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L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

PERFORMANCE TESTING OF PROTOTYPE LIVE LOADED PACKED STEM SEALS FOR LARGE GATE VALVES IN PRESSURIZED HOT WATER

by

N.E. POTHIER

Presented at the 7th International Conference on Fluid Sealing,
September 24 to 26, 1975
Organized and Sponsored by BHRA Fluid Engineering
Held at the University of Nottingham, England

Chalk River Nuclear Laboratories
Chalk River, Ontario

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Mise à l'essai de la performance de joints prototypes à tige et à garniture de charge active pour les grandes vannes destinées à l'eau chaude pressurisée*

par

N.E. Pothier

*[illegible]

Résumé

Des joints prototypes à tige et à garniture de charge active destinés aux grandes vannes ont été soumis à des essais en laboratoire. Le fluide expérimental était de l'eau déminéralisée à 547 K, 8.27 Mpa et pH 10. Neuf configurations de garniture ont été mises à l'essai: trois types commerciaux différents de garnitures en amiante/graphite et trois tailles différentes pour chaque type de garniture.

Des joints conventionnels et des joints à tige et à garniture de charge active sont brièvement comparés. Les fuites et la friction des tiges ainsi que la consolidation de la garniture sont décrites.

Dans tous les essais, on a observé des taux de fuite inférieurs à 10 g d^{-1}. On a également observé que la friction des tiges dépendait dans une certaine mesure de l'expansion thermique de la tige.

L'Energie Atomique du Canada, Limitée
Laboratoires Nucléaires de Chalk River
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SUMMARY

Prototype live loaded packed stem seals for large gate valves have been tested in a laboratory. The test fluid was demineralized water at 547 K, 8.27 MPa and pH 10. Nine packing configurations were tested; three different commercial brands of asbestos/graphite valve packings and three different sizes for each packing brand.

Conventional and live loaded packed stem seals are briefly described. Stem leakage, packing consolidation and stem friction data are given.

For all tests, leakage rates of less than 10 g d^{-1} were observed. It was also observed that stem friction was significantly affected by thermal expansion of the stem.

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1. INTRODUCTION

The pressurized systems of the CANDU-PHW[a] power reactors contain many valves of various types and sizes. Due to the high costs of heavy water and reactor valve maintenance, valve stem leakage can significantly affect the economics of reactor operation. The leakage target for a valve stem seal is 2 g d^{-1} per centimeter of stem circumference (Ref. 1).

Early experience with the Douglas Point (DP) reactor[b] showed that conventional packed valve stem seals required frequent and costly maintenance efforts in order to maintain acceptable leakage rates (Ref. 2). A program was undertaken at the Chalk River Nuclear Laboratories (CRNL) to develop an improved valve stem seal which could be installed on the DP valves and incorporated on valves for other CANDU-PHW reactors.

As a result of the program, a spring loaded packed stem seal, using commercial asbestos/graphite packings, was developed. This spring loading is designated live loading. As part of the overall program, a series of 27 tests was conducted to obtain leakage, packing consolidation and stem friction data for 76.2 mm diameter prototype stem seals in pressurized hot water. Details and results of the tests are given below.

2. THEORY

During the early part of the valve stem seal development program at CRNL, it was experimentally observed that packing axial stress (stress at gland follower/packing interface) was the predominant parameter affecting stem leakage. The observed relationship between stem leakage rate (G) and packing axial stress (σ_g) for small stem seals (10 mm and 16 mm diameter stems) is given in Equation 1 (Ref. 3).

$$G \propto \sigma_g^{-7.3} \qquad ...(1)$$

A conventional double packed stem seal is shown schematically in Fig. 1. Although the packing axial stress may be initially set at a high level, the prevailing stress will decrease with time. This is because of two interacting factors; (1) decreasing packing length,

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(a) CANDU-PHW - CANada Deuterium Uranium-Pressurized Heavy Water

(b) Douglas Point - 200 MW CANDU-PHW reactor due to packing consolidation; and (2) decreasing gland bolt load, due to decrease in bolt strain as the gland follower moves into the stuffing box with packing consolidation. Because of the strong relationship between leakage and packing axial stress (Equation 1), frequent re-torquing of the gland bolts is necessary to maintain low leakage rates.

A live loaded double packed stem seal is shown schematically in Fig. 2. The Belleville spring stacks have a spring rate such that the packing axial stress remains above a minimum value, as the packing consolidates, for the service life of the packing. The spring rate of the Belleville spring live load stacks is based on the following parameters: (1) the desired maximum packing axial stress, (2) the minimum packing axial stress which must prevail in order to attain acceptable leakage, and (3) the amount of packing consolidation in service at the required packing stress. The latter two parameters are properties of the packing material.

3. EQUIPMENT

3.1 Prototype Stem Seals

Nine prototype stem seals (see Fig. 3) were tested. The only significant differences between the prototype stem seals were the different packing brands and the different packing sizes for each packing brand (see Table 1).

The packing materials were manufactured by three different companies: Canadian Johns Manville Co. Ltd., Crane Packing Co. Ltd., and Hopkinsons Ltd. Tradenames have been protected by coding the packings tested.

For each test, the packing axial stress was initially set at 82.7 MPa and maintained within the 82.7 - 68.9 MPa range.

3.2 Test Rigs

Three different test rigs were used (see Fig. 3). The only significant difference between the test rigs was the size of the stuffing box (i.e. the length and diameter of stuffing box bore of the three test rigs were made to suit the three packing sizes, respectively). The main dimensions for the three test rigs were:

Stem diameter:	76.2 mm
Lantern ring/stuffing box diametral clearance:	0.102 - 0.254 mm

Stem/lantern ring diametral clearance:	0.330 - 0.406 mm
Stem stroke (non-rotating):	150 mm
Stem finish:	0.305 μm AA or better

3.3 Test Fluid

The test fluid for all the tests was demineralized water doped with LiOH. The nominal fluid conditions were:

Temperature	547 K
Pressure	8.27 MPa
pH	9.5 - 10.5

3.4 Measuring Methods

A closed and separate leakage collection system was used for each test rig. Each leakage collection system consisted of a short 3 mm diameter stainless steel tubing line connecting the rig leak-off port to a condenser and a short 6 mm diameter poly-flo tubing line connecting the condenser to a 150 ml plastic bottle. The stem leakage was determined by periodically weighing, to the nearest 0.01 g, the leakage collection bottle.

