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ACCELERATED SERVICE TESTS OF PINTLE BEARINGS

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ABSTRACT

Accelerated service tests of pintle bearings with different combinations of materials for the pintles and cups, different pressures, and different conditions of lubrication were made under conditions similar to those which might obtain in practice as to the line of thrust and angle of swing. The bearings were under water during the tests.

The results indicated that of the materials tested one must be phosphor bronze to give satisfactory service for pressures as great as 2,000 lb/in.^{2} Pintles of H-monel, M-monel, and S-monel, gave satisfactory service at this pressure with phosphor-bronze cups.

Cups of stainless steel, chromium steel, chromium-nickel steel, malleable cast iron, and monel alloys were scored badly after only a few cycles when tested under a pressure of 2,000 lb/in.^{2} Aluminum-bronze cups were worn excessively at a comparative small number of cycles. Phosphor bronze was the only cup material tested in this investigation which gave satisfactory service with a pressure as great as 2,000 lb/in.^{2}

A stainless-steel pintle and phosphor-bronze cup provided with grooves for water circulation and tested under a pressure of 4,000 lb/in.^{2} withstood more than 288,000 cycles, the number of cycles expected in 20 years' service. A stainless-steel pintle and phosphor-bronze cup lubricated with white lead or with grease having a lead-soap base and asphalt content, did not fail when tested under a pressure of 6,000 lb/in.^{2} and subjected to more than 288,000 cycles.

CONTENTS

I. INTRODUCTION

The contemplated use of relatively large lock gates in the Tennessee River Valley development made it seem advisable to study, with more than the usual care, the properties of the materials used in the various elements of the gates so that long, continuous, and satisfactory service might be expected. The pintle bearings, consisting of pintles and cups, are important parts of the lock gates. Because of the heavy weight of the gates, either large pintles or high bearing pressures on the pintles must be used. Few data are available as to the relative wearing qualities of different materials for pintles or cups or as to the greatest pressures which would give satisfactory service for pintle bearings of given materials.

The War Department, United States Engineer Office, therefore requested the National Bureau of Standards to make accelerated service tests of pintle bearings with different combinations of materials, pressures, and conditions of lubrication.

II. SPECIMENS AND TESTING PROCEDURE

Pintles having a diameter of 26 inches and subjected to bearing pressures of 2,100 lb/in.^{2} are contemplated for use at the Pickwick Lock, Tennessee River. The tangent of the angle between the axis of the pintle and the line of the resultant force on the surface of the pintle is about 0.4. The gates will swing through an angle of 70°, requiring about 1 minute for opening or closing. The pintle bearings will, of course, be under water. The estimated traffic through the lock may require the operation of the gates about 40 times a day. A life of 20 years or 288,000 cycles may be considered as satisfactory service.

It was desired that the tests at the National Bureau of Standards be carried out under conditions as similar to these as practicable, with, however, a smaller pintle.

A pintle diameter of 1 inch was considered satisfactory, and the dimensions of the pintles and cups are shown in figure 1. For the purpose of calculating bearing pressures on the pintles, the area in bearing was considered as the projected area of the cup hemisphere on a plane normal to the line of thrust and was equal to the area of half a circle, plus the area of half an ellipse, as indicated in figure 1. The tangent of the angle between the pintle axis and the line of thrust was maintained at the 0.4 value and the angle of swing for each cycle was 70°. All tests were made with the pintle bearing under water. It was necessary to conduct the tests at a faster rate than that at which the gates would be operated to obtain results within a reasonable time. Consequently, the tests were made at the rate of about 120 cycles per minute.

It is recognized that, under actual service conditions, time, water temperature, and presence of silt may have important effects on the corroding and wearing qualities of pintle bearings. These factors, which were not effective in the accelerated tests, should be given consideration in the selection of materials on the basis of the results of these tests.

The tests were carried out in a screw-power beam and poise testing machine having a capacity of 50,000 lb. To secure stability as the relative motion between the pintle and cup took place, two tests were made at the same time, as shown in figures 2 and 3.

The cups remained stationary during the tests. They were restrained from turning in the blocks in which they were placed, as shown in figure 1, by setscrews. As wear occurred each cup was adjusted vertically by means of the threaded plug in the cup block (see fig. 1) so as to maintain the correct angle for the line of thrust. Horizontal measurements (H) between pins on the thrust bars and vertical measurements (V) between the upper surface of a small rod set in the base of the testing fixture and the center of the pin connecting the thrust bars (see fig. 3 and 4) could be made at any time as a check on the correctness of the angle of thrust.

The pintles were held in pintle supports, as shown in figure 1, and prevented from rotating with respect to the supports by setscrews. The bottom of the pintles rested on threaded plugs in the supports

