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INVESTIGATIONS OF DIFFERENT TYPES OF GASKETS FOR ILC CAVITY FLANGES

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INTRODUCTION

Accelerator cavities are among the most important components of the future International Linear Collider (ILC); the connection of their end flanges with the beam pipe plays a crucial role in the cavity reliability and performance. The ILC is supposed to use about 20000 cavities and several thousands of cold flanges; that is why the reliability of the seal, the reduction of costs and time for their assembly and the decrease of the junction dimensions are the key points for the construction of the new machine and its efficient operation [1].

At INFN-Pisa mechanical R&D was started to check the possibility of finding new design for these flanges starting from standard TESLA flange configurations [2].

We report the status of this R&D and the plans for the future.

The report describes the procedures adopted to carefully test the He leak rate of several types of vacuum seals: the Ultra-Flex gasket (by Garlock), the diamond-shaped gaskets (TESLA configuration) and Helicoflex spring-type gaskets (by Garlock).

All tests were performed at room temperature and at liquid nitrogen (LN_2) temperature (77 K) and after thermal cycles between these two values.

The leak tests were performed at the VIRGO (Cascina) and INFN-Pisa cryogenic laboratories. At INFN-Pisa the tests were performed using the Model 979 Helium Mass Spectrometer Leak Detector by VARIAN equipped with an internal turbo molecular high vacuum pump and mechanical external dry scroll pump, the operating sensitivity range of this device is $1 \cdot 10^{-10}$ to $1 \cdot 10^{-4}$ mbar · l/s while the minimum detectable leak is $< 5 \cdot 10^{-11}$ mbar · l/s.

Some leakage measurements were also carried out with the Ultra-Flex gasket at the LASA laboratory (Milan).

We also report the results of the tests performed in the INFN-Pisa clean room aimed to measure particle contamination while the assembling of the flange connections.

In the end, a «Quick Disconnect System» (QDS) (from Garlock company) was tested using a new conical flange design and an external clamp; with this system we tested two kinds of gaskets: the Helicoflex and the Ultra-Flex.

1. GOALS

The primary goals of these tests and measurements are to investigate possibilities of using a seal with a low setting load, to minimize the flange dimensions, to reduce the distance between cavities, and to simplify the assembly procedure of the flange connections which must meet the basic requirement of no particle contamination during the assembly.

Other goals are to simplify the tightening procedure and to find an alternative way to close cavity flanges during the assembly phases.

Figure 1 shows an isometric view of the TESLA cavity. The photo in Fig. 2 illustrates the flange connection between the superconducting cavities in the ILC cryomodule prototype assembly at Fermilab.

2. GARLOCK ULTRA-FLEX GASKET

The Ultra-Flex gasket (cross section in Fig. 3) is a new kind of metallic o-ring developed by Garlock to replace the standard elastomer o-ring with the same advantage of standard metallic o-ring (low permeability,

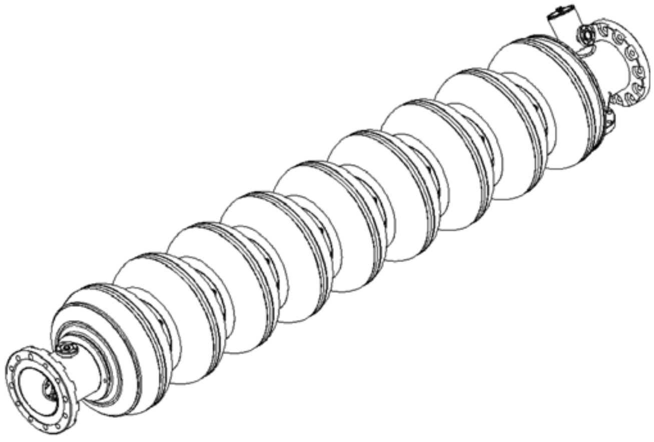


Fig. 1. TESLA cavity design

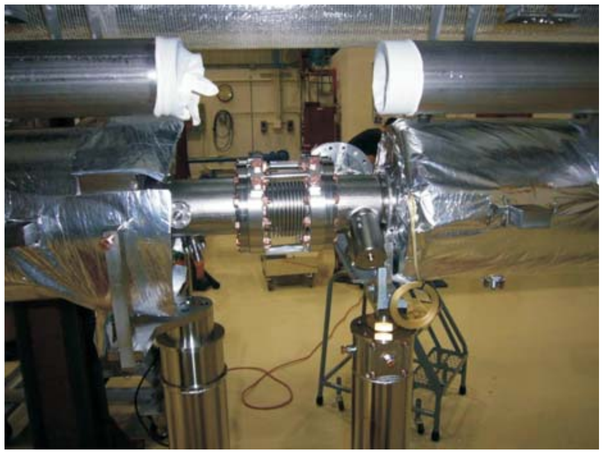


Fig. 2. Cavity flange connection in the cryomodule

high purity, low out-gassing, etc.) plus the advantage to properly seal the vacuum volume even with lower applied load (90% less than the standard Helicoflex gasket).

For better understanding of the sealing behavior which is described below in this paper, a typical load/compression plot for a standard Helicoflex gasket [3] is shown in Fig. 4.

Notation:

- Y_0 is the load on the compression curve above which the leak rate is at the required level.
- Y_2 is the load required to reach optimum compression e_2.
- Y_1 is the load on the decompression curve below which the leak rate exceeds the required level.

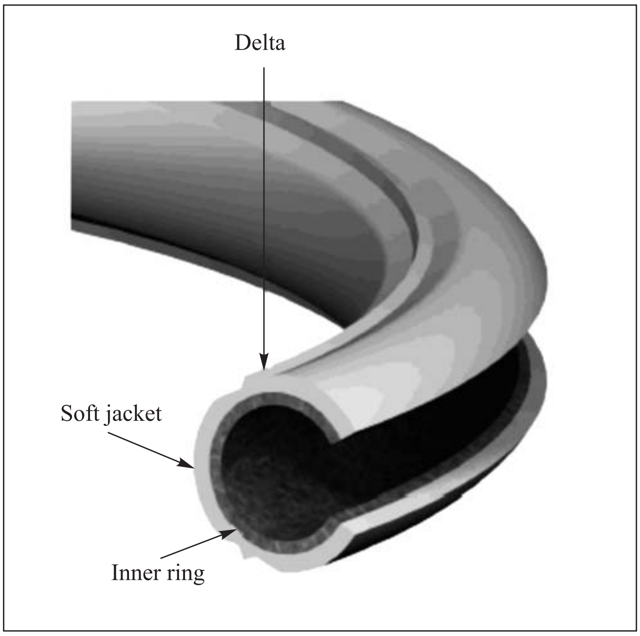


Fig. 3. Ultra-Flex gasket section

- e_2 is the optimum compression.
- e_c is the compression limit beyond which there is a risk of damaging the spring.

Garlock produced ten customized Ultra-Flex gaskets for INFN-Pisa to match the dimensions of the standard groove in the TESLA cavity flange design.

In this way we can test them using flanges already designed for a similar kind of study (see [1, 4]). The inner ring in these Ultra-Flex gaskets is made of Inconel (X-750) and the soft jacket is of aluminum (A5), which gives the non-magnetic properties to the gasket.

The Ultra-Flex 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).

The dimensions and nominal properties (given from the company) of these gaskets are as follows:

- internal diameter — 99.6 mm,
- external diameter — 106.1 mm,

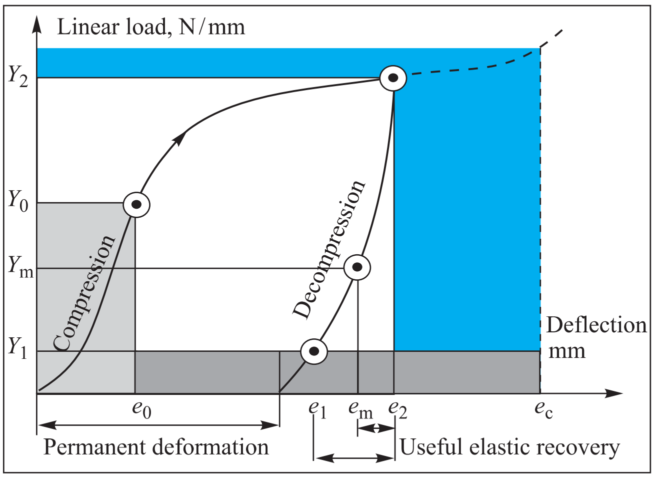


Fig. 4. Helicoflex characteristic curve

- tore 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.

