Approved for public release by the
Director of the National Institute of
Standards and Technology (NIST)
on October 9, 2015.

NATIONAL BUREAU OF STANDARDS REPORT

7344

WATER FAUCET WASHERS

by

R. D. Stiehler, G. G. Richey,
E. A. Koerner and R. W. Young

to

Navy Bureau of Yards and Docks
Army Engineers
Air Force

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. Research projects are also performed for other government agencies when the work relates to and supplements the basic program of the Bureau or when the Bureau's unique competence is required. The scope of activities is suggested by the listing of divisions and sections on the inside of the back cover.

Publications

The results of the Bureau's research are published either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three periodicals available from the Government Printing Office: The Journal of Research, published in four separate sections, presents complete scientific and technical papers; the Technical News Bulletin presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: Monographs, Applied Mathematics Series, Handbooks, Miscellaneous Publications, and Technical Notes.

A complete listing of the Bureau's publications can be found in National Bureau of Standards Circular 460, Publications of the National Bureau of Standards, 1901 to June 1947 ($1.25), and the Supplement to National Bureau of Standards Circular 460, July 1947 to June 1957 ($1.50), and Miscellaneous Publication 240, July 1957 to June 1960 (Includes Titles of Papers Published in Outside Journals 1950 to 1959) ($2.25); available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
0705-20-07504	September 29, 1961	7344

WATER FAUCET WASHERS

Final Report

January 1, 1960 to June 30, 1961

by

R. D. Stiehler, G. G. Richey,
E. A. Koerner and R. W. Young

to

Navy Bureau of Yards and Docks
Army Engineers
Air Force

IMPORTANT NOTICE

NATIONAL BUREAU OF STANDARDS REPORTS are usually preliminary or progress accounting documents intended for use within the Government. Before material in the reports is formally published it is subjected to additional evaluation and review. For this reason, the publication, reprinting, reproduction, or open-literature listing of this Report, either in whole or in part, is not authorized unless permission is obtained in writing from the Office of the Director, National Bureau of Standards, Washington 25, D. C. Such permission is not needed, however, by the Government agency for which the Report has been specifically prepared if that agency wishes to reproduce additional copies for its own use.

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

WATER FAUCET WASHERS

by

R. D. Stiehler, G. G. Richey,
E. A. Koerner and R. W. Young

Summary

A study of the performance of faucet washers was undertaken by the National Bureau of Standards in 1959. For this purpose, a simulated service tester was designed and constructed. This tester applied a constant closing torque on the washers and permitted 12 washers to be tested simultaneously. Laboratory measurements of weight changes in hot air and water, of stiffness before and after conditioning, and of compression set were also made on the washers and the results of these tests were compared with service performance.

No correlation was noted between the laboratory measurements and service performance. It was concluded that in the light of our present knowledge a simulated service test is required to evaluate faucet washers. Further studies would have to be made in order to determine which characteristics of washers govern performance.

The results of the simulated service tests showed nylon washers to be outstanding. Field trials of these washers should be made to determine overall performance in use. The results also showed that rubber washers satisfactory for both hot and cold water service are available. However, there was a marked difference in the performance of the rubber washers tested so that a laboratory service test is required to ascertain those having the desired quality.

Introduction

When the National Bureau of Standards agreed to undertake this project in 1959, water faucet washers were being procured under Military Specification Mil-W-19016. This specification required the washers to be made of polychloroprene synthetic rubber (Neoprene) and had requirements for tensile strength, elongation, hardness and specific gravity. This specification had two weaknesses: (1) it was not possible to measure tensile strength and elongation on the washers themselves, and (2) the performance of washers supplied under this specification varied greatly. The wastage of water and the labor for replacement that result from faulty or short-lived washers warranted the purchase of the highest quality washers. Therefore, there was a great incentive to improve the specification.

