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THE DIAPHONE

Its History and Detailed Description

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The diaphone is an instrument, using compressed air for producing sound, and is used extensively by the Coast Guard Service for fog signal purposes. There are more United States fog signals using this instrument than any other type of air horn. The diaphone is essentially a cylindrical slide valve, reciprocated by a very efficient self-governing air motor. The slide valve alternately opens and closes ports through which air is discharged, in puffs, into a resonator to produce a very distinctive sound familiar to all mariners.

Before delving into the details of construction and explaining the action of the diaphone, it is deemed appropriate to give a few facts concerning the development of the instrument.

The original idea of the diaphone is credited to Hope-Jones, a designer of pipe organs, who intended to use it in connection with these instruments. Hope-Jones' diaphone required a pressure of ninety (90) pounds for an instrument which would be of sufficient size to be useful as a fog signal. In 1902, John P. Northey of Toronto, Ontario, Canada, purchased the diaphone from Hope-Jones and proceeded to develop it. In 1904, Mr. Northey separated the motor and speaking air supplies; using ninety (90) pounds pressure for the motor air, and thirty (30) pounds pressure for producing the sound. In this instrument, the motor air took about 10% of the total air consumption. During 1907, further improvement was accomplished when the design was altered to include cushion chambers at both ends of the piston stroke which permitted the reduction of motor air pressure to that of the speaking air; that is, thirty (30) pounds, or less if desired. This improvement brought the development up to the form in which we find it in the diaphone which has been sectored to illustrate this article. In 1922, a further refinement was made by constructing the piston and cylinder with a step. This improvement greatly facilitates the process of inserting the piston and prevents damage to it by automatically aligning the piston so that it can be properly placed in position in the cylinder. In 1930, the diaphone was further improved by Rodney V. Northey, son of J. P. Northey, who designed one capable of producing two tones; one tone similar to the tone of the standard diaphone, which is to be described, and the other tone of much lower frequency, which under some atmospheric conditions has greater carrying power in fog.

The Canadian Government officials were the first to recognize the possibilities of the diaphone for fog signal use. Their first order for sixteen (16) instruments was placed in 1904. In 1906, the Newfoundland Government followed their example and ordered their first instruments; and Trinity House (England) made its first purchase in 1907. The first diaphone used by the U.S. Lighthouse Service was placed in commission at Buffalo Breakwater North End Light Station in August, 1914.

On December 12, 1932, the U.S. Lighthouse Service acquired from J.P. Northey the patents, drawings, patterns and rights to manufacture diaphones for fog signal purposes in the United States. Since that time they have been manufactured under the supervision of the personnel of the former 10th Lighthouse District, and the Cleveland Coast Guard District. At present there are over two hundred diaphone instruments in use in the U.S. Coast Guard Service.

Now to return to the description. The instrument to be described is the Type "F" Standard Diaphone. Drawing No.264-S illustrates one of the latest types with stepped pistons, but the photographs used to explain action are of an older model equipped with flat back single diameter piston. The drawing shows the general arrangement of diaphones, its operating valves, resonator and fittings. The air supply to the magnet, motor and speaking valves is from a common source. The operating pressure is usually 35 to 40 pounds gauge. The magnet valve acts as a pilot valve and is controlled by an electrically operated code device or signal controller. When circuit is completed by this device, air is conveyed to the piston chamber at the bottom of the motor valve. Thus, pressure is exerted against piston, causing the piston to rise and force the valve to open and allow the pressure to flow to motor chamber of diaphone. At the same time, air is forced to piston chamber at bottom of speaking valve, which in turn causes piston to lift speaking valve and permit air to flow to speaking air chamber of diaphone. The reciprocating slitted piston permits the air to escape, in puffs, through ports in cylinder to the resonator and produce the distinctive sound by which diaphones are recognized. The grunt at the end of the blast is caused by the slowing up of the piston due to the cutting off of the air supply to the motor valve while air pressure is still maintained for a fraction of a second in the speaking air chamber. This is due to the slow dissipation of the air pressure in the control pipe between the motor and speaking valves and in the piston chamber of the speaking valve preventing the piston of this valve from dropping as rapidly as the piston of the motor valve. When magnet valve is closed ports in it are opened which void the pressure in the control pipe between it and the motor valve very rapidly and allows it to respond quickly to the impulses given by the electric code device.

The action above described will now be more fully explained by means of photographs taken of an old Type "F" diaphone which had sectors cut from it to expose the numerous details involved in the action of the instrument:

Figure 1 is a view looking at the back of the diaphone to show how it was cut; "A" is the casing; "B" the cover; "C" the cylinder; "D" the piston; "E" motor air supply connection; "F" flanged speaking

