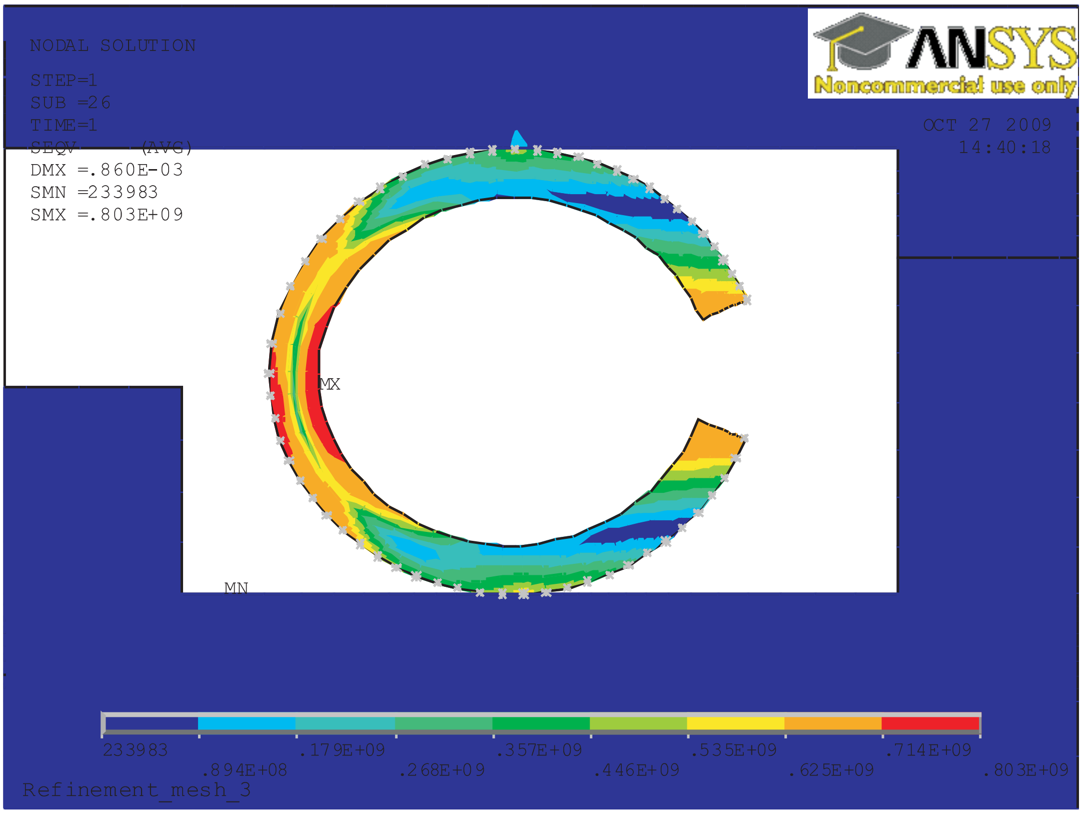

Fig. 9. Equivalent Von Mises stress

torus, 4.65 mm. After the applied load has reached the optimum linear load, approximately 28.5 N/mm, the load is reduced to evaluate the spring-back of the gasket. It means that the bottom flange was moved in the opposite direction until we had no contact between the gasket and bottom flange.

We can notice that in the plot obtained with our model the slope of the curve during the compression