This project was established in 1959 to obtain performance data on faucet washers and compare these data with their physical characteristics. It was initially planned to use a simulated service tester supplied by the Crest Manufacturing Co. This tester was received in January 1960 and was found to be unsuitable for this project. A survey was made of testers used by various organizations. None of the testers reviewed applied a constant closing torque on the washer throughout the test. Therefore, it was decided in consultation with the Sponsors of the project to design and construct a new tester. Work on the tester was started in the last quarter of Fiscal Year 1960.

Design of Tester

The tester as initially designed and constructed is shown in figure 1. Two things in this design cause difficulties: (1) the beaded chain fatigues rapidly and (2) the large clearance in the screw threads and guide permits misalignment of the valve stem by the closing torque. In the final design, braided venetian-blind cotton cord replaces the beaded chain and an outboard bearing prevents misalignment of the stem by the closing torque. Figure 2 is a schematic diagram of the final design showing two of the twelve positions.

The design of the tester included twelve valves, permitting twelve washers 17/32 inch in diameter to be tested simultaneously. American-Standard valve R-1432 was used since it was designed with replaceable stem, seat and screw threads and since the inlet and outlet water connections of this valve were separated by about five inches from the handle. These features facilitated the design and operation of the tester. The double screw thread of this valve had a lead of 1/4 inch; that is a 360-degree revolution of the stem raised or lowered the washer 0.25 inch. The stem was turned through an angle of about 90 degrees during each opening and closing. The stems of the valves were actuated by a 1/2 h.p., 120 v, 1750 rev/min AC motor operating through a 40 to 1 reduction gear and connecting links. Thus, there were about 44 closures per minute.

The inlets to the valves were connected to common supply pipes of hot and cold water. The hot water was maintained at about 85° C (185° F). The cold water was essentially at the temperature of the water in the city mains. The outlets of the valves were connected to pieces of tubing that emptied into a common 2-inch drain pipe.

As shown in figures 1 and 2, the closing torque was applied by a dead weight acting on a pulley about 6 inches in diameter. This design caused the torque to remain constant from the beginning to the end of the test. Initially, beaded chain was used to connect the dead weights and the pulleys. This chain fatigued rapidly. Therefore, the chain was replaced with textile cords ordinarily used for venetian blinds. New cords were used for every test.

Materials

A total of 28 different washer compositions were received from the following suppliers:

American-Standard Plumbing and Heating Division
Crest Manufacturing Company, Inc.
Garlock Packing Company
Good Manufacturing Co., Inc.
Kirkhill, Inc.
Radiator Specialty Company
Wolverine Brass Works
Woodward-Wanger Co.

The following number and types of washers were included: 3 fiber, 3 sandwich, 11 flat rubber, 7 beveled rubber, and 3 plastic materials. The rubber washers were analyzed for type of rubber, and the International Rubber Hardness of all washers was measured with a micro tester. The composition and hardness of the washers are given in Table 1. The hardness of the washers in International Rubber Hardness Degrees (IRHD) ranged as follows:

Rubber washers	90 to 98
Fiber, sandwich and Teflon washers	99.5 to 99.9
Delrin and nylon washers	over 99.9

Procedure

In the first test, a study was made of the effect of torque on performance. Three torques were employed, namely, 6.8, 13.6, and 20.4 lb-in. The twelve positions on the tester were divided into three groups of four positions, each group having one of the three torques. Four types of washer were used, one of each type was tested at torques of 6.8 and 13.6 lb-in and four of each type were tested at a torque of 20.4 lb-in. At this highest torque, the washers were allocated to the four positions in accordance with a latin-square statistical design.

In subsequent tests, a torque of 20 lb-in was used on all positions. Generally, 12 types of washers were included in a test and 4 runs were made so that a minimum of 4 washers of each type was included in the test. The washers were allocated among the 12 positions in accordance with a statistical design.