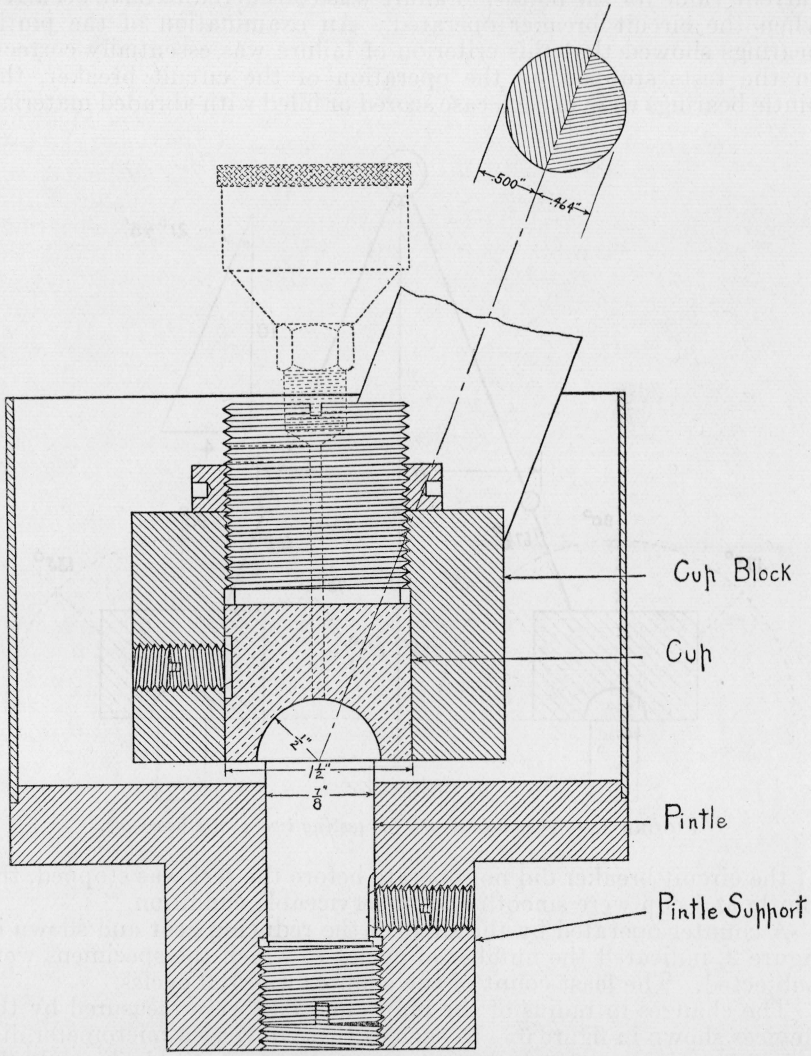

FIGURE 1.—*Testing fixtures.*

which could be adjusted vertically so that the centers of the two pintle hemispheres were at the same elevation above the tops of radial and thrust bearings, shown in figure 4. This adjustment was necessary only because of slight variations in the lengths of the pintle stems. The pintle supports, filled with water to cover the pintles, are shown in figure 5. The supports were connected by a link and were oscillated through the 70° angle by a 0.5-hp electric motor and a reducing gear, shown in figure 2. The indication of an ammeter in the armature circuit of the motor was used as a measure of the relative power necessary to oscillate the pintle supports. A circuit breaker in the power line supplying this motor was adjusted to stop the test when the ammeter reading was about as large as the safe current value for the motor. Failure was considered to have occurred when the circuit breaker operated. An examination of the pintle bearings showed that this criterion of failure was essentially correct. In the tests stopped by the operation of the circuit breaker, the pintle bearings were in each case scored or filled with abraded material.

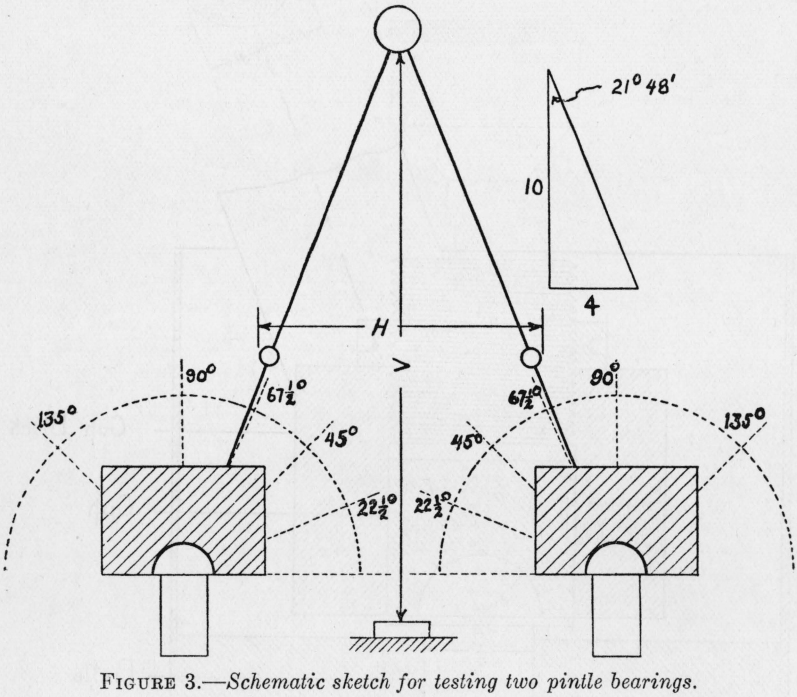

FIGURE 3.—*Schematic sketch for testing two pintle bearings.*

If the circuit breaker did not operate before the test was stopped, the pintle and cup were smooth and in serviceable condition.

A counter operated by the shaft of the reducing gear and shown in figure 2, indicated the number of cycles to which the specimens were subjected. The least count of the counter was 100 cycles.

