СООБЩЕНИЯ
ОБЪЕДИНЕННОГО
ИНСТИТУТА
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ
Дубна

E13-2010-92

J. Budagov, A. Sissakian, G. Shirkov, A. Sukhanova, G. Trubnikov, A. Basti[1],
F. Bedeschi[1], A. Ragonesi[1], R. Kephart[2], D. Mitchell[2]

INVESTIGATIONS ON HELICOFLEX GASKETS FOR **ILC** CAVITY FLANGES

[1] INFN, Pisa, Italy
[2] FNAL, Batavia, USA

2010

INTRODUCTION

We continue our previous tests [1] to find a new design for TESLA style cavity flanges [2–4] using Helicoflex gaskets and a Quick Disconnect System (QDS) (from the Garlock company). For these tests the measurement set-up was changed by replacing the stainless steel flanges with a niobium–titanium (Nb–Ti) structure closed with two stainless steel (SS) flanges to better simulate the real work conditions.

The main goals of these new tests are to check the cleaning of this new configuration and the influence of different materials in the cavity string assembly.

In the INFN-Pisa cryogenic laboratory, He leak tests were performed with these new set-ups at room temperature and at liquid nitrogen (LN_2) temperature (77 K), and after thermal cycles between these two values.

And in the INFN-Pisa clean room, tests were performed to measure particle contamination during the assembling of the flange connections following the procedure developed in the previous studies [1].

1. DESCRIPTION AND MEASUREMENTS OF THE TEST STRUCTURES

Two identical structures made at Fermilab were used by the ILC group of INFN-Pisa for these tests. The structures, called endgroups, were assembled from two Nb–Ti alloy flanges connected to a central Nb tube by electron-beam welding. The technical drawings of the structures were prepared by D. Mitchell and are shown in Figs. 1, 2 and 3.

We designated the first structure as sample N1 and the other one as sample N2. The endgroup flanges from each side were marked as A and B.

Another structure was made at the INFN-Pisa workshop with the same nominal dimensions and configuration, but the material of all components was 316L stainless steel (sample N3) (see Fig. 5). In this structure the

