LATEST DEVELOPMENTS IN SEALING OF ACCELERATORS.

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INTRODUCTION.

For many years engineers involved in the design of sophisticated vacuum and ultra-high systems such as accelerators had been looking for a static metal seal which would offer the same advantages as an elastomer O-Ring, which means to be adaptable to the same light-duty flange configuration where low thermal inertia and limited weight are priority parameters. Within a special collaboration agreement between the C.E.A.(the French Atomic Research Center) and LE CARBONE LORRAINE - CEFILAC ETANCHEITE it was decided to look into this field.

The HELICOFLEX △ seal is the answer to this challenge. It is now commercialized and can be manufactured in diameters ranging from 10 mm to 2 m with all types of metallic materials compatible with ultra-high vacuum conditions. As shown hereafter, its fully-metallic design puts the HELICOFLEX △ seal in a better position than elastomer seals for many applications.

PERFORMANCES OF SEALS REQUIRED BY NEW ACCELERATORS.

The new types of accelerator require new sealing performances, such as :

- Ultra-high vacuum (10^{-11} mbar).
- Metallic construction.
- High efficiency at extreme temperatures negative or positive.
- Compatibility with aluminium - indium flanges without risk of damage on sealing surfaces.
- Low outgassing rate.
- Resistance to radiations.
- Steady sealing performance over the life of the accelerators.

As described in the paragrah "discussion", the HELICOFLEX delta fulfils all those characteristics, but, let's first define the principle of this seal and its main characteristics.

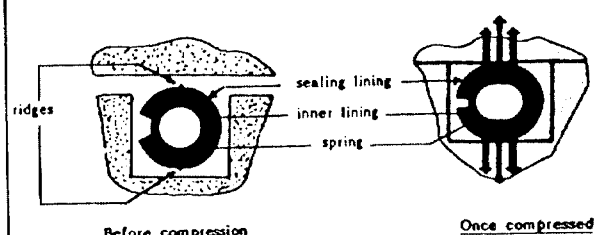
The HELICOFLEX △ seal is circular cross section seal exclusively made from metallic materials. It is a static seal which can be installed in-between flat face, raised-face, orgrooved flanges. It includes in its primary design (the HNV type) the following compoments

- The spring.
- The inner lining.
- The sealing lining.

THE SPRING.
The spring is of the close-wound type and provides the adequate reaction of the seal against the flange faces, which reaction is initiated by the tightening load applied on the bolts. It will ensure over the whole seal life a double function which we can call reaction load generation and springback storage, thus allowing external phenomenons (such as creeping, bolts relaxation, temperature changes, ...) to occur without losing the required sealing level. In order words, the spring maintains between the sealing lining and the flange faces the most intimate contact which guarantees the seal performance over a long period of time.

THE INNER LINING.
The inner lining ensures a uniform distribution of the spring reaction load against the sealing lining.

THE SEALING LINING.
The sealing lining made from a metallic material is meant to be plastically deformed against the micro-defects of the flange faces. It has 2 sharp ridges which feature the HELICOFLEX △ seal.
As can be seen on sketch NR 1, those ridges made on each side of the torus in line with the spring median axis are acting as contact circles. Due to their profile, they generate a high specific pressure and gradually disappear with increasing compression. This leads to a very good sealing performance ($Q \leqslant 1.10^{-11}$ MPa m3 s^{-1}) which can be reached already very early in the compression phase.
Let's emphasize the fact that because of its metallic nature, the sealing lining material exposed to this high specific pressure will penetrate the micro-defects of the flange faces much more efficiently than an elastomer material which always tends to creep before getting to an intimate contact.



Sketch Nr 1

HELICOFLEX △ CHARACTERISTIC CURVE

The analysis of the HELICOFLEX △ characteristic curve (figure 2) allows a different approach of the various points mentionned earlier.
This curve is giving the compression load variation (Y-axis) expressed in terms of linear load (Newton per mm of seal circumference) versus the resulting compression (X-axis) expressed in mm.
Two different phases can be noticed on this curve : compression and decompression which lead to the following remarks :

- a low compression load value (100N/mm) at working point Y2 where metal to metal contact between the flanges is ensured.
- a large safety margin due to the fact that the sealing threshold at point Y0 is reached much earlier in the compression phase than the actual working point Y2.

A quite significant effective springback [1] (especially high value compared to other types of metal seal) which can be identified on the decompression curve, going from working point Y2 down to point Y1 below which the required sealing level would be lost.
In practice it means the possibility of having the optimal compression load decreased by approximately 80 % before losing the required sealing level.