The optimum compression gap (according to the producer's recommendation) is 0.55 mm.

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

This experimental plot is shown in Fig. 5; curve *1* represents the load/compression plot and curve *2* is the leakage/compression plot.

From the plot it is seen 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.

Characteristic parameters for these Ultra-Flex gaskets are summarized in Table.

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 the plot in Fig. 4 it is also called «useful elastic recovery».

From the plot in Fig. 5 it is seen that the gasket spring-back for our Ultra-Flex 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.

2.1. Ultra-Flex Gasket He Leak Tests

2.1.1. First Test of the Ultra-Flex Gasket at INFN-Pisa. To test the UHV leak tightness of these gaskets at room temperature and under cold conditions, we use the same flange configuration developed at LASA to perform some similar studies (see [1, 4]). The external

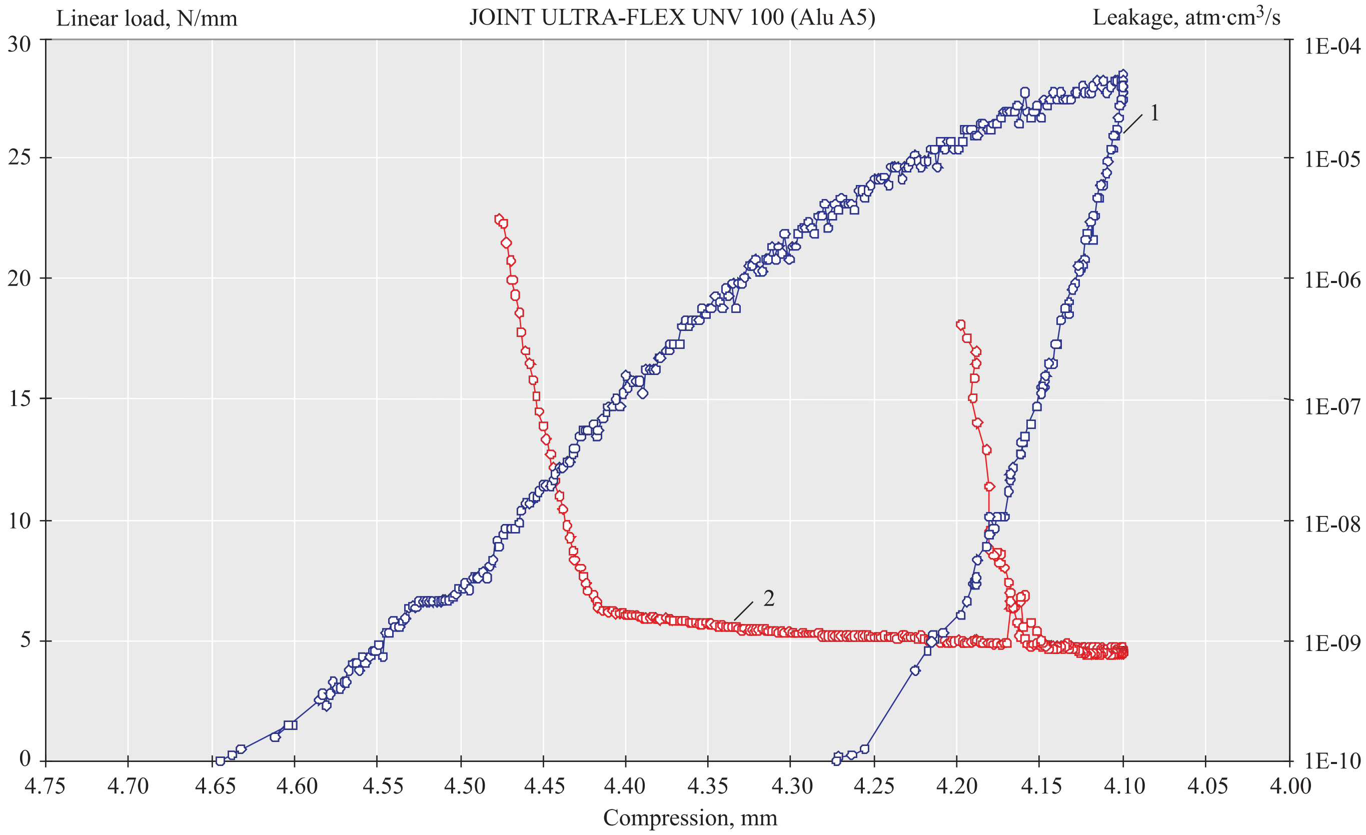


Fig. 5. Ultra-Flex experimental plot from Garlock

Characteristic parameters for Ultra-Flex gaskets (UNV 100)

Y_0, N/mm	e_0, mm	Y_2, N/mm	e_2, mm	Y_1, N/mm	e_1, mm
13	> 4.45	28.5	4.10	15	4.15

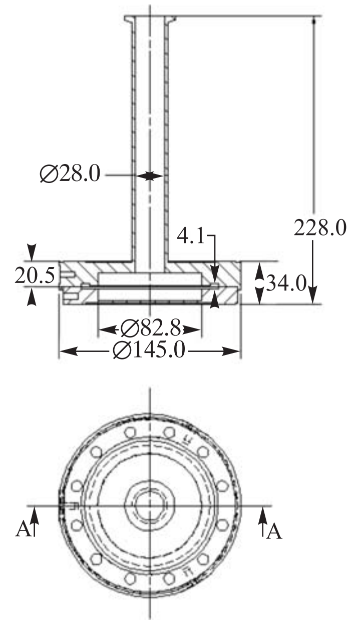


Fig. 6. Test flange assembly

dimensions of these flanges, the internal dimensions of the groove for the o-ring and the number and type of screws to tighten them are the same as for the flanges located at the ends of the 1.3 GHz TESLA cavities.

In this setup a small vacuum volume was obtained by coupling a blind stainless steel flange to the second one with a pipe (about 200 mm long) to create a connection system (DN25) with the flex pipe of the leak detector (see Fig. 6).

To connect the DN25 flange to the flex pipe of the leak detector, we used a gasket made of indium wire with a diameter of 2 mm.

Figure 7 gives the dimensions of the flange groove on a bigger scale.

In Fig. 8, *a* and *b* photos of the flanges and the leak test setup are shown.

According to the plot of the producer, the optimum vacuum sealing for our Ultra-Flex gaskets can be reached by applying a working force Y_2 of 26 N/mm to a total contact force of 8401 N. This value gives a tightening torque of 1.5 Nm on twelve M8 bolts (with a friction coefficient of 0.2).

We tested two different configurations at room temperature: one with 12 steel bolts tightened with a dynamometric wrench set at 5 Nm and the other one tightened by applying a torque of 16 Nm, because it is not easy to check the friction coefficients and the torque of 1.5 Nm is very low for this screw dimension.

With helium gas flowing in the plastic bag around the flange at room temperature we obtained the best result with the second configuration.