The changes in radius of the pintle and cup were measured by the devices shown in figure 6. In each of these devices a micrometer dial gage was rigidly attached to a base plate. A V block could be rotated about a pin set in the base plate. The axis of the pin intersected the axis of the dial-gage spindle and passed through the center of the spherical surface of the pintle or cup when the specimen was set against a stop on the V block. Since the pintle or the cup could be rotated in the V block and the V block rotated about the axis through the center of the sphere, the devices could be used for radius measurements over nearly the entire hemispherical surfaces of the

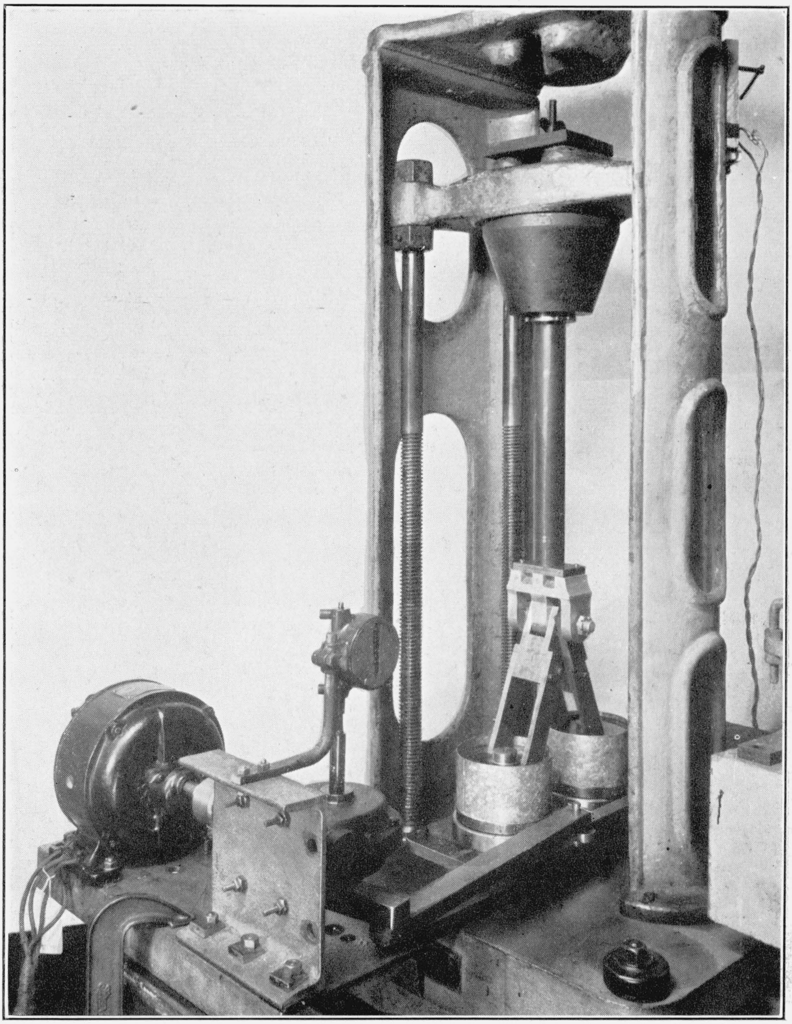

Figure 2.—*Apparatus assembled in the testing machine.*

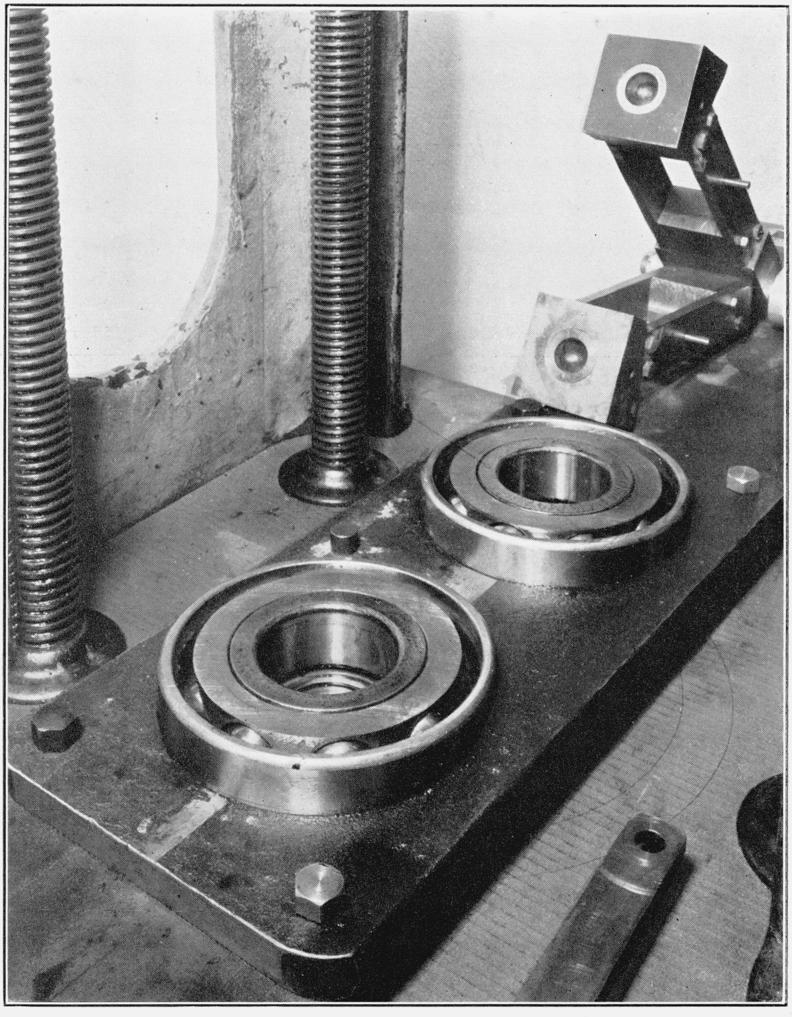

FIGURE 4.—*Combination thrust and radial bearings and the cup-holding assembly.*

