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**A RELIABLE GALVANOMETER
MOVEMENT FOR USE IN
SPACE APPLICATIONS**

by

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SUMMARY

The Report describes the tests performed on a small galvanometer movement, using a pivot-jewel bearing, to assess its suitability for use in space applications. Although only a small number of units was tested, the results suggest that with minor modifications, the mechanism is reliable under a space environment and well suited to certain satellite applications due to its small size, weight, and extremely low power consumption.

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CONTENTS

	<u>Page</u>
1 INTRODUCTION	3
2 DESCRIPTION OF GALVANOMETER MOVEMENT	3
3 TESTS PERFORMED ON GALVANOMETER MOVEMENTS	4
3.1 Movement response tests	4
3.2 Vibration environmental tests	5
3.3 Vacuum environmental tests	5
4 TEST RESULTS	6
4.1 Results of tests on standard instruments	6
4.2 Results of tests on modified instruments	7
5 CONCLUSIONS	8
Acknowledgements	9
Appendix A Galvanometer movement vibration specification	10
Tables 1-4	12-13
Illustrations	Figures 1-12
Detachable abstract cards	-

1 INTRODUCTION

In certain photometric experiments at present being designed for use in satellites and sounding rockets, operation under daylight conditions is required. One of the problems with this type of experiment is to prevent damage occurring to the photo-detector, due to excessive radiant energy falling on its cathode if the image of either the Sun or the Sunlit Earth enters the field of view of the optical system.

A small galvanometer movement manufactured by S. Smith and Sons has been tested by the Royal Aircraft Establishment to assess its suitability for use as a Sun/Albedo shutter in such experiments.

This introduction is followed by a brief description of the standard galvanometer at present produced by S. Smith and Sons and the modifications implemented, at the request of the Royal Aircraft Establishment, in order to obtain the improved mechanical performance necessary for its use in space applications. The environmental and electrical tests to which a small sample of these instruments were subjected is outlined and the results of these tests given.

2 DESCRIPTION OF GALVANOMETER MOVEMENT

The galvanometer movement shown in Fig.1 is 0.56 inch diameter, 0.5 inch long and weighs 0.3 oz. The coil, having a dc resistance of 1 K Ω , is wound on an aluminium former to which is attached a light vane. The complete coil assembly weighs approximately 0.02 oz, and is supported by pivots rotating in a synthetic jewel bearing. The pivots used in the standard instrument, Fig.2, are manufactured from an ordinary oil hardened silver steel, 800-900 Vickers. The radial field in which the coil moves is provided by a centrally mounted cylindrical magnet producing a flux density of approximately 4000 gauss which, with the normal return spring fitted, gives the instrument a sensitivity of approximately 200 microamp for full scale deflection.

The first eight movements obtained for testing were of standard design except for the following features. No lubricant was added to the bearings and the return hair-springs were removed and replaced by ligaments to provide the necessary electrical connections to the coil. The hair-springs were removed to decrease the response time of the movement.

Initial tests performed on these galvanometer movements at the Royal Aircraft Establishment showed that the material used to manufacture the standard pivots, is not suitable if the instrument is to be used in rocket-borne experiments. After consultation with S. Smith and Sons a new pivot material was selected and fitted to a further eight mechanisms. This material was a fretting-corrosion resistant, non-magnetic stainless steel having a hardness of 770-520 Vickers. The radius of these new pivots, manufactured under the trade name 'Revapoint' by M. Schneider-Hogi Ltd., Switzerland, was 0.0024 inch at the bearing surface as against a radius of 0.002 inch used for the pivots in the standard instruments.

An additional mechanism was obtained with the galvanometer coil wound on a split aluminium former, thus eliminating eddy current damping, to assess the improvement obtained in the movement response time.

3 TESTS PERFORMED ON GALVANOMETER MOVEMENTS

The movements were tested to assess their ability to withstand the severe vibration associated with the initial launch phase of the rocket, and their subsequent ability to function satisfactorily for many operations under space conditions. Other requirements of the mechanisms were that they should be small, light, require low power to operate, and have a fast response time.

At the commencement of this assessment programme some urgency existed in determining the suitability of the galvanometers for use in satellites. It was therefore decided, since the vibration facility was not readily available, to commence the time-consuming tests of long term operation under vacuum on half of the mechanisms and subject the other half to the vibration specification at a later date. This method of testing was adopted with the first eight standard instruments obtained. However, because this form of testing does not follow the logical sequence of events which would be experienced under flight condition, the modified mechanisms were first vibrated and then subjected to long term testing under vacuum conditions. In all cases the minimum current required to obtain full scale deflection of the movements was measured, thus providing means by which any later deterioration could be checked without necessitating destructive inspection.

3.1 Movement response tests

The response time of the instruments was measured using a pulse interval time counter. Start and stop pulses were obtained from photo-diodes as the

vane of the galvanometer passed across two illuminated pin holes, spaced for a movement deflection of approximately 30° .

The response time of a typical instrument, before environmental testing, is plotted in Fig.3 for various values of coil current. Also shown is the improved response obtained by splitting the coil former. From these curves it can be seen that little improvement in the response time would be obtained for coil currents above 250 microamp. This value of current was consequently adopted as being realistic for carrying out the life testing of the mechanism under vacuum, section 3.3, although higher values can be used without risk of damage to the movement.

3.2 Vibration environmental tests

The vibration testing of the galvanometers was carried out at A.W.R.E. Aldermaston, to the levels detailed for the testing of the U.K.3 satellite tape recorder, see Appendix A. This particular specification was adopted primarily because it was believed to be representative for the class of satellite under consideration, and there also existed the added advantage of combining the tests with those of the tape recorder which were to be carried out in the near future.

The mechanisms were mounted in counter-bored holes in an aluminium alloy cube of 12 inches side and held in position by two clips, Fig.4. The cube also provided the mounting facility for the tape recorder.

Due to vibrator amplitude limitations some reduction of the sinusoidal acceleration levels originally specified was found to be necessary, details of these are given in Appendix A. During the tests rms acceleration was monitored continuously using an accelerometer mounted on the block.

3.3 Vacuum environmental tests

The life testing of the galvanometers was carried out at Elliott Automation Ltd., as part of a Ministry contract placed for the testing of space bearings, gears, and slip rings. The movements were mounted in a small glass envelope, Fig.5, provided with two sealed-in electrical contacts through which connection to the coils of the mechanisms was made. Since only two electrical contacts were available, periodic checks on the sensitivities during these tests had to be made as a combined measurement. Current values given in the relevant tables, section 4.1, however, are the individual sensitivity

values for each of the movements. (The combined current was resolved into the individual currents on the assumption that the coil resistances of each movement was constant at the value measured at the start of the test.)

