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Report

ELASTOMER SEAL FOR A LARGE TOROIDAL VACUUM CHAMBER

S SKELLETT
F CASEY
H BLAKE

CULHAM LABORATORY
Abingdon Oxfordshire

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S Skellett, F Casey and H Blake

UKAEA Culham Laboratory, Abingdon, Oxon OX14 3DB, UK

ABSTRACT

An aluminium toroidal vacuum chamber for use at 10^{-6} torr, whose overall diameter is in the region of 5 metres, was built from 4 component parts which resulted in joint lines in the horizontal and vertical planes crossing each other in 4 places. A viton seal was developed which allows a vacuum tight joint to be made without the need for tightly toleranced fitting of the mating faces and also overcomes the difficulty of ensuring a reliable seal at cross-over joints. Ease of maintenance and repair in situ are important factors of the design. An assembly which presented the geometry of the sealing problem was tested and is described here. Various adhesives for bonding Viton were examined for the manufacture of the seal. The most suitable adhesive was found to be Loctite S496, chosen for its bond strength and convenience in use. A device for preparing and bonding the Viton in situ is described.

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INTRODUCTION

The RFX shell is an aluminium toroidal vacuum chamber assembled from four component parts which present joint lines in the horizontal and vertical planes. The vacuum within the chamber is 10^{-6} torr and the maximum operating temperature of the chamber is 50°C and a vacuum sealing system using Viton has been chosen. The joint design presents several problems:

(a) At several points there is a cross over in the sealing line.

(b) It is inadvisable to trap the sealing ring in such a way that removal requires separating the torus component parts.

(c) It is desirable that the design does not impose high manufacturing or fitting tolerances on the torus (which is 5m overall diameter).

(d) Many of the joints must be made initially in situ. It is also necessary to repair any leaks in situ, possibly by cutting out the offending section and replacing it.

This philosophy has produced a design which uses a moulded Viton strip, of cross section and installation as shown in Fig 1, fitted across the joint line and held by plastic clamps. The strip needs to have bonded butt joints, due to limitation of length in moulding, and the cross over regions are covered with specially moulded sections which need to be bonded to the main strip on assembly.

The work covered in this paper consists of an investigation to find the most suitable adhesive for Viton and to develop a technique for preparing ends and making a butt joint on the site of the machine.

Further to this, two assemblies of the 'dumb-bell' seal and its clamping system were made to simulate typical parts of the RFX chamber (including the cross over problem) and were vacuum tested in order to verify the mechanical performance of the design.

1. COMPARISON OF ADHESIVES

1.1 Adhesives Tested

(a) Du Pont Viton adhesive

(b) Vita Coate adhesive, supplied by E Braude (London) Limited. This is a rather similar material to (a) and was suggested by certain 'O' ring manufacturers.

(c) Araldite AV138 with hardener HV998 (CIBA-Geigy (UK) Limited)

(d) Cyanoacrylate Alpha Ace E, produced by Alpha Techno, Japan - UK agents Stancourt Sons & Muir.

(e) Cyanoacrylate Loctite (Ireland) Limited - types IS06, IS12, IS150

(f) Cyanoacrylate Loctite (UK) Limited - type S496

1.2 Comments on the Application of the Various Adhesives

(a) Viton adhesive and Vita Coate both need the surface to be treated with a primer before applying the adhesive and require curing at 150°C for 10 minutes after making the bond. The joint requires 2 days to reach full strength.

(b) Araldite AV138 is a two-part mixture of pasty consistency, easy to apply but requires 24 hours to cure at normal temperature.

(c) Cyanoacrylates are fairly easy to apply to small areas. They bond instantly on impact so need very careful jigging to bring the surfaces into accurate alignment at contact. They reach full strength in about 3 hours.

1.3 Tensile Tests

A number of butt joints in simple 'O' ring cords and the dumb-bell section were made, using the various adhesives, and the tensile breaking loads were measured. It was found generally that a load somewhat lower than this value, if applied for a duration of several days, would cause failure. However it was possible to find a maximum static load which was no longer time dependent. The initial specification for this joint required it to withstand temperature cycling 5 times in succession between 20°C and 100°C, the heating time being ½ hour and the cooling time 1½ hours. After this temperature cycling the long duration load test was again carried out and the new value recorded. It was generally found that the bond strength was diminished after temperature cycling. The temperature requirement was later relaxed to 60°C by which time the Loctite S496 was emerging as the most suitable adhesive. Further tests cycling S496 at 60°C were therefore carried out and their results are included here.