The amount of packing consolidation was determined by periodic measurement, to the nearest 0.025 mm, of the gland follower gap (distance d_1, Fig. 3).

The test rig stem was actuated using a hydraulic cylinder and a hydraulic power unit (i.e., reservoir, piston pump and electric drive motor unit). The stem friction load, due to friction at the packing/stem interface, was calculated using the hydraulic cylinder pressure data observed during stem actuation. The accuracy of the measuring method is within 2 kN.

The packing axial load was determined by measuring, to the nearest 0.025 mm, the length of the Belleville spring stacks and using a stack load vs stack length calibration curve. From these data the packing axial stress was calculated.

4. TEST PROCEDURE

Three samples for each of the nine packing configurations were tested. The following test procedure was used for each test:

(1) The stem, lower ring, total amount of primary packing, split brass ramming sleeve and Belleville spring live load mechanisms were installed on the test rig (see Fig. 4).

(2) The Belleville spring stacks were compressed by torquing the stack nuts to an extent producing a nominal packing axial stress at the split brass sleeve/packing interface of 82.7 MPa.

(3) The Belleville springs live load mechanism and split brass sleeve were disassembled.

(4) The lantern ring, secondary packing, gland follower and Belleville spring live load mechanism were assembled on the test rig (see Fig. 3).

(5) The Belleville spring stacks were compressed by torquing the stack nuts to an extent producing a nominal packing axial stress of 82.7 MPa.

(6) The stem was actuated either once or twice.

(7) The packing axial stress was reset at 82.7 MPa, nominal.

(8) The two test rig isolation valves were opened to permit the test fluid to flow through the test rig.

(9) For the duration of the test run (38-50 d), the following measurements were made daily (weekdays only) except where otherwise noted:

- (a) stem leakage;
- (b) gland follower gap (d_1, see Fig. 3);
- (c) gland follower load; the gland follower load was readjusted to provide a nominal packing axial stress of 82.7 MPa whenever it had decreased to 68.9 MPa, nominal;
- (d) stem friction whenever the stem was actuated (once weekly).

(10) The test rig was isolated and allowed to cool.

(11) The stem was actuated once.

(12) The test rig was completely disassembled and the components were visually examined.

5. TEST RESULTS

5.1 Stem Leakage

Typical observed leakage vs time data for each packing configuration tested are given in Fig. 5. The initial leakage rate was unsteady for some of the tests, but for all the tests the observed leakage rate was nearly constant for the latter two-thirds of the test period. The observed steady-state leakage rates for all the tests are given in Table 2.

5.2 Packing Consolidation

The observed packing length and packing consolidation data are given in Table 3. Typical packing consolidation vs time data, based on the packing length observed immediately after step (7) of the test procedure, are given in Fig. 6.

For packing brands A and B, the packing consolidated more rapidly during the first few days relative to that for the remainder of the test period. For packing brand C, most of the packing consolidation occurred in a stepwise manner with each stem actuation and packing axial stress readjustments. Packing extrusion, between the stem and the gland follower (see Fig. 7) occurred during five of the nine tests conducted with packing brand C.

5.3 Stem Friction

Stem friction readings were taken at the start and end of the down-stroke and upstroke parts of each stem actuation. For all stem actuations, the stem was downstroked first then upstroked. The stem stroke was 150 mm, non-rotating. For some of the packing configuration samples, stem friction readings were not observable with the equipment used for the upstrokes because the stem upstroked itself due to the hydrostatic force of the test fluid acting on the lower end of the stem.

Typical stem running friction data for each packing configuration are given in Table 4. Typical breakaway stem friction was within 110% of the initial downstroke running friction.

From the data given in Table 4, it can be seen that the stem friction loads decreased between the start and end of each downstroke and increased between the start and end of each upstroke. This is attributed to variations in temperature along the axial length of the stem. That is, under steady conditions before a stem actuation, due to a temperature gradient, the diameter of the stem was likely gradually larger with increasing distance from the top of the stem. As the stem was downstroked, a smaller diameter passed through the packing. Also, during the downstroke the portion of the stem previously not in contact with the hot test fluid, came in contact with it, became hotter and expanded. Thus during the upstroke, the upper part of the stem was larger in diameter when it passed through the packing than it was on the downstroke.

Stem friction loads, taken at room temperature conditions, were constant throughout the actuation cycle and were similar to that for the start of the downstroke at hot conditions.

5.4 Stem Surface Condition

After the first stem actuations, for all the tests, it was observed that the section of the stem that passed through the packing became coated with a layer of graphite (see Fig. 8). Graphite is a major constituent of the three packing brands tested (see Table 1).

For the packing brands A and B tests, longitudinal scratches, up to about 0.025 mm deep, on the surface of the stem were observed. These scratches were located all around the section of the stem that passed through the packing during stem actuation and are attributed to the Inconel wire component of the packings.

Longitudinal scratches, up to about 0.076 mm deep on the surface of the stem were also observed for the packing configuration C1 and C2 tests (see Fig. 9). These scratches were located on one side only of the section of the stem that passed through the packing during stem actuation. This indicates that the stem rubbed against the gland follower, lantern ring and/or lower ring during stem actuation. This is attributed to stem misalignment, due in turn to an uneven distribution in the amount of packing material around the stem.

It is considered that the observed stem longitudinal scratches did not significantly affect stem leakage. A likely explanation for this is that, as the scratches were created, they quickly became filled with the packing material, especially graphite. This, in turn, was likely due to the prevailing 82.7-68.9 MPa packing axial stress.

6. DISCUSSION

6.1 Stem Leakage

The observed leakage rates (Table 2) were all less than 1 g d^{-1} per centimeter of stem circumference and within the leakage target range given in Section 1.