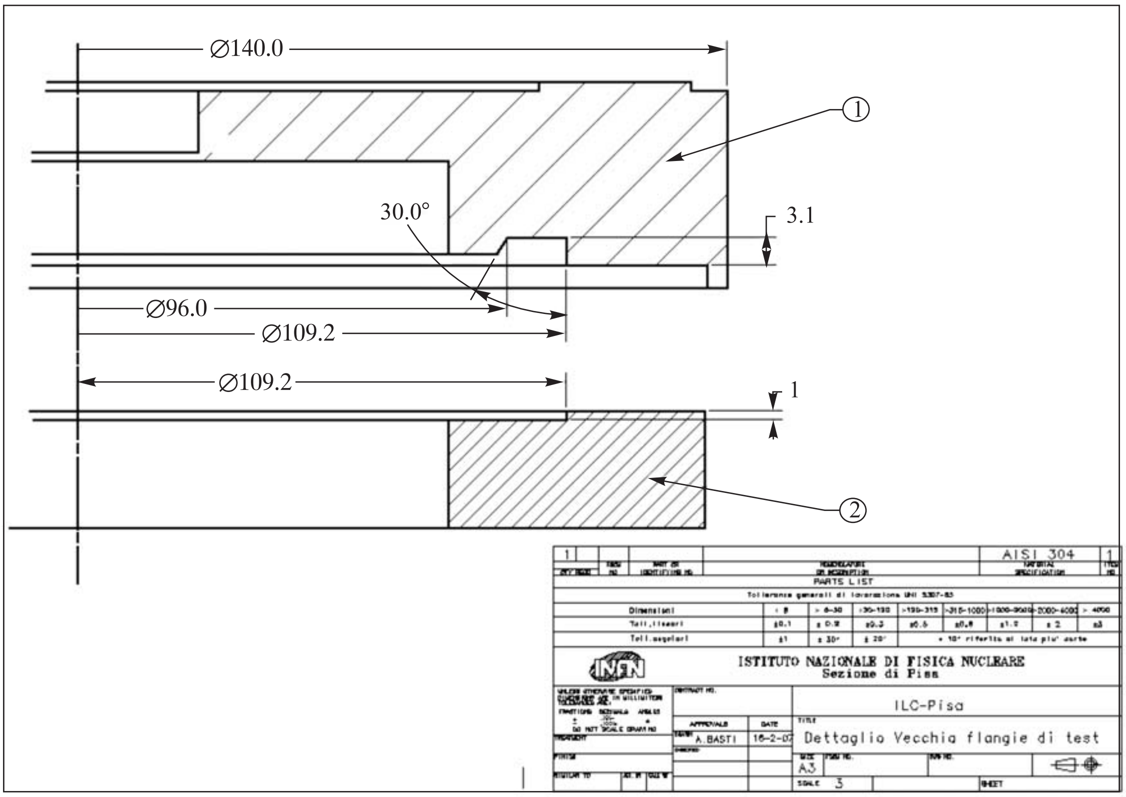


Fig. 7. Details of flange groove dimensions

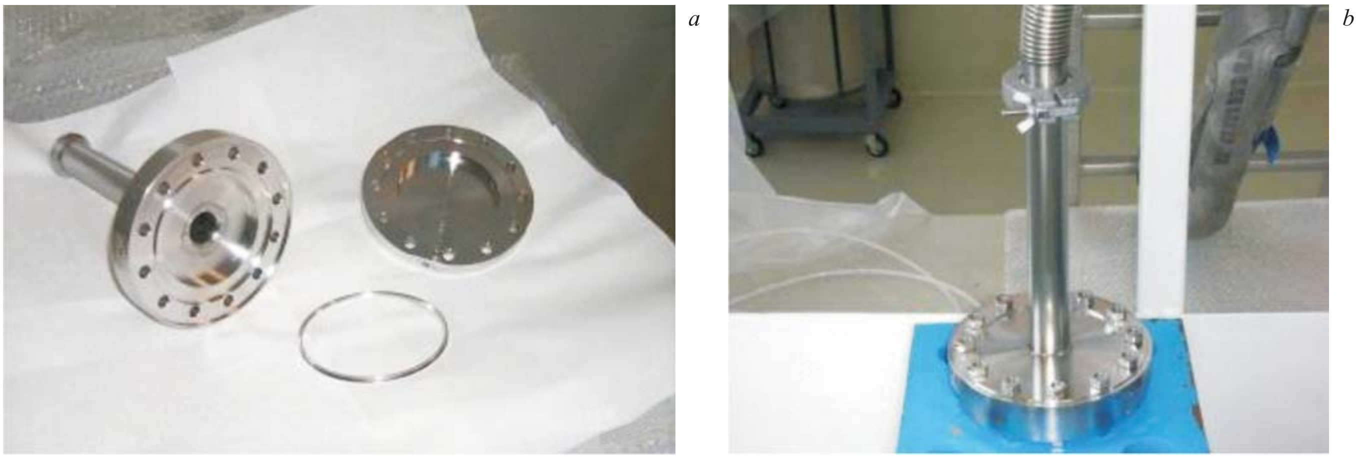


Fig. 8. *a*) Three elements of the leak test measurement are visible: the blind flange, the flange with a connection pipe and the Garlock Ultra-Flex gasket; *b*) the measurement setup connected through a flex pipe to the leak detector (not visible in this photo)

***T* = 300 K**

Vacuum level = (6.3 – 6.7) · 10^{-3} mbar

Leak rate background < 10^{-11} mbar · l/s

He gas flowed inside the plastic bag for 3–5 s

Vacuum level = (6.3 – 6.7) · 10^{-3} mbar

He leak rate = 2.5 · 10^{-9} mbar · l/s

After putting the flanges into a Dewar with liquid nitrogen for about 5 min, we performed similar measurement at 77 K. Figure 9 shows a few moments of the leak test measurement performed with the Ultra-Flex gasket at cryogenic temperature with the following:

***T* = 77 K**

Vacuum level = (6.3 – 6.7) · 10^{-3} mbar

Leak rate background < 10^{-11} mbar · l/s (at 300 K)

He gas flowed inside the plastic bag for 3–5 s

He leak rate = 3.4 · 10^{-8} mbar · 1/s (at 77 K)

It was inferred from these first tests that the Ultra-Flex gasket showed a good vacuum seal at room temperature (inside the request specifications) and undesired small leaks at 77 K.

2.1.2. Second Test of the Ultra-Flex Gasket at INFN-Pisa. As reported in the previous subsection, the Ultra-Flex gasket was conceived to ensure a high-performance vacuum seal with a low applied load (90% less than the standard Helicoflex gasket). With our specific measurement setup, it was very difficult to evaluate

Fig. 9. Leak test measurement of the stainless steel flanges with the Ultra-Flex gasket at 77 K

the friction coefficient between the clean and degreased bolts and the stainless steel flange (the same gasket and flanges were used for the contamination measurements in the INFN-Pisa clean room, see Sec. 3). Due to this difficulty, the relationship between the force applied to the gasket and the torque applied to the bolts had a large uncertainty.

With this limitation, the second test was planned to be performed using a setup very similar to the one adopted for the diamond-shaped gasket test: the stainless steel flange with a pipe, the Nb–Ti blind flange and the Ultra-Flex gasket. The two flanges and the gasket were coupled by using only 6 bolts (instead of 12 available) and applying a torque of 20 Nm to each of the bolts (configuration 4 during the contamination measurement). The first measurement was performed at room temperature with the usual technique applying a plastic bag and the result obtained is as follows:

***T* = 300 K; Blind flange Nb–Ti; 6 bolts at 20 Nm; Ultra-Flex gasket**

Vacuum level = $5.7 \cdot 10^{-3}$ mbar

Leak rate background = $9.7 \cdot 10^{-10}$ mbar · l/s

No changes were detected after the He gas flowed inside the plastic bag for 3–5 s

For the test at cryogenic temperature we decided to follow the thermal cycling technique as described above: two cycles of keeping the setup at 77 K for 10 min and then at 300 K for 6 min. This procedure was followed with the other kinds of gaskets too (see Subsec. 2.1.4).

After this phase the plastic bag was filled with helium gas for a few seconds and the result obtained is the following:

***T* = 77 K; Blind flange Nb–Ti; 6 bolts at 20 Nm; Ultra-Flex gasket**

Vacuum level = $6.0 \cdot 10^{-3}$ mbar

Leak rate background = $5.5 \cdot 10^{-9}$ mbar · l/s

He gas flowed inside the plastic bag for 5 s and after about 10–15 s the values are

Vacuum level = $8 \cdot 10^{-3}$ mbar

He leak rate = $8.4 \cdot 10^{-6}$ mbar · l/s

A clear vacuum seal problem appeared due to the thermal cycling between room and liquid nitrogen temperatures; for this reason we repeated the leak measurement at room temperature to verify the setup status.

We waited until the background conditions of the previous test were restored, replaced the plastic bag, and performed a leak test at room temperature:

***T* = 300 K; Blind flange Nb–Ti; 6 bolts at 20 Nm; Ultra-Flex gasket**

Vacuum level = $6.7 \cdot 10^{-3}$ mbar

Leak rate background = $5.5 \cdot 10^{-9}$ mbar · l/s

He gas flowed inside the plastic bag for 3–5 s and after a few seconds we had

Vacuum level = $7 \cdot 10^{-3}$ mbar

He leak rate = $3.5 \cdot 10^{-7}$ mbar · l/s

The vacuum seal problem detected at 77 K creates a permanent deformation of the mechanical assembly of the flanges and the o-ring.