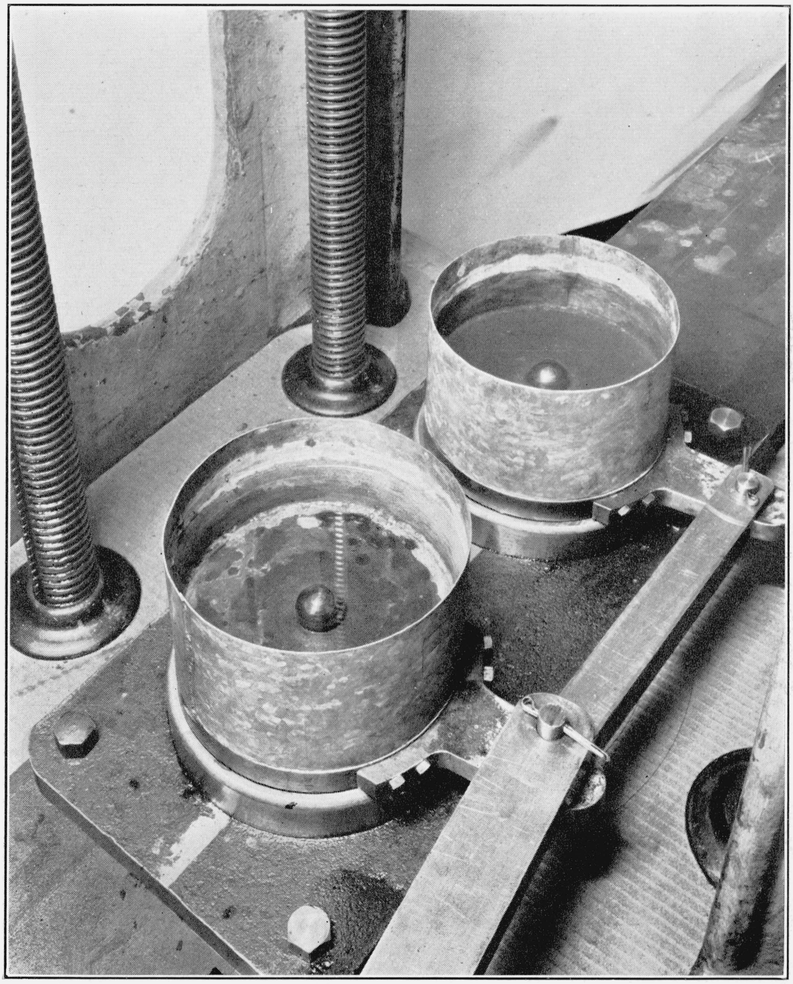

FIGURE 5.—*Pintles in the oscillating pintle supports, covered with water.*

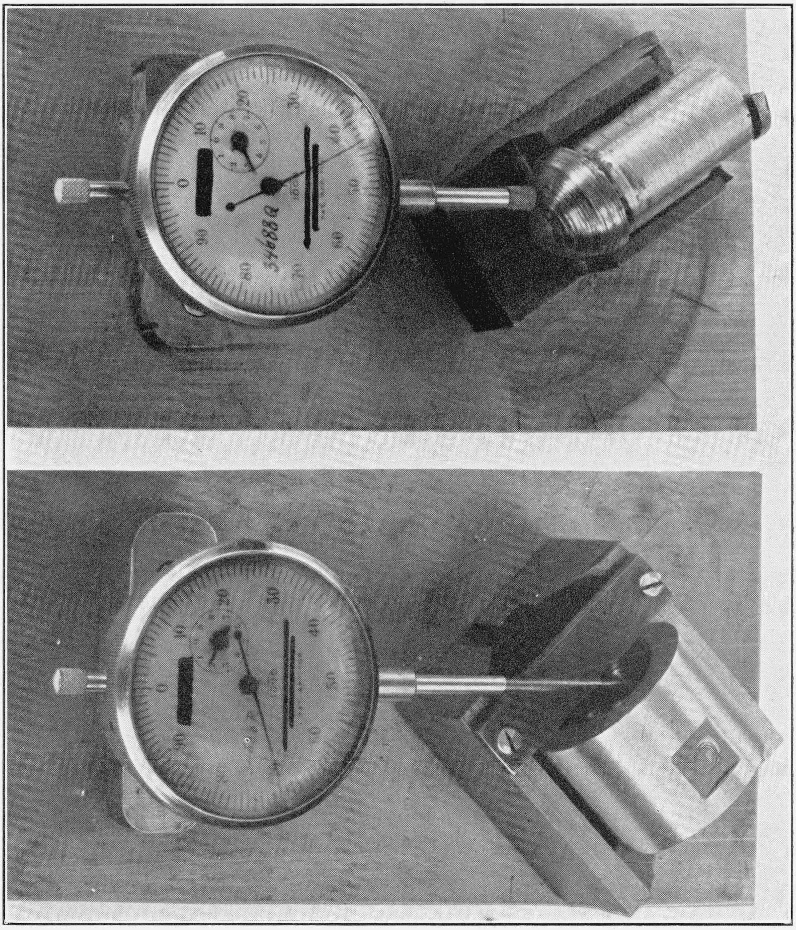

FIGURE 6.—*Devices for measuring the change in radius of the pintles and cups.*

specimens. Readings were taken, however, only in the plane determined by the lines of thrust and the line connecting the centers of the pintles and at the five positions in this plane shown in figure 3. Radius readings were taken before the test was started and after the test was completed. The difference between the readings at any of the five positions was the change in radius for that position. The dial gages were graduated to 0.001 in., and readings were estimated to 0.1 division. Readings at any position generally checked each other within 0.3 or 0.4 of a division as the specimens were removed from and again placed in the V blocks between readings.