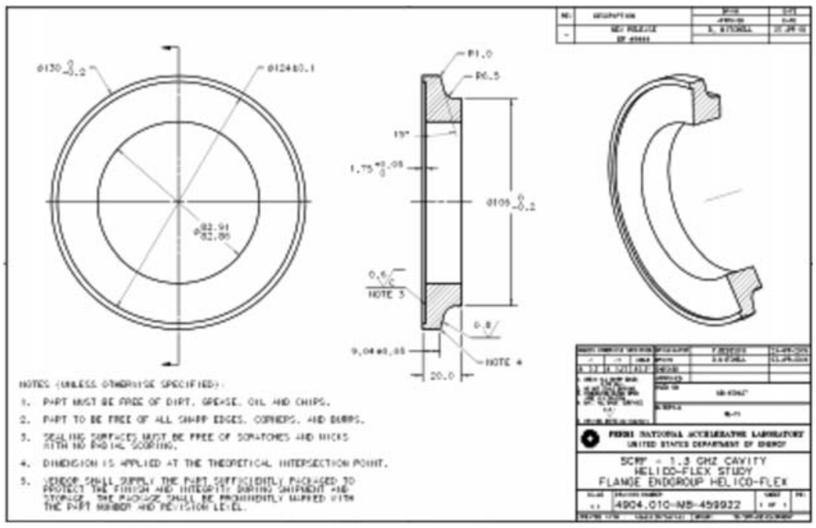

Fig. 1. Endgroup flange made of Nb–Ti

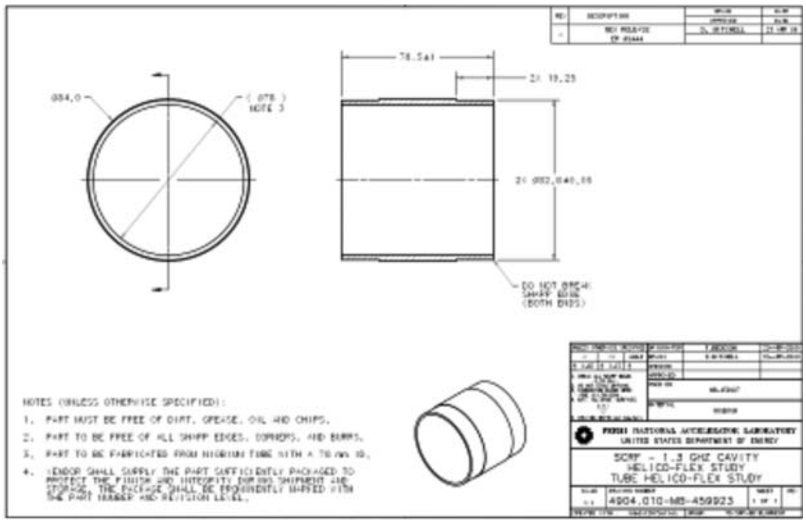

Fig. 2. Nb central tube

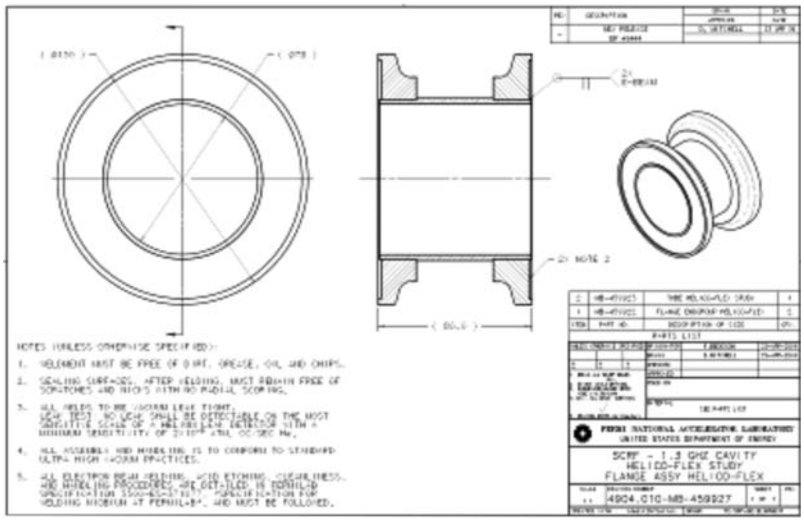

Fig. 3. Endgroup structure assembly

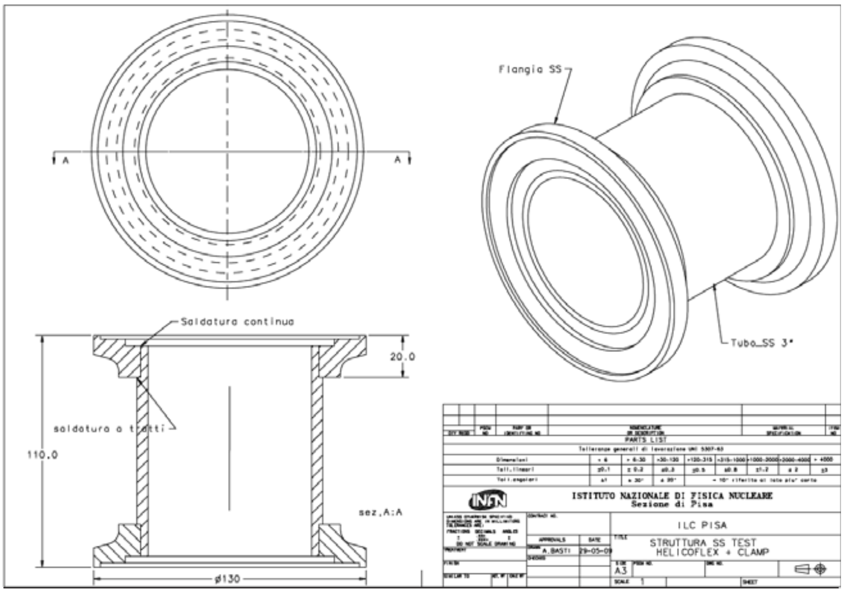

Fig. 4. Test structure made of stainless steel

external diameter and the length of the central tube are slightly different in comparison with the test structures received from Fermilab (see Fig. 4).