1.4 Test Results

Table 1 summarises the results obtained.

Joints which are properly bonded with good mating faces and complete covering of faces with adhesive showed a good consistency of performance. A tolerance band of ± 20% should be applied to the tabulated figures.

Table: Comparison of Various Viton Adhesives

Test Piece	Breaking Stress		Long Duration Static Load					
			Before Thermal Cycling		After Thermal Cycling 60°C		After Thermal Cycling 100°C	
	lbf/in^2	MPa	lbf/in^2	MPa	lbf/in^2	MPa	lbf/in^2	MPa
Unjoined cord 7mm dia	1020	7.00	510	3.50	460	3.17	340	2.34
Viton adhesive 7mm dia cord	510	3.52	170	1.17			120	0.83
Vita Coate 7mm dia cord	273	1.88	70	0.48			26	0.18
Araldite AV138 7mm dia cord	426	2.94	256	1.76			120	0.83
Alpha Ace E 7mm dia cord	426	2.94	204	1.40			85	0.59
Loctite IS06 cord Loctite IS12 cord Loctite IS150 cord	Results not recorded though always considerably inferior to Loctite S496							
Loctite S496 cord	680	4.69	325	2.24	215	1.48	120	0.83
Unjoined dumb-bell section	1370	9.45	370	2.55	300	2.07	250	1.72
Loctite S496 Dumb-bell section	568	3.92	265	1.83	160	1.1	95	0.66

1.5 Choice of Most Suitable Adhesive

From the table it is seen that Loctite S496 has the highest strength and under the comments on applications it is seen to have the advantage of simplicity in use.

1.6 Joint Preparation

In all cases, in order to achieve a smooth joint without steps or cracks, it is necessary to use a technique for preparing the mating surfaces which ensures intimate contact and accurate location. Various jigs and cutting methods were used, including freezing the elastomer and grinding it. The finally selected method used a circular saw blade 45mm diameter x 0.1mm thick, 0.35 teeth/mm rotating at 4000 rpm. The teeth were ground to a razor edge.

Straight butt joints were chosen in favour of scarfed joints in the interest of being able to accurately locate the butting edges in a simple jig. The cutting and joining jig for the dumb-bell section is shown in Fig 2. The Viton seal is clamped into the blocks on the jig with the cutting lines as close to the blocks as possible so that it is well supported. The circular knife was fitted to a portable drill and set up on machine slides to give an accurately controlled plane of cut in this series of tests. A further development of this jig to give it full portability will use a small air driven chuck which will be linked to the jig using a mechanism to give the same cutting line. A soap solution was used as a lubricant during the cutting operation. Using the same jig the two ends to be joined are clamped, one in each block. One of the blocks is fixed, the other arranged to slide in order to bring the mating surfaces accurately together. After setting the seal ends in the clamps and ensuring that they abut accurately, the sliding clamp is drawn back and the seal ends are sprayed with Loctite "IS quick clean", one end only is then given a thin coat of adhesive and using the sliding clamp the seal ends are then brought into contact and a firm pressure is maintained for about a minute which gives the joint sufficient strength for its removal from the jig. Ultimate strength is achieved in 3 hours.

2. VACUUM TESTS ON DUMB-BELL SEALS

2.1 Introduction

Vacuum tests were necessary to test in practice the mechanical arrangement designed for the RFX shell vacuum seals:

(a) To establish that a vacuum tight bond would be made between two sections of the dumb-bell seal.

(b) To find a suitable clamp for clamping straight sections of the gasket and the corner radius portion of the cross over dumb-bell. Also to determine suitable bolting pitch.

(c) To differentiate between leaks (if any) and permeation of gas through the Viton wall.

In order to simulate the RFX shell, two rigs were made. The external shell contour was represented by a large aluminium ring, approximately equal to the minor cross section of RFX. This ring is shown in Fig 3. To simulate an internal contour and to test a cross over dumb-bell, a rig was made from 25mm plate, 500mm x 500mm and rolled to a radius approximately the same as the RFX inner major radius. Figure 4 shows the arrangement. In both rigs the dumb-bell was clamped to a machined face and straddled a machined recess which was later evacuated. Clamps were made from nylon to Culham drawing no CR/52/3, as shown in Fig 4. In both rigs the dumb-bell seals had four bonded butt joints.