2.1.3. Ultra-Flex Gasket He Leak Test at LASA. The leak tests performed at INFN-Pisa were repeated at the LASA laboratory (Milan) with the Ultra-Flex gasket at 300 and 77 K.

For this purpose two stainless steel flanges (one with a pipe and the other blind) machined in Milan were used. This setup is the same as that previously used at LASA to test the performance of the aluminum diamond-shaped gasket [1].

We screwed all twelve M8 bolts and tried to evaluate the minimum torque avoiding helium leak rate at room temperature. Starting with 0.5 Nm and increasing the applied torque in steps of 0.5 Nm, we reached the final goal with 2 Nm applied to each bolt (see Fig. 10). With this torque we did not reach the contact between the flanges (and also the optimum gasket compression according to the Garlock recommendations).

***T* = 300 K; Stainless steel flanges; 12 bolts at 2 Nm; Ultra-Flex gasket**

Vacuum level = $1.0 \cdot 10^{-3}$ mbar

Leak rate background = $2.0 \cdot 10^{-10}$ mbar · l/s

No changes were detected after the He gas flowed around the setup

The leak test at cryogenic temperature was performed by the procedure used at the LASA laboratory to test the standard aluminum diamond-shaped gasket and with the same equipment. According to the procedure, we did not wrap the flanges with a plastic bag before

Fig. 10. Leak test during the torque application at LASA

putting them into liquid nitrogen. A larger plastic bag containing the flanges and the Dewar aperture was prepared (see Fig. 11). Then the flanges were put in contact with liquid nitrogen and as soon as thermal equilibrium was reached (no visible bubbles around the flanges) we took out the flanges from liquid nitrogen keeping them inside the plastic bag. In these conditions some helium gas at room temperature was fluxed within the liquid nitrogen and the leak rate measurement was performed. Using this procedure, we obtained the following results:

***T* = 77 K; Stainless steel flanges; 12 bolts at 2 Nm; Ultra-Flex gasket**

Vacuum level = $1.0 \cdot 10^{-3}$ mbar

Leak rate background = $2.4 \cdot 10^{-10}$ mbar · l/s

No changes were detected after the He gas flowed inside the plastic bag

After this measurement the bag was opened, the flanges were left at room temperature and checked for

Fig. 11. Ultra-Flex gasket test at LASA

Fig. 12. Ultra-Flex gasket flanges after the dip in nitrogen at LASA

the He leakage while blowing helium around them (see Fig. 12).

We observed some peaks of $(1.3 - 1.4) \times \times 10^{-6}$ mbar · l/s leak rate during this period of time.

We waited until the flanges reached the room temperature and checked the leak rate with the plastic bag again; we did not detect any variations with respect to the background level.

After that we tried to increase the torque applied to the bolts having two flanges in contact and the optimum compression gap of the o-ring was increased as well. Increasing the torque in steps of 0.5 to 5 Nm per bolt, we reached the goal.

With this configuration, the leak rate measurements were repeated at room and nitrogen temperatures.

***T* = 300 K; Stainless steel flanges; 12 bolts at 5 Nm; Ultra-Flex gasket**

Vacuum level = $1.0 \cdot 10^{-3}$ mbar

Leak rate background = $5.0 \cdot 10^{-10}$ mbar · l/s

No changes were detected after the He gas flowed around the setup

***T* = 77 K; Stainless steel flanges; 12 bolts at 6 Nm; Ultra-Flex gasket**

Vacuum level = $1.0 \cdot 10^{-3}$ mbar

Leak rate background = $1.5 \cdot 10^{-10}$ mbar · l/s

No changes were detected after the He gas flowed inside the plastic bag

Again, we detected some helium leak rate peaks during the transition between the liquid nitrogen temperature and room temperature but as soon as the flanges were at thermal equilibrium, the detected leak disappeared.

Finally, we also detected some leak rate peaks while warming locally the flanges with a heat gun. The tests performed at LASA confirmed the problems found in Pisa.

2.1.4. Diamond-Shaped Gasket He Leak Test. Additional tests were performed with a diamond-shaped gasket like that developed for TESLA at the LASA laboratory in Milan. The seal test at cryogenic temperature was performed by the procedure adopted by our INFN-Milan colleagues.

The measurement setup was changed by replacing the stainless steel blind flange with a Niobium–Titanium (Nb–Ti) one, and the diamond-shaped gasket was compressed by applying a torque of 24 Nm to all 12 bolts to ensure good sealing (according to the information obtained from the LASA colleagues). This mechanical setup was then wrapped with a plastic bag to contain the helium gas as was done in the previous tests. The results obtained are given below.

***T* = 300 K; Blind flange Nb–Ti; 12 bolts at 24 Nm; Diamond-shaped gasket**

Vacuum level = $5.3 \cdot 10^{-3}$ mbar

Leak rate background = $1.3 \cdot 10^{-9}$ mbar · l/s

No changes were detected after the He gas flowed inside the plastic bag for 3–5 s

To avoid some possible difference in the final results due to the adopted procedure, the test at cryogenic temperature was performed after a thermal cycling of the mechanical elements.

The flanges setup was wrapped, as usual, with a plastic bag to create a small test volume to be filled with helium gas. Then they were immersed in the Dewar with liquid nitrogen (LN_2) and were kept for about 10 min. Next the set was kept at room temperature for about 6 min. These two steps making up a thermal cycling were repeated again: before blowing helium gas in the plastic bag and performing the seal test measurement. The results obtained with this method are as follows:

***T* = 77 K; Blind flange Nb–Ti; 12 bolts at 24 Nm; Diamond-shaped gasket**

Vacuum level = $5.3 \cdot 10^{-3}$ mbar

Leak rate background = $2.7 \cdot 10^{-9}$ mbar · l/s

He gas flowed inside the plastic bag for 5 s and after about 10–15 s we had the values:

Vacuum level = $5.7 \cdot 10^{-3}$ mbar

He leak rate = $2 \cdot 10^{-8}$ mbar · l/s

Considering that a metallic gasket should guarantee almost identical behavior at room temperature and liquid nitrogen temperature, this result indicates a vacuum seal problem at 77 K. For this reason we decided to test again the diamond-shaped o-ring by the procedure previously adopted for the Garlock Ultra-Flex.

The plastic bag was changed and then the setup was immersed in the Dewar with liquid nitrogen for about 5 min (the time necessary to bring the system into thermal equilibrium with LN_2). While the flanges were kept in the Dewar, the plastic bag was filled with helium gas for about 5 s. The results obtained with this method are as follows:

***T* = 77 K; Blind flange Nb–Ti; 12 bolts at 24 Nm; Diamond-shaped gasket**

Vacuum level = $5.7 \cdot 10^{-3}$ mbar

Leak rate background = $2.7 \cdot 10^{-9}$ mbar · l/s

He gas flowed inside the plastic bag for 5 s and after about 10–15 s we had

Vacuum level = $7 \cdot 10^{-3}$ mbar

He leak rate = $1.3 \cdot 10^{-8}$ mbar · l/s

The tests performed of the standard Al diamond-shaped gasket showed its good performance at room temperature, but at 77 K and after thermal cycles, when we tried to check the He leak keeping it inside the nitrogen Dewar, as we did with the Ultra-Flex, we also found some small leaks for this kind of gasket.

3. FIRST PARTICLE CONTAMINATION MEASUREMENTS

We tested the particulate release during the assembly of the flanges with the o-ring. In this section we describe the measurements made in association with our earlier measurements of He leak with both Ultra-Flex and diamond-shaped gaskets. The measurements were performed in the INFN-Pisa 1,000 class clean room (see Fig. 13 and Fig. 15) under a laminar flow hood, which improves the cleaning class to 100 around the experimental setup.