6.2 Packing Consolidation

For the packing configurations A2, A3, B2, and C3, the packing length had nearly stablized before the end of the test period (see Fig. 6). Thus, the observed packing consolidation data (Table 3) for these samples are considered good estimates of long-term in-service packing consolidation for similar stem seals. For packing brand A, the amount of packing consolidation seems to depend on packing size, the amount being smaller with increasing packing size (see Table 3, column 6).

The packing consolidation data (Table 3, column 5) show that if a valve is actuated a few times immediately after packing and the packing axial stress is reset, the subsequent amount of in-service packing consolidation is significantly reduced.

For diametral clearances between stem and lantern ring, stem and gland follower, etc., of 0.330 - 0.406 mm, extrusion of the packing brand C is likely. Thus smaller clearances or other means of preventing packing extrusion is considered necessary, if the selected minimum packing axial stress is to be maintained.

6.3 Stem Friction

The stem friction data given in Table 4 show that stem friction is significantly greater for packing brand A relative to that for brands B and C. Also from Table 4, it can be seen that, for nearly all tests where stem friction at end of upstroke was observed, the largest stem friction load occurred at the end of the upstroke. The percentage difference in observed stem friction loads between end of upstroke and start of downstroke seems to depend on the packing annular width; being less for the wider packing samples (see Table 4, column 8; rows 4 - 6 and 7 - 9, rows 13 - 15 and 16 - 18, and rows 19 - 21, 22 - 24 and 25 - 27).

It is considered that if the stem stroke had been longer than 150 mm. larger stem friction loads would likely have been observed at the end of the upstrokes. Considering an actual gate valve with a 76.2 mm diameter stem, the stem stroke would likely be 450 - 610 mm. Thus the data given in Table 4 cannot be readily applied for estimating maximum stem friction loads for actual valves.

During a single test, conducted with a 76.2 mm diameter stem, 460 mm stroke (non-rotating) test rig packed almost similarly to packing configuration A2, the observed stem friction load near the end of the upstroke was about twice that near the start of the downstroke (Ref. 4). The test fluid conditions were similar to that for these tests. Thus it is considered that if the friction load data given in column (2), Table 4, is multiplied by a factor of two for packing sizes 1 and 2 and by a factor of 1.6 for packing size 3, good estimates of the maximum stem friction load for similarly packed valves would be obtained.

7. CONCLUSIONS

Based on the above, the following conclusions are made:

(1) Given that the packing axial stress is maintained within the 82.7 - 68.9 MPa range, leakage rates of 10 g d^{-1} or less are likely for valve stem seals similar to any of the nine packing configurations tested.

(2) For a packing axial stress of 82.7 - 68.9 MPa and diametral clearances between stem and gland follower of 0.330 - 0.405 mm, packing extrusion is likely for packings constructed similarly to that of brand C. This is not so for packings constructed similarly to that of brands A or B.

(3) For 76.2 mm diameter valve stems, stem friction is significantly affected by thermal expansion of the stem.

REFERENCES *

(1) Atomic Energy of Canada Limited Specification, Unpublished.

(2) Dixon, D.F. "Valves for Primary Heat Transport Systems for Canadian Power Reactors". AECL-3858 (March 1971).

(3) Doubt, G.L. "Atomic Energy of Canada Limited Report on Valve Packing Tests". AECL-5120. To be published shortly.

(4) Doubt, G.L. Private Communication, September 1974.

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* AECL-XXXX - Report published by Atomic Energy of Canada Limited.

TABLE 1

BASIC PACKING CONSTRUCTION AND PACKING CONFIGURATION

Basic Packing Construction	Packing Size	Packing Form	Amount of Packing		Packing Configuration Code
			Primary Packing[(a)]	Secondary Packing[(b)]	
Brand A Packing consisted of a braided asbestos yarn outer jacket (reinforced with Inconel wire and coated with graphite) with an asbestos and graphite inner core.	1	Split ring 3.2 mm by 3.2 mm cross section	3 split rings	2 split rings	A1
	2	Split ring 6.4 mm by 6.4 mm cross section	3 split rings	2 split rings	A2
	3	Split ring 12.7 mm by 12.7 mm cross section	3 split rings	2 split rings	A3
Brand B Similar to above, except supplied by a different manufacturer.	1	Split ring 3.2 mm by 3.2 mm cross section	3 split rings	2 split rings	B1
	2	Split ring 6.4 mm by 6.4 mm cross section	3 split rings	2 split rings	B2
	3	Split ring 12.7 mm by 12.7 mm cross section	3 split rings	2 split rings	B3
Brand C Mixture of graphite, asbestos and a lubricant.	1	Loose material compacted into an annulus 3.2 mm wide	Similar volume as for A1 and B1	Similar volume as for A1 and B1	C1
	2	Loose material compacted into an annulus 6.4 mm wide	Similar volume as for A2 and B2	Similar volume as for A2 and B2	C2
	3	Moulded into half rings, 12.7 mm by 12.7 mm cross sect.	3 rings	1 ring	C3

(a) Packing below the lantern ring (see Lp, Fig. 3)
(b) Packing above the lantern ring (see Ls, Fig. 3)

TABLE 2

OBSERVED STEADY-STATE LEAKAGE RATES (g/d)

Packing Brand	Packing Size		
	1	2	3
A	0.70 4.82 4.83	2.83 6.88 3.20	0.05 0.01 0.03
B	0.21 0.09 0.16	0.22 0.16 0.12	0.02 0.03 0.04
C	4.67 4.66 7.69	5.44 4.41 3.04	1.84 0.71 0.45