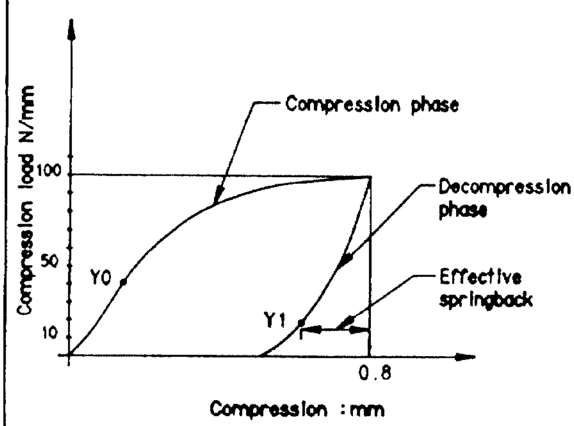


FIGURE 2

Caracteristic curve

The HELICOFLEX seal can be designed with all kind of lining materials.

Some compression tests, which have been followed by CEA at Pierrelatte (French Atomic Center) [2] have enabled to define the necessary compression load to obtain the Helium sealing with each of these linings.

The table here after insists on the low compression load required by this metallic seal.

Tableau des valeurs caractéristiques / ***Table of characteristic values***

Revêtements ductiles / *Ductile linings*

Etanchéité HELIUM / *HELIUM sealing*																				
Aluminium / *Aluminium*							Argent / *Silver*							Cuivre / *Copper*						
Ø tore/torus dia th (mm)	Ø tore/torus dia sur saillants on ridges	Type	Y_2 daN.cm⁻¹	e_2 (mm)	HV mini	T° maxi	Ø tore/torus dia th (mm)	Ø tore/torus dia sur saillants on ridges	Type	Y_2 daN.cm⁻¹	e_2 (mm)	HV mini	T° maxi	Ø tore/torus dia th (mm)	Ø tore/torus dia sur saillants on ridges	Type	Y_2 daN.cm⁻¹	e_2 (mm)	HV mini	T° maxi
2	1,9	HNV 100	90	0,6	65	150	1,8	1,7	HNV 200	130	0,5	100	240	1,74	1,64	HNV 100	130	0,34	110	350
2,7	2,6	HNV 270	90	0,8	65	220	2,5	2,4	HNV 200	140	0,6	100	280	2,44	2,34	HNV 200	140	0,44	120	380
3,4	3,3	HNV 200	100	0 9	65	250	3.2	3,1	HNV 200	140	0,6	100	300	3,14	3,04	HNV 200	140	0,54	120	380
4,9	4,8	HNV 200	120	0.9	65	280	4.8	4,7	HNV 200	140	0,8	100	370	4,64	4,54	HNV 200	140	0.64	120	450
5,6	5,6	HNV 200	130	1	65	320	5,6	5,4	HNV 200	160	0,8	110	400	5,54	5,34	HNV 200	160	0.64	120	480
6,9	6,7	HNV 200	140	1,1	65	340	6,7	6,5	HNV 200	180	0,9	120	450	6,54	6,34	HNV 200	180	0.74	130	520

Revêtements non ductiles / *Non-ductile linings*

Etanchéité HELIUM / *HELIUM sealing*																				
Nickel / *Nickel*							Inox - Tantale / *Stainless steel - Tantalum*							Inconel / *Inconel*						
Ø tore/torus dia th (mm)	Ø tore/torus dia sur saillants on ridges	Type	Y_2 daN.cm⁻¹	e_2 (mm)	HV mini	T° maxi	Ø tore/torus dia th (mm)	Ø tore/torus dia sur saillants on ridges	Type	Y_2 daN.cm⁻¹	e_2 (mm)	HV mini	T° maxi	Ø tore/torus dia th (mm)	Ø tore/torus dia sur saillants on ridges	Type	Y_2 daN.cm⁻¹	e_2 (mm)	HV mini	T° maxi
1,6	1,5	HNV 100	140	0,25	140	380	1,6	1,5	HNV 100	160	0,25	140	420	1,5	1,4	HNV 100	160	0,25	140	450
2,4	2,3	HNV 100	160	0,30	140	420	2,4	2,3	HNV 100	180	0,30	150	480	2,4	2,3	HNV 100	200	0,30	150	500
3,3	3,2	HNV 200	180	0,35	150	480	3,3	3,2	HNV 200	200	0,35	160	500	3,3	3,2	HNV 100	230	0,35	170	550
4,7	4,6	HNV 200	230	0,40	170	600	4,7	4,6	HNV 200	230	0,40	170	650	4,5	4,4	HNV 100	250	0,40	180	700
5,2	5,1	HNV 200	220	0,45	190	650	5,2	5,1	HNV 200	290	0,45	190	700	5,4	5,3	HNV 100	340	0,45	200	700
6.2	6,1	HNV 200	360	0,50	210	650	6,2	6,1	HNV 200	360	0,50	210	700	6,2	6,1	HNV 100	400	0,50	220	700

MAIN REFERENCES FOR HELICOFLEX △ SEALS

Such seals are now being used on many ultra-high vacuum systems operating in the industry and the main research institutes. Some examples are mentionned below :

CERN.