The envelope after evacuation was sealed and the pressure monitored by an ion gauge which also provided means for maintaining the pressure, within limits, due to any outgassing from the galvanometer movements. The drive current to the instruments was provided by a multi-vibrator switching at a rate of 43 operations per minute and delivering a drive current of 250 microamp to each coil.

Testing of the four standard mechanisms under vacuum was terminated after some 2800 hours, giving a total of 6.9×10^6 operations at pressures in the range 2×10^{-10} torr to 3×10^{-8} torr. The pressure/life graph for these tests is given in Fig.6.

The vacuum life testing of four of the modified mechanisms was conducted for 2500 hours at room temperature, a total of 6.6×10^6 operations, after which the encapsulated assembly was operated in a refrigerating cabinet at $-25^\circ \pm 5^\circ \text{C}$ for a further 1.3×10^6 operations. This was followed by heating the assembly in a small oven at $+60 \pm 2^\circ \text{C}$ during which time a further 1.2×10^6 operations were performed.

The pressure history of the vacuum test chamber is shown in Fig.7. During the room and low temperature tests the pressure was maintained in the low 10^{-8} torr range but rose to 10^{-6} torr during the period at $+60^\circ$ due to outgassing from the mechanisms.

4. TEST RESULTS

4.1 Results of tests on standard instruments

The minimum current required to obtain full scale deflection of the mechanisms before commencement of the tests are given in Table 1. These measurements were made against the slight return spring action exerted by the coil ligaments.

The four galvanometers supplied to Elliott Bros. for vacuum life testing were again checked for full scale sensitivity after mounting in the vacuum capsule, thus establishing that no damage had occurred during the installation. These results together with the periodic sensitivity checks made during the vacuum life testing are given in Table 2. Since the spring action exerted

by the ligaments is small, return of the movement to the biased position did not always occur and the sensitivity checks were made for deflection of the instruments in both directions.

An apparent deterioration in the performance of mechanisms Serial numbers 5 and 8, occurred after about fifteen-hundred hours of operation, approximately 4×10^6 operations. However, the instruments appeared to have recovered by the time the next sensitivity checks were made after approximately 2600 hours, 6.7×10^6 operations. The apparent deterioration in the performance of the galvanometers at the 1500 hour mark was not explained. Sensitivity checks made in air after the vacuum tests showed the full scale deflection currents, to be approximately the same as those measured at the commencement of the tests, (see Table 1).

Examination of the bearings under a microscope showed both the jewel and pivot to be in perfect condition with no visible signs of wear, Fig.8, however minute rust-colored deposits were found to exist on all bearing surfaces. Similar deposits were also found to exist on the surfaces of both untested mechanisms and the modified instruments having stainless steel corrosion resistant pivots. Although it was suspected that these deposits resulted from fretting corrosion, (which may have occurred to the untested mechanisms during transportation since no lubricant was present in the bearings), this fact was not positively established.

The standard pivot-sapphire combination showed the necessary properties to withstand wear. However, they were found to be too brittle to withstand the severe vibration environment, and fracturing occurred at the tips of the pivots causing the coil assembly to become slack in its bearings. The movements however still functioned, and something approaching normal operation could be obtained by raising the coil current to approximately 0.5 milliamp.

4.2 Results of tests on modified instruments

After the modified instruments were vibrated to the specification given in Appendix A, their sensitivities were measured and are compared with the pre-testing values given in Table 3. All movements appeared to be slightly sticky in operation and reluctant to return to the biased stop position under the action of the slight torque, approximately 2% of the operating torque, provided by the ligaments. Two randomly selected mechanisms were stripped and the pivots and jewels examined under a microscope. Although the jewels

were found to be in perfect condition some slight deformation had occurred at the tips of the pivots. A shadow graph of a pair of pivots is shown in Fig.9. The damage to the pivot tips was not considered to be serious and vacuum life testing on four of the remaining galvanometers was started.

The minimum full scale deflection current for each mechanism was again recorded at various times during the vacuum tests. The apparent small deterioration of the bearings as indicated by the increase in the drive current required, Table 4, was not substantiated by the values obtained for either the sensitivity or response measurements conducted in air at the completion of the above tests. These, with the exception of galvanometer Serial number 25, were in reasonable agreement with the pre-testing values obtained, Table 3. Galvanometer Serial number 25 was found to stick at approximately 90% of its full scale deflection with a coil current of 10 microamp. The current had to be increased to 250 microamp before the remaining 10% of its travel was obtained. This sticking persisted until several operations at 250 microamp had been performed, after which the full scale deflection current settled down to a level of 10 microamp.

Examination of the bearings under a microscope showed no serious signs of wear had occurred during the life testing, Fig.10, however in addition to the rust-coloured deposits found on the bearing surfaces of the original instruments, a quantity of small unidentified particles were also found. Since the instruments were assembled under clean conditions it has been assumed that the particles were introduced during the vibration tests, during which time no protective covering was used. A photograph showing the contamination found on one of the pivot-jewel bearings is shown in Fig.11.

5 CONCLUSIONS

The test results for both the standard and modified instruments show the pivot-jewel bearing to be highly suitable for use under vacuum conditions when light loads are involved. In addition the size, weight, and extremely low power consumption of the galvanometers make them ideal for use in certain satellite borne experiments.

The marked increase in drive current of standard mechanisms Serial numbers 5 and 8 after 1500 hours of operation together with the sticking of galvanometer Serial number 25, both temporary conditions, has been tentatively attributed to the dust and small particles found to exist on later examination

of the bearings. This point of view is further substantiated by the fact that neither the pivot nor the jewel showed any signs of wear. In any event the movements still operated satisfactorily at the required current level of 250 microamp, a value well below the current rating of the coil.

The improved response of the instrument obtained by elimination of eddy current damping was considered to be significant.

Although useful information was obtained from vacuum testing of the standard instruments the pivot material proved to be liable to fretting corrosion and too brittle, to withstand the severe vibration to which it was subjected. The modified mechanisms using the stainless steel 'nevapoint' pivots however appeared to have the necessary toughness to withstand the vibration. The slight distortion of the tips of the pivots caused during vibration was not considered to be serious. Also this preferred design showed no marked increase in drive current at any time during the vacuum tests.

The sample of devices tested was too small for statistical conclusions to be drawn, but the performance of the modified units was encouraging. This galvanometer movement merits serious consideration for use in instruments to be flown in space vehicles where calibrated deflections of the mechanism are not required.

Acknowledgements

The author wishes to acknowledge the assistance of Mr. W. A. Ware of Space Department, R.A.E. in helping to organize the testing of the mechanisms, and also for his advice given throughout the assessment programme.

Appendix AGALVANOMETER MOVEMENT VIBRATION SPECIFICATION

A.1 The movements were mounted in a twelve inch aluminium cube as indicated in Fig.12 with the meter pivots in the ZZ axis.