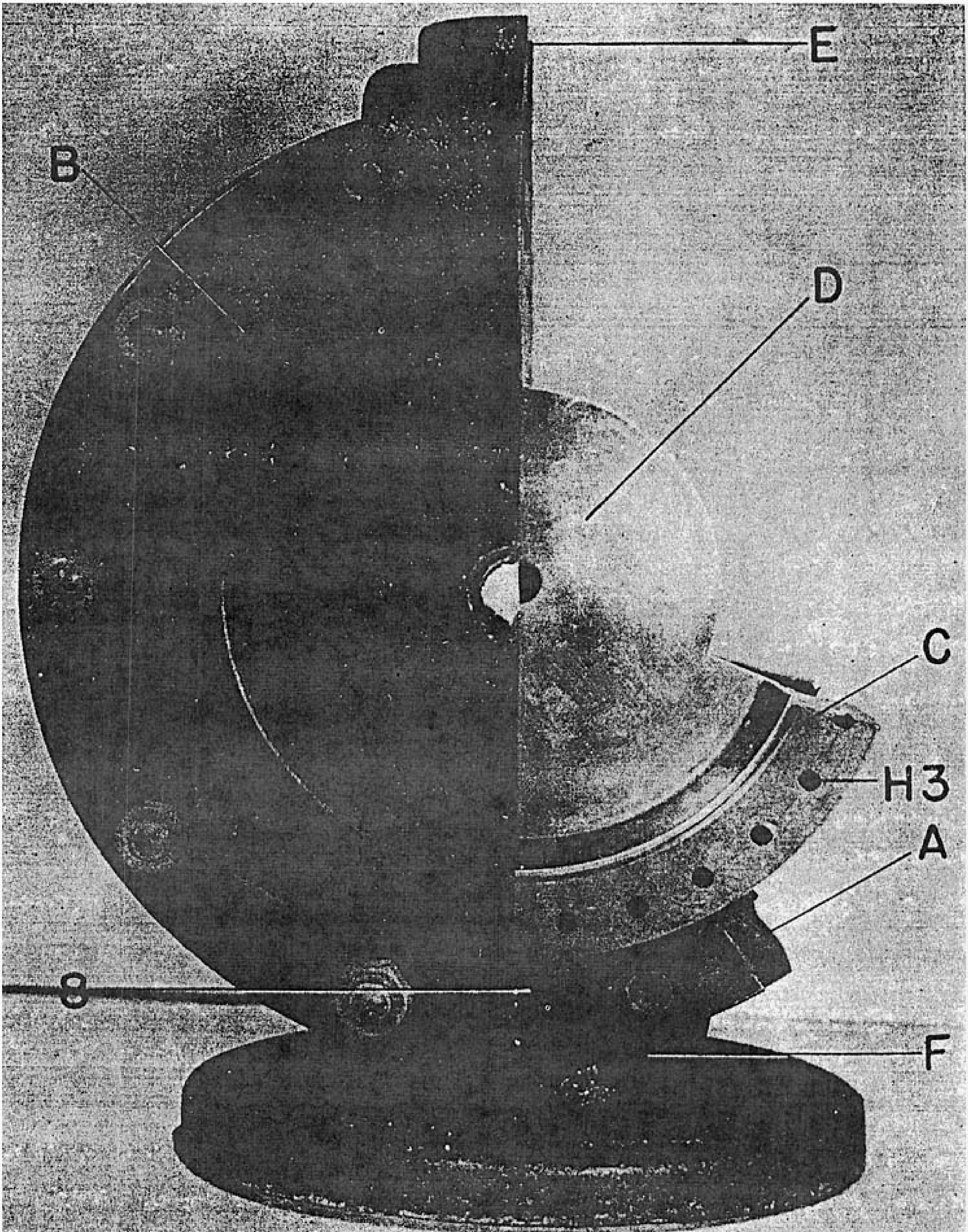

FIG. 1

air supply connection; (8) one of the ten slots through which the exhaust of motor air escapes to the atmosphere; (H3) one of a series of holes which serve as a communication between two of the circular slits in the motor end of the cylinder.

Figure 2 is a view of the section of the casing to show its division by ribs into two chambers; (M) the motor air chamber; (S) the speaking air chamber; (5), (6) and (7) are the ribs that are lapped to the cylinder to make air tight joints to confine the air to these chambers when cylinder is pressed into place; (E) is the threaded boss; and (F) the flanged connection referred to in Figure 1.

Figure 3 shows a complete cylinder in position in sectored casing. It shows the ribs (R) which support the slitted speaking section; the lands (9), (10) and (11) are the result of lapping cylinder to ribs to casing; the series of holes (H1) lead to circular slit #1 in bore of motor end of cylinder and the series of holes (H2) lead to circular (exhaust) slit #3 (notice the manner in which motor air chamber (M) and speaking air chamber(S) are produced by the tapered lapped joints between cylinder and casing); (8) is side view of motor exhaust slot or groove mentioned in Figure 1.

Figure 4 shows sectored cylinder in place in sectored casing. In this the cylinder is at a slightly different angle than shown in Figure 1. This position was chosen to show more clearly the interconnection between slits #2 and #4 (see lower portion of motor section of cylinder, which is the enlarged diameter of bore). When cover and gasket (G) are in place, the ends of these holes are closed and communication is made from slit #2 over piston head to slit #4 which will be illustrated in next view. Series of holes (H1) permit passage of air from motor chamber (M) through slit #1; series of holes (H2) connect slit #3 with chamber formed by casing and reduced outside diameter at rear of cylinder and with atmosphere through slots (8) shown in Figures 1, 2 and 3; (CS) are the circular slits which permit the escape of air pressure from speaking air chamber (S); (Q) is threaded hole for dowel which holds cylinder in position after it has been pressed into place.

Figure 5 shows sectored casing with cylinder, piston and cover in place and shows piston at the beginning of its stroke. If air pressure is admitted to motor air chamber, it will pass through series of holes (H1) through slit #1 around circular chamber (O) formed by face of cylinder and inner face of piston head through series of holes in piston (H4) and into circular groove in piston (L). The pressure exerted against inner head of piston causes piston to move backward until it reaches the position shown in Figure 6. The air pressure will then flow on through holes (H2) and groove (L), through slit #1, through holes (H3) to slit #4 into the chamber (U) formed by cover and back head of piston. The pressure per unit of area being equal on front head and rear head, the piston will be forced to travel in the reverse direction; that is, toward front of diaphone, because the area of back head is a great deal larger than the front end. It will continue to travel in this direction until the position shown in Figure 7 is reached.