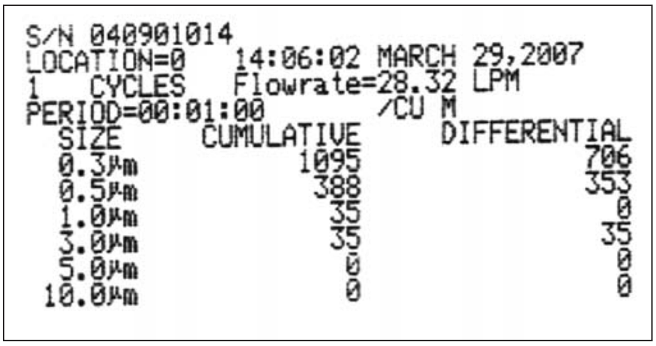
The measurements were made with a particle counter (by Pacific Scientific Instrument).

This device measures airborne particles in several size ranges and displays the number of particles in each range. The basic components of the device are the sensor, the vacuum source and counting electronics; a vacuum pump pulls the sample through the sensor where any particles present are detected. The sensor has a light source (a He–Ne laser diode) illuminating the view volume; the particles passing through the view volume scatter the laser light which is then collected and focused onto a photodiode.

The examined air volume was that inside the flanges (see previous sections). The measurement was made by inserting the probe of the particle counter into the pipe of the test flange. The detected air flow rate was 28.32 liters per minute (LPM) and the size of particle was 0.3, 0.5, 1, 3, 5 and 10 μm (see Fig. 14).

All the objects within the hood which were used during the operations were carefully cleaned. In addi-

Fig. 13. Setup for the first contamination measurements



S/N 040901014
LOCATION=0 14:06:02 MARCH 29,2007
1 CYCLES Flowrate=28.32 LPM
PERIOD=00:01:00 /CU M

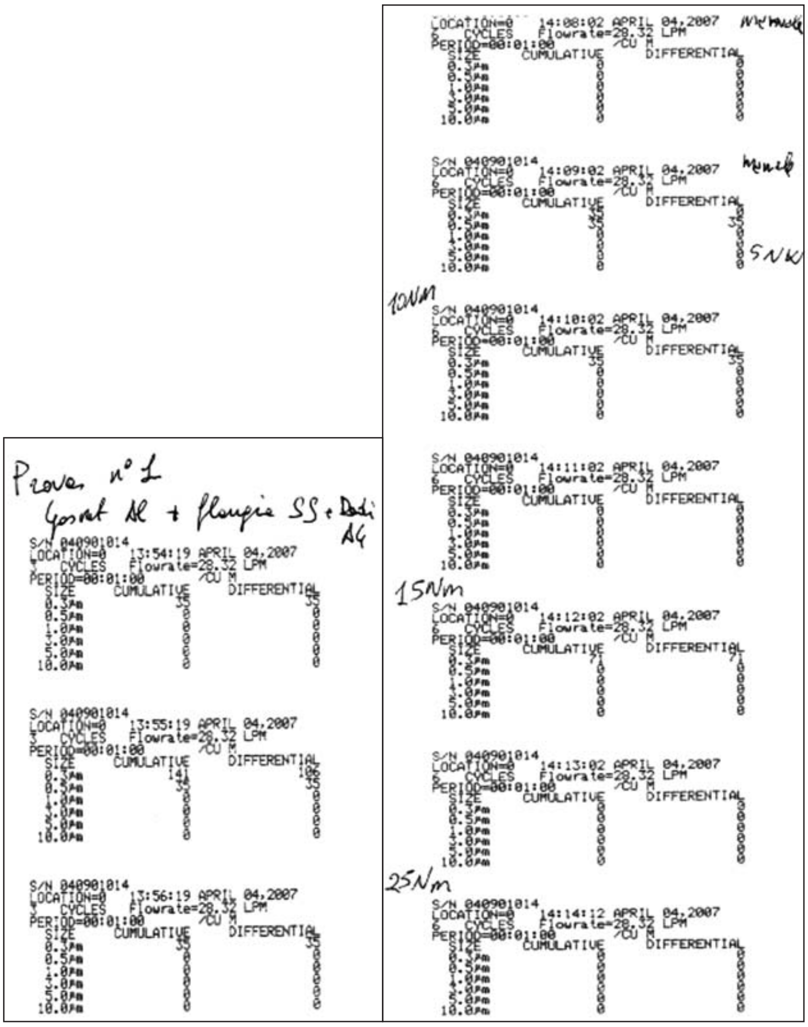
SIZE	CUMULATIVE	DIFFERENTIAL
0.3μm	1095	706
0.5μm	388	353
1.0μm	35	0
3.0μm	35	35
5.0μm	0	0
10.0μm	0	0

Fig. 14. An example of data output from the particle counter

Fig. 15. Flange tightening in the clean room during measurement

tion, before each measurement the flanges, the gasket and the bolts were kept in an ultrasonic bath with acetone for 15 min. After this preliminary phase, we checked with the particle counter that the number of detected particles was zero (for all the sizes) in the air around the setup. During the test we also fixed the data acquisition steps of the counter.

The air quality was monitored during the mounting of the gasket and the insertion of the bolts, then during the tightening of the bolts by manual dynamometric



Prova n° 1
Gasket Al + flangia SS + Dadi AG

S/N 040901014
LOCATION=0 13:54:19 APRIL 04,2007
3 CYCLES Flowrate=28.32 LPM
PERIOD=00:01:00 /CU M

SIZE	CUMULATIVE	DIFFERENTIAL
0.3μm	35	35
0.5μm	0	0
1.0μm	0	0
3.0μm	0	0
5.0μm	0	0
10.0μm	0	0

S/N 040901014
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3 CYCLES Flowrate=28.32 LPM
PERIOD=00:01:00 /CU M

SIZE	CUMULATIVE	DIFFERENTIAL
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0.5μm	35	35
1.0μm	0	0
3.0μm	0	0
5.0μm	0	0
10.0μm	0	0

S/N 040901014
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PERIOD=00:01:00 /CU M

SIZE	CUMULATIVE	DIFFERENTIAL
0.3μm	35	35
0.5μm	0	0
1.0μm	0	0
3.0μm	0	0
5.0μm	0	0
10.0μm	0	0

LOCATION=0 14:08:02 APRIL 04,2007
6 CYCLES Flowrate=28.32 LPM
PERIOD=00:01:00 /CU M

SIZE	CUMULATIVE	DIFFERENTIAL
0.3μm	0	0
0.5μm	0	0
1.0μm	0	0
3.0μm	0	0
5.0μm	0	0
10.0μm	0	0

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6 CYCLES Flowrate=28.32 LPM
PERIOD=00:01:00 /CU M

SIZE	CUMULATIVE	DIFFERENTIAL
0.3μm	35	0
0.5μm	35	35
1.0μm	0	0
3.0μm	0	0
5.0μm	0	0
10.0μm	0	0

5NK

10NM

S/N 040901014
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0.5μm	0	0
1.0μm	0	0
3.0μm	0	0
5.0μm	0	0
10.0μm	0	0

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SIZE	CUMULATIVE	DIFFERENTIAL
0.3μm	0	0
0.5μm	0	0
1.0μm	0	0
3.0μm	0	0
5.0μm	0	0
10.0μm	0	0

15Nm

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6 CYCLES Flowrate=28.32 LPM
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1.0μm	0	0
3.0μm	0	0
5.0μm	0	0
10.0μm	0	0

S/N 040901014
LOCATION=0 14:13:02 APRIL 04,2007
6 CYCLES Flowrate=28.32 LPM
PERIOD=00:01:00 /CU M

SIZE	CUMULATIVE	DIFFERENTIAL
0.3μm	0	0
0.5μm	0	0
1.0μm	0	0
3.0μm	0	0
5.0μm	0	0
10.0μm	0	0

25Nm

S/N 040901014
LOCATION=0 14:14:12 APRIL 04,2007
6 CYCLES Flowrate=28.32 LPM
PERIOD=00:01:00 /CU M

SIZE	CUMULATIVE	DIFFERENTIAL
0.3μm	0	0
0.5μm	0	0
1.0μm	0	0
3.0μm	0	0
5.0μm	0	0
10.0μm	0	0

Fig. 16. Data results with configuration 1

wrench to achieve the right preset load. In these measurements the contamination was measured for the following configurations:

1. Aluminum diamond-shaped gasket — Stainless steel flanges — Stainless steel screws — CuNiSil nuts;
2. Aluminum diamond-shaped gasket — Stainless steel flange — Nb–Ti blind flange — Stainless steel screws — CuNiSil nuts;
3. Ultra-Flex gasket — Stainless steel flanges — Stainless steel bolts;
4. Ultra-Flex gasket — Stainless steel pipe-flange — Nb–Ti blind flange — Stainless steel screws — CuNiSil nuts.