2.2 Vacuum Tests on the Large Ring and Internal Ring

The ring was pumped by a 2" oil diffusion pump. A typical pressure obtained was 5×10^{-4} torr. The ring was heated to $50^{o}C$ by heating tapes and the dumb-bell seal was enclosed in a polythene bag to contain the search gas. The 'Edwards' mass spectrometer was used on all dumb-bell tests.

No leaks were indicated by the mass spectrometer until 5 minutes after the helium search gas was injected into the polythene bag. This apparent leak was in fact permeation of helium through the dumb-bell wall, as was proved by a simple test to determine the response time of the mass spectrometer, as follows. A fibre of less than 0.00005mm diameter was placed on the sealing face of the dumb-bell causing a leak. This leak was measured as 4×10^{-6} torr litre/second. Helium was injected into the polythene bag diametrically opposite this leak and it was found that there was full scale deflection in less than 10 seconds (x 1 scale) which indicated that for a response of 5 minutes, permeation and not a leak was being measured.

The internal radius/cross over rig was attached directly on to the mass spectrometer. Tests were carried out at ambient temperature with the rig enclosed in a bag to contain the search gas. The straight clamps were nylon as in the previous test but the corner radius clamps were turned from aluminium bar and cut into quadrants, see Fig 4. No leak was indicated on the mass spectrometer. The sensitivity was also checked to ensure that the mass spectrometer was working.

There were no unexpected difficulties in the assembly of these two rigs, although it was found to be important that the clamp was bent to the same radius as the mating surface. A pre-stretch of 5% was applied to the dumb-bell seal on the external diameter to avoid 'cockling' and there was no tendency for the seal to be 'sucked in' by the vacuum. The relatively short length of the corner clamps for the cross over meant that they did not need to be bent to the radius of the surface.

2.3 Permeation Tests

An attempt was made to perform permeability tests on the large ring rig to check established data for Viton. The leak tests conducted as described were used to obtain a leak rate value over a period of some hours. In the first instance the total length of dumb-bell was used but it was found that the area of Viton was too great as the mass spectrometer reached the extreme of its range (i.e. approximately 10^{-5} torr/litre second) without a levelling off in the leak rate. To reduce the area and hence bring the leak rate values within the range of the mass spectrometer, a length of dumb-bell 39 cm long was selected. The object here was to obtain results for random lengths of dumb-bell without including a bonded joint. If the results were similar then a test including a bonded joint would reveal any difference in permeability due to the joint. However the figures obtained, plotting leak rate per cm^2 against time, showed very inconsistent results.

To try to control the variables and produce more accurate results a rig was made with a dumb-bell seal just 14 cm long, this rig was pumped directly by the mass spectrometer and tests again carried out in the usual way at 50^oC. The results were again inconsistent and Fig 5 shows two tests on separate days. No satisfactory conclusions were drawn from the results and the graphs are presented without comment. However these recorded permeability values are far lower than the values taken for the basis of RFX design.

2.4 Prolonged Vacuum Tests on Bonded Joint

After the large ring had been pumping for approximately one month a leak developed at one of the bonded joints (greater than 3×10^{-5} torr litre/sec). A visual examination at the site of the leak revealed a slight imperfection of the surface. This was treated with 'twin pack araldite' to re-build the seal surface without breaking and remaking the joint. The rig was heated and pumped for a further month with no leak occurring. The rig was then shut down in September 1977 but left assembled. On 26 January 1978 the seal was again vacuum tested and found to be leak tight, particular attention was paid to the repaired joint which showed no sign of deterioration. NB. This test was carried out at ambient temperature.

The seal remains assembled and from time to time will be re-pumped and tested to check that there is no deterioration in the bond.

2.5 Conclusions

The design of the vacuum seal for the RFX shell is seen to be quite practical. Viton moulded in the 'dumb-bell' cross sectional form provides a method of sealing access joints in large components without demanding tight fitting tolerances and the cross over joint problem is solved. A suitable adhesive, where butt joints are required in the Viton, is Loctite S496 and a light, portable tool suitable for making in situ joints has been developed.