A.2 Independent sinusoidal frequency tests were applied in each of the three axes indicated, and followed by independent random motion tests again in each of the three axes.

A.3 The sinusoidal frequency vibration was applied by sweeping the applied frequency from the lowest to the highest frequency once for each range specified in Table 1. The rate of change of frequency was proportional to the frequency at the rate of 2 octaves/min.

Table A.1Sinusoidal logarithmic sweep

Axis	Frequency range Hz	Test duration min	Acceleration g or displacement
ZZ	5-50	1.66	±2.3 g*
	50-100	0.5	0.8 in D.A.
	100-200	0.5	±4.0 g
	200-500	0.66	±10.0 g
	500-2000	1.0	±21.0 g
XX and YY	5-50	1.66	±1.0 g
	50-100	0.5	0.02 in D.A.
	100-200	0.5	±10.0 g
	200-2000	1.66	±10.0 g

*or within the maximum amplitude limit of the vibrator see A.5.

A.4 Gaussian random vibration was applied for each axis with the acceleration waveforms clipped at three times the rms acceleration specified in Table 2. The control accelerometer response was equalised such that the specified acceleration spectral density values were within ±3 db throughout the frequency band. The filter 'roll off' characteristic above 2000 Hz was at the rate of 40 db/octave or greater. A three minute run at 1/10 full scale was effected in order to check the spectrum shape before applying full level.

Table A.2
Random vibration

Axis	Frequency range Hz	Test duration min	S.D. level g^2/Hz	Acceleration (approx.) g rms
ZZ XX YY	20-2000	4 (each axis)	0.07	11.5

A.5 All levels were raised and held as specified in Table 1 with the exception of those frequencies affected by excursion limitation of the vibrator in the range 5-7 Hz, in the ZZ axis. Over this range acceleration levels were reduced from ± 2.3 g to the following:-

5 Hz ± 0.9 g

6 Hz ± 1.35 g

7 Hz ± 1.8 g

In addition it was arranged that frequencies 5-9 Hz were dwelt on for six seconds each instead of sweeping through these frequencies.

Table 1

STANDARD MOVEMENT SENSITIVITIES

Galvanometer serial numbers	F.S.D. current microamp	
	Before vacuum/life tests	After vacuum/life tests
3	4.6	4.0
4	2.0	2.0
5	2.0	2.0
8	3.2	2.0

Table 2

STANDARD MOVEMENT SENSITIVITIES DURING VACUUM TESTS

Operation time in vacuum (hours)	F.S.D. current microamp				Direction
	Serial number 3	Serial number 4	Serial number 5	Serial number 8	
0	0	4.0	4.0	0	↑ ↓
	4.0	0	0	5.0	
1500	4.0	7.0	87.5	3.75	↑ ↓ ↑
	3.2	0	4.25	41.2	
	2.0	7.5	175	3.25	
2642	0	5.0	5.0	0	↑ ↓
	0	3.0	3.0	0	
	0	1.5	2.25	0	
	0	2.75	3.25	0	
	5.75	0.12	1.25	6.0	
	2.0	0.87	1.5	3.0	
	1.75	0	1.75	7.25	
	2.25	0.37	0.62	5.5	

Table 3

MODIFIED MOVEMENT SENSITIVITIES

Galvanometer serial number	F.S.D. current microamp		
	Before testing	After vibration tests	After vibration and vacuum tests
21	3.0	4.5	Not tested
22	1.0	2.0	4.0
23	4.0	6.5	4.5
24	1.0	3.0	Not tested
25	2.2	6.0	10.0
26	3.5	2.0	Not tested
27	1.5	3.0	4.5
28	6.7	8.0	Not tested

Table 4

MODIFIED MOVEMENT SENSITIVITIES DURING VACUUM TESTS

Operation time in vacuum (hours)	F.S.D. current microamp				Direction
	Serial number 22	Serial number 23	Serial number 25	Serial number 27	
0	21.0	10.0	4.0	9.25	↑ ↓
	0	5.5	8.5	8.5	
166	10.75	10.5	6.25	23.0	↑ ↓
	10.75	10.75	22.5	5.0	
665	20.0	6.5	6.25	20.5	↑ ↓
	4.75	8.5	11.25	6.5	
2570	5.5	3.25	2.25	6.25	↑ ↓
	0	2.0	3.75	4.25	
2666	5.0	3.37	2.75	7.5	↑ ↓
	0	1.5	2.5	1.25	
3466	16.25	5.0	6.5	8.0	↑ ↓
	0	6.0	8.75	8.25	