TABLE 3: OBSERVED PACKING CONSOLIDATION DATA

1	2	3	4	5	6
Packing Configuration Code	Packing Length[b] After Test Procedure Step (5) (mm)	Packing Length After Test Procedure Step (7) (mm)	Packing Length After End of Test Run (mm)	% Packing Consolidation After Test Procedure Step (7) - Based on Length Given in Column 2	% Packing Consolidation After End of Test Run - Based on Length Given in Column 2
A1	11.175	10.875	9.825	2.68	12.08
"	11.250	11.150	10.200	0.88	9.33
"	10.925	10.750	9.750	1.60	10.75
A2	22.225	21.725	20.400	2.25	8.21
"	21.350	21.025	19.850	1.52	7.03
"	21.750	21.350	19.900	1.84	8.51
A3	44.625	43.925	42.000	1.57	5.88
"	44.625	44.325	42.150	0.67	5.55
"	46.900	46.300	43.800	1.28	6.61
B1	11.475	11.225	10.150	2.18	11.55
"	12.100	11.775	10.700	2.68	11.57
"	11.800	11.700	10.575	0.85	10.38
B2	20.625	20.000	18.250	3.03	11.52
"	20.125	19.750	18.000	1.86	10.56
"	20.250	20.000	17.775	1.23	12.22
B3	45.625	44.825	40.800	1.75	10.58
"	44.650	44.350	40.450	0.67	9.41
"	45.625	45.025	40.850	1.32	10.46
C1	14.375	13.850	12.725	3.65	11.48[a]
"	14.850	14.350	13.725	3.37	7.58
"	14.600	13.925	12.225	4.62	16.27[a]
C2	25.600	24.850	23.625	2.93	7.71
"	23.675	21.775[a]	20.775	8.03	12.25[a]
"	26.000	25.525	24.900	1.83	4.23
C3	41.725	41.275	40.400	1.08	3.18
"	44.950	43.725	37.250	2.73	17.13[a]
"	44.800	43.500	37.125	2.90	17.13[a]

(a) Packing extrusion occurred
(b) Packing Length = Lp + Ls (See Fig. 3)

TABLE 4: OBSERVED STEM FRICTION LOAD DATA

(1) Packing Configuration Code	(2) Average Stem Friction Load For the Last Three Hot Actuations - Downstroke	(3)	(4)	(5) Average Stem Friction Load For the Last Three Hot Actuations - Upstroke	(6)	(7)	(8) % Increase Between Start of Downstroke and End of Upstroke
	Start (kN)	End (kN)	% Decrease Between Start & End	Start (kN)	End (kN)	% Increase Between Start & End	
A1	26	14	46	-	-	-	-
"	40	26	35	-	-	-	-
"	28	20	29	-	-	-	-
A2	56	32	43	42	82	95	46
"	56	36	36	40	74	85	32
"	56	34	39	40	72	80	29
A3	98	72	26	76	120	58	22
"	112	90	20	82	136	66	21
"	112	80	29	80	130	63	16
B1	14	4	71	-	-	-	-
"	18	8	56	-	-	-	-
"	20	8	60	-	-	-	-
B2	32	10	69	-	56	-	75
"	24	10	58	-	-	-	-
"	36	16	56	-	54	-	50
B3	68	42	38	48	92	92	35
"	56	32	43	-	74	-	32
"	68	40	41	54	82	52	21
C1	28	20	29	-	40	-	43
"	28	20	29	-	40	-	43
"	26	16	38	-	40	-	54
C2	42	32	24	-	56	-	34
"	40	26	35	-	50	-	25
"	44	32	27	50	62	24	41
C3	72	56	22	64	84	31	17
"	52	36	31	40	50	25	-4 (a)
"	54	36	33	40	50	25	-7 (a)