At first, we carefully checked all structures for compliance with the parameters before carrying out performance tests. Therefore, we only measured the tolerances and quality features which will be important for our studies.

The dimensional measurements were performed with a standard CMM machine located in the clean room of the INFN-Pisa laboratory.

Table 1 presents the results of the measurements together with the nominal dimensions coming from the technical drawings obtained from the company specification of the Helicoflex gaskets.

After these measurements we checked the quality of the groove surfaces of each flange. According to the producer's (Garlock) technical data sheet for the Helicoflex gasket, the surface finish (R_a) of this area must be in the range from 0.2 to 0.8 μm with an optimum value of 0.6 μm, wich is true for the circular Helicoflex gasket

Fig. 5. Test structures N1 and N3

Table 1. Test structure dimensions (in mm)

Parameter	Nominal dimensions	Sample N1	Sample N2	Sample N3
External diameter, side A	$130_{-0.2}$	129.784	129.806	129.869
Groove diameter, side A	$124_{\pm 0.1}$	123.943	123.998	123.799
Internal diameter, side A	—	78.107	78.319	82.669
Depth of the groove, side A	$1.75^{+0.05}$	—	—	—
External diameter, side B	$130_{-0.2}$	129.798	129.789	129.869
Groove diameter, side B	$124_{\pm 0.1}$	123.962	123.975	123.996
Internal diameter, side B	—	78.128	78.197	82.759
Depth of the groove, side B	$1.75^{+0.05}$	—	—	—

made for Ultra High Vacuum and with the Delta shape section (HNV type).

We used a Mitutoyo Surftest-211 roughness measuring instrument (see Fig. 6) to check the surface quality (see Fig. 7). The instrument allows measuring R_a, R_y, R_z, and R_q with a resolution of 0.01 μm in the measurement range of 10 μm. The cutoff length can be switched to 0.8, 2.5, or 0.25 mm, we used the 0.8 value that is the standard cutoff length for $R_a < 12.5$ μm.

In Table 2 we report the results of our surface roughness measurements.

The conclusions of these measurements are as follows:

- all dimensions of our test stuctures are within the tolerances of the design;
- all values of R_a are within the specification range except the value found for side A of sample N2.

Fig. 6. Mitutoyo surface roughness tester Surftest-211

Fig. 7. General view of the surface quality check set-up

Table 2. R_a value (in μm) for all structures

Direction	Sample N1		Sample N2		Sample N3	
	Side A	Side B	Side A	Side B	Side A	Side B
In tangential direction	0.37	0.23	1.5	0.57	0.35	0.43
In tangential direction	0.34	0.21	1.04	0.68	0.41	0.38
In tangential direction	—	—	—	—	0.3	—
In radial direction	0.4	0.38	1.06	0.41	0.39	—
In tangential direction	0.34	0.28	0.55	—	—	—
In tangential direction	—	0.27	—	0.55	—	—

2. GARLOCK HELICOFLEX AND QUICK-DISCONNECT SYSTEM

After the tests [1] with the standard flange configuration, we investigated a possible change in the flange design, comprising a different closure system.

In the new design, instead of the screws we used the flanges of conical shape and a radial clamp which transfers the load generated by a big screw to the two flanges. This system is called a Quick Disconnect System (QDS) by the Garlock company (see Fig. 8).

These clamps provide a faster and simpler assembly procedure.