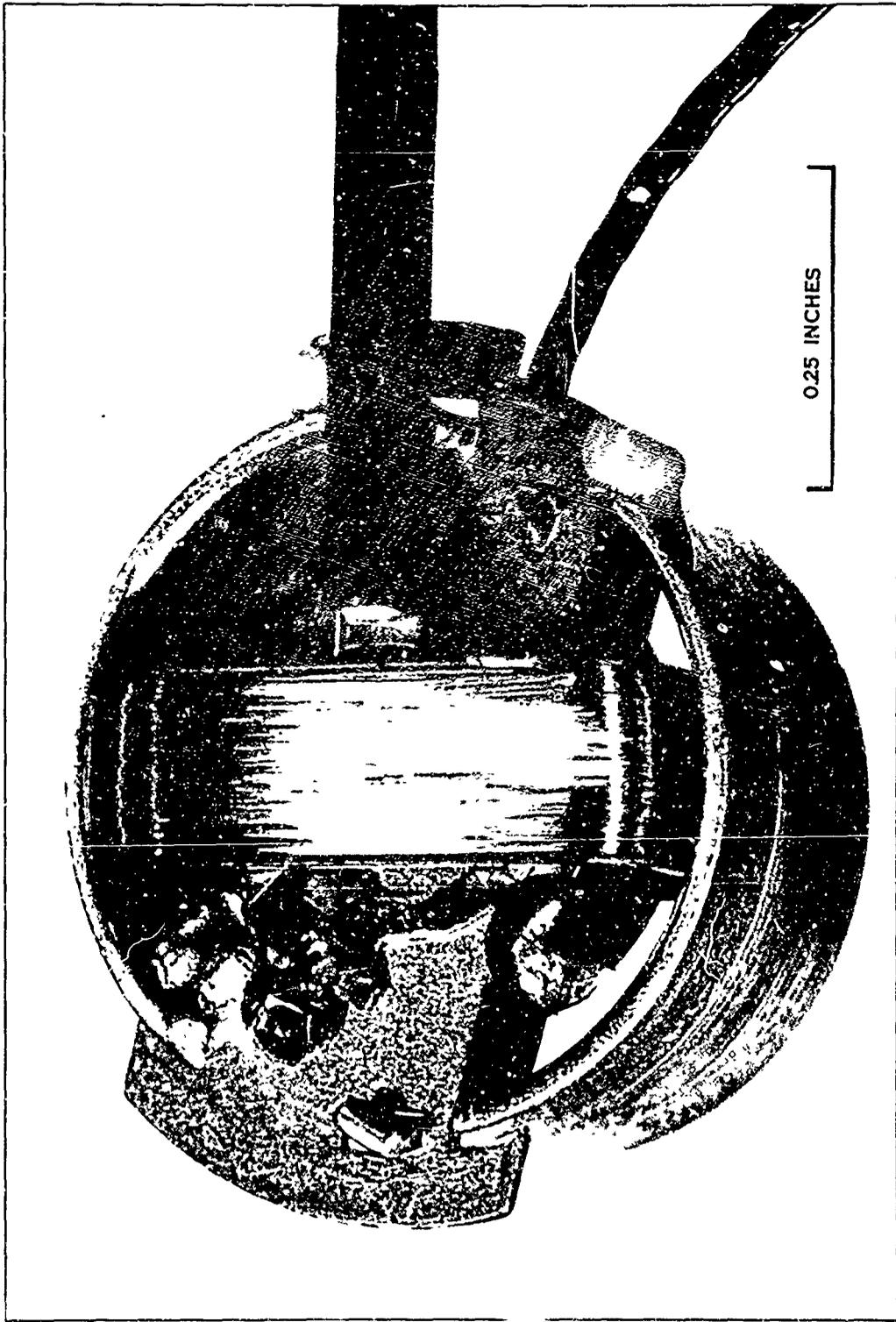
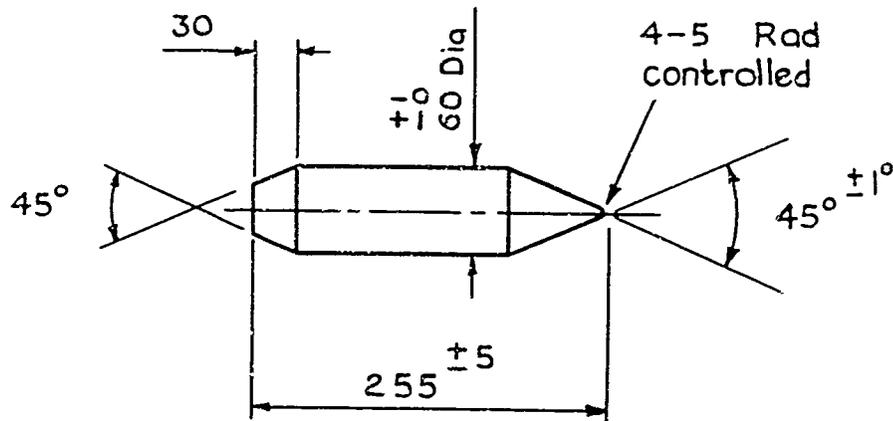