After installing the washers in the tester, the angular position of a fixed point on each stem was measured with a protractor to the nearest degree. Measurements were made with the stem turned to the closed position under the full closing torque. The tester was started. The water pressure was adjusted to about 10 lb/in^2 when 6 valves were opened and about 30 lb/in^2 when all valves were closed. After a prescribed number of closures (generally every 1000 for the first 5000 closures), the angular position of the stem was measured in the same manner as initially. Examination was made for leaks during these measurements. If the change in angular position for a washer exceeded 150 degrees, the opening mechanism for this washer was made inoperative and the test of the other washers continued until a prescribed number of closures was completed.

The washers were examined upon removal from the tester. The washers were also weighed before and after test. However, the change in weight was not a useful index for judging performance because of the absorption of water and extraction of water solubles.

Effect of Closing Torque

The effect of the magnitude of the closing torque was studied using a fiber washer, a sandwich washer, and two flat rubber washers. As mentioned previously, the following closing torques were used: 6.8, 13.6, and 20.4 lb-in. At the high closing torque, some of the washers were worn through completely in less than 60,000 closures. Therefore, the washers being tested at 20.4 lb-in torque were replaced at the end of 60,000 closures and four washers of each type were tested at this torque while only one washer of each type was tested at each of the lower torques. The test was discontinued after 400,000 closures, when the following change in angular position of the stem was noted:

Washer	Torque		
	6.8 lb-in	13.6 lb-in	20.4 lb-in[a/]
F-3A	53° *	64° *	112°
S-3A	56 *	78 *	112
CR-6A	54	81 *	118
CR-2A	26 *	92	155 +

a/ At 60,000 closures
* Leaks observed during test

The small amount of wear, most of which appeared to be set during the early part of the test, and the leaking that occurred indicated that a closing torque of greater than 13.6 lb-in was required. The results at the high closing torque are not reliable since the test should have been stopped before 60,000 closures and insufficient measurements were made during the early portion of the test. No leaking was observed at the high torque. Since a rapid test was desired, no attempt was made to explore the effect of closing torque between 13.6 and 20.4 lb-in. A torque of 20 lb-in was chosen for subsequent tests and the number of closures was limited to 15,000.

Comparison of Commercial Washers

Two tests were made in which 23 commercial washers were compared. These washers included the following types: 3 fiber, 3 sandwich, 4 nitrile rubber (3 flat and 1 beveled), 11 polychloroprene rubber (4 flat, 5 beveled, 1 concave, and 1 special), and 2 rubber washers (1 flat and 1 beveled) made from a blend of natural rubber and SBR.

The results of test are given in Table 2 which gives the change in angular position of the stem after 1000, 5000, and 15000 closures. A comparison of washers in this table leads to the following conclusions:

1. There was a large variation in the performance of different commercial washers.

2. Some rubber washers performed as well as the fiber and sandwich washers in these tests with very hot water (85° C, 185° F).

3. The performance of rubber washers was not correlated with the type of rubber.

4. The beveled washers having the same composition as flat rubber washers tended to perform better.

5. The sandwich washers had a relatively small change in angular position of the stem. However, this change was sufficient in many instances to cut through the outside layer and leave an annular ring. This ring separated and clogged the exit port in several instances.

Effect of Cold and Hot Water

Twelve of the washers that performed best in tests 2 and 3 were used in a test to study the effect of cold and hot water. This test was made during December 1960 and January 1961 when the temperature of the cold water was 4° to 5° C (39° to 41° F). In a preliminary test, it was found that the main change in angular position of the stem occurred during the early portion of the test. Between 15,000 and 100,000 closures in cold water the angular position changed only 12 degrees on the average. Therefore, a comparison was made of 15,000 closures in cold water, followed by 15,000 closures in hot water.

The results are given in Table 3. They indicate that the rubber washers perform better in cold water and the fiber and sandwich washers perform better in hot water. The total angular change for 30,000 closures (15,000 at 5° C and 15,000 at 85° C) tends to be less than for 15,000 closures at 85° C listed in Table 2. This effect may be due to water absorption at 5° C that reduces the severity of test at 85° C. This behavior warrants further study. However, the relative performance of the washers is comparable in Tables 2 and 3, within the precision of test.