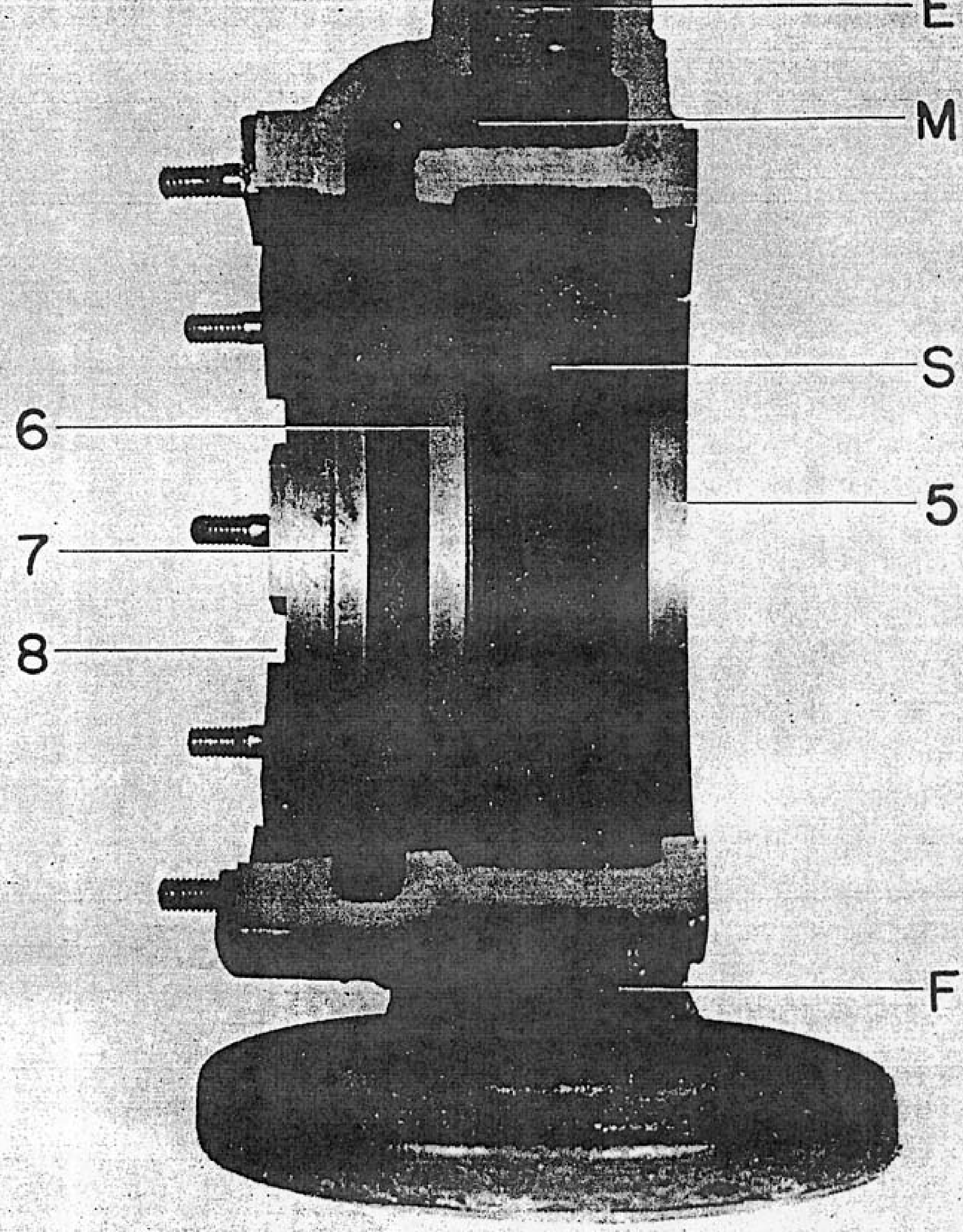

FIG. 2

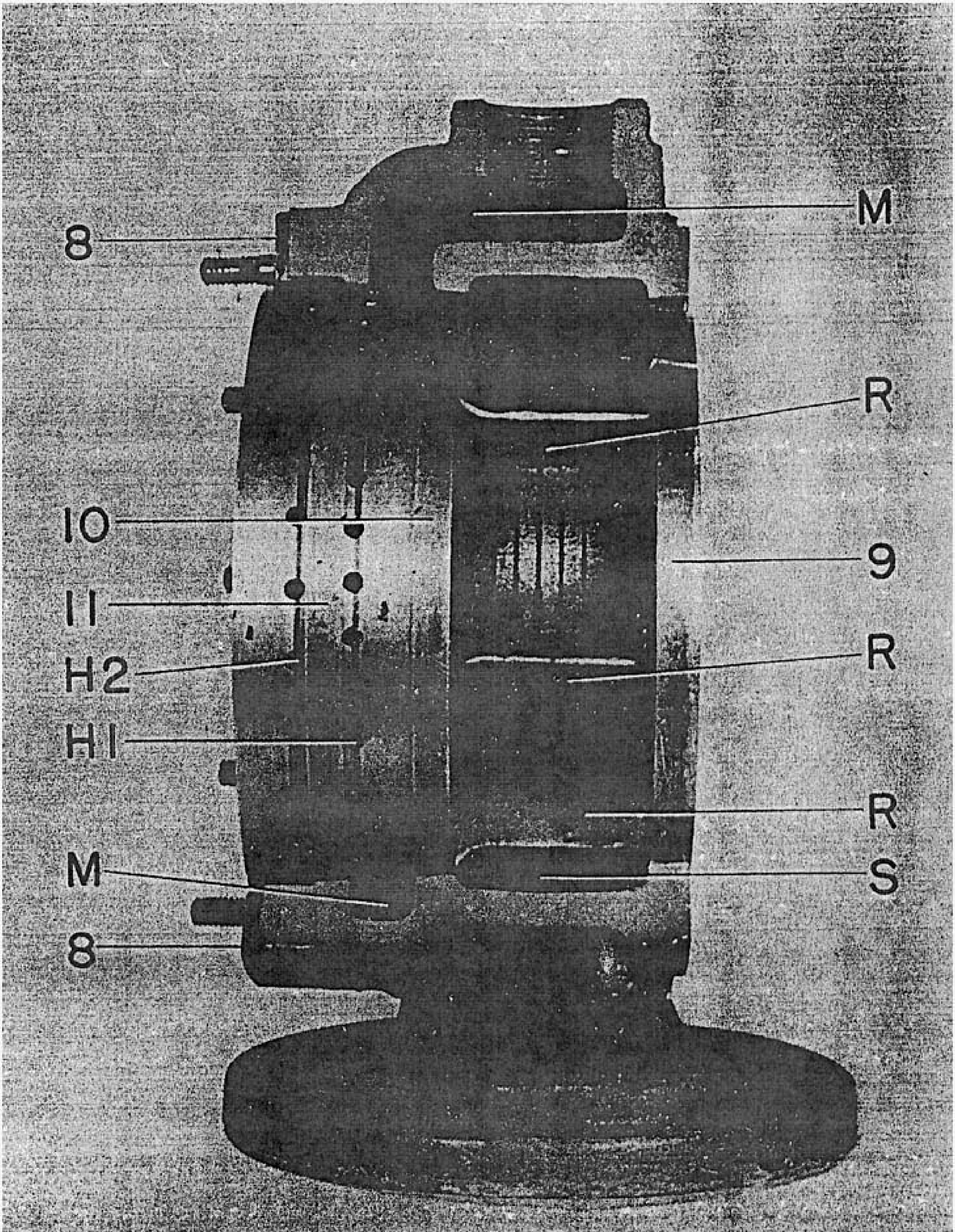

FIG. 3

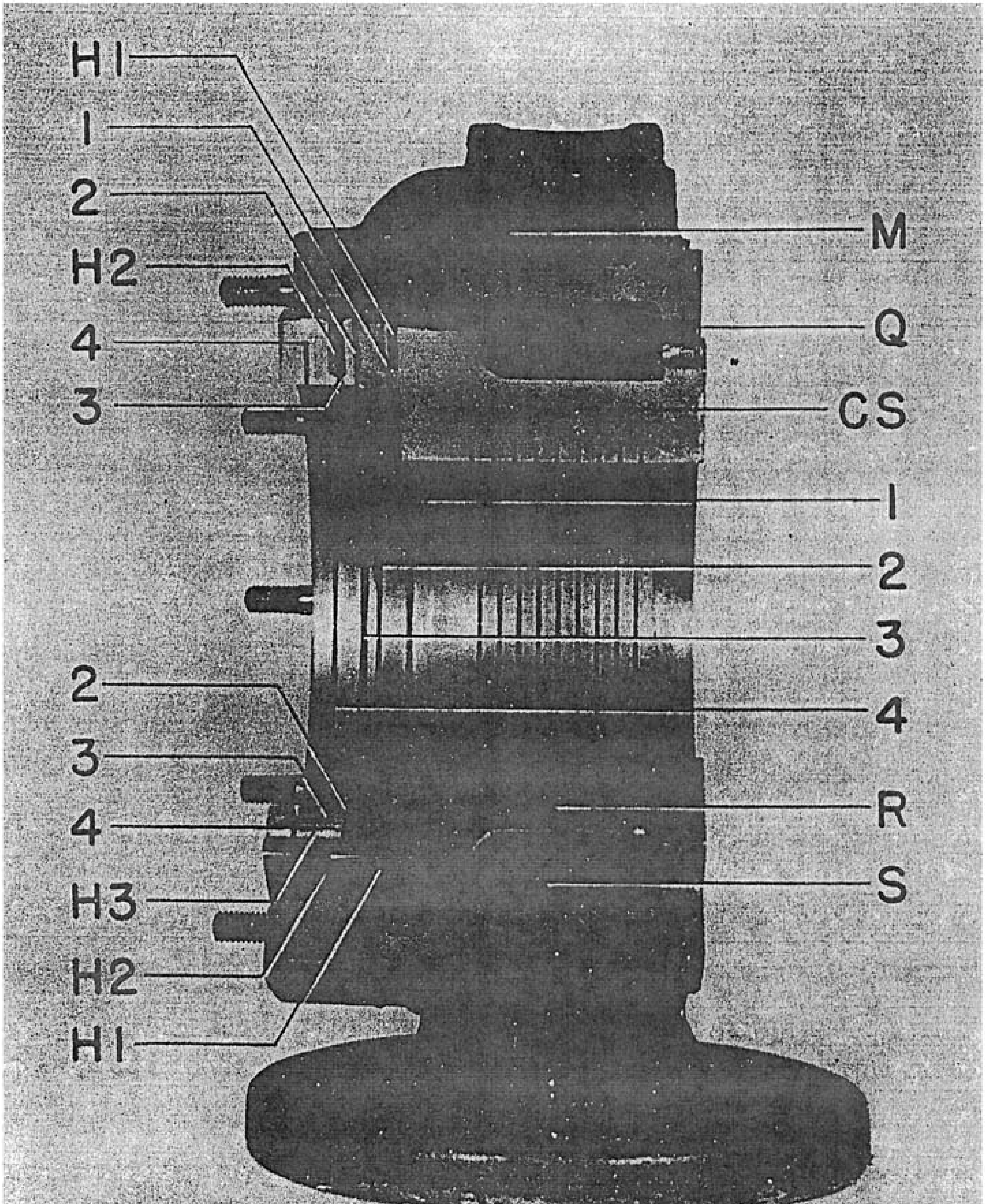

FIG. 4

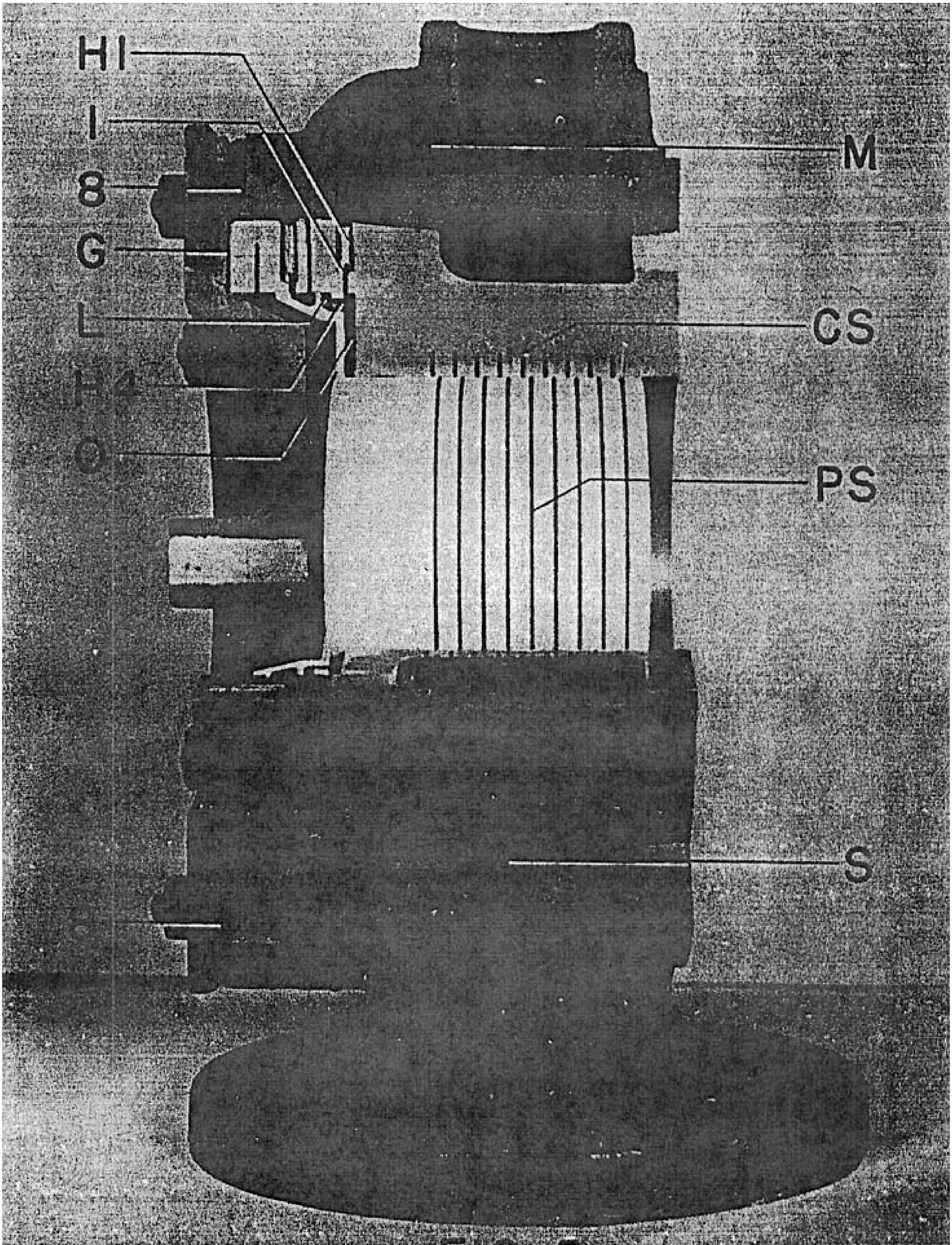

FIG. 5

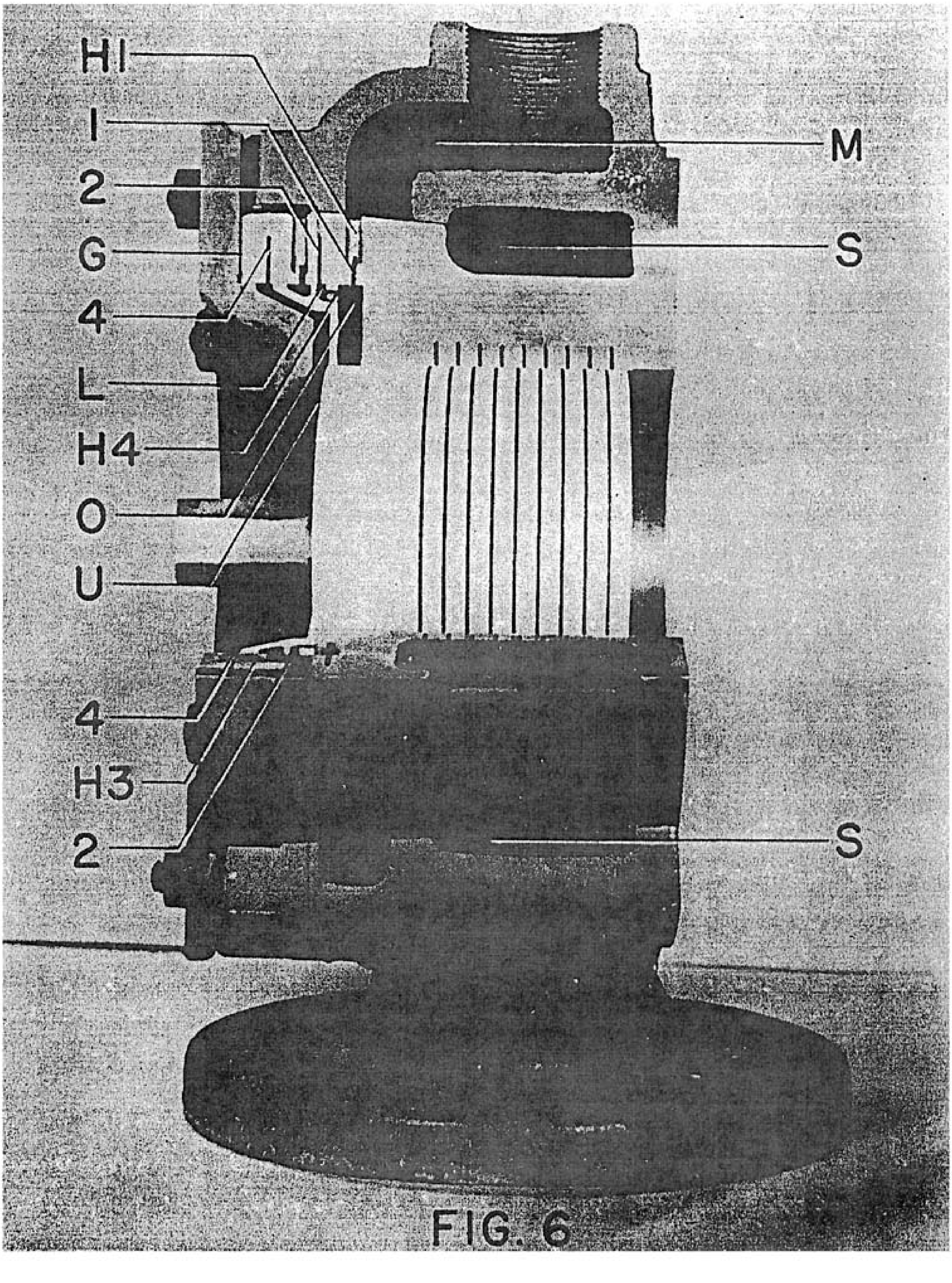

FIG. 6

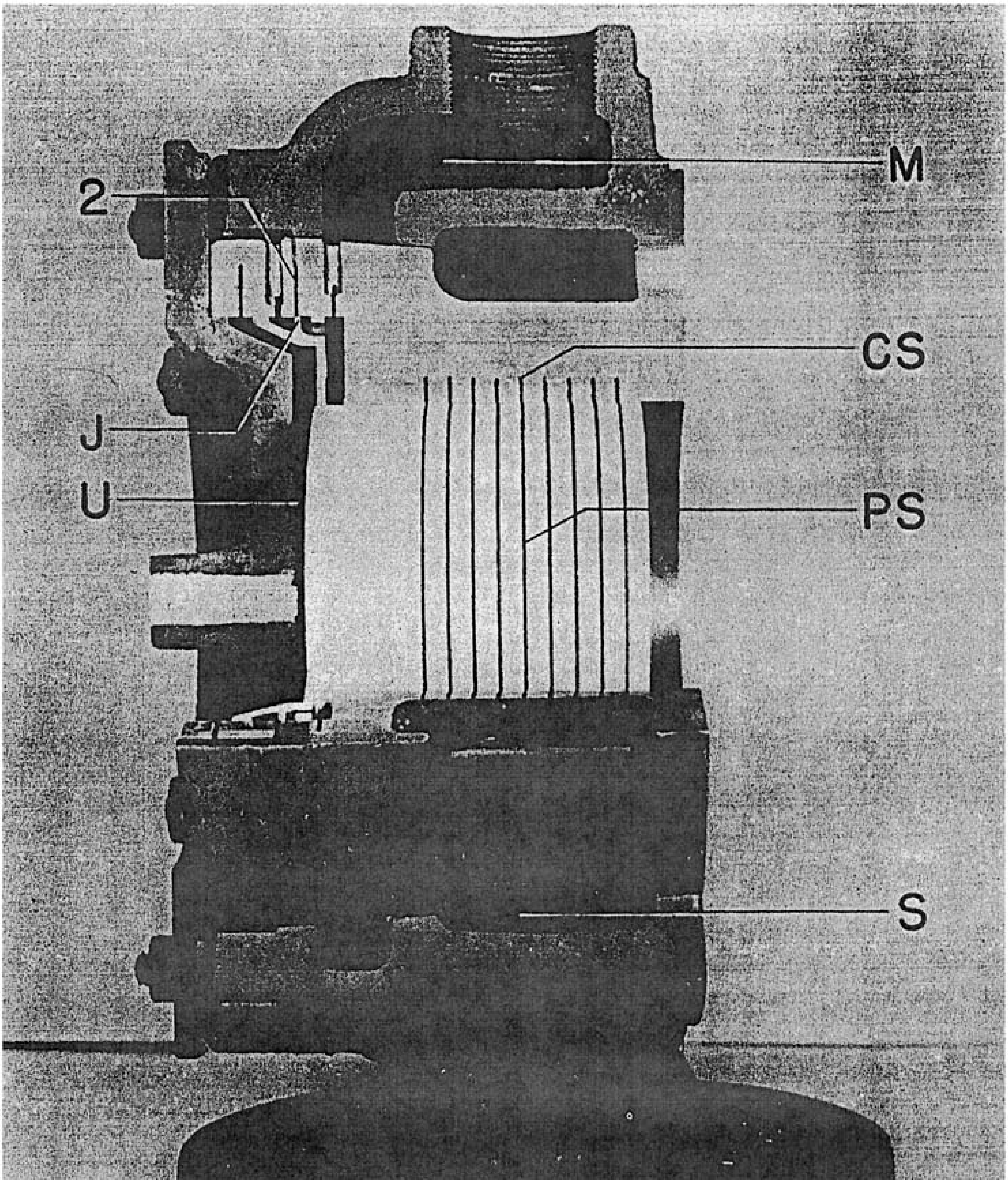

FIG. 7

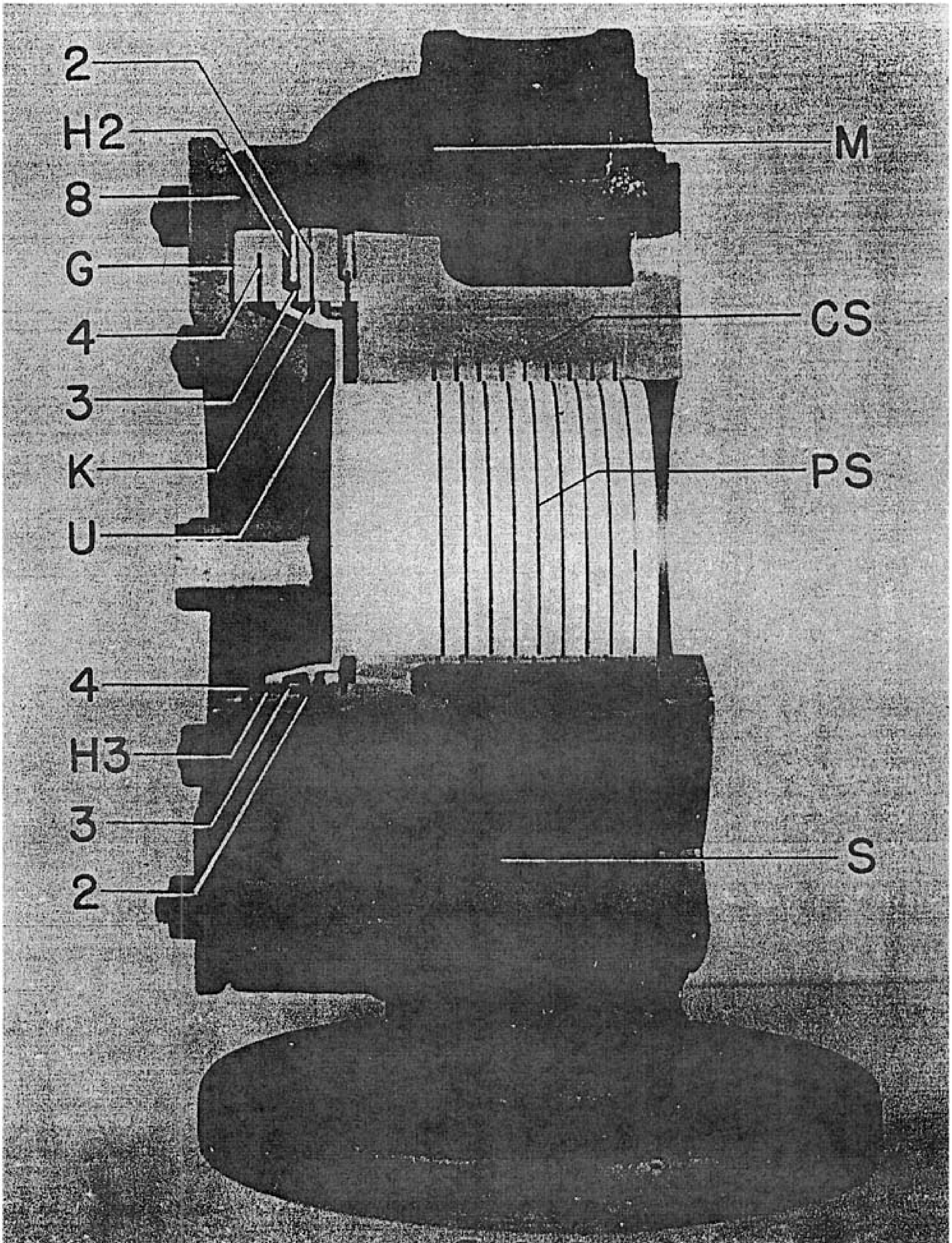

FIG. 8

At this point the air supply to slit #2 is cut off by ring (J). Momentum will cause it to continue to travel in this direction until it reaches the position shown in Figure 8. At this point, the triangular groove (K) in piston will allow the pressure in chamber (U) to escape through slit #4, holes (H3), slit #2, slit #3, holes (H2) through (8) to atmosphere, then pressure still being on front of piston head the cycle of steps described will be repeated as long as motor air pressure is maintained; that is, until magnet and motor valves are shut off by code device. In passing through these steps, the circular slits (PS) of piston uncover the circular slits (CS) of cylinder (the position shown in Figure 7) twice during each cycle, once on the back stroke