Fig.1 Standard galvanometer movement

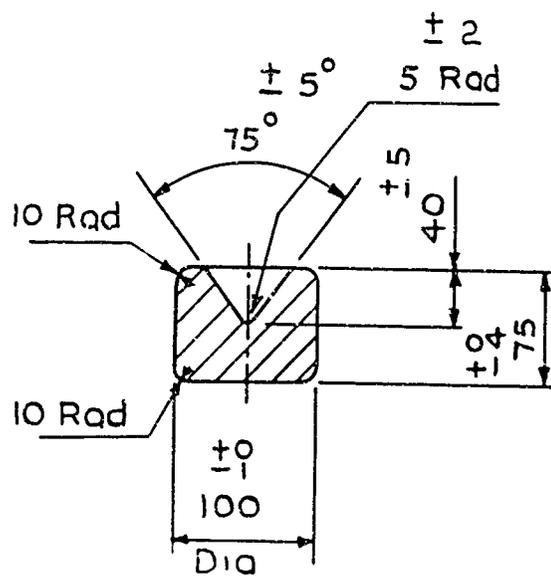
Fig. 2

004 901086



Units 1/100 m/m
Scale 20/1

Hardened steel pivot



Units 1/100 m/m
Scale 20/1

Sapphire jewel bearing

Fig. 2

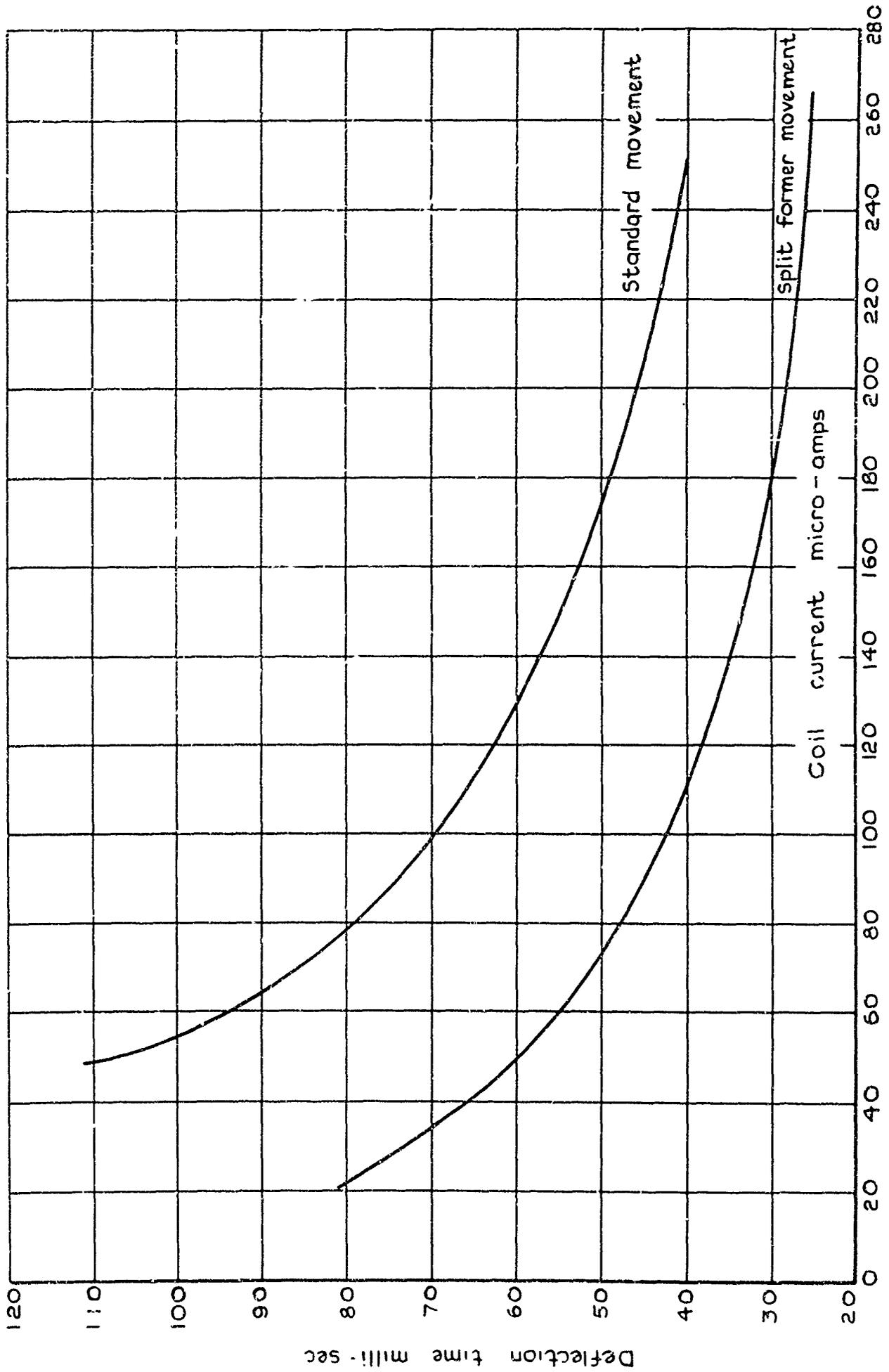


Fig.3 Movement response characteristics

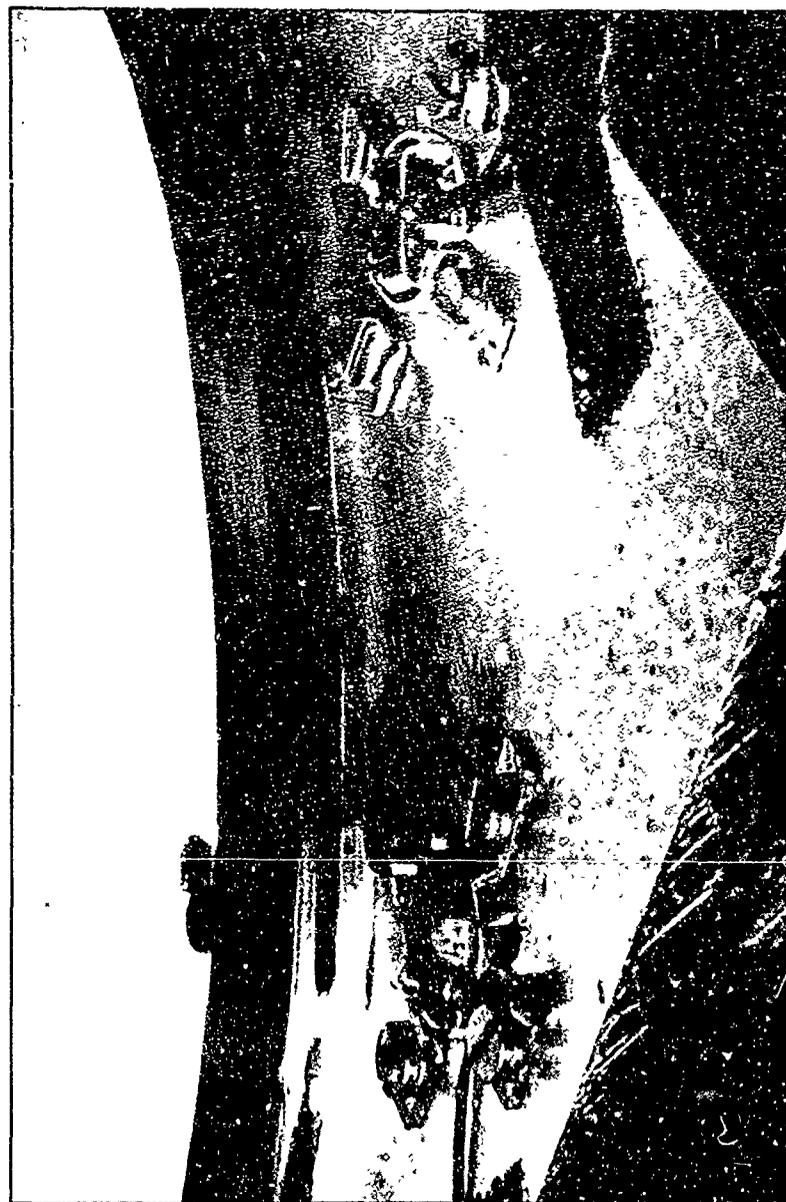