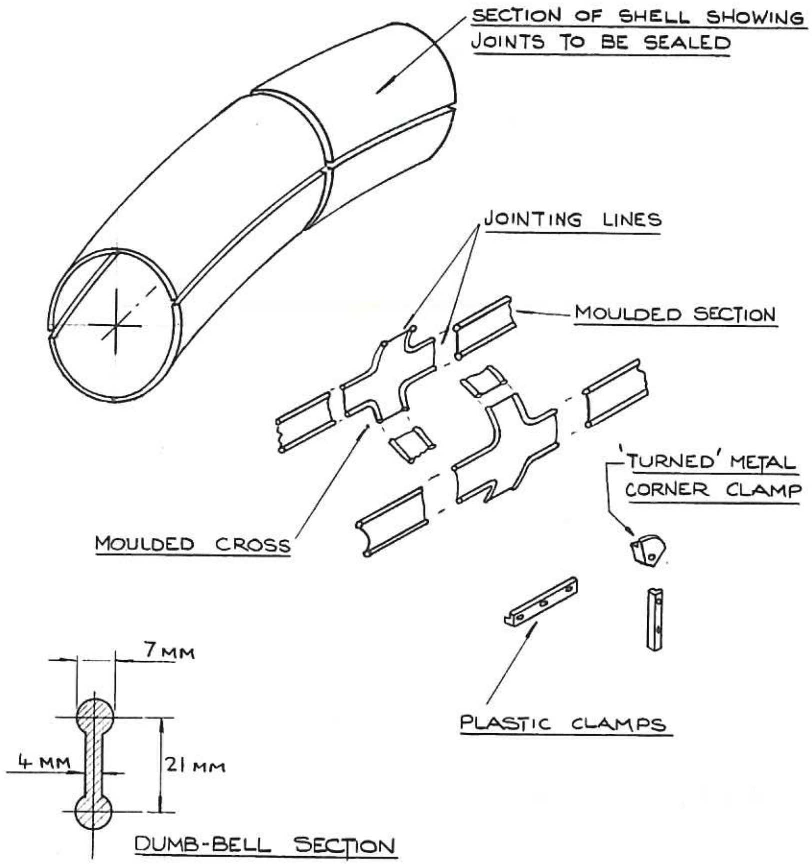

Fig.1 Exploded view of shell sealing arrangement.

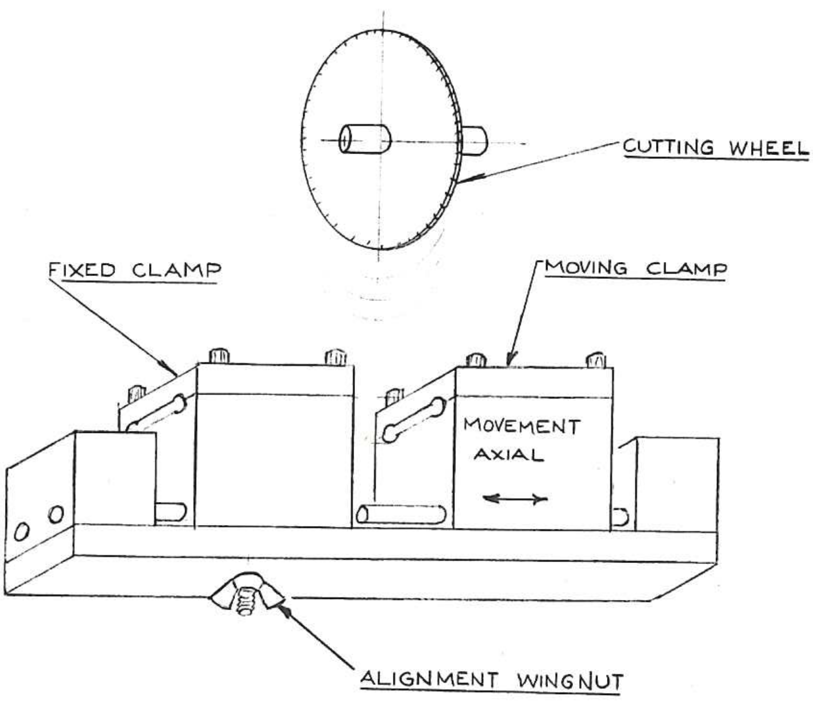

Fig. 2 Cutting and joining rig.