The 450 Gev prolon accelerator SPS (Super Proton Synchroton) was refurbished using HELICOFLEX △ seal between 80 mm diameter and 400 mm diameter in order to conform with following new specifications :

1) Necessity to reach a vacuum of pressure of 5.10^{-10} mbar (average) together with an allowable leak rate of 2.10^{-10} mbar $l.s^{-1}$ (maxi per seal).
2) Necessity to absorb the synchrotron radiation whenever the SPS is used as L.E.P. pre-injection device.

For this special application, in addition to its features described earlier (resilience and high specific pressure), the HELICOFLEX △ seal is built in such a way that the inside diameter is acting as a support for a Tungsten piece which is used to limit the synchrotron radiation and which requires an accurate positionning within 0.2 mm.

Several thousands of those seals have already been supplied for this application.

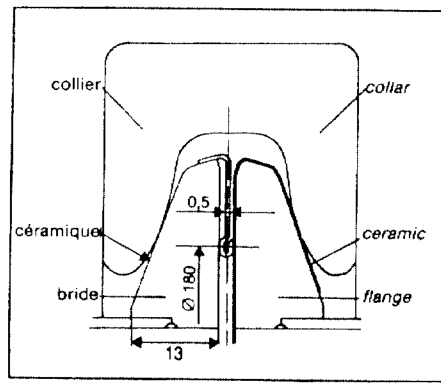
INDIA.

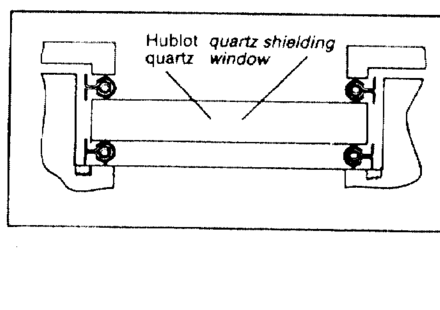
India has very important natural Thorium reserves and therefore holds a leading position worldwide as far as Thorium production is concerned.

A Thorium process plant has been built which required important ultra-high vacuum systems. HELICOFLEX △ seals ranging from 10 mm diameter to 800 mm diameter have been supplied for the sealing of the ISO-PNEUROP flanges used on those installations, quantities being typically of 100 to 300 pieces per size.

BROOKHAVEN.

The Brookhaven laboratory in USA is also using the HELICOFLEX △ seal for variuos applications including the sealing of quartz sight-glasses.





DISCUSSION

The standard HELICOFLEX seal without ridge requires despite of great sealing properties, a too important tightening load with respect to high and ultra-high vacuum systems used on particles accelerators, so the idea of concentrating the specific force on a ridge without interfering with the performance was attractive but difficult to carry out.
Today, the technical problems are solved and we can say that the HELICOFLEX △ fulfils the requirements of ultra-high vacuum systems.
It guarantees the already mentionned performances, which means that :

- a $10.^{-11}$ mbar vacuum is ensured by the manufac--turing quality of the ridge.
- it is made from a metallic strip and a spring in "super" alloy, such as Nimonic 90 or Inconel X750.
- this metallic materials can withstand temperatures from 18° K up to 1000° K.
- the superficial hardness of aluminium sealing lining is lower than hardness of aluminium flanges, differential hardness being around 40.
- polishing and cleaning operations are carefully carried out, thus allowing an extremly low outgassing rate.
- all metallic materials used can resist to radiations, we can mention aluminium, silver, super-allow...
- the spring ensures an internal elasticity which enables the seal to "breathe" and to prevent from deterioration of the intimate contact between the flange and the sealing lining.

CONCLUSION

The originality of the HELICOFLEX seal design has led to numerous applications on accelerators or ultra-high vacuum systems.
However, its application field is not limited and could be widely extended at the demand of conceptors.
It has already been selected for various other applica--tions where the basic requirements can only be fulfilled by this solution.

Examples are :
- Space application : low weight and an unlimited life.
- Cryogenics : low thermal inertia and high reliability.
- Electronic : replacement of viton seals to improve vacuum and cleanness.

[1] T.Wickberg, 11th International Vacuum Congress in Köln, FEM calculation of UHV ALL-Metal demontable joints for LEP.

[2] R.Devillepoix, Report N° 27 French Atomique Center, Evaluation of Helicoflex performances in Iso-Pneurop standard flange.