Fig.4 Method of mounting movements on aluminium block

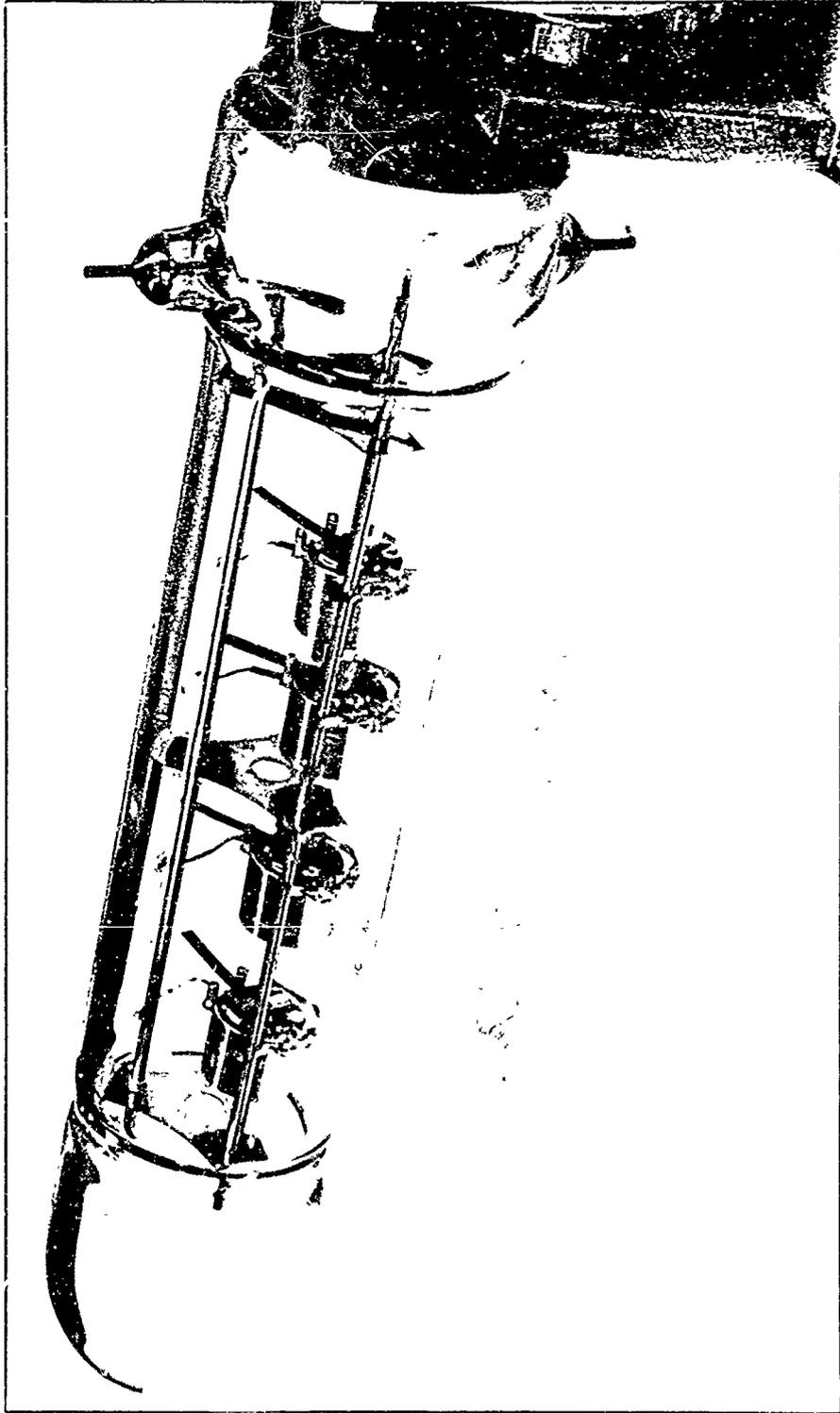


Fig.5 Movements mounted in capsule for vacuum life testing

Fig.6

004 901088

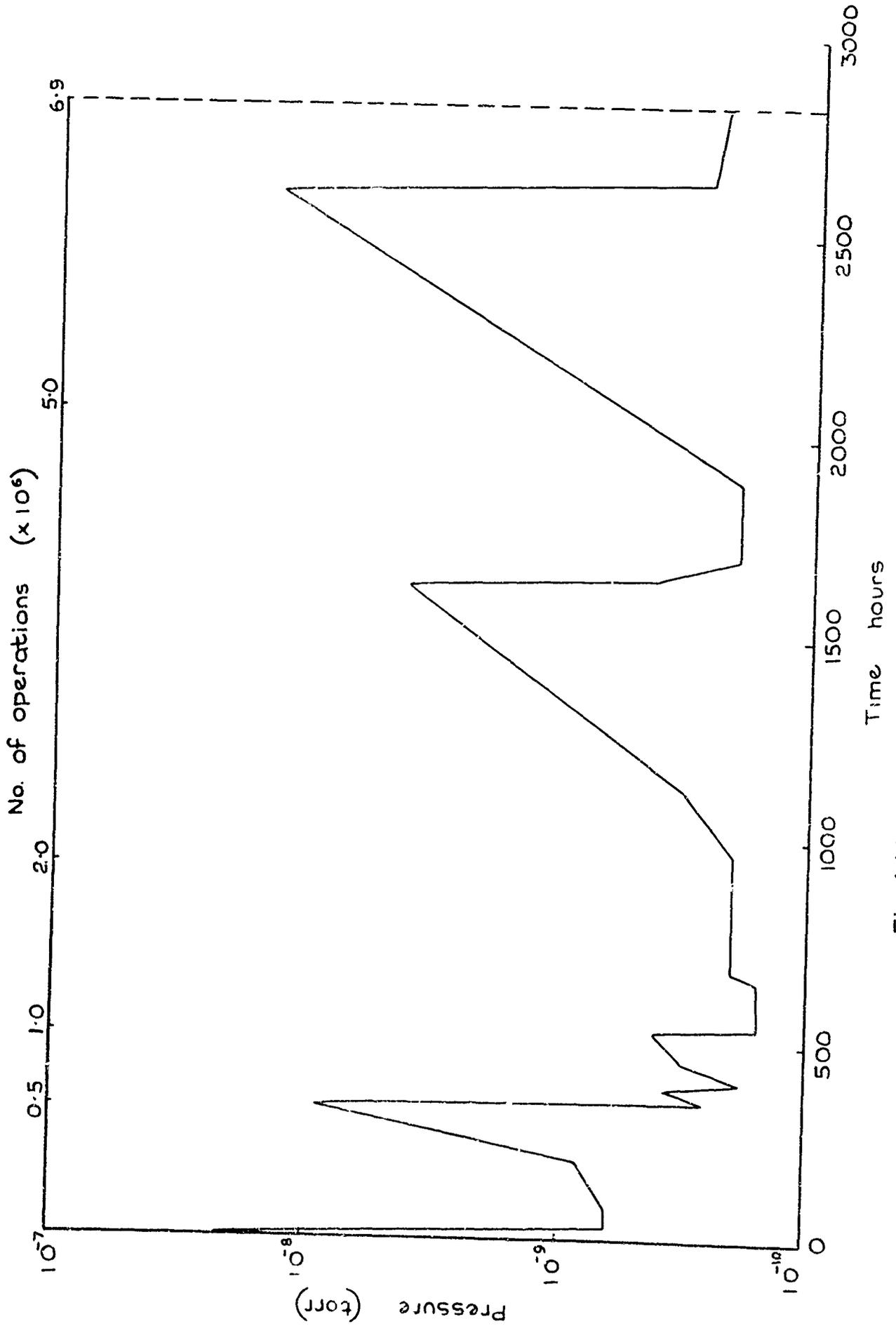


Fig.6 Vacuum-life history of standard movements

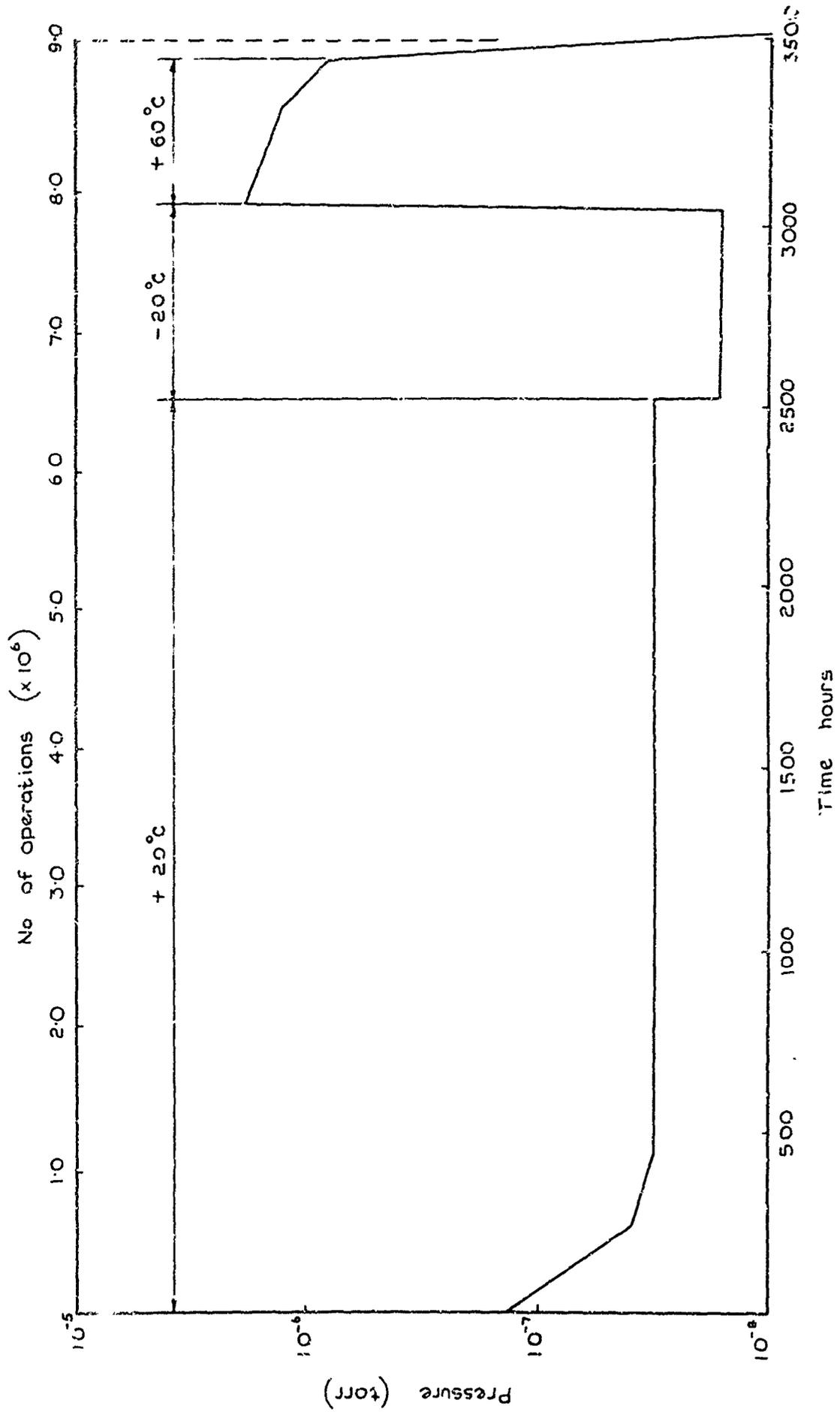