The advantages of using this system are briefly 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 to be used with flanges with the internal dimensions of the tube 102 mm, similar to the TESLA cavity extremity tubes.

We modified the TESLA style cavity flange design according to the dimensions of the conical flanges that fit it (see Fig. 1), so that it could be used with this clamp.

After the first tests with it we decided to put a Teflon layer (20 or 40 μm) on top of this clamp to reduce the friction between the internal clamp surfaces and the external conical parts of the flanges.

Finally we ordered four clamps with these dimensions and Teflon surface treatment.

In Fig. 9 a Garlock clamp used in our test is shown.

With this sealing system, the Garlock advises to use standard Helicoflex gaskets with an external integrated centering ring (see Figs. 10 and 11).

To improve this minimum configuration, we ordered Helicoflex gaskets of this design from the Delta seal family (see Fig. 12), they had two small ridges or «Delta» on the face of the seal to reduce the helium leak rate to the minimum. This is the best choice for the ultra high vacuum applications.

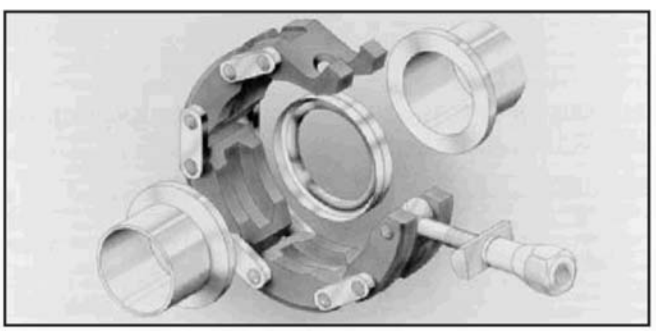

Fig. 8. Garlock quick disconnect system

Fig. 9. Garlock clamp with Teflon cover

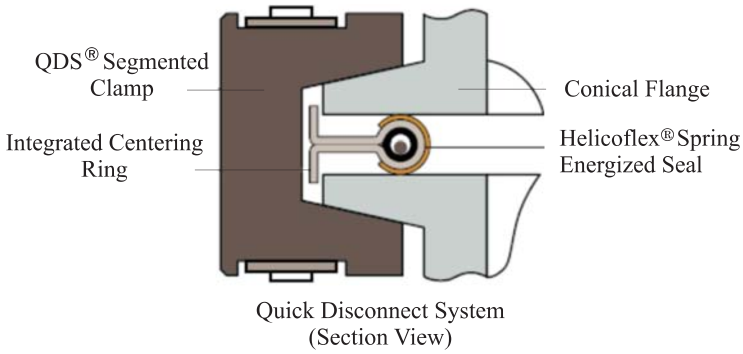

Fig. 10. Detail of the Garlock QDS + Helicoflex

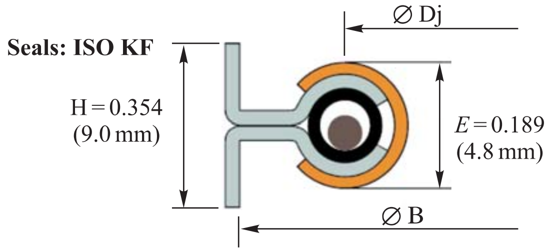

Fig. 11. Detail of a Helicoflex type gasket

The Helicoflex that we used for our tests are designated HNV-290P and have the following dimensions:

- external diameter = 130.1 mm (B);
- internal diameter = 113.9 mm (Dj);
- tore diameter = 4.9 mm.

The material of the inner lining is Inconel 600, while the outer jacket is made of aluminum alloy 1100.

Finally, we asked the company to produce for us these Helicoflex following a special cleaning procedure in which they clean the components before the assembly, perform the welds in controlled atmosphere, and store and ship the gaskets in special closed plastic bags.

