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TECHNICAL NOTE

Investigation on metallic high vacuum gaskets in conjunction with quick-disconnects for circular and large rectangular flanges.

## Purpose

A certain number of special vacuum tanks will have to be incorporated into the main ring vacuum system of the SPS. These tanks will house pulsed magnets for injection, ejection and beam dumping, septum magnets, scraping targets and other voluminous equipment which must work under vacuum. Although the design fo cylindrical tanks, where the equipment is mounted through circular end flanges, it not completely excluded, the design of tanks, similar to the one shown in fig. 1, is more desirable for the ease of mounting and access to the equipment. The strong base-plate of rectangular shape serves as mounting reference, support plate and bottom of the tank. The vacuum tank covers the equipment like a cheese hood and can be easily taken away, allowing access to the equipment from all sides. Pumps, gauges, feed-throughs etc., are connected through the bottom plate. Only the alignment references are fed through the top cover by means of metal bellows, forming a plug-in system which establishes a reference point, in direct contact with the equipment to be aligned. With such a tank design, the need for large seals of rectangular shape, of sizes up to 3000 x 600 mm, is obvious. In view of the radiation level expected around the machine, organic materials are excluded and the seal must be metallic. In order to make full use of the advantage(fast interventions to the equipment) of this type of tank design, the large flange between bottom plate and cover must be equipped with a quick disconnect system, rather than bolts and nuts. However, the applicable sealing force with a quick disconnect is limited.

The purpose of the work described in the present note was to find a metallic gasket in conjunction with a quick disconnect system for these special vacuum tanks. As the tests were done mainly on circular flanges, the results obtained are also useful for the design of other types of flanges.

## Considerations for the choice of seal

There exists a large number of different designs of metallic vacuum seals (ref. 1) and many of them are commercially available. However, each of these systems has its disadvantages like high sealing force, complicated flange machining, seal delicate to place, sticking of seal to flanges etc. Unfortunately there is no ideal seal, which satisfies all points of the following specification:

1) Reliable zero leakage on highest sensitivity of lead detector.
2) Only one defined sealing line in order to avoid leaks due to marks left by previous seals.
3) Static seal without differential pumping or pressurising system.
4) Low sealing force required, which can be applied with quick disconnect.
5) Flange couplings must be short with a minimum of components.
6) Must withstand moderate bakeouts.
7) Easy and cheap machining of flange surfaces.
8) Both mating flanges must be of equal design (sexless)
9) Easy and quick positioning of gasket in any position
10) Exact centering of flanges one to another
11) Both flanges rotatable without particular ring (only for circular flanges)
12) Sealing surface not exposed to risk of damage in handling
13) Flanges should withstand a great number of closures without damage.
14) No weld in the seal
15) Design adaptable to any shape and size of flanges
16) No excessive requirements on the flatness of the flanges
17) Gasket re-usable or very cheap.

Some of these requirements are contradictory so that a compromise has to be made for the choice of a sealing system. When the characteristics of the different groups of seals are compared for their suitability to the above requirements, most of the existing designs can already be eliminated. Of course, a choice of priorities among the above requirements has to be made.

Systems which use a wire as gasket need relatively high sealing forces, the wire is difficult to place or needs a special jigg or ring. The wire is welded in one place. A soft wire, which would need less force, runs the risk of creeping and sticking to the surfaces. Wire gaskets can be ruled out for these reasons.

A design with knife edges which cut into a plate, like the "Conflat", T or similar systems, needs high forces, the flanges as well as the gaskets are relatively expensive and fragile, non-circular flanges cannot be made and the use of softer materials run the same risk of creeping and sticking as wires.

The use of lead or indium in a groove, which prevents it from creeping, presents too many uncertainties like oxyde inclusions, bad adhesion in the groove. The metal must be remolten after a number of closures, which is only possible for horizontal flanges. The removal of the gasket material is a difficult operation.