Fig.7 Vacuum-life history of modified movements

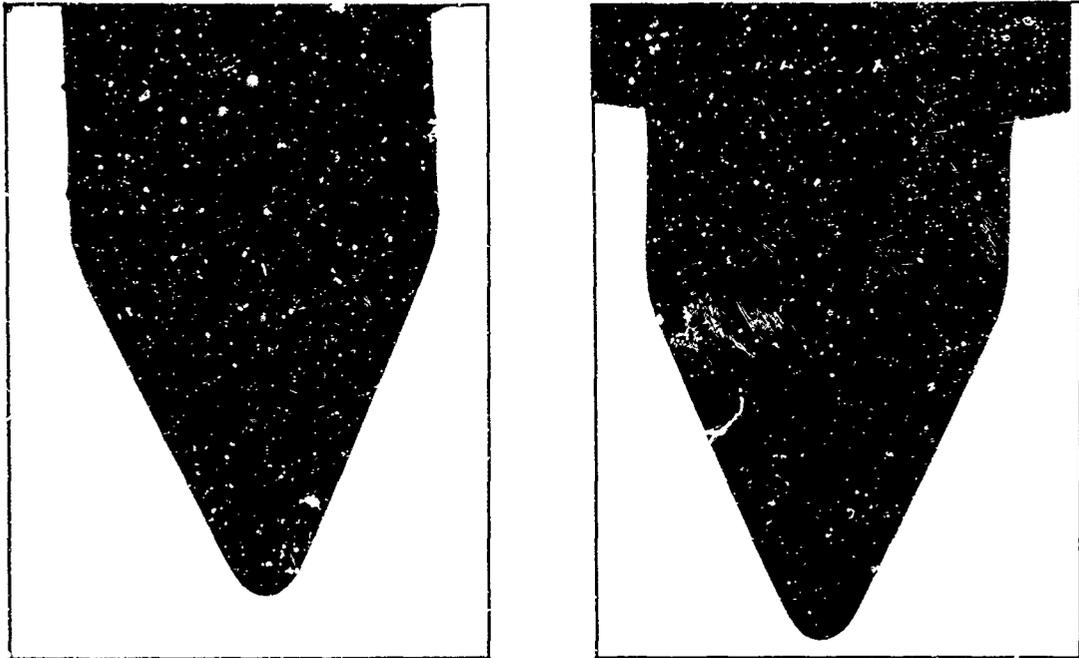


Fig.8 A pair of standard pivots after vacuum/life testing

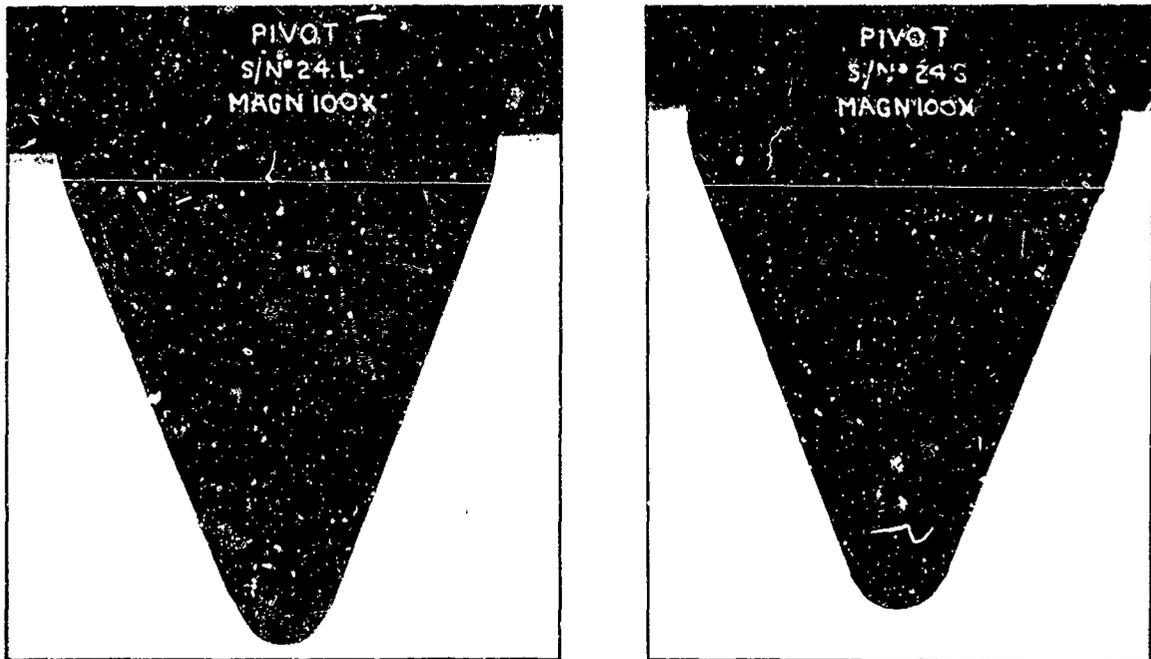


Fig.9 Shadowgraph of modified pivots after vibration (Magnification x100)

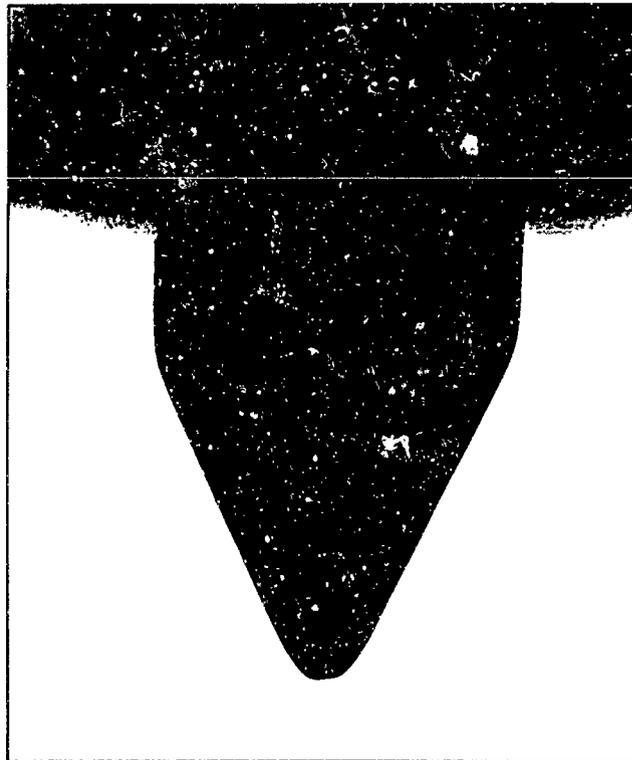