In general, we found that the best way to reduce the setup contamination during the assembly phase is to mount the gasket between the flanges and press them without bolts, then insert screws and nuts in their final positions. Using this procedure we always detected almost zero particles at the beginning of the measurements.

In the measurements with configurations 1 and 2, we looked for particulates during the flange assembly and during the tightening of the bolts with steps of 5 Nm to the final torque of 25 Nm for each bolt. With these two configurations, we always detected almost no particles during all operations (see, for instance, the results with configuration 1 in Fig. 16).

During the measurement with configuration 3 we applied the maximum torque of 5 Nm to all twelve bolts in one step. In configuration 4 we mounted only six bolts and applied the torque in four steps from 5 to 20 Nm. In both configurations we detected the occurrence of some particles inside the flanges when we applied the last torque to the screws. For configuration 3 we measured the following values:

- size 0.3 μm = 600,
- size 0.5 μm = 459,
- size 1.0 μm = 353,
- size 3.0 μm = 177,
- size 5.0 μm = 106.

The inference from these first measurements was that we did not detect any particles when the Al diamond-shaped gasket was used. With the Ultra-Flex gasket we observed some particles, and thus additional investigations are needed.

4. NEW CAVITY FLANGE DESIGN AND QUICK DISCONNECT SYSTEM

After the tests with the standard flange configuration, we investigated a possible change in the flange design to use a different system to close the flanges.

In this variation, instead of the screws we use flanges of conical shape and a radial clamp that transfers the load generated by a big screw to the two flanges. This system is called «Quick Disconnect System» (QDS) by the Garlock Company (see Fig. 17).

These clamps provide a faster and simpler assembly procedure.

The advantages of using this system are briefly in the following:

- Reduction of the space between the cavities.
- Reduction of the total length of the ILC machine.
- Reduction of the cavity string assembly time in the clean room.

These advantages should also affect the cost of the cavity assembly and of the ILC machine as a whole without any change in performance.

The only minor disadvantage of this system is that it requires a change in the cavity end flange design.

From Garlock we received a standard clamp (see Fig. 18) to be used with flanges with the internal dimensions of the tube 102 mm, similar to the TESLA cavity extremity tubes.

Two sets of conical flanges were prepared according to the Garlock design (see Fig. 19) to repeat all the previous tests with the Ultra-Flex and Helicoflex gaskets and the connection clamp.

The designs of the new flanges and their assembly are illustrated in Figs. 20–25.

We modified the new flanges, which allowed more reliable measurement of particulate release. In the blind flange, we added an opening that is welded to a small DN25 flange; this flange is closed during the He leak tests with a standard cup having an indium o-ring gasket, but it is open during the new contamination mea-

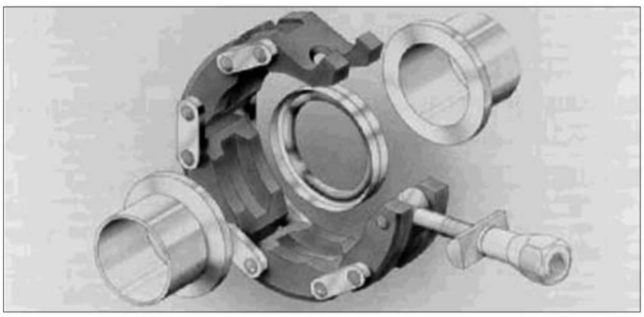

Fig. 17. Quick disconnect system

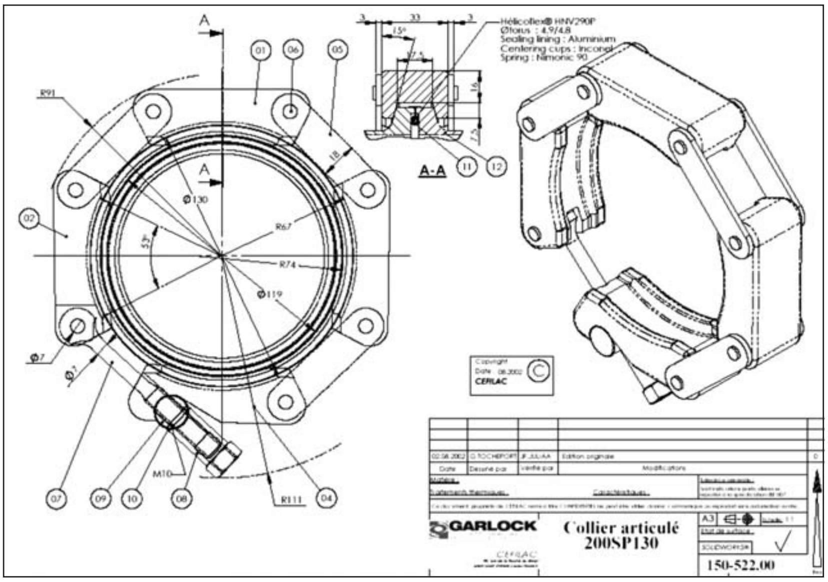

Fig. 18. Garlock clamp

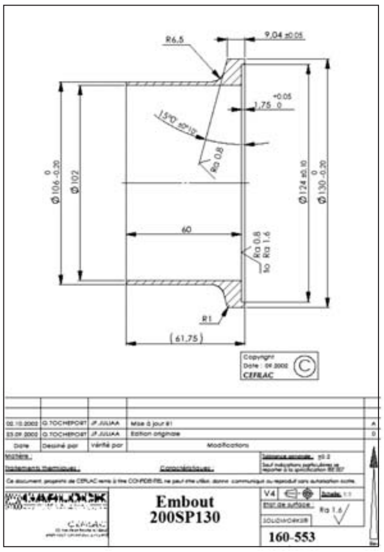

Fig. 19. Garlock flange design

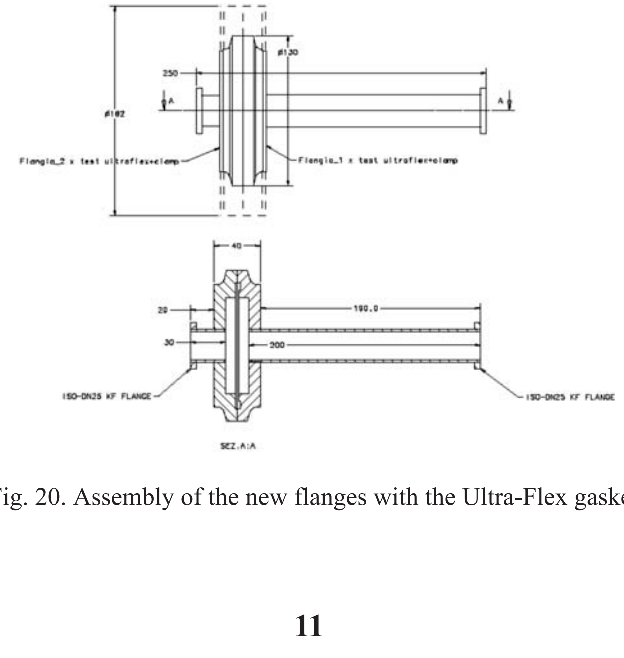

Fig. 20. Assembly of the new flanges with the Ultra-Flex gasket

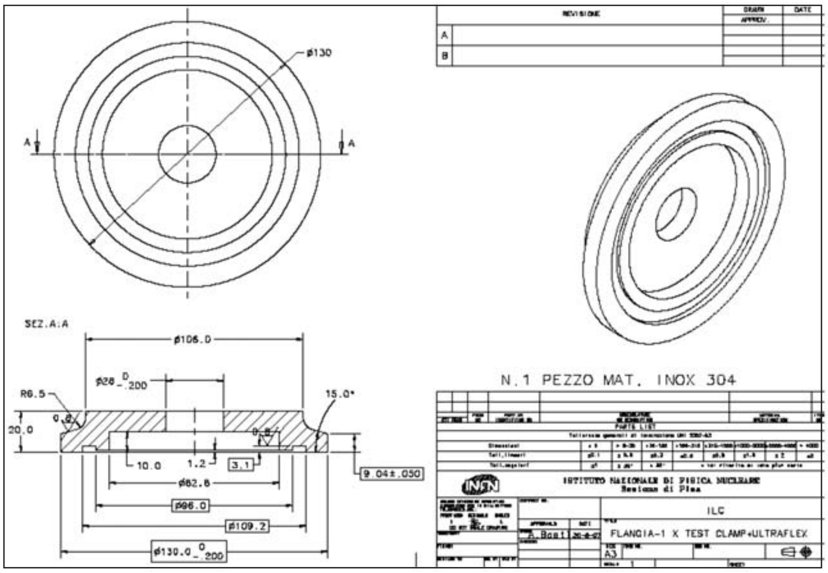

Fig. 21. Construction drawing of new first flange for the test with the Ultra-Flex gasket