Elastic profile seals (C-seal, tubes etc), satisfy best the low force requirements. They also compensate to a certain extent waviness of the flanges. It is not clear if they are reliable concerning absolute leak tightness. The maximum leakage rates, guaranteed by the different manufacturers, are indicated to be between $10^{-7}$ and $10^{-9}$ Torr l $sec^{-1}$. These seals are expensive. Nevertheless they can be considered at least as a possible solution for non-circular flanges.

Foil gaskets offer certain advantages. Foils are cheap and the gasket can be easily made, even by handcutting with a pair of scissors, and therefore, there is no need to be limited to standardised flange diameters. The foil gasket is made from one piece without weld. The foil must not be much less than 0.1 mm thick in order to permit easy handling. Ears or pinholes for centering the gasket can easily be made by punching techniques. Softer materials, resulting in lower sealing forces, can be used, so long as work hardening takes place during the compression of the gasket in order to prevent it from creeping. The flanges must be absolutely flat or easily deformable in order to produce a parallel sealing line. Consequently, foils should be considered for our applications.

## Elastic profile seals

Twenty-five companies capable of producing this kind of gasket had been invited to offer a seal according to our specification (attached). Only two propositions which could be technically satisfactory were offered to us.

### 1. AVICA - Pressure Science

The well-known C-seal (Fig. 2) made from inconel with an indium plating can be produced up to a size of 3000 mm x 600 mm. It is placed in a groove or positioned with a spacer plate. The sealing force is 30 Kg/linear cm of seal, the minimum radius in the corners is of the order of 40 mm. However, AVICA has never produced such a big seal of rectangular shape for vacuum application. The price for one gasket for the inflector tank will be of the order of 2.500.- Fr. which makes us hesitate to employ such gaskets.

### 2. CEFILAC

They propose a gasket made from an inner core consisting of a longitudinally wound spiral spring placed in a C-shaped hardened thin-walled steel profile, which is covered by a thin aluminium foil making the actual seal. (Figure 3). Large seals of rectangular shape can be produced with a minimum corner radius of about 50 mm. The sealing force is 100 Kg/cm of seal.

Exact prices have not yet been given, but from discussions with the representative of this firm, it appeared that this type of gasket for the size of the inflector tank would not cost more than 500.-fr per piece. CEFILAC will submit an offer for five gaskets for the prototype inflector tank, which has a rectangular flange of 882 x 417 mm equipped with a quick disconnect system

## Foil seals

A series of tests have been carried out in the BT-Group, mainly on circular flanges, in order to find the best combination of flange profile and foil, which gives a leak-tight seal with a the lowest possible sealing force.

The first series of tests was carried out with the flanges (figure 4) with a sealing diameter of 170 mm. A radius profile of r = 5 mm was machined onto one flange. The aim was to find out the influence of material, hardness and thickness of different foils on the force which must be applied to obtain a tight seal, which means zero leakage indication on the highest sensitivity of a helium leak detector. The pair of flanges was bolted together by 10 M 8 screws and connected to the leak detector. The screws were tightened in successive steps with intermediate leak checking, until zero leakage occurred. The torque on the bolts was measured by means of a dynamometric key.

### Test 1 :

Aluminium foil (composition not known) 0.1 mm thick, annealed.
Tight at 1 mKg
One flange was heated with an air blower to $\approx 50^{\circ}$C.
Tight, when hot and after cool-down.
After demounting, the width of the sealing line was measured to be 0.9 mm on both faces of the gasket.
The Micro-Vickers hardness of the gasket was for the basic material 22.2 MHV and 32.4 MHV in the zone where the seal had been compressed.
The penetration depth of the radius into the aluminium foil is calculated to be 0.02 mm.

Test 2:

Aluminium foil, same as above but not annealed (hard) 0. 1 mm thick.

Tight at 2 mKg

One flange was heated, as above

Tightness was preserved

The width of the sealing line was 0.9 mm

Hardness of the gasket : Basic material 47 MHV
Compressed zone 47.3 MHV

Test 3:

Lead foil of 0.6 mm thickness.

Impossible to tighten, the lead flows away from the radius at any pressure applied to the gasket.

Hardness of the gasket : Basic material 9.8 MHV
Compressed zone 11.1 MHV

During these three tests the plane flange had several radial scratches over the sealing line. These were polished out and further tests were made.