(a) Extrusion of the packing occurred

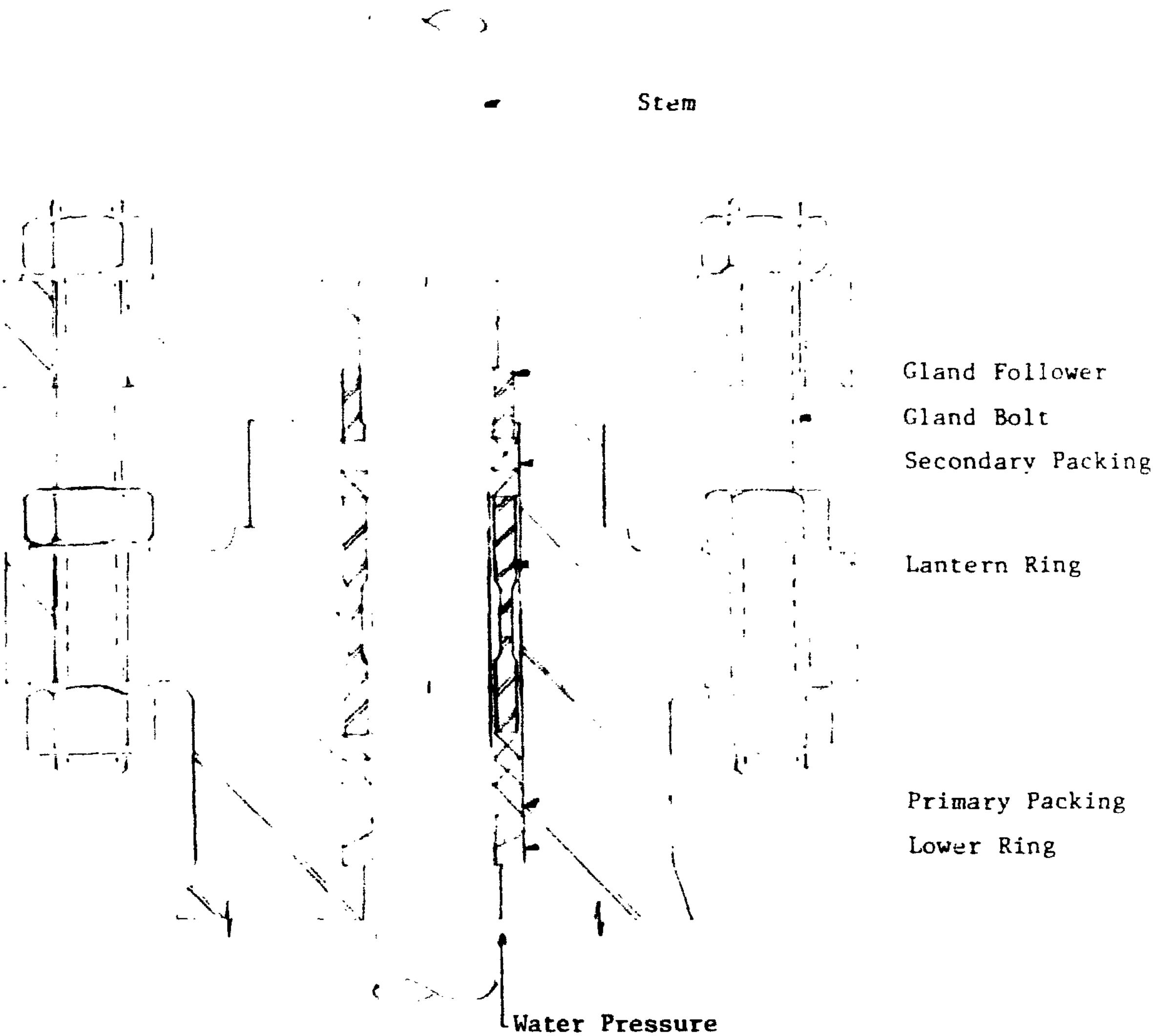


FIG. 1 CONVENTIONAL DOUBLE PACKED VALVE STEM SEAL

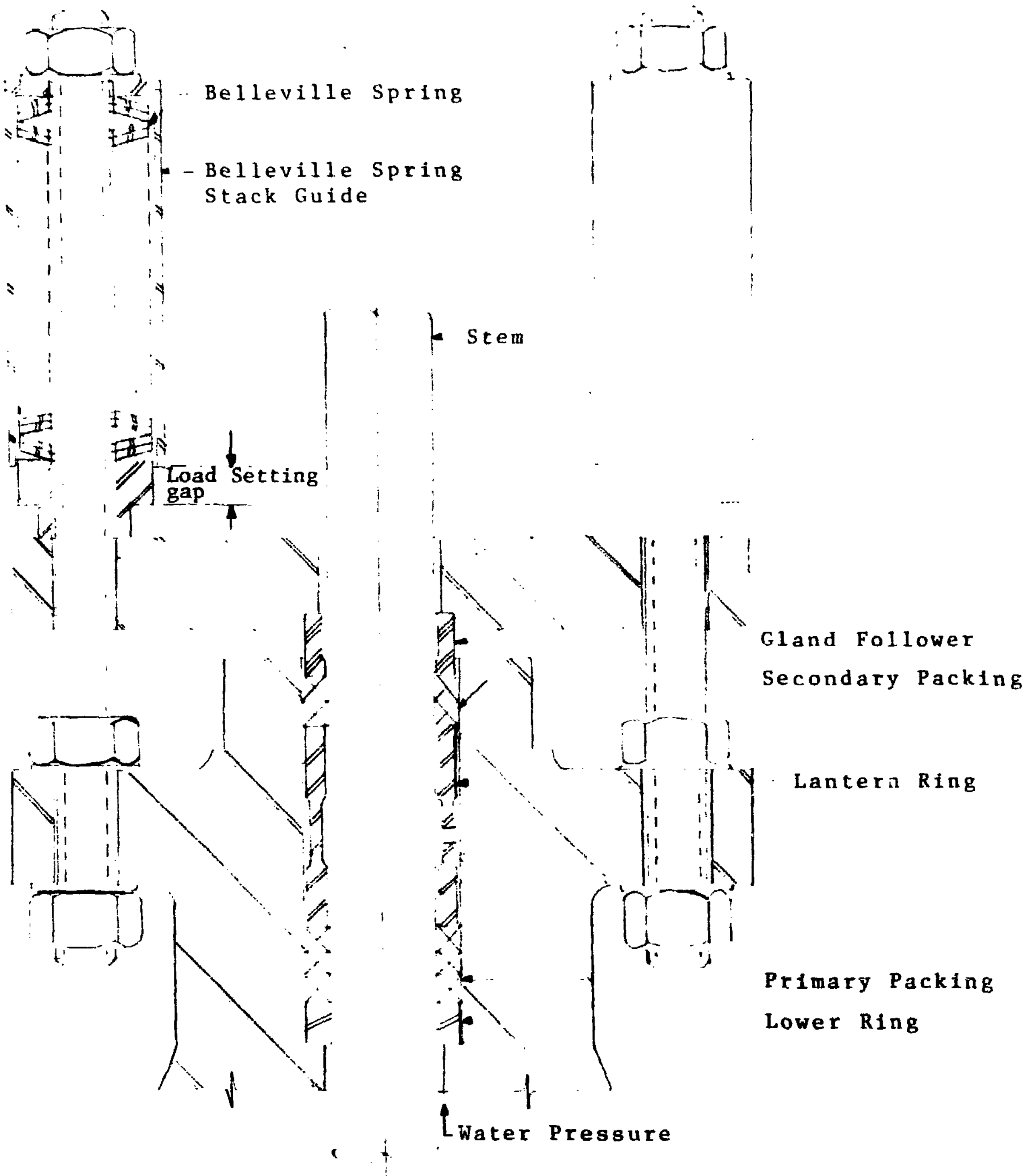


FIG. 2 LIVE LOADED DOUBLE PACKED VALVE STEM SEAL