III. PROGRAM OF TESTS

In a preliminary investigation of this kind it seemed impractical before the tests were started to decide definitely upon the whole program. As the tests progressed, a consideration of the results available at the time governed the conditions for the later tests. The program of tests as the investigation was carried out may be considered as divided in three series of tests. The materials used and the conditions of test are given under the discussion of results in tables 2, 3, and 4.

In the tests of series A, different combinations of materials for pintles and cups were used. The tests were made under a pressure of 2,000 lb/in.^{2}, the pintle bearings were not lubricated, and the cups were ungrooved.

The tests of series B were also made under a pressure of 2,000 lb/in^2. The tests of series B were made for the purpose of comparing the wearing life of cups without grooves with those in which two grooves, about ⅛ in. wide and 1/16 in. deep, were cut along meridian circles of the hemispherical bearing surface at right angles to each other, one of the grooves being in the plane of the lines of thrust. A vertical hole was drilled in the cup and a vertical hole and a horizontal hole were drilled in the threaded plug, as shown by the dotted lines of figure 1, so that water circulation over the bearing surfaces or at least through the grooves was possible for test 18. For the comparison of ungrooved cups and grooved cups with lubrication, a plain compression grease cup, holding about 1 cubic inch, was screwed into the vertical hole of the cup plug as shown in figure 1, and the horizontal water circulation hole was closed. A pressure of about 50 lb/in.^{2} on the lubricant was obtained by screwing the cover of the grease cup by hand.

The cups in the tests of series C were grooved and the bearings were lubricated as indicated in table 3, the tests being made with greater bearing pressures than were used in the other series.

An attempt was made to use greater pressures than are given in table 3 for series C, but the motor driving the pintle supports did not have sufficient power.

IV. RESULTS AND DISCUSSION

1. CHEMICAL COMPOSITION OF MATERIALS

The chemical composition of the materials used for pintles and cups is given in table 1.

TABLE 1.—*Chemical composition of materials used for pintles and cups*

Material	Analysis furnished by	C	Mn	S	P	Si	Ni	Cr	Mo	Cu	C	Fe	Al	Sn	Zn	Pb
		%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Aluminum bronze	NBS	-----	0.11	-----	-----	-----	5.0	----	------	80.0	----	5.2	9.2	0.14	0.25	----
Chromium steel	WD	0.14	.40	0.016	0.013	0.32	------	5.15	0.50	------	----	------	----	----	----	----
Malleable cast iron	M	2.4 to 2.6	.40 to .55	.04 to .08	.15 to .19	1.9 to 2.1	------	----	.3 to .4	.8 to 1.0	0.6 to 0.8	------	----	----	----	----
Monel:																
H-Monel	M	.10	.50	.020	-----	1.25	61.00	----	------	34.0	----	2.75	----	----	----	----
K-Monel	M	.16	.50	.005	-----	.20	65.00	----	------	27.0	----	1.50	3.45	----	----	----
M-Monel	M	.15	1.10	.010	-----	.10	67.00	----	------	28.0	----	1.70	----	----	----	----
S-Monel	M	.10	.50	.020	-----	3.50	60.00	----	------	33.0	----	2.75	----	----	----	----
Nickel steel	WD	.36	.65	.022	.031	.21	3.43	----	------	------	----	------	----	----	----	----
Nickel-chromium steel	WD	.38	.55	.025	.024	.15	3.28	1.31	------	------	----	------	----	----	----	----
Phosphor bronze	NBS	-----	-----	-----	.46	-----	------	----	------	80.2	----	------	----	10.9	----	8.3
Stainless steel A	M	.12 max	.40 to .50	.025 max	.025 max	.50 max	------	12 to 15	.50 max	------	----	------	----	----	----	----
Stainless steel B	M	.08 to .20	.40 to .50	.025 max	.025 max	.50 max	7 to 9	17 to 19	------	------	----	------	----	----	----	----

NBS=National Bureau of Standards.
WD=War Department.
M=Manufacturer.

2. TESTS OF SERIES A—DIFFERENT COMBINATIONS OF MATERIALS

Table 2 gives the results of the tests of series A. The change in radius measurements for the tests of series A are given to an enlarged scale in figure 7. The pintles and cups for tests 1 to 6, inclusive, are shown after test in figure 8. The pressure of 2,000 lb/in.^{2} was evidently great enough to produce failures, i. e., operation of the circuit breaker on the driving motor, in some of the pintle bearings with a small number of cycles. Failure in each case was due to excessive wear or to scoring. It appeared from an examination of the specimens that the failure was due to the material in the cup rather than in the pintle. In fact, the only satisfactory tests were those for which phosphor bronze was used as the cup material. Tests were not made with phosphor bronze as a pintle material.