and once on the forward one. Each time this happens a puff of air is expelled from speaking chamber through these slits into the resonator causing the vibrations which produce the sound.

It will be noticed that the slits 1 and 4 are cut some distance from the face of the chambers and this forms cushions to take up the shock, assist the movement, also limit the stroke of the piston and give the piston its snappy action.

Until a modern frequency analyzer was available, it was thought that the fundamental frequency was the predominating note that was produced by the instrument but these analyses show that this is not the case; the predominating intensities are shown to come from harmonic frequencies other than the fundamental. Tests show that the Type "F" diaphone has a fundamental frequency of 107 to 115 but that the second harmonic has an amplitude six or seven times as great as the fundamental. For further study of the frequencies of diaphones and other types of fog signals the reader is referred to a report dated March 12, 1937 of tests made at Cape Henry, Virginia, during October and November, 1936, by the former Bureau of Lighthouses.

Diaphones are made in the following sizes: Types "B", "CC", "F", F2T", "G" and "K". A Type "C" was formerly made but is superseded by the "CC". Only one type "K" is in use by the U.S. Coast Guard Service. It is located at Farallon Island, California.

The air consumption varies with the pressure and condition of the diaphone. The average consumption for various sizes at 35 pounds gauge pressure is as follows:

TYPES	CUBIC FEET PER SECOND
B	2-1/2
CC	4
F	13
F2T	15
G	24
K	36

In planning a fog signal employing a diaphone, the air receiver capacity should be such that down draw will not be greater than five (5) pounds during a six second blast. This is the length of a synchronized blast, used at stations having a radio beacon, and consists of a one second blast, one second silence and a five second blast, or a total of six seconds.

The air compressor should be of ample size. Their capacity should be sufficient to allow them to replenish the air consumed by one blast or group of blasts and permit the compressor to unload before the next blast or group