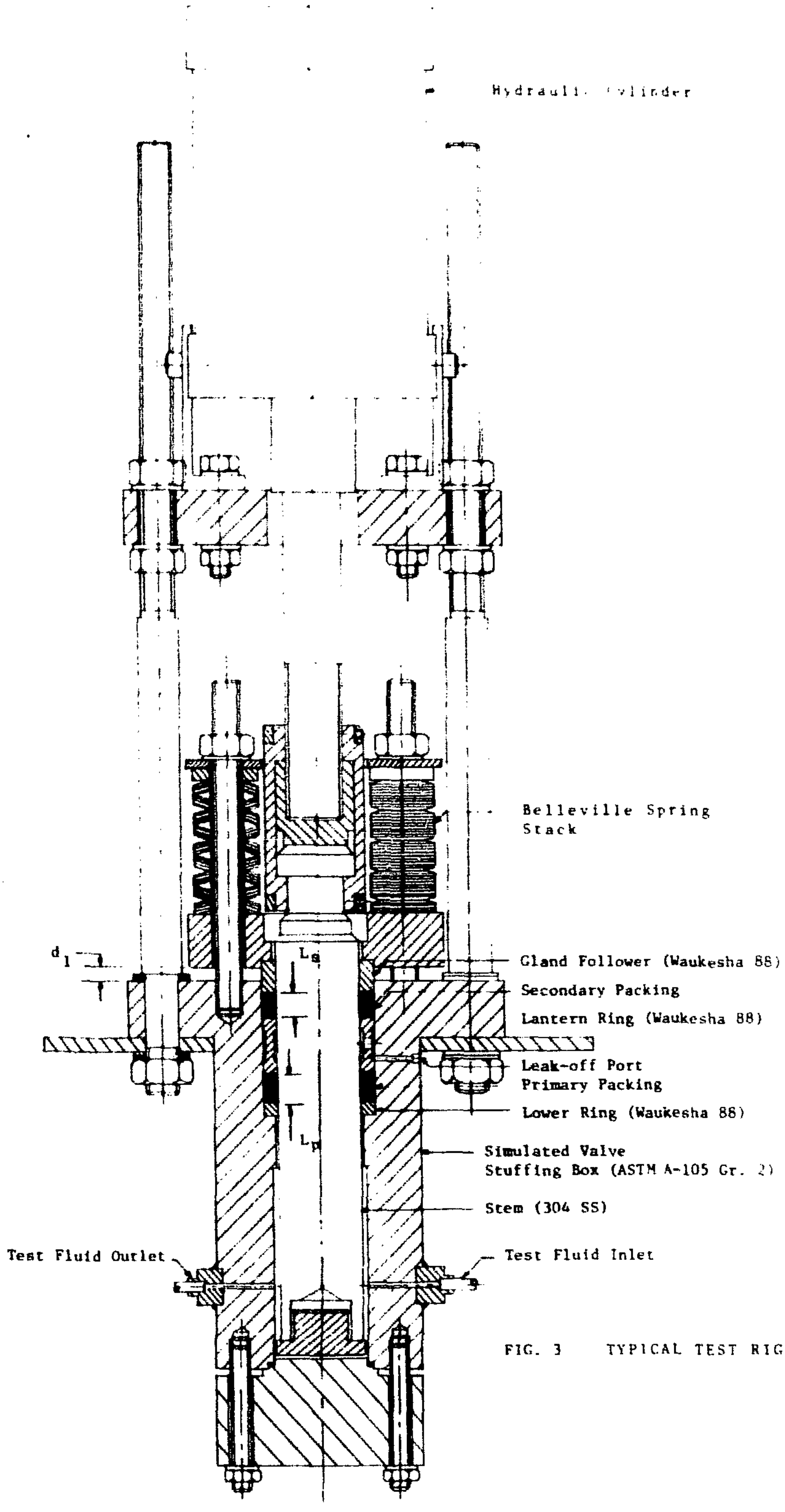


FIG. 3 TYPICAL TEST RIG

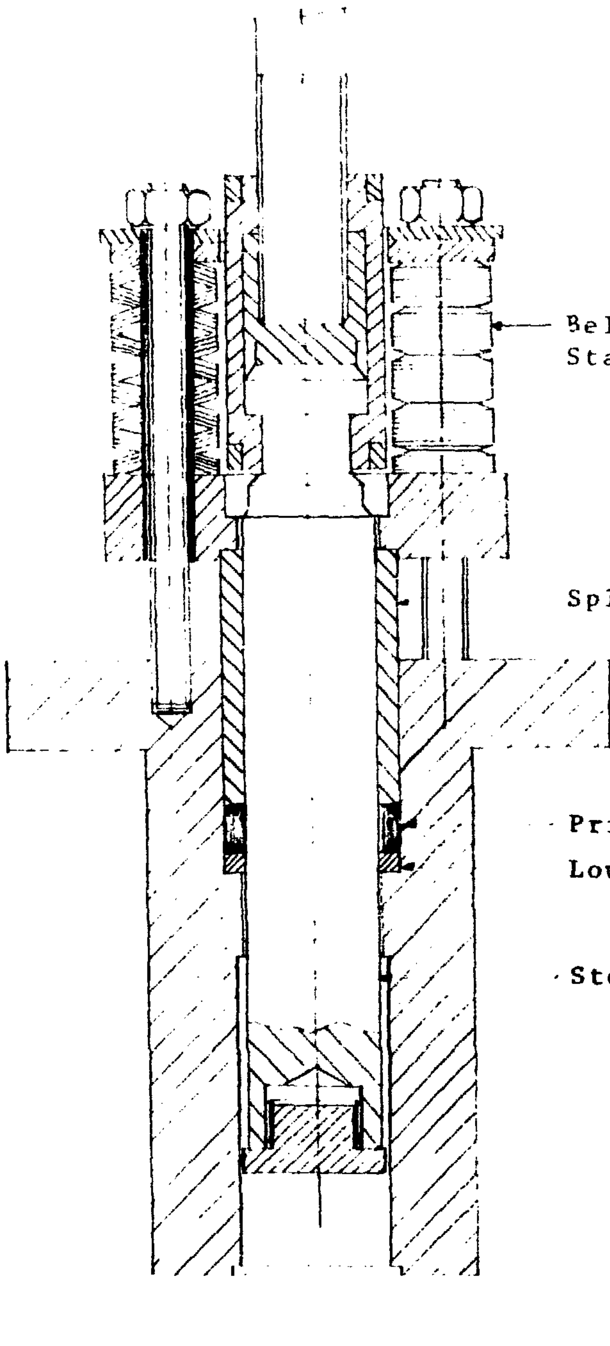
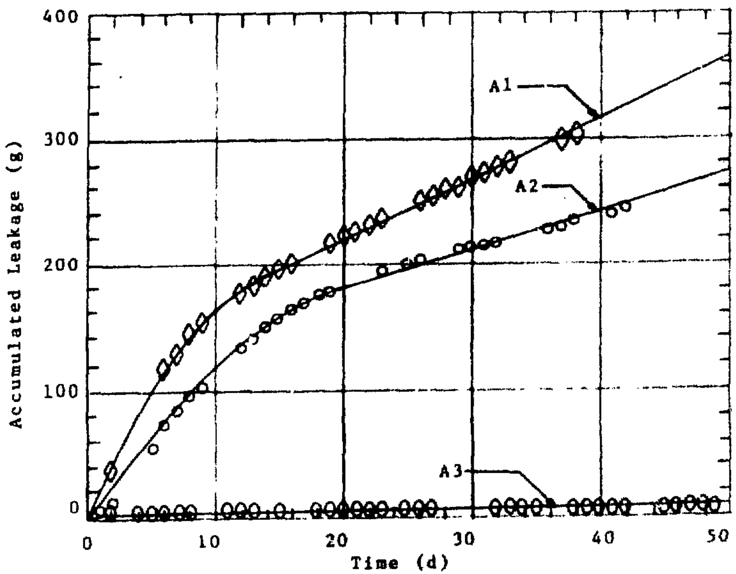
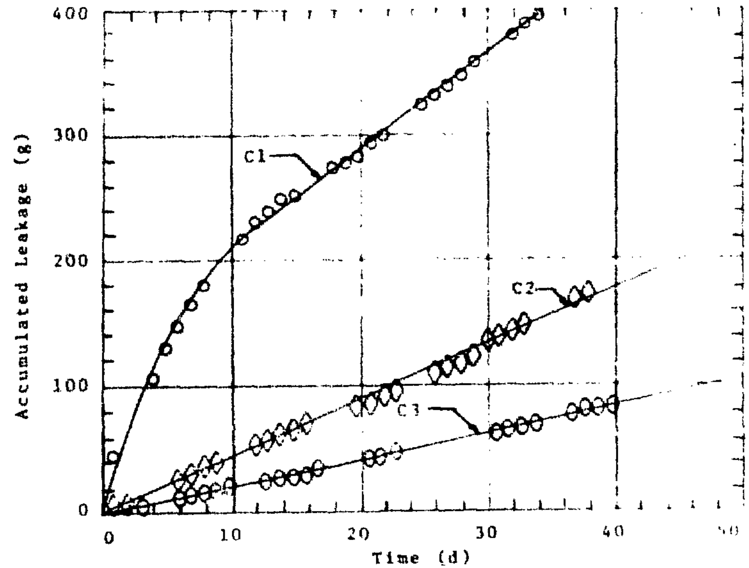