TABLE 2.—*Results of accelerated-service tests of pintle bearings—series* A

Different combinations of materials; pressure 2,000 lb/in.^{2}; cups ungrooved; pintle bearings not lubricated

Test	Pintle material	Cup material	Cycles	Description of bearing after test
1	Nickel steel	Phosphor bronze	225,300	Pintle and cup slightly scored. Very little wear.
2	do	Aluminum bronze	1,100	Pintle and cup scored badly.
3	Stainless steel A	Stainless steel B	400	Do.
4	Chromium steel	Chromium steel	200	Do.
5	do	Nickel-chromium steel	100	Do.
6	Nickel steel	Malleable cast iron	100-	Do.
7	K-monel	S-monel	100-	Pintle and cup scored slightly.
8	M-monel	do	100-	Do.
9	S-monel	H-monel	100-	Pintle and cup scored badly.
10	do	S-monel	100-	Do.
11	Stainless steel A	H-monel	100-	Do.
12	do	S-monel	118	Do.
13	H-monel	Phosphor bronze	290,400	No failure.
14	K-monel	do	273,000	Pintle and cup scored slightly.
15	M-monel	do	400,800	No failure.
16	S-monel	do	288,000	Do.

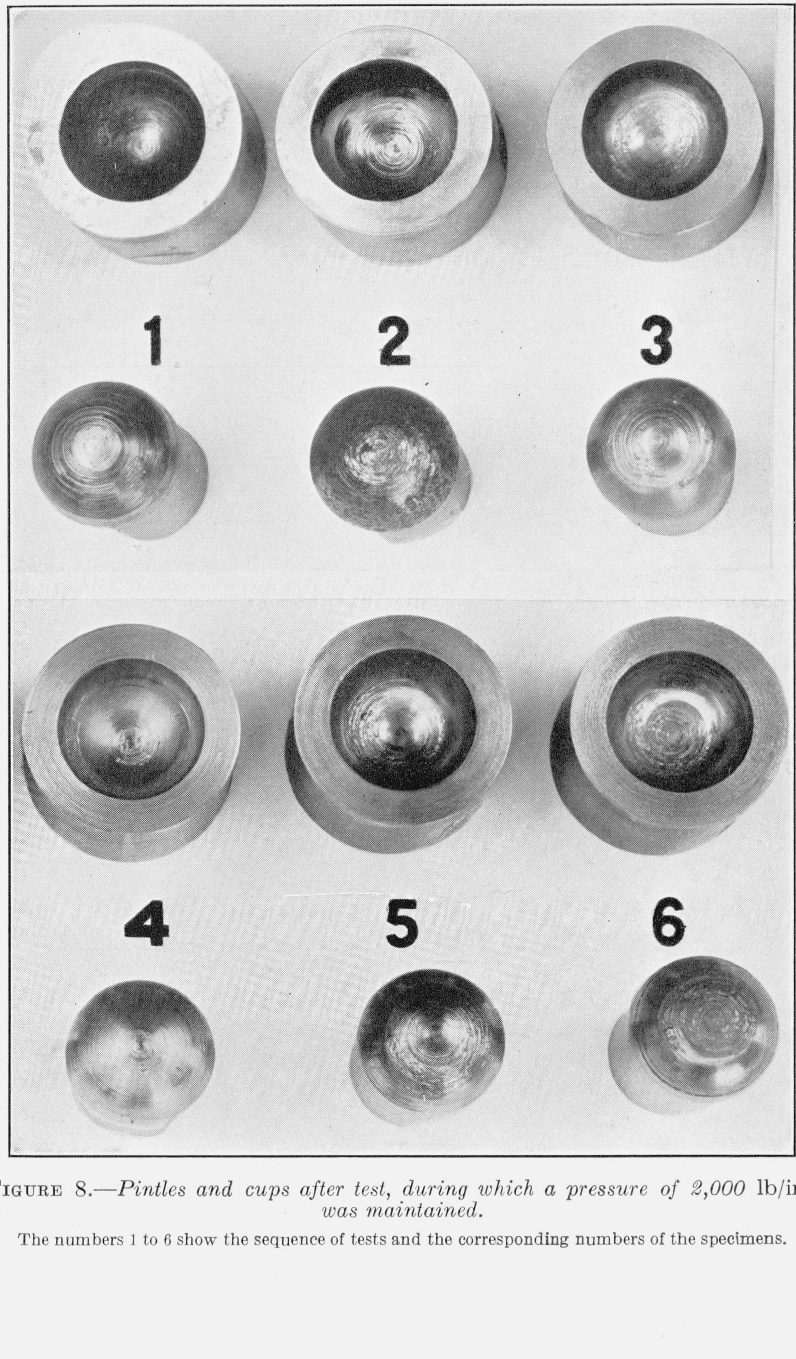

FIGURE 8.—*Pintles and cups after test, during which a pressure of 2,000* lb/in.^{2} *was maintained.*

The numbers 1 to 6 show the sequence of tests and the corresponding numbers of the specimens.

Table 2 shows that when phosphor bronze was not used for the cup material, scoring occurred at a very small number of cycles for the steels, the cast iron, and the monel metal. The aluminum-bronze cup was worn excessively.