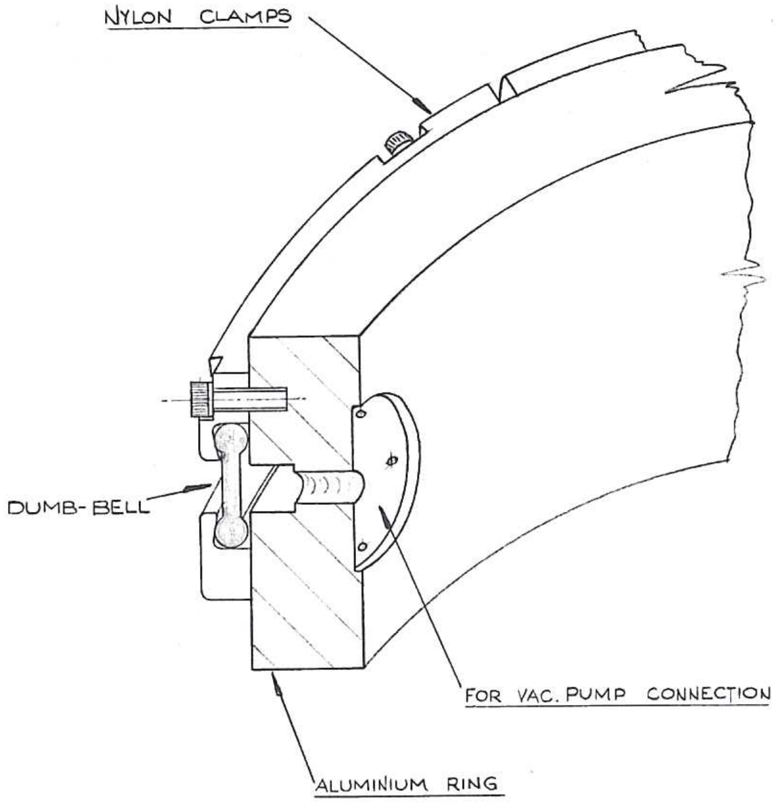

Fig. 3 Rig for testing a dumb-bell seal on an external diameter.

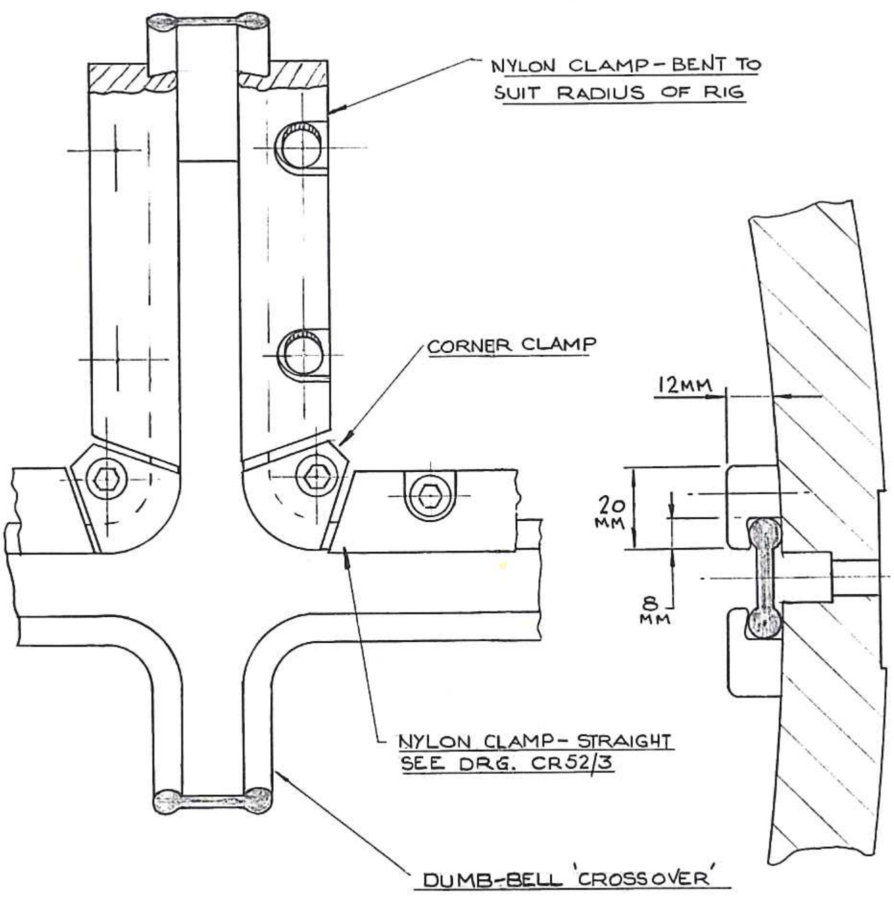

Fig. 4 Rig for testing a dumb-bell seal on an internal diameter.