of blasts occur. The sizes usually used are compressors having actual deliveries of not less than 18 C.F.M. for Type "B"; 40 C.F.M. for Type "CC"; 115 C.F.M. for Type "F" or "F2T" and 225 C.F.M. for Type "G".

The following are instructions for installing and servicing diaphones:

These instructions embody some of the procedure involved in making the original installation of the compressors and diaphone equipment, because experience shows that if the plant is properly installed in the first place, very little trouble with the apparatus will occur.

Some of the details of these directions may seem elementary or axiomatic; they are given because of the need of a clean air supply for diaphones or any air signal cannot be over-emphasized.

Every air compressor intake should be equipped with an efficient air filter of liberal size for the capacity of the compressor.

All pipe that is used in connection with the air supply should be free from rust, scale and flux. Any foreign matter of this nature will score pistons and cylinders and ruin the instrument. To insure that there is nothing in the bore of the pipes that can become loose and be carried through the system, all pipe should be vigorously hammered for its entire length and be turned during the process and then thoroughly cleaned out with a spiral brush or swab or be blown out with air pressure. Use air pressure to clean out all valves and fittings before placing them in the line. After pipe has been cut to length, ends should be reamed or filed to remove any burrs or fins. After threading, thread should be cleaned with a plater's brush dipped in kerosene. A lubricant consisting of white lead in oil and graphite, in proportions of 10 pounds of lead to one pound of flake graphite (applied to the male thread only) will assist in preventing the generation of heat and will allow the pipe and fitting to come apart if that is required.

Drop-forged fittings and welded joints are recommended for all permanent installations.

For the control valve piping, 3/8" O.D. annealed copper tubing and S.A.E. flared type fitting are recommended.

All, piping should be arranged to drain to receivers where condensation can be blown off periodically.