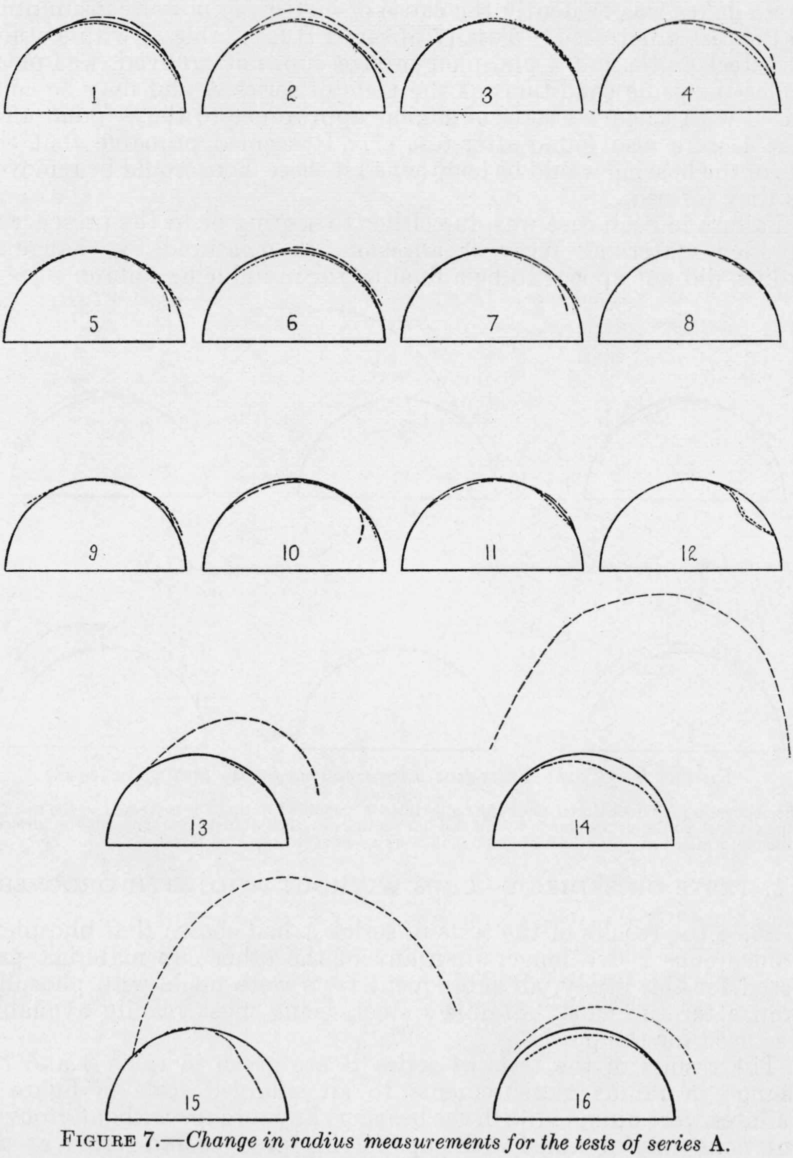

FIGURE 7.—*Change in radius measurements for the tests of series* A.

The change in radius measured along the radial lines is magnified 25 times as compared to the radius of the original pintle surface shown by the full-line semicircle. The dotted line represents the surface of the pintle after test. The dash line represents the surface of the cup after test.

The power required for the tests of the pintles of monel metal with phosphor-bronze cup (tests 13, 14, 15, and 16) was greater than for test 1, in which nickel steel was used as the pintle material. The pintle materials, H-monel, M-monel, and S-monel, with phosphor bronze cups not grooved and the bearing not lubricated, were the only ones tested under a pressure of 2,000 lb/in.^{2} which withstood as many as 288,000 cycles.

At the completion of test 1, black metallic flakes were found between the phosphor bronze and the nickel steel. The presence of these flakes was evidently the cause of increasing power consumption as the test progressed. Test 17 of series B (see table 3) with a stainless-steel pintle and a phosphor-bronze cup, not grooved, was made under the same conditions as the tests of series A and may be compared with them. Flakes of similar appearance to those found after test 1 were also found after test 17. It seemed probable that the life of the bearing would be lengthened if these flakes could be removed as they formed.

Failure in each case was due either to scoring or to the presence of abraded material. Wear or abrasion, as measured by change in radius, did not appear to be a final factor in inducing failure.

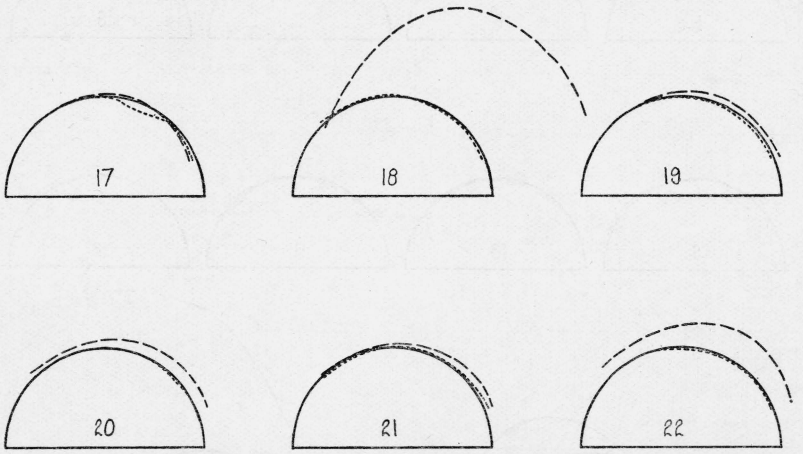

FIGURE 9.—*Change in radius measurements for the tests of series B.*

The change in radius measured along the radial lines is magnified 25 times as compared to the radius of the original pintle surface shown by the full-line semicircle. The dotted line represents the surface of the pintle after test. The dash line represents the surface of the cup after test.

3. TESTS OF SERIES B—CUPS WITHOUT AND WITH GROOVES

Since the results of the tests of series A had shown that phosphor-bronze cups lasted longer than any of the other cup materials proposed for this study, all subsequent tests were made with phosphor bronze for the cups. Stainless steel, being most readily available, was used for the pintles.