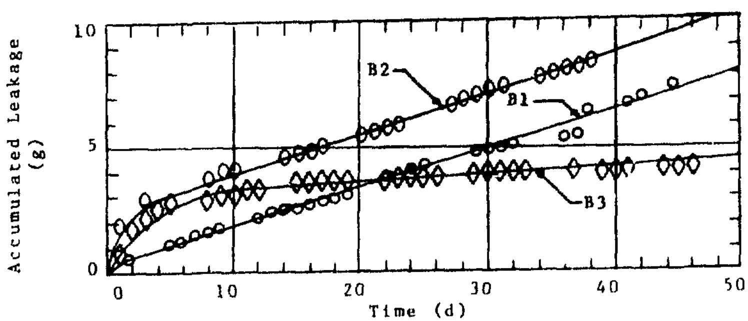
FIG. 4 COMPRESSION OF PRIMARY PACKING



(a) PACKING BRAND A

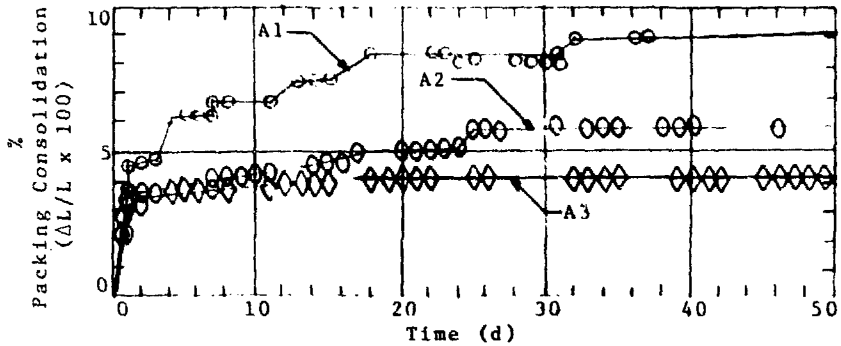


(c) PACKING BRAND C

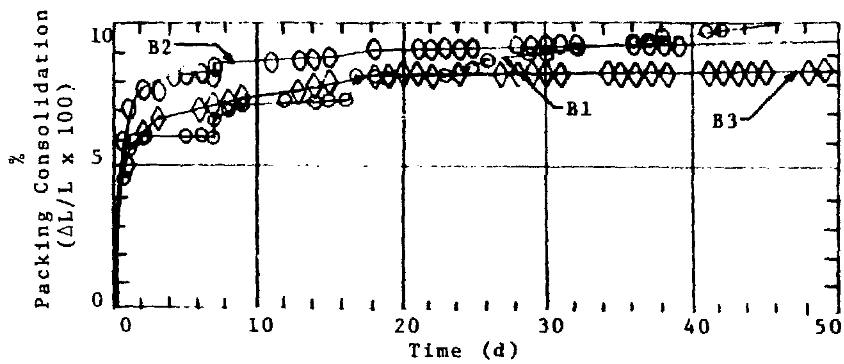


(b) PACKING BRAND B

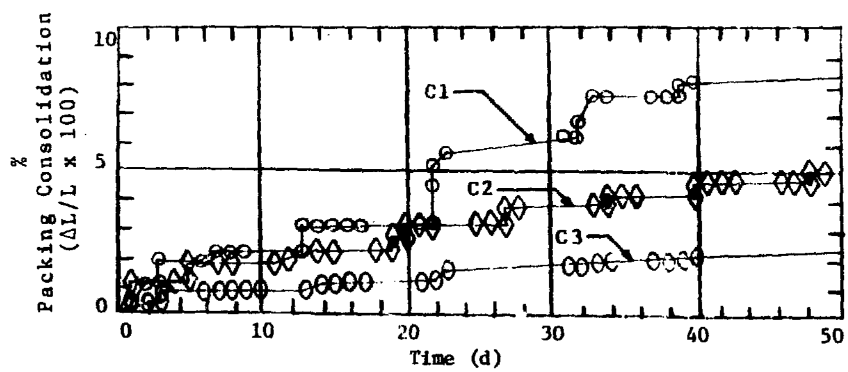
FIG. 5 TYPICAL OBSERVED LEAKAGE VS TIME DATA