Performance of Plastic Washers

Three types of plastic washers were obtained; namely, Delrin, Nylon, and Teflon. These washers were compared with the three flat rubber washers: NBR-1A, NBR-2A, and CR-1A. The test consisted of 15,000 closures at 10° to 11° C (50° to 52° F) and 15,000 closures at 85° C. Six washers of each type were tested instead of four as in previous tests.

The results are given in Table 4. The angular changes for the plastic washers are much less than those for the rubber washers both at 10° and 85° C. Particularly striking is the low angular change for the Nylon washer, N-1A. The appearance of this washer at the end of the test was excellent.

Laboratory Measurements

Seven washers of each type were conditioned in water at 95° C for 14 days. Seven other washers were similarly aged in air. The change in weight and the penetration of a ball about 0.4 mm in diameter under a load of about 115 g were measured to determine the effect of these aging conditions.

Two washers of each type were conditioned in water at 95° C for 6 days. These washers were compressed 20% and placed in water at 95° C for 72 hours. After recovery for 30 minutes in water at 23° C, the set was measured.

The results of these laboratory tests are given in Table 5. The fiber and sandwich washers absorb a large amount of water within 1 day. Water soluble material is then leached from these washers. The rubber washers can be divided into 2 groups with respect to water absorption. Polychloroprene washers absorb about 30% of their weight and the others about 5%. Of the plastic washers, Nylon washers absorb about 7% of their weight, Delrin washers about 1%, and Teflon washers absorb a negligible amount of water.

The weight loss in air after 14 days at 95° C was less than 1% for NBR-1A and the 3 plastic washers. The polychloroprene washers lost almost 3% in weight. Except for F-2A and NBR-2A, the other washers lost from 4 to 10%. Washer F-2A gained in weight after losing about 4% the first day. Presumably the increase resulted from oxidation.

Conditioning the washers in air at 95° C for 14 days caused an increase in stiffness (decreased penetration of ball) of all washers except F-2A and the 3 plastic washers. These results should be indicative of the stiffening that occurs during shelf-aging of washers.

Conditioning the washers in water at 95° C for 14 days caused a decrease in stiffness (increased penetration of ball) of all washers except NBR-3A, Delrin, and Teflon washers. NBR-3B, R-1A, R-1B, and Nylon washers softened only slightly.

The compression set of washers NBR-1A and NBR-2A did not exceed 15%; whereas, that of the other washers was high ranging from 28 to 78%.

Discussion

A comparison of the laboratory results in Table 5 and the simulated service results in Tables 2, 3, and 4 show very little correlation between them. Even if the comparison is restricted to the rubber washers, the laboratory and service results are not correlated in any simple manner.

It was originally planned to conduct service tests on some of the washers conditioned 14 days at 95° C in air and in water. Lack of time and funds prevented making these tests before the project was terminated on June 30, 1961. Such tests might have indicated some degree of correlation. In any case, further work would be necessary to determine the characteristics of washers responsible for their performance in service. With our present knowledge, a service test would be the only satisfactory means for evaluating faucet washers procured by the Government.

A change of 180 degrees in the angular position of the stem in the service test described in this report corresponds to a linear motion of 0.125 inch. Therefore, the angular degrees in Tables 2, 3, and 4 can be converted to changes in thickness of the washer. On this basis, the following procedure and requirement are suggested for specification purposes:

The washer shall not decrease in thickness by more than 0.050 inch where it contacts the faucet seat when tested in the following manner:

Each of four washers selected at random from the lot shall be subjected to 15,000 closures in a simulated service test using standard faucets having smooth replaceable seats. The closures shall be made at a rate of 45±5 per minute. The temperature of the water flowing through the faucet at each opening shall be 85±2° C. The pressure of the water shall be at least 8 psi when the faucet is open and at least 25 psi when the faucet is closed. The closing torque on the faucet stem shall be between 20 and 21 pound-inches. The decrease in thickness of the washer in contact with the seat shall be determined from the angular position of the faucet stem at the start and end of the test and the lead of the screw on the stem; the full closing torque shall be applied to the stem during all measurements. The average of the values obtained for the four washers shall be used for determining compliance with the requirement.