The results of the tests of series B are given in table 3 and the change in radius measurements to an enlarged scale in figure 9. Failures were obtained with the bearings having cups without grooves, but none was obtained with cups having grooves and tested at the 2,000 lb/in.^{2} pressure. The number of cycles, upward of 400,000, to which each of the three combinations having grooved cups was subjected, indicates that the water circulation, white-lead lubrication, or grease lubrication would give satisfactory service at this pressure, provided valid conclusions may be drawn from the results of these short-time tests. The results of test 19 show that cups without grooves and with white lead as a lubricant lasted for more than 288,000 cycles.

TABLE 3.—*Results of accelerated service tests of pintle bearings, with ungrooved and with grooved cups and lubrication—series* B

[Pressure 2,000 lb/in.^{2}; pintles made of stainless steel A; cups made of phosphor bronze]

Test	Lubrication	Cups	Cycles	Description of bearing after test
17	None	Ungrooved	103, 000	Pintle and cup slightly scored. Black flakes present.
18	Water circulation	Grooved	405, 300	No failure. The pintle was smooth. The cup was worn so that the groove in the area of direct thrust was nearly worn out.
19	White lead	Ungrooved	318, 000	Pintle and cup slightly scored. Black flakes had closed the lubrication hole in the cup.
20	do	Grooved	1, 000, 700	No failure. Pintle and cup were smooth. The groove in the thrust area was bridged over by bronze and the white lead could not be forced through the grooves by the grease cup.
21	[a] grease	Ungrooved	156, 000	The pintle was smooth. The cup was slightly scored. Black flakes were present.
22	[a] grease	Grooved	844, 700	Pintle and cup were smooth. The grease cup was filled three times during the test. Grease could be forced through the grooves at any time.

[a] With lead-soap base and asphalt content.

4. TESTS OF SERIES C.—GROOVED CUPS AND PRESSURE GREATER THAN 2,000 LB/IN.^{2}

The results of the tests of series C are given in table 4, and the change in radius measurements to an enlarged scale in figure 10. Failure did not occur for these tests at 288,000 cycles, but the tests were stopped as indicated in the table.

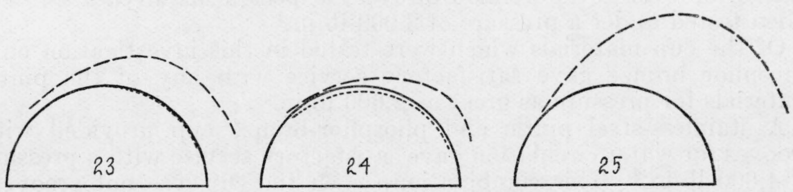

FIGURE 10.—*Change in radius measurements for the tests of series* C.

The change in radius measured along the radial lines is magnified 25 times as compared to the radius of the original pintle surface shown by the full-line semicircle. The dotted line represents the surface of the pintle after test. The dash line represents the surface of the cup after test.

There was practically no wear on any of the pintles. The cup lubricated with white lead showed, roughly, one-quarter of the wear that occurred on the cup lubricated with the grease. The cup with water circulation and under 4,000 lb/in.^{2} pressure showed relatively little wear, about twice as much as the cup lubricated with white lead and tested with the 6,000 lb/in.^{2} pressure.

TABLE 4.—*Results of accelerated service tests of pintle bearings, with grooved cups, lubrication, and large bearing pressures—series* C

[Pintles made of stainless steel; cups made of phosphor bronze]

Test	Lubrication	Pressure	Cycles	Description of bearing after test
		lb/in.^{2}		
23	Water circulation	4,000	301,400	No failure. Pintle and cup were slightly scored. The grooves in the cups were full of bronze flakes.
24	White lead	6,000	290,200	No failure. Pintle and cup were not scored. The groove in the thrust area of the cup was bridged over by bronze and the white lead could not be forced through the grooves by the grease cup.
25	[a] Grease	6,000	336,900	No failure. Pintle and cup were not scored. The groove in the thrust area of the cup was bridged over by bronze, but the grease could be forced through the grooves at any time during the test.

[a] With lead-soap base and asphalt content.

Tests were attempted with the monel alloys as pintles and pressures greater than 2,000 lb/in.^{2} The motor driving the pintle support did not, however, have sufficient power to drive the pintle support with these higher pressures.

The results of tests 13, 14, 15, and 16 (table 2) with monel-metal pintles were more satisfactory than for test 1, nickel-steel pintle (table 2) or for test 17, stainless-steel pintle (table 3) at a pressure of 2,000 lb/in.^{2}

V. SUMMARY AND CONCLUSIONS

Pintles of H-monel, M-monel, and S-monel, used with phosphor-bronze cups not grooved and with the pintle bearing not lubricated were the only pintle materials investigated which withstood as many as 288,000 cycles (the number of cycles expected in 20 years' service) when tested under a pressure of 2,000 lb/in.^{2}

Of the cup materials which were tested in this investigation only phosphor bronze gave satisfactory service with any of the pintle materials for pressure as great as 2,000 lb/in.^{2}

A stainless-steel pintle and phosphor-bronze cup provided with grooves for water circulation gave satisfactory service with a pressure of 4,000 lb/in.^{2} This combination, when the cup was not grooved, did not withstand 288,000 cycles at the lower pressure of 2,000 lb/in.^{2}

Satisfactory service with pressures as high as 6,000 lb/in.^{2} was obtained by using stainless-steel pintles and phosphor-bronze grooved cups lubricated with either white lead or a grease having a lead-soap base and asphalt content.

WASHINGTON, September 24, 1935.