Test 4:

Aluminium foil like test 1 annealed, 0.1 mm thick.

Tight at 0.45 mKg

Heated one flange to 50$^{\circ}$C - tightness was preserved.

After letting the flange assembly twice up to atmospheric presure, followed by pump-down, a small leak occurred. The torque had to be increased to 1.3 mKg to obtain tightness again. Further flooding and pumping cycles no longer affected the seal. This was the only occasion that such a phenomenon was observed.

Heating of one flange and repetitive flooding, at least 3 times where done in all further tests.

Test 5:

Aluminium Foil (from other sources, but of unknown composition), hard 0.1 mm thick, hardness 49.2 MHV.

Tightness was obtained at 1 mKg

The width of the sealing line was only 0.5 mm

Test 6:

Aluminium foil as above but annealed, hardness 27.9 MHV

Tight at a torque of 1 mKg

Width of the sealing line was 0.55 mm.

Test 7:

Aluminium foil, same source as above but 0.2 mm thick, hard.

Tightness was obtained at 1.3 mKg.

First conclusions

Tests 1 and 2 have shown a substantial difference in sealing force between annealed and hard foil. Tests 4 to 7 did not show this effect. This may mean, that the soft foil offers an advantage only in the presence of surface scratches. A great amount of work hardening takes place in the annealed gasket, which guarantees a stable seal. Pure aluminium in the solution treated condition should have a hardness of 15 MHV.

Assuming that the penetration depth of the profile into the gasket is the most important factor for proper sealing, one could approximately calculate the radius of the profile which would seal with, let's say, half the force as compared to radius of 5 mm which was used up to this point. We use the formula for the elastic case, which is not quite true here, but which could give an indication of the maximum force applicable to the seal material, the maximum pressure for the case of a round bar against a plate becomes :

$$p^2_{max} = \frac{P\ E}{2\ \pi\ 1\ r\ (1 - \upsilon^2)}$$

$P/1$ for 1 mKg $\approx$ 16 Kg/mm

$E = 7000$ Kg/mm$^2$

$\upsilon = 0.39$

$r = 5$ mm

$$p_{max} = \left(\frac{16 \times 7\ 000}{6,28 \times 5 \times (1 - 0,39^2)}\right)^{\frac{1}{2}} =$$

$$= 68.6\ \text{Kg/mm}^2$$

This pressure is high enough to deform the aluminium plastically. As the width of the deformed sealing line was measured to be 0.9 mm, the lower limit for the pressure must be :

$$\min p = P/1\ w\ \frac{16}{0.9} = 17.7\ \mathrm{Kg/mm^2}$$

which is about the elastic limit of aluminium in the half hard condition. The penetration depth of the profile into the foil is :

$$h \approx \frac{w^2}{8\ r} = \frac{0.9^2}{8 \times 5} = 0.02\ \mathrm{mm}$$

so a radius which gives the same penetration depth for a sealing line w of only 0.5 mm width becomes :

$$r = \frac{h}{2} + \frac{s^2}{8\ h} = \frac{0.02}{2} + \frac{0.5^2}{8 \times 0.02} = 1.56\ \mathrm{mm}$$

The flange was therefore modified to have a radius of 1.5 mm.

Test 8:

Aluminium foil annealed, 27.9 MHV, 0.1 mm thick.
Tight at a torque of 0.45 mKg
Flooding of the volume and heating of one flange did not affect the seal.
Two screws were loosened and retightened to the same value, the tight seal was re-established, doing the same on a third screw, a leak appeared.
Width of sealing line 0.5 mm, it's hardness 31.2 MHV.

Test 9:

Aluminium foil hard 49,2 MHV, same conditions as test 8 tightness was obtained at 0.45 mKg.
Flooding and heating did not affect the seal, loosening one screw brought a leak, this was retightened with the same torque.

Tests 10 and 11

were repetitions of the above tests and brought the same results.

A mounting jigg (Figure 5) was made, in order to allow the application of direct pressure to the centre of the flange over a dynamometer, so that the pressure could be read in Kg. The flanges were no longer heated from test 12 on.