The excellent performance of the Nylon washer justifies field trials of this washer. It is important to note that this washer is harder than the fiber washers. It is expected that a tight closure with this washer can be obtained only with seats in good condition. The psychological factor may also be important in using this washer. For these reasons, it is recommended that an experimental field trial precede any extensive use of this washer.

Rubber washers can be obtained that perform as satisfactorily in hot water as fiber washers. Since washers in actual use are subjected to milder conditions than in the simulated service test, the performance of rubber washers may be expected to be relatively better. Thus, there appears to be no need of using different washers for hot and cold water faucets.

Conclusion

1. Further work is needed to determine the characteristics of washers that govern their performance in service.

2. A simulated service test is required to evaluate faucet washers in the light of our present knowledge.

3. The excellent performance of Nylon washers in a simulated service test warrants an experimental field trial of these washers.

4. Rubber washers satisfactory for hot and cold water service are available, eliminating the need for stocking two types of washers.

USCOMM-NBS-DC

Table 1

Composition and Hardness of Washers

Code*	Composition	Hardness- IRHD		
		Min.	Max.	Ave.
F-1A	Fiber	99.0	99.8	99.5
F-2A	"	99.6	99.9+	99.9
F-3A	"	99.0	99.7	99.5
S-1A	Sandwich	99.4	99.9+	99.7+
S-2A	"	99.2	99.9	99.7
S-3A	"	98.7	99.8	99.5
NBR-1A	Nitrile Rubber	93.3	94.8	94.5
NBR-2A	"	88.2	91.6	89.9
NBR-3A	"	94.1	97.3	95.8
NBR-3B	"	96.6	98.5	97.6
CR-1A	Polychloroprene	96.3	98.5	97.5
CR-1B	"	97.0	98.2	97.6
CR-2A	"	94.1	97.3	96.1
CR-2C	"	94.4	96.6	95.7
CR-3A	"	95.2	98.2	97.4
CR-3B	"	94.1	98.0	96.9
CR-4A	"	89.9	93.3	91.4
CR-4B	"	93.7	98.2	96.0
CR-4D	"	93.7	98.0	96.4
CR-5A	"	91.6	95.2	93.4
CR-5B	"	91.2	94.8	93.4
CR-6A	"	94.4	98.0	96.9
CR-6B	"	96.3	98.2	97.4
R-1A	Blend NR and SBR	95.2	97.6	97.0
R-1B	"	94.8	97.3	96.0
D-1A	Delrin	99.9	99.9+	99.9+
N-1A	Nylon	99.8	99.9+	99.9+
T-1A	Teflon	99.4	99.8	99.6

* Suffix letters signify the following:

A- flat washer
B- beveled washer
C- concave bevel
D- special flat washer in brass holder designed to permit closure without rotation

Table 2

Performance of Commercial Washers at 85° C

Washer	Test	Change in Angular Degrees of Stem After		
		1000 closures	5000 closures	15000 closures
F-1A	2	13	34	42
F-2A	2	22	27	36
F-2A	3	12	30	42
F-3A	3	17	28	38
S-1A	2	16	29	52
S-2A	2	19	32	45
S-3A	3	27	44	52
NBR-1A	2	14	31	59
NBR-2A	2	18	43	87
NBR-3A	2	54	99	136
NBR-3B	3	45	96	139
CR-1A	2	28	41	64
CR-1B	3	20	29	45
CR-2C	2	18	56	88
CR-3A	2	36	66	86
CR-3B	3	20	53	65
CR-4A	3	56	87	134
CR-4B	3	19	38	59
CR-4N	3	34	62-149*	72-160*
CR-5A	2	83	131	- **
CR-5B	3	37	69	82
CR-6B	3	23	46	60
R-1A	2	28	74	116
R-1B	3	43	124	158
Coefficient of Variation, %		23	20	15

* Each value is the average for two washers. All other values are averages for four washers.