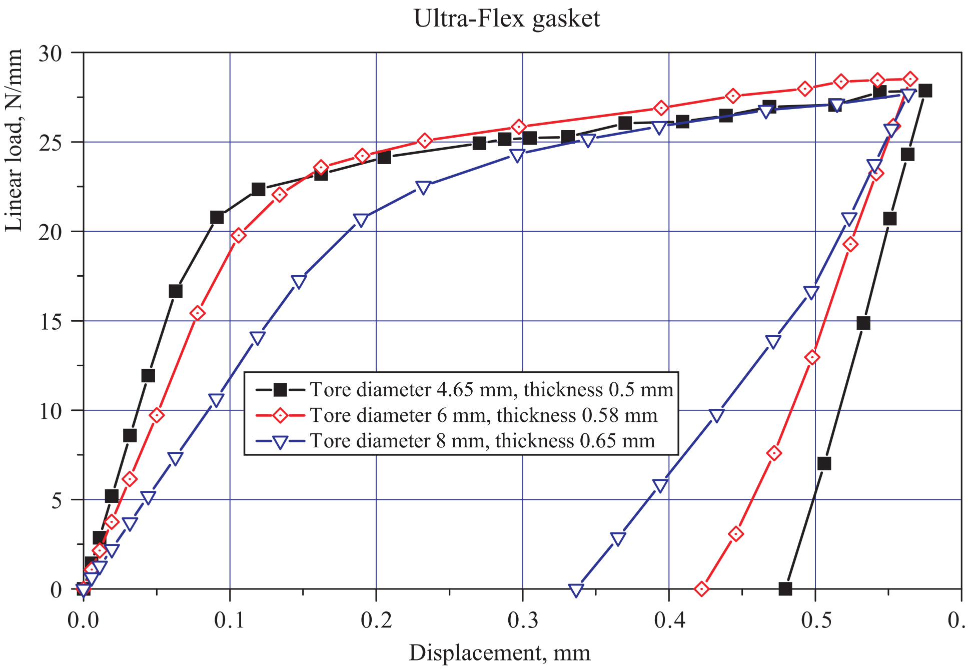

Fig. 10. Linear load versus gasket displacement for different torus diameters obtained with our FEA model

phase is a little different from that of the experimental plot (Fig. 3). We suppose this is due to neglecting the outer aluminum layer of the Ultra-Flex gasket in the FEA model.

But it is also important to notice that the maximum linear load however is very close to the same value in the experimental plot, and the decompression region is also very similar to the experimental data.

The total reaction force evaluated with FEA model is about 9006 N. This value is comparable with the experimental tightening force found during the He leak tests [1], approximately 8400 N.

Figure 9 shows the equivalent Von Mises stresses in the gasket obtained with this analysis, the maximum value is about 803 MPa.

After this first analysis we used this model to predict the behavior of the Ultra-Flex gaskets with a bigger torus diameter.

The outer diameter and the thickness of the torus were increased in such a way that the maximum compression load calculated with the model was close to the value for the case with a tore diameter of 4.65 mm; this avoids changing the flange dimensions and the system to apply the external load.

At first we increased the tore diameter to 6 mm with a thickness of 0.58 mm and then to 8 mm with a torus thickness of 0.65 mm.

The results of this analysis are shown in the plot in Fig. 10.

To compare the achieved results for various torus diameters, we determined the difference between the torus diameter and the current size of the gasket along the Y axis during the compression/decompression procedure and designated that as displacement of the gasket.

The load-compression curves are shown in Fig. 10 for three different tore diameters 4.65, 6 and 8 mm and thickness of 0.5, 0.58 and 0.65 mm, respectively.

It is seen from the plot that if the torus diameter is increased to 8 mm, the spring-back is four times bigger (0.2 mm) than for the torus diameter 4.65 mm (0.05 mm).

CONCLUSION

At the end of our first tests with the Ultra-Flex gasket we decided that additional investigation should be done to better understand the behavior of these metallic o-rings, and perhaps we need to increase the diameter of the torus and the spring-back value correspondingly.

We built a FEA model that reproduced the performance of our Ultra-Flex gasket with the TESLA-style cavity flanges. We used this model to study better this kind of o-ring and to try to optimize the torus diameter.

We found with this model that if we increase the torus diameter to 8 mm and the thickness to 0.65 mm, the gasket spring-back increases to about 0.2 mm, which is comparable with the spring-back for the standard Helicoflex gasket.

We know that with our FEA model we cannot simulate the correlation between the leakage and the gasket compression, and we also need to consider that, increasing the gasket torus diameter, we can have more microplasticity of the o-ring that can create problems with the tightness of the joint.

But we think that this is a starting point to place the order at the company for Ultra-Flex gaskets with a bigger torus diameter and to continue our R&D looking for a good alternative solution to cavity flange design for the future ILC accelerator.

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Анализ методом конечных элементов уплотнений Ultra-Flex
для фланцевого соединения резонаторов ILC

Проведено численное моделирование (с применением программного комплекса конечно-элементных расчетов ANSYS) промышленного уплотнения Ultra-Flex. Основная цель — определение оптимальных геометрических параметров уплотнения с целью уменьшения значения остаточной деформации. Модель FEA показывает, что если увеличить диаметр тора с 4,65 до 8 мм и толщину с 0,5 до 0,65 мм, то полезное упругое восстановление уплотнения значительно увеличится: с 0,05 до 0,2 мм.

Работа выполнена в Лаборатории ядерных проблем им. В. П. Джелепова ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 2010

Budagov J. et al. E13-2010-93
FEM Analysis of Ultra-Flex Gasket for ILC Cavity Flanges

Numerical simulation of a new kind of metallic gasket by Garlock company, the Ultra-Flex, has been carried out using the ANSYS code for finite element analysis. The main purpose was to determine the optimal geometrical parameters of the seal for our application in ILC cavity flanges. The FEA model shows that if the gasket tore diameter is increased from 4.65 to 8 mm and its thickness is increased from 0.5 to 0.65 mm, the useful elastic recovery (spring-back) of the gasket will drastically increase, from 0.05 to 0.2 mm.

The investigation has been performed at the Dzhelepov Laboratory of Nuclear Problems, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 2010

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