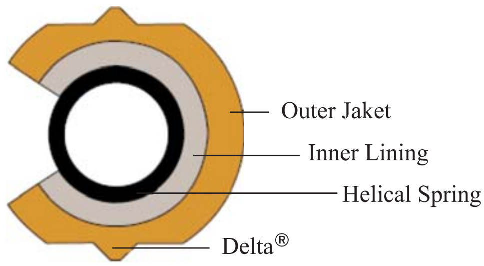

Fig. 12. Garlock Helicoflex Delta seal

3. PARTICLE CONTAMINATION MEASUREMENTS WITH SAMPLE N1

A set-up was assembled to hold the Nb–Ti structure (sample N1) and to close it with two SS flanges by means of the quick disconnect system and the Helicoflex gaskets described in the previous section.

The first SS flange has an opening that is welded to a small DN25 flange; that flange is closed during the He leak tests with a standard cup having an indium o-ring gasket, but it is open during the contamination measurements, thus allowing a laminar flow of clean air inside the volume enclosed by the flanges.

The second SS flange has a pipe (about 200 mm long) conceived to create a connection system (DN25) with the flex pipe of the leak detector for leak rate measurements. To connect this DN25 flange to the flex pipe of the leak detector, we used a gasket made of indium wire with a diameter of 2 mm.

The measurements were performed at the INFN-Pisa 1,000 class clean room (see Fig. 13) under a laminar flow hood, which improves the cleaning class to 100 around the experimental set-up [1].

Recall that the procedure consisted of the following:

1) accurate cleaning of all parts (the flanges, the clamp and o-ring);

2) set-up of all parts under the hood in the clean room;

3) flow of clean air inside the flanges for a certain period of time (usually 2–3 hours);
4) start to check the cleaning of air inside the structure with the machine;
5) waiting until no particles are detected inside (zero values of all particle sizes);
6) mounting of the flange and measuring of the air quality (with steps of 1 min);
7) mounting of the clamp around the flanges and measuring the air quality (with steps of 1 min);
8) final tightening of the clamp and measurement of the air quality (with steps of 1 min).

Fig. 13. Set-up for the contamination measurements of sample N1 in the Pisa clean room

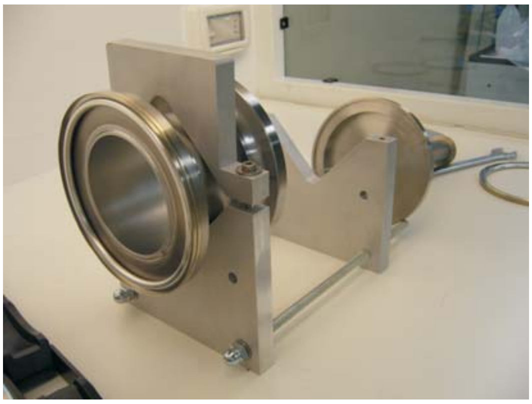

Fig. 14. Sample N1 before the closing

Fig. 15. Sample N1 closed with the Helicoflex gaskets during measurements

Figures 13, 14 and 15 show the set-up and sample N1 closed with two SS flanges during the particle contamination measurements.

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

This device measures airborne particles in several size ranges and displays the number of particles in each range. The measurement was made by inserting the probe of the particle counter into the pipe of one SS flange.