** Three of the four washers wore through before 15,000 closures were made.

Table 3

Effect of Cold and Hot Water on Washer Performance

Washer	Change in Angular Degrees of Stem after				
	1,000- at 5°C	15,000- at 5°C	1,000- at 85°C	15,000- at 85°C	closures Total
F-1A	8	24	6	8	32
F-2A	10	28	5	15	43
F-3A	18	34	5	18	52
S-1A	12	24	10	19	43
S-2A	15	38	9	15	53
S-3A	21	38	7	21	59
NBR-1A	2	9	5	20	29
NBR-2A	2	15	11	48	63
CR-1A	4	9	12	43	52
CR-1B	6	19	15	31	50
CR-4B	5	13	8	42	55
CR-6B	5	17	10	27	44

Table 4

Performance of Plastic and Rubber Washers

Washer	Change in Angular Degrees of Stem After				
	1,000- at 10°C	15,000- at 10°C	1,000- at 85°C	15,000- at 85°C	closures Total
NBR-1A	3	11	8	27	38
NBR-2A	5	14	15	54	68
CR-1A	4	10	9	37	47
D-1A	1	8	6	15	23
N-1A	2	8	3	8	16
T-1A	3	9	7	20	29

Table 5

Results of Laboratory Tests

Washer	Wt. Gain in Water[1] 1 day %	Wt. Gain in Water[1] 14 days %	Wt. Loss in Air[1] 1 day %	Wt. Loss in Air[1] 14 days %	Penetration of Ball orig. µ	Penetration of Ball air[2] µ	Penetration of Ball water[2] µ	Comp. Set[3] %
F-1A	46	41	4.2	5.2	34	22	139	33
F-2A	61	57	4.0	2.2	17	17	136	35
F-3A	29	21	5.5	9.7	30	20	133	28
S-1A	57	45	3.6	4.1	27	20	156	38
S-2A	42	30	4.4	5.6	31	24	147	42
S-3A	45	31	4.5	5.5	32	21	145	37
NBR-1A	3	5	0.6	0.9	116	97	143	15
NBR-2A	3	4	0.6	1.5	182	131	226	11
NBR-3A	2	3	1.9	5.7	90	36	89	78
NBR-3B	3	4	2.2	6.2	80	34	93	54
CR-1A	8	33	1.1	2.4	77	54	224	33
CR-1B	8	28	1.2	2.6	76	54	242	59
CR-2A	7	28	1.2	2.7	106	62	239	52
CR-2C	7	29	1.0	2.8	116	69	286	47
Cr-3A	9	38	1.1	2.8	86	57	327	60
CR-3B	7	31	1.0	2.7	94	60	288	47
CR-4A	8	28	1.2	3.0	158	103	345	44
CR-4B	8	25	1.1	2.7	99	65	260	49
CR-4D	4	19	1.0	2.6	92	68	228	-
CR-5A	8	32	1.0	2.3	156	99	404	49
CR-5B	8	32	1.0	2.6	115	67	332	39
CR-6A	8	29	1.0	2.6	88	60	262	57
CR-6B	7	28	0.9	2.7	72	48	237	63
R-1A	2	6	2.6	4.0	106	69	124	49
R-1B	2	5	2.6	3.9	108	74	129	60
D-1A	-	0.9	-	0.3	10	12	12	53
N-1A	-	7	-	0.8	9	11	21	56
T-1A	-	0.04	-	0.01	39	42	38	72