Test 12 :

Aluminium foil like in test 1, 22.2 MHV, 0.1 mm thick
Tightness was obtained at sealing forces of 5000 Kg.
The circumferential pressure is

$$\frac{5000}{53\ \text{cm}} = 94.3\ \text{Kg/cm of seal}$$

Test 13:

(see page 13)

Test 14:

As test 12, but using bolts
Tight at 0.7 mKg

Test 15:

As above but aluminium of 27.9 MHV hardness
Tight at 1 mKg
At this point we obtained 99.8% pure aluminium with a hardness of 27 MHV.

Tests 16 and 17:

were carried out with these aluminium foils.
Tightness was obtained at 1.2 mKg respectively 6000 Kg.

Test 18 :

With a normal aluminium foil of 0.5 mm thickness, a tight seal could not be obtained even with a force of 6000 Kg. The flange profile was changed to a sharp edge with an angle of $120^{o}$ (Figure 6).

Test 19:

Using the pure aluminium of 27 MHV .
The seal was tight at a sealing force of 3000 Kg.
After demounting it was realized that the foil was nearly out by the angle.

Test 20:

Same test with aluminium foil of 47 MHV
Tight at 4000 Kg. Thereafter the force was increased to 6000 Kg, the gasket was cut, but the sealing was still tight.

Test 21:

Aluminium of 0.5 mm thickness,hard still small leak at 6000 Kg, foil was not cut.

Test 22:

as 19

Test 23:

Without gasket
Tight at 4000 Kg !!!

Test 24:

Test 23 was repeated 6 times, each time displacing the centre of the flanges one to each other.
Three times it was tight with a pressure up to 6000 Kg;
the flat flange was clearly marked with a fine line, where the $120^{o}$ angle was cutting into the material.

The sharp edge was machined off so that the sealing surface consisted of a 0.2 mm wide flat. (Figure 7).

Test 25:

Aluminium foil 27 MHV 0.1 mm thick
Tight with a sealing force of 4000 Kg

Test 26:

Same profile but foil 0.03 mm thick, hard.
Tight at 5000 Kg.

Test 27:

Aluminium foil 47 MHV 0.1 mm thick, same profile
Tight at 4000 Kg.

Test 28:

For comparison a pair of conflat flanges OD 215 was tested in the same manner. At 6000 Kg it was still leaking, the seal was barely marked.

Test 29:

An aluminium gasket of the type used in the PS Booster was compressed between two flat flanges.
Tightness was obtained at 4000 Kg.

Test 33:

The profile of the flange was modified to a radius of 0.25 mm. With the pure aluminium foil of 27 MHV, tightness was obtained at a force of 3000 Kg. The foil was nearly cut.

Test 34:

The same profile, but harder aluminium 47 MHV.
Tight at 2500 Kg. The pressure was increased to 3000 Kg; the gasket was still intact.

Tests 30 to 32:

It was attempted to tighten a small square flange by means of quick disconnect clamps. (Figure 8). Two aluminium foils were used as a seal, in conjuction with a stainless steel wire, of 3 mm diameter, which was sandwiched in between. (Figure 9). At all tests, small leaks occurred due to the non parallelism of the wire at the point where the weld was made. The weld had been worked only by filing which is too unprecise a method in view of the rather small penetration depth of the wire into the foil. At this point in our experiments, there has so far been no time to try other production methods.

A pair of flanges has been produced according to Figure 10. The idea was to have two similar (sexless) flanges, which are centered one to another, by means of the three setpins on each flange. They remain rotatable, except for the case, where the setpins of both flanges fall together, the pins of one flange must then be demounted. The sealing surface consists of a profile with a radius of 1.5 mm, which can easily be obtained by turning on a lathe. An aluminium foil of 0.1 mm is used as a gasket, which can be fixed to the flange during vertical mounting by means of ears which have holes, fitted over the setpins (Fig. 11). The pins may have small circular grooves to insure that the gasket does not slip off. This sealing system is similar to the commercialised Keenol system, where two foils are used between two flat flanges with an intermediate spacer which bears the radius and serves for the centering of the flanges. (Fig. 12). However, in our proposal, the flanges have only one gasket and the centering is done by the fixed mounted setpins outside the vacuum instead of by a third component, the spacer ring of the Keenol system, which is in the vacuum and which may need a second man to hold it in place during mounting. The three setpins serve as well as protection for the sealing radius if the flange is put on a table. The tightening force is applied by means of a clamp similar to those used at the PS booster. (Figure 23).