(a) PACKING BRAND A



(b) PACKING BRAND B



(c) PACKING BRAND C

FIG. 6 TYPICAL OBSERVED PACKING CONSOLIDATION VS TIME DATA

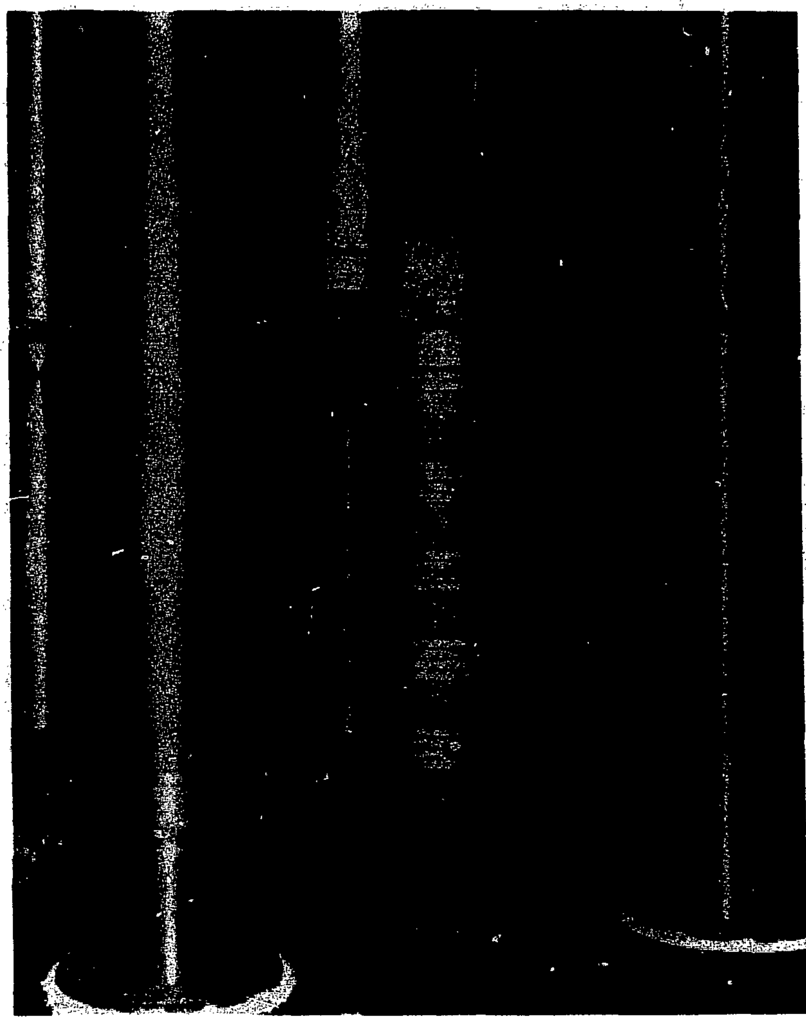


FIGURE 7 : Packing extrusion between stem and gland follower

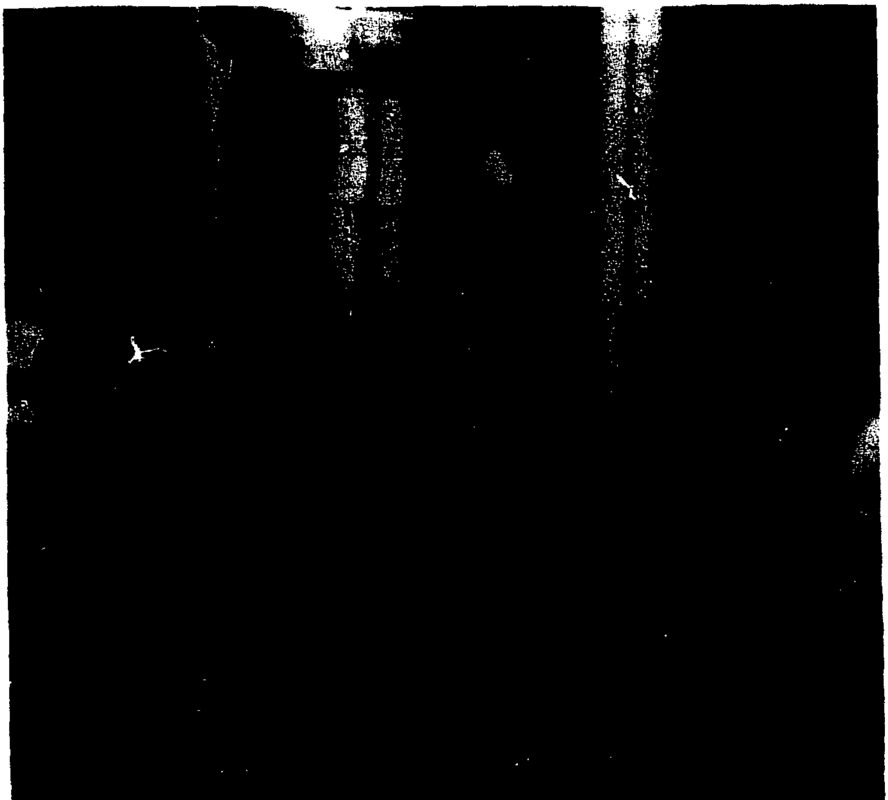


FIGURE 8 : Graphite layer on stem surface after 1st actuation

FIGURE 9 : Longitudinally scratched stem surface

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