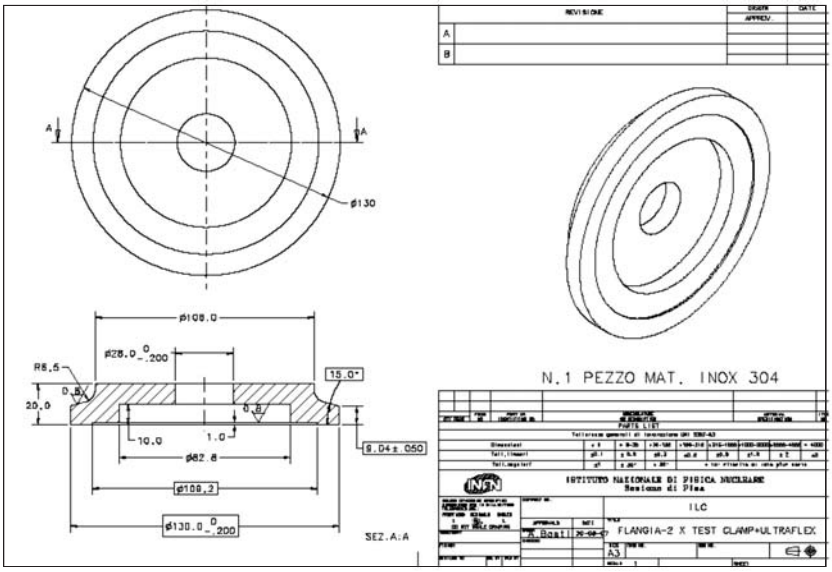

Fig. 22. Construction drawing of new second flange for the test with the Ultra-Flex gasket

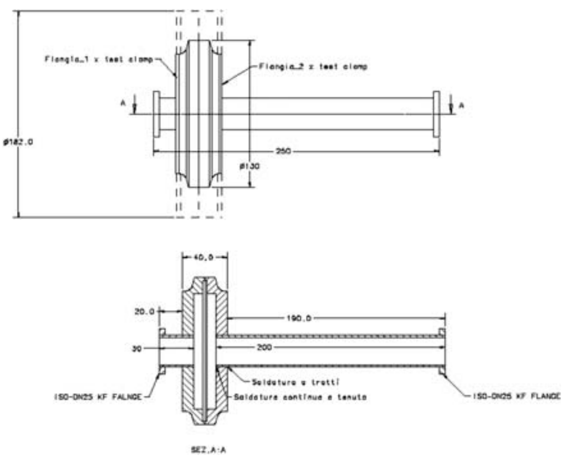

Fig. 23. Assembly of flanges for the test with the Helicoflex gasket

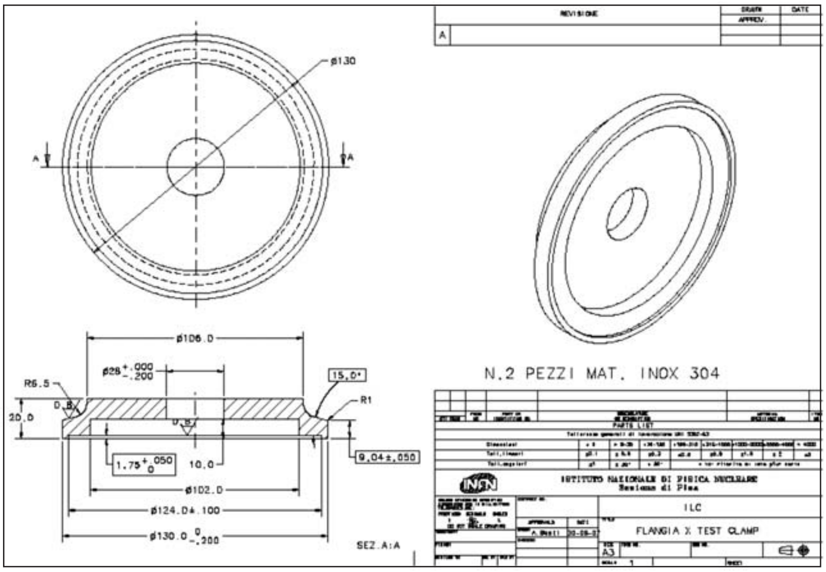

Fig. 24. Construction drawing of flanges for the tests with the Helicoflex gasket

Fig. 25. Photo of the new flange assembly

surements, thus allowing a laminar flow of clean air inside the volume enclosed by the flanges (see Sec. 5 below).

4.1. He Leak Test. The Helicoflex is a standard type of gasket for cryogenic applications in nuclear power plants and for the aerospace applications.

It has the advantages of the standard metallic o-ring (low permeability, high purity, low out-gassing, etc.) plus the advantages arising from its high elasticity.

The resilient characteristic of the Helicoflex seal ensures useful elastic recovery during its service. This elastic recovery enables the Helicoflex seal to accommodate minor distortions in the flange assembly due to the temperature and pressure cycling.

For the best sealing applications the Y_0 value should occur early in the compression curve and the Y_1 value should occur near the end of the decompression curve. The compression and decompression cycles of the Helicoflex seal are characterized by the gradual flattening of the compression curve. The decompression curve, which differs from the compression one, is the result of the hysteresis effect and permanent deformation of the spring and the jacket (see the plot in Fig. 4).

4.1.1. «Helicoflex Gasket + Clamp» He Leak Tests. Several He leak tests on Helicoflex closed with the conical flanges and the clamp were performed at room temperature, at 77 K and after the thermal cycle between these two values following the procedures described in Subsec. 2.1.

The photos in Figs. 26, 27 and 28 show some phases of these leak tests.

***T* = 300 K; Helicoflex gasket + clamped flanges**

Vacuum level < 10^{-4} Torr

Leak rate background = $0.4 \cdot 10^{-10}$ mbar · l/s

No changes were found after the He gas flowed inside the plastic bag for 3–5 s

Fig. 26. Helicoflex test at room temperature

Fig. 27. Helicoflex test in liquid nitrogen

Fig. 28. Helicoflex test inside a Dewar

***T* = 77 K; Helicoflex gasket + clamped flanges**

Vacuum level < 10^{-4} Torr

Leak rate background = $0.5 \cdot 10^{-10}$ mbar · l/s

No changes were detected after the He gas flowed inside the plastic bag

Four cycles between *T* = 300 K and *T* = 77 K; Helicoflex gasket + clamped flanges

Vacuum level < 10^{-4} Torr

Leak rate background = $0.5 \cdot 10^{-10}$ mbar · l/s

No changes were detected after the He gas flowed inside the plastic bag (measured at room temperature after the cycles)

The result of these tests is that the Garlock QDS with the standard Helicoflex showed very good UHV leak tightness in all conditions.

4.1.2. «Ultra-Flex Gasket + Clamp» He Leak Test. The first measurement was carried out at room temperature by using the usual technique with a plastic bag and yielded the following result:

***T* = 300 K; Ultra-Flex gasket + clamped flanges**

Vacuum level < 10^{-4} Torr

Leak rate background = $0.3 \cdot 10^{-10}$ mbar · l/s

Leak rate = $8.5 \cdot 10^{-10}$ mbar · l/s

No changes were detected after the He gas flowed inside the plastic bag for 3–5 s

For the test at cryogenic temperature we decided to follow the thermal cycling technique as described above: four cycles of keeping the setup for 10 min at 77 K and then warming it up with a heat gun.