Test 13:

It was not possible to tighten the seal, using an aluminium foil of 0.1 mm thickness.
The flanges were checked for flatness and roundness and it was found that deviations up to 0.6 mm existed, which may have been introduced during welding. Both flanges had to be remachined.

Test 35

With the remachined flanges using 0.1 mm aluminium foil of 27 MHV. With a torque of 1.5 mKg on the spindle screw, tightness was obtained.
The width of the sealing line, measured on the foil, was 0.4 mm.

Test 36

Same as above, but the pressure was increased to 3 mKg.
The width of the sealing line was 0.6 mm in this case.

Conclusions and further solutions envisaged

Circular flanges

The tests have shown that a reliable seal can be established by using an aluminium foil, compressed between two profiles, or one profile and a flat surface. The form of this profile does not have any small flat surface or different radii which has any influence on the reliability of the seal. The sealing force to be applied, in order to establish a reliable seal, decreases with decreasing radius of the profile, the lower limit for the width of this profile is given, when the foil starts to be cut. Envisaging a radius, which is easy to machine on circular flanges, this optimum lies between r = 1.5 and r = 0.25, the latter only for the harder foils.

The reliability of the seal is determined by the depth of penetration of the profile into the foil, rather than the width of the sealing line. With a force of 100 Kg/cm of sealing length, a reliable seal was obtained in all of the tested cases, except for the 0.5 mm thick foil and the distorted flanges. This force is low, compared with most of the existing designs. The use of a lighter and cheaper clamp than that of the PS booster could be envisaged. The thickness of the foil seems to be of some importance; there the optimum lies around 0.1 mm, thinner foils are anyhow difficult to handle and much thicker ones hard to cut.

Concerning the hardness of the foils, the results are not quite clear. In some of the tests, a softer foil could be tightened with a lower force, than a harder foil, but in the range between 27 and 47 MHV the difference is not obvious. It may be that in the presence of surface defects, a softer foil has some advantages by filling the scratches more easily at the beginning of the application of the pressure.

The tested flange Fig. 10 fulfils the requirements laid down in the above specification for the ideal seal, except points 15 and 16. It can only be made easily in circular shape, so another solution has to be found for rectangular flanges. The requirement on the flatness of the flanges is quite high, like for any foil seal. This problem can be overcome, however, by the design of flanges, which are elastic enough to compensate for deformations when clamped together, or by some type of necked flanges which are strong enough in order not to deform during the welding. The fabrication and handling of these flanges is quite easy.

The pair of flanges which was repeatedly tight without gasket with a relatively low sealing force, represents an astonishing result. By the choice of appropriate materials, one could perhaps develop such a sealing system at least for a limited number of closures. The problem of flatness does, however, also apply to this type of seal.

## Rectangular flanges

Until now, one has not succeeded in tightening the pair of non-circular flanges like shown in fig. 8. However, the reasons are well understood. The sealing line imprinted on the foils of test 30 to 32 using the intermediate stainless steel wire looks very similar to those produced in the successful tests with the circular flanges. The leak occurs only near the weld of the wire, where the filling took place. A production method for such a wire has still to be found, but we believe that this can be solved.

A rectangular tank of the dimensions 882 x 417 mm is being produced. It is equipped with a quick disconnect clamping system, which allows to apply a maximum pressure of 130 Kg/cm of seal. Several gasket systems can be tried on this prototype, which has simply two fine machined flat flanges.

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References:

1) M. Lebeau, Les joints d'étanchéité métalliques, statiques et démontables et leur application au vide. MPS/MLV 69-1.

2) B. Monnier, Joints Métalliques, MPS/MU - Note/V 66-8.