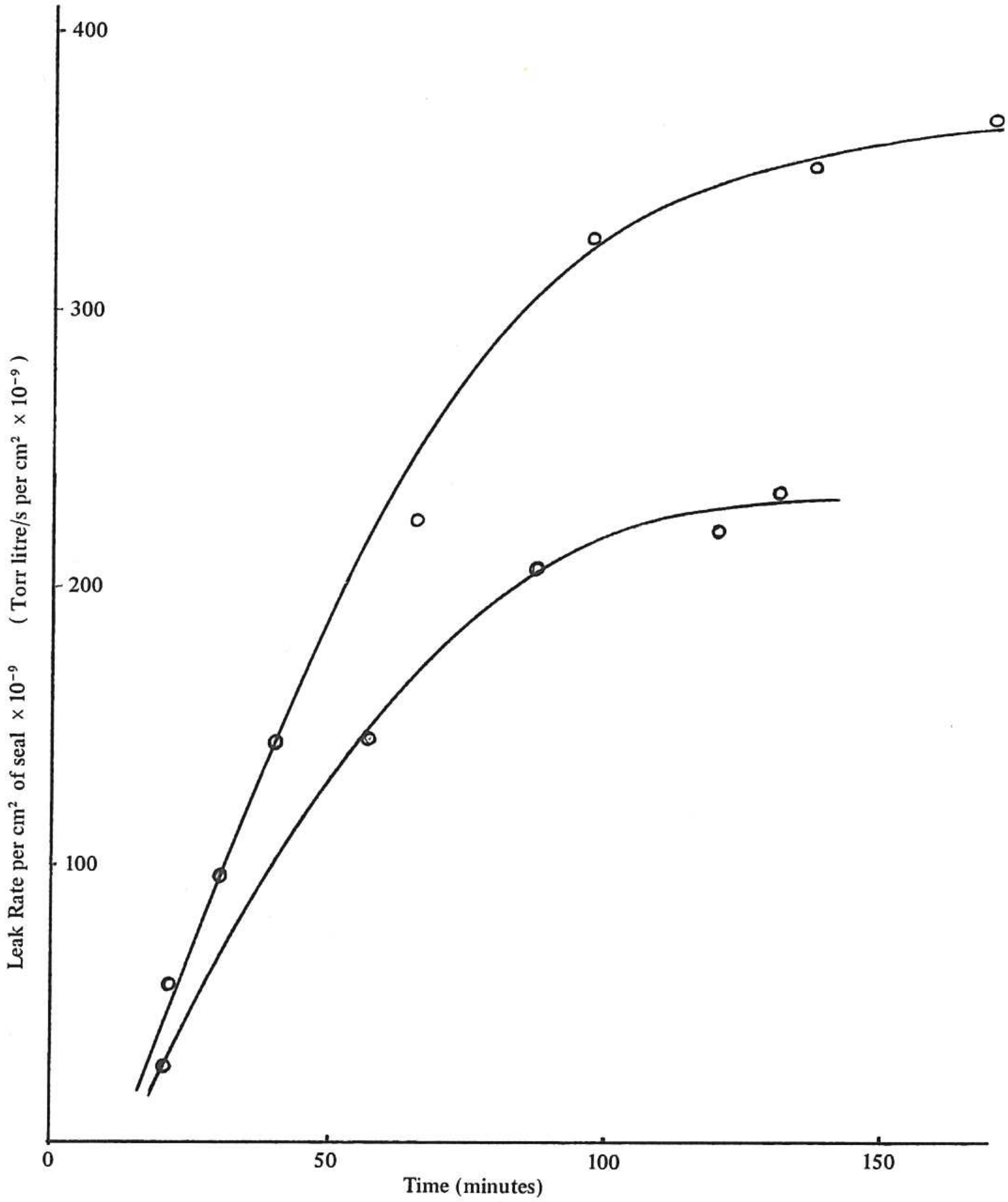
400
300
200
100
0
50
100
150
Time (minutes)
Leak Rate per cm² of seal × 10⁻⁹ (Torr litre/s per cm² × 10⁻⁹)

Fig. 5

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