1/ At 95° C
2/ Conditioned 14 days at 95° C
3/ 72 hrs. in water at 95° C

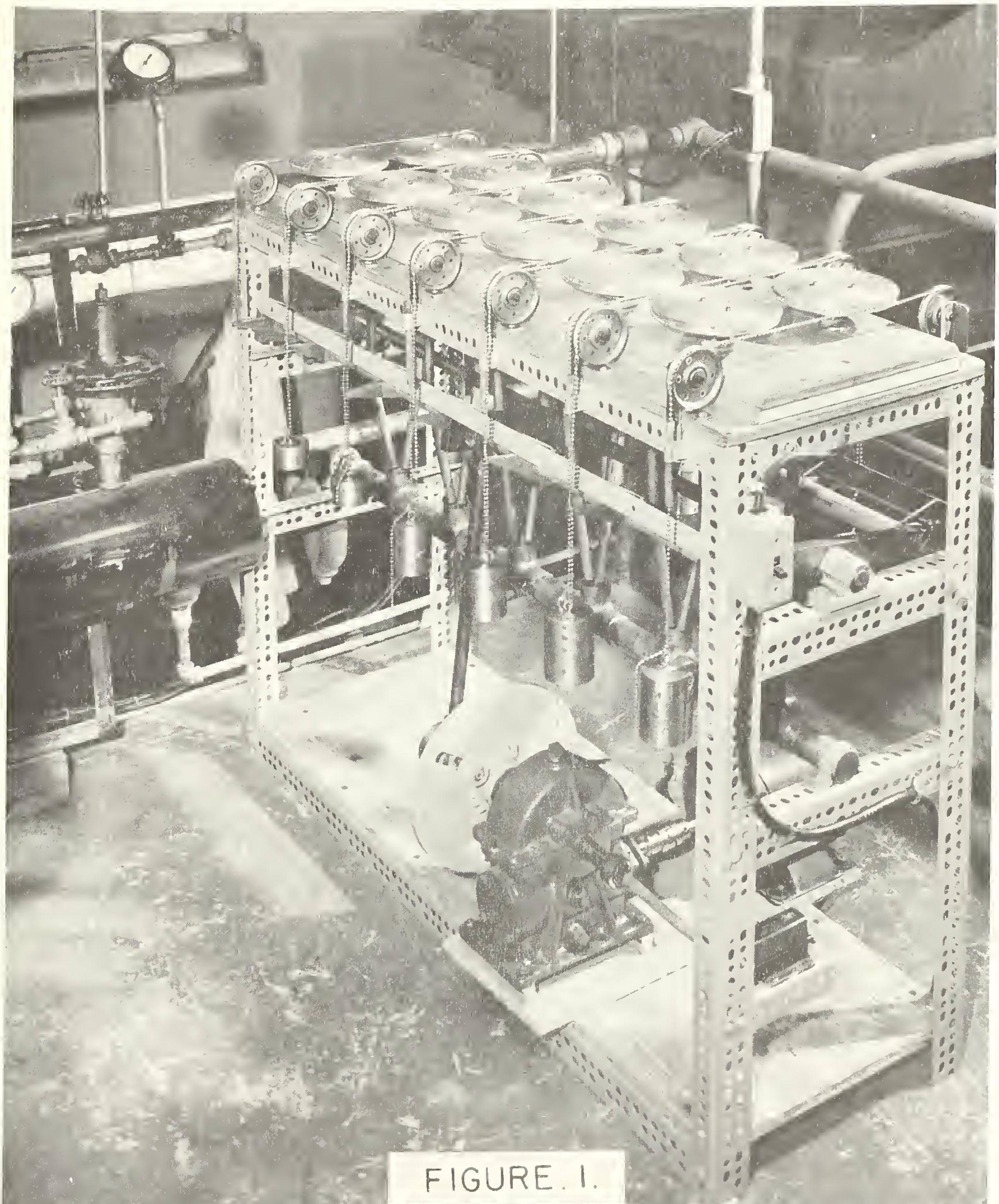

FIGURE. I.