The detected air flow rate was 28.32 liters per minute (LPM) and the particle size ranges were 0.3, 0.5, 1, 3, 5 and 10 μm (see Fig. 16).

```
S/N 040901014
LOCATION=1    14:05:32 OCTOBER 08,2009
INF CYCLES    Flowrate=28.32 LPM
PERIOD=00:01:00        /CU M
  SIZE        CUMULATIVE       DIFFERENTIAL
  0.3µm            282                 106
  0.5µm            177                  35
  1.0µm            141                 106
  3.0µm             35                   0
  5.0µm             35                   0
 10.0µm             35                  35

S/N 040901014
LOCATION=1    14:06:32 OCTOBER 08,2009
INF 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

S/N 040901014
LOCATION=1    14:07:32 OCTOBER 08,2009
INF CYCLES    Flowrate=28.32 LPM
PERIOD=00:01:00        /CU M
  SIZE        CUMULATIVE       DIFFERENTIAL
  0.3µm           1448                 141
  0.5µm           1306                 353
  1.0µm            953                 565
  3.0µm            388                 247
  5.0µm            141                 141
 10.0µm              0                   0

S/N 040901014
LOCATION=1    14:08:32 OCTOBER 08,2009
INF 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. An example of data output from the particle counter machine

We noticed that the crucial point was the assembly of the flanges and the clamps. This is because too much contact between the metallic surfaces during these operations could cause production of particles detectable by our machine.

It is necessary to take into account that this kind of o-ring has an external centering ring and we mounted both flanges and the clamp around the flanges manually.

If we are able to mount the flanges accurately without having too much friction between the metallic surfaces, slightly press the flanges against each other, and mount the clamp carefully, the machine does not detect particles.

After some trials we learned to do these operations, and finally we were able to assembly the SS flange and the clamp without generating particles inside.

```
S/N 040901014
LOCATION=1    14:15:32 OCTOBER 08,2009
INF 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

S/N 040901014
LOCATION=1    14:16:32 OCTOBER 08,2009
INF 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

S/N 040901014
LOCATION=1    14:17:32 OCTOBER 08,2009
INF 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. 17. An example of the data during the stepwise closing of sample N1 in clean room

After the connection of the SS flange, the Helicoflex gasket, and the clamp, the final operation was to press the flanges one against the other by means of the single clamp screw that allows squeezing the clamp and moving the conical flanges very easily. During this operation the particle counter machine continued to detect zero particles inside the test structure.

We repeated this procedure for both flanges and clamps to close sample N1 with the same good results.

Figure 17 shows an example of the data from the machine during one of the phases described above for sample N1.

4. He LEAK TEST WITH SAMPLE N1

Several He leak tests of sample N1 closed with the conical flanges, clamps, and Helicoflex gaskets were performed at room temperature, at 77 K, and after the thermal cycle between these two values following the procedures described in [1].

The first measurement was performed at room temperature (see Fig. 18) with the usual technique applying a plastic bag filled with helium, and the result obtained is as follows:

***T* = 300 K**

Vacuum level < 10^{-4} Torr

Leak rate background = $1.7 \cdot 10^{-10}$ mbar · l/s

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

The same measurement was performed at 77 K.

The test structure was immersed into the Dewar with liquid nitrogen, kept for the time necessary to have the system at thermal equilibrium with LN_2, pulled out of the Dewar, and immediately inserted into the plastic bag filled with helium.

The results were as follows:

***T* = 77 K**

Vacuum level < 10^{-4} Torr

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

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

He leak rate = $7.7 \cdot 10^{-10}$ mbar · l/s (at 77 K).

We decided to follow the thermal cycling technique as described in [1]: two cycles — keeping the set-up at 77 K and then quickly heated by a heat gun to 300 K. After this phase at room temperature the set-up was inserted into the plastic bag filled with helium gas for a few seconds and the result is the following:

Two cycles between *T* = 300 K and *T* = 77 K

Vacuum level < 10^{-4} Torr

Leak rate background = $1.4 \cdot 10^{-10}$ mbar · l/s

He leak rate = $2.4 \cdot 10^{-10}$ mbar · l/s (at 300 K)

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

Figures 19, 20 and 21 show some phases of these leak tests.

Fig. 18. The sample N1 He-leak test at room temperature

Fig. 19. The sample N1 test in liquid nitrogen

Fig. 20. The sample N1 test during heating with a heat gun

Fig. 21. Sample N1 inside the nitrogen Dewar

5. PARTICLE CONTAMINATION MEASUREMENTS WITH SAMPLE N2

The measurements described in Section 3 were also repeated for sample N2. The same procedure was used.