***T* = 77 K; Ultra-Flex gasket + clamped flanges**

Vacuum level < 10^{-4} Torr

Leak rate background = $0.1 \cdot 10^{-10}$ mbar · l /s

He gas flowed inside the plastic bag for 5 s and after about 10–15 s we had

Vacuum level < 10^{-4} Torr

He leak rate = $1.5 \cdot 10^{-7}$ mbar · l/s

We tried to repeat the leak measurement at room temperature to verify the setup status.

***T* = 300 K; Ultra-Flex gasket + clamped flanges**

Vacuum level < 10^{-4} Torr

Leak rate background = $0.5 \cdot 10^{-10}$ mbar · l/s

He gas flowed inside the plastic bag for 3–5 s and after a few seconds we had

Vacuum level < 10^{-4} Torr

He leak rate = $1.2 \cdot 10^{-8}$ mbar · l/s

The Ultra-Flex gasket used with the Garlock QDS showed some problems in cold condition and after the thermal cycles.

We think that the causes of that are the same as in the previous tests made with the standard flanges, the low spring-back of this kind of o-ring with these dimensions.

5. SECOND SET OF PARTICLE CONTAMINATION MEASUREMENTS

The measurements described in Sec. 3 were also repeated as described above with the conical flange connections using the standard Helicoflex or Ultra-Flex gaskets. During these new measurements we opened the blind flange and put the particle probe inside the internal volume of the flange thus creating a flow of clean air inside the flange during the measurements, and for that reason the long pipe of the second flange was put in direct contact with the air flow coming from the hood (see Fig. 29).

The procedure was as follows:

1. Accurate cleaning of all parts (two flanges, the clamp and the o-ring);
2. Setting all parts under the hood in the clean room;
3. Blowing clean air inside the flanges for a certain period of time (usually 2–3 h);
4. Checking the air cleaning inside the flange with the device;
5. Waiting until no particles were detected inside (zero values of all particle sizes, see Fig. 30);
6. Mounting the clamp and measuring the air quality (with steps of 1 min).

The photos in Figs. 30, 31, and 32 show the setup and the phases of these new measurements.

5.1.1. «Helicoflex Gasket + Clamp» Measurement. Three tests were performed in the INFN-Pisa clean room to look for the particle release inside the flanges during their tightening.

In all the tests we detected some particles inside the flange during measurements.

We were not able to determine whether these particles arose from the plastic deformation of the Helicoflex o-ring or from the friction between the conical flanges and the clamp. For that reason we decided to perform other tests in which we used an already tested Helicoflex (cleaned before the new use) and we put Teflon tape on the internal surfaces of the clamp area in contact with the flanges. With this configuration, we detected almost zero particles during several closings and openings, so we think that part of the particles detected during the previous test with the Helicoflex arose from the friction contact between the clamp and the conical flanges.

We decided to order more Helicoflex gaskets to repeat the tests with Teflon on the clamp surface.

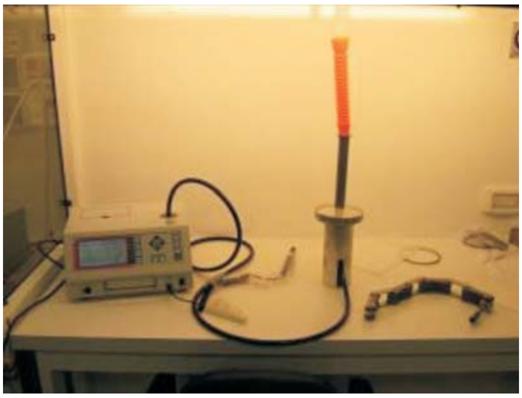

Fig. 29. Setup in the clean room for the second stage of measurements

Fig. 30. Particle counter probe inside the bottom flange

Fig. 31. Tightening procedure of the flanges

Fig. 32. The end of measurements

5.1.2. «Ultra-Flex Gasket + Clamp» Measurement. We carried out only one test with the Ultra-Flex gasket and the clamp connection in the INFN-Pisa clean room. In this test we used the clamp with the Teflon coating described above.

By the end of the test we also found some particles inside the flanges, this time only particles of smaller sizes:

- size 0.3 μm — 247,
- size 0.5 μm — 147,
- size 1.0 μm — 104,
- size 3.0 μm — 0,
- size 5.0 μm — 0.

We detected occurrence of particulates at the end of the compression, and this appears to be the critical point of this operation.

If we compare these values with those of Sec. 3, we see that this time we improved the cleaning of the tightening operations, which we think is because we managed to improve the way of holding the probe inside the flange in the volume and the flow of clean air inside the flange during measurements.

6. CONSIDERATIONS

All He leak tests on the gaskets (aluminum diamond-shaped and Garlock Ultra-Flex gaskets) performed at room temperature with the standard flange design showed good vacuum sealing with a measured He leak rate of $(1.3 \cdot 10^{-9} \pm 10\%)$ mbar · l/s and $(9.7 \cdot 10^{-10} \pm 10\%)$ mbar · l/s, respectively.

Using the Ultra-Flex gaskets we noticed some weak points during the thermal cycling that sometimes caused local leaks inside the vacuum volume. We think that reason of that is a very low value of spring-back (50 μm) that we found in the experimental leak rate/load/compression plot for this kind of gasket.

Additional investigation should be carried out to better understand the behavior of these metallic o-rings, and perhaps we need to increase the diameter of the tore and of the spring-back value.

The contamination measurements performed in the INFN-Pisa clean room demonstrated that an appropriate assembling sequence reducing the contamination within the vacuum volume was found. With the Ultra-Flex gasket, some contaminants were measured even with the best assembly sequence. The source of the contaminants could be plastic deformation of the softer jacket of the o-ring, but this conclusion should be more deeply investigated.

A different flange closing system was investigated.

This system was developed by the Garlock company and is based on external clamp acting on conically shaped flanges; the screws are no longer needed in this case.

We tested this system with the standard Helicoflex and Ultra-Flex gaskets.

Using the Helicoflex, we did not find any He leaks in all tests at room temperature, at nitrogen temperature (77 K) and after thermal cycling between these two values.

Using the Ultra-Flex, we performed only one test and we found no leak at room temperature but some leaks after the thermal cycles $(1.5 \cdot 10^{-7}$ mbar · l/s).

We repeated the contamination measurement in the INFN-Pisa clean room with the clamp and the Helicoflex and Ultra-Flex gaskets.

We solved the problems arising from the friction between the clamp and the flanges using a Teflon tape on the internal surfaces.

We plan to perform more tests with Helicoflex gaskets produced by the company with a cleaning procedure; during this procedure they will clean the spring before putting it inside the gasket, they will perform the welding of the external jacket of the o-ring in a clean area with blowing dry air inside the gasket and then they will perform a final cleaning of the gasket before the shipping.

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Будагов Ю. А. и др. E13-2009-25

Исследования различных типов уплотнений для фланцев резонаторов ILC

Дано описание методов, разработанных для определения уровня течи в вакуумных уплотнениях нескольких типов. Испытания проводились при комнатной температуре, температуре жидкого азота и после термоциклирования между этими двумя температурными уровнями. Также представлены результаты испытаний, проведенных в «чистой комнате» в лаборатории ИНФН (Пиза, Италия), по измерениям загрязнения частицами во время сборки фланцевых соединений. Были проведены испытания «системы быстрого разъединения» с использованием нового конического фланца и внешнего зажима. Два типа уплотнений — геликофлекс и ультрафлекс — были испытаны с помощью этой системы.

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

Сообщение Объединенного института ядерных исследований. Дубна, 2009

Budagov J. A. et al. E13-2009-25

Investigations of Different Types of Gaskets for ILC Cavity Flanges

The paper describes the procedures adopted to carefully test the He leak rate of several types of vacuum seals. All the tests were performed at room temperature and at liquid nitrogen (LN_2) temperature (77 K), and after thermal cycles between these two temperature levels. The paper also reports the test results in the INFN-Pisa clean room aimed to measure particle contamination while assembling the flange connections. The tests of the Quick Disconnect System using a new conical flange design and an external clamp were carried out. Two types of gaskets: the Helicoflex and the Ultra-Flex, were tested with this system.

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

Communication of the Joint Institute for Nuclear Research. Dubna, 2009

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