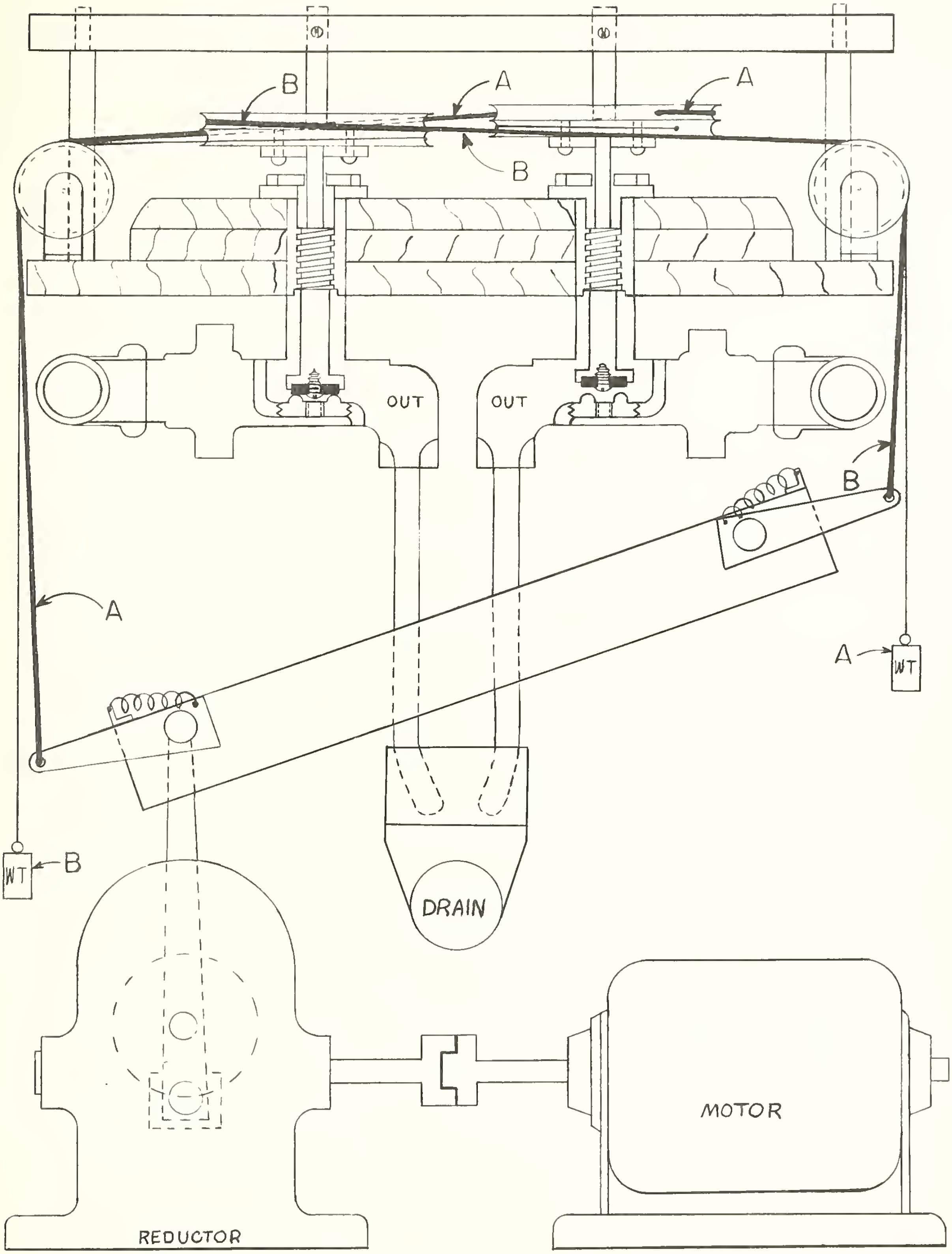

FIGURE. 2.

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics. Electrolysis and Metal Deposition.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Crystal Growth. Physical Properties. Constitution and Microstructure.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

Radio Systems. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

NBS