Fig.10 Shadowgraph of a pair of modified pivots after vacuum/life testing

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Fig.11

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Fig.11 Contamination of a modified jewel - pivot bearing after testing

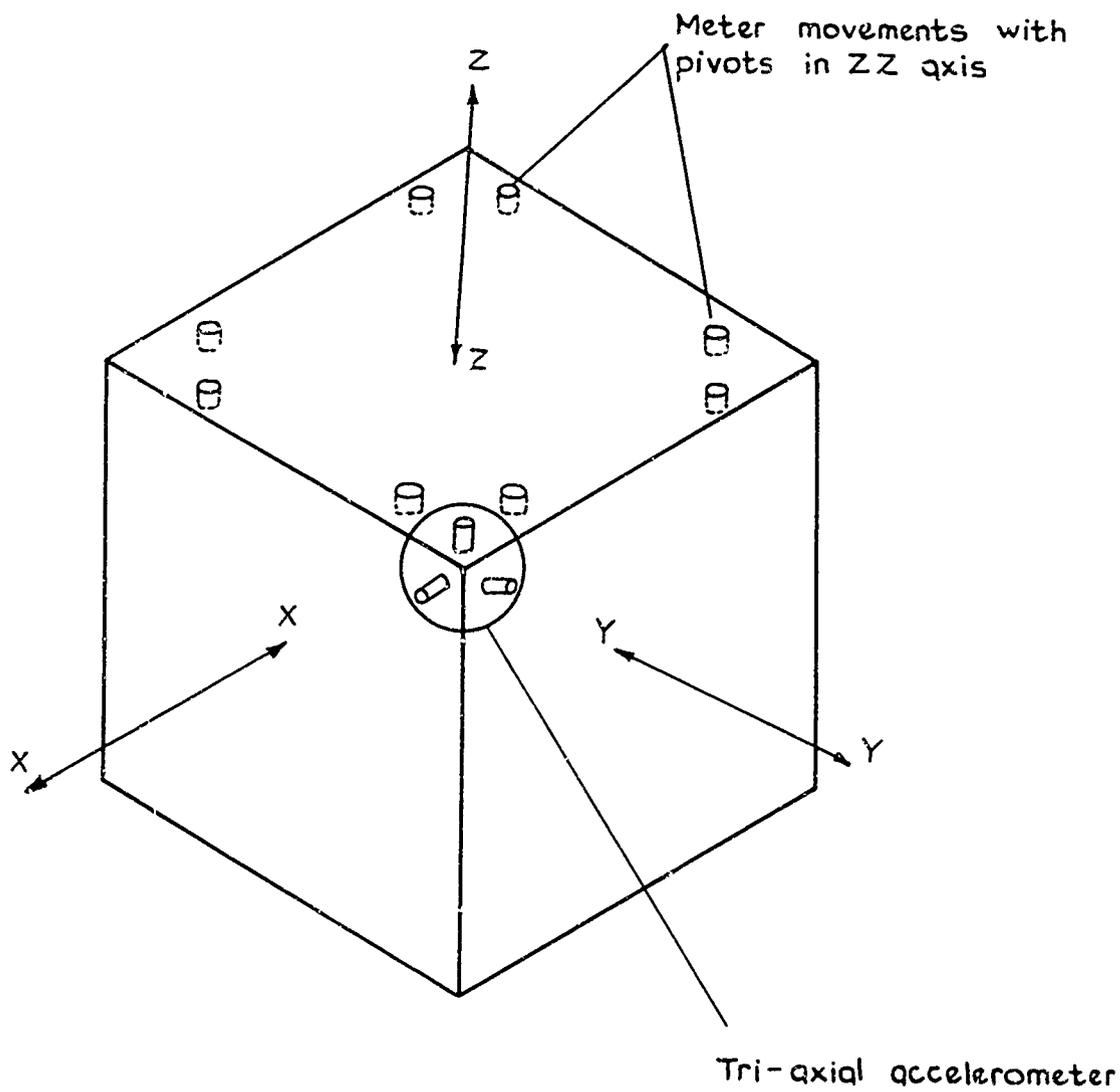


Fig.12 Meter movements on 12 in aluminium cube