Again, we needed some time to mount with care the flanges and the chains, but after these crucial phases we did not notice generation of particles inside the test structure. In a special way during the closing of the chains, our particle counter machine did not detect anything inside and the total operation was very clean.

6. He LEAK TEST WITH SAMPLE N2

The measurement was performed with sample N2 only at room temperature and the result is as follows:

***T* = 300 K**

Vacuum level < 10^{-4} Torr

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

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

It is important to notice that in this sample we found a flange with a bad-quality surface inside the groove (out of design tolerance), but that did not influence the result of the He leak test, at least at room temperature.

PARTIAL CONCLUSION

The tested set-up showed very good UHV leak tightness in all conditions. Different materials in the set-up (Nb–Ti and SS) did not change the He leak rates, and we think that the elasticity of the Helicoflex assures a good solution for that aspect.

The particle contamination measurements showed that the crucial phase was the mounting of the flanges and the chains, because in these phases we had friction between the metallic surfaces, which caused production of particles that were detected by the counter machine.

But during the tightening of the clamp we did not notice any particles to come from the squeeze of the Helicoflex gasket.

Before the final tests with samples 1, 2 and 3, we decided to improve the mounting procedure by creating a simple tool that allows us to hold the structures in the right position, to move them easily with respect to each other, and to test the possibility of mounting the flanges in a cleaner way.

REFERENCES

1. *Budagov J. et al.* Investigations of Different Types of Gaskets for ILC Cavity Flanges. JINR Commun. E13-2009-25. Dubna, 2009.
2. *Zapfe-Düren K., Herrmann F., Hubert D., Schmüser P.* A New Flange Design for the Superconducting Cavities for TESLA // Proc. of the 8th Workshop on RF Superconductivity, Abano Terme, 1997 / Eds. V. Palmieri and A. Lombardi (INFN, LNL-INFN (Rep) 133/98) 457.
3. *Michelato P., Monaco L., Panzeri N.* Report about New Design for Components: Cold Flange. CARE Note-06-002-SRF, 2006.
4. *Monaco L, Michelato P., Pagani C., Panzeri N.* Experimental and Theoretical Analysis of the TESLA-like SRF Cavity Flanges // Proc. of EPAC 2006, Edinburgh, Scotland. P. 463–465.

Received on August 5, 2010

Будагов Ю. и др. E13-2010-92

Исследования уплотнений Helicoflex для фланцевого соединения резонаторов ILC

Достигнуто надежное соединение сверхпроводящих ниобиевых резонаторов благодаря применению конических фланцев из сплава Nb–Ti в сочетании с системой быстрого разъединения (фирмы «Garlock»). Фланцевое соединение испытано на вакуумную плотность при комнатной температуре и температуре жидкого азота, уровень течи $< 10^{-9}$ мбар · л/с. Применение данного фланцевого соединения существенно упростит конструкцию, на порядок снизит время монтажа/демонтажа и, как ожидается, сократит длину вакуумной камеры ускорителя.

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

Сообщение Объединенного института ядерных исследований. Дубна, 2010

Budagov J. et al. E13-2010-92

Investigations on Helicoflex Gaskets for ILC Cavity Flanges

A reliable joint of the Nb superconducting cavities is achieved due to the use of the conical Nb–Ti flanges together with a Quick Disconnect System (from the Garlock company). The joint was tested at room temperature and liquid nitrogen temperature (77 K), the measured leak level is $< 10^{-9}$ mbar · l/s. This flange assembly simplifies the design, reduces the assembly time by an order of magnitude, and is expected to decrease the accelerator vacuum chamber length.

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

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

Редактор *Е. И. Кравченко*

Подписано в печать 3.11.2010.
Формат 60 × 84/8. Усл. печ. л. 1,27. Уч.-изд. л. 1,72. Тираж 305. Заказ № 57149.

Издательский отдел Объединенного института ядерных исследований
141980, г. Дубна, Московская обл., ул. Жолио-Кюри, 6
E-mail: publish@jinr.ru
www.jinr.ru/publish/