The size of the pipe connecting receivers with diaphones must be at least the same size as speaking valve; if the pipe is long or if it contains several bends or elbows it should be made one size larger.

General arrangements of valves, diaphones, piping and supporting devices are shown on the rotoprints furnished for U.S. Lighthouse Service Book of Reference and Standards. There are conditions where it will be more convenient to arrange them in some other way but it is believed, however, that the typical arrangement will be satisfactory for most cases.

In placing diaphones it is absolutely necessary that they be supported so that no strain will be brought upon casing. The resonator should be placed in position and permanently fastened so studs on diaphone will slide into holes of resonator flange without forcing when diaphone is resting on flange of elbow. Cases have been known when it was impossible to remove the piston from the cylinder due to the strain imposed on the casing because the lugs of the resonator were mounted on a slightly uneven bearing and bolts were drawn up after diaphone had been permanently installed.

After resonators and diaphones have been installed as outlined above it is necessary to remove covers of diaphones and remove the pistons. The lower covers of operating valves should also be removed so that pistons which control movement of valves can be taken out. These should drop out, but if they do not, top covers and valve stems must be removed and then a stick can be used to apply a little force to top of pistons to aid in their removal. With pistons of valves and diaphones removed to a safe place, where rush of air will not disturb them, a compressor should be started and allowed to pump up system to maximum pressure. The code machine should now be allowed to operate; this will permit air to be blown through motor-valve control pipes. Allow air to blow through these pipes until it is definitely known that nothing but clean air is being transmitted. If a two-tone diaphone or one with separate cams for motor and speaking valves is used, the same procedure as above should be followed with speaking valves. After cylinders of valves and the surface of pistons have been wiped clean and a little light oil has been applied to their surfaces the valves are reassembled.

If a single cam timer is used only the motor valves are reassembled. The code machine is started again or valve of timer is operated manually; the motor valves will now be operated and air will rush from open cylinder of diaphone carrying any foreign matter that is in the pipes, valves or diaphones except in that portion supplying the speaking valves. After air has been blown through motor valves of diaphones until it is certain all foreign matter has been expelled, the tubing connecting timer or magnet valve with motor valve is removed and a temporary tube is connected from timer or magnet valve to speaking valve and the same procedure as outlined for motor valve is repeated with speaking valve.

When a two-cam timer is used, motor and speaking valves can be operated simultaneously. Cylinder bore of diaphone should be wiped clean and its surface and surface of piston should be given a coat of light oil, piston and cover of diaphone should be replaced, all tubing may now be connected as required for permanent installation and signal will be ready for operation.

If above operations are carefully performed and filters on intakes of compressors are kept in efficient condition, it will not be necessary to dismantle any part of diaphone installation except for the replacement of worn leather valve disc.

To replace a leather disc on a valve stem, grip the lower valve stem between fiber or lead jaws in a vise, then remove lock nut, cap, which are threaded, and old leather disc. In an emergency any suitable leather may be used, but best results will be obtained by using leather discs made especially for this purpose. Place leather on stem with smooth side down, then replace cap, screwing it down firmly upon leather by hand, and replace lock nut.

A careful mechanic can remove the cylinder from the casing, but this should never be necessary. If something has been carried to one of the chambers between the casing and cylinder and it cannot be removed by shaking the diaphone, the cylinder may be removed as follows: Remove cover and piston (position of registering mark should be as noted); also remove four threaded dowels which will be found in face of diaphone. A metal or wooden toggle, a little longer than outside diameter of casing, is supported on 3/8" or 1/2" blocks on the rim of casing at piston end; another toggle is made for the resonator end of the cylinder. This toggle should be short enough so that it will pass into casing with the cylinder. A 3/4" or 5/8" bolt is used with the toggles, A strain should be put on bolt and if cylinder does not move after considerable tension has been placed on bolt the resonator end of the cylinder should be tapped with a rawhide mallet or toggle may be struck a few blows with a lead hammer. After cylinder has been removed entire interior surface of casing and outside surface of cyliner should be thoroughly cleaned with kerosene or gasoline, using a plater's brush to get into recesses and corners. The surface of the cylinder and the lands of the casing should be wiped with a chamois. The chamois is used so that no lint will be left on the lapped lands. The cylinder is replaced, putting it into position with the toggles and the bolt, being careful to get registering marks in line. Sufficient pressure is used to pull the cylinder into position and the threads in the dowel holes are fair, so that dowels will start without crossing the thread.

As with any equipment, it is a good principle not to take anything apart except when necessary. A sticky piston in one of the valves is easily determined by sluggish action of signal. A worn piston and cylinder will make itself known by the increased air consumption.

If for any reason it is necessary to use a spare piston, the piston should be allowed to stand near open diaphone for several minutes so that its temperature will be the same as that of cylinor. Frequently spare pistons are stored in a warm place and are several degrees warmer than the cylinder. If piston is forced into cylinder before its temperature is the same as the cylinder temperature both the piston and the cylinder surfaces are liable to be scored.

The safety valves are set to pop at the proper pressure, usually 45 pounds; the unloaders on compressors are set to unload at 35 to 40 pounds. If high and low pressure receivers are used the reducing valve is set to the pressure at which it is desired to operate the diaphones, approximately 35 pounds; the safety valve on low pressure receiver or receivers is set to 40 pounds; the one or ones on the high pressure to a pressure five pounds above the pressure to which the unloaders on compressor are set. The setting of unloaders depends upon the pressure for which the compressors were designed.

The foregoing directions apply to all types of diaphones. If two-tone diaphones are being operated it may be necessary to adjust tone of the low note, although this is done during the initial test. This is accomplished by removing the knurled brass cap directly below the flange of the resonator, this exposes the slotted end of the regulating valve. A one-quarter inch hollow set screw will be found which locks the position of regulating valve. This screw should be loosened after which a large screw driver is used to operate regulating valve. At first the valve should be tightly closed. If the diaphone is now operated it should act exactly like standard diaphone giving a grunt but no prolonged low note. Now with both motor and speaking valves open allowing the diaphone to operate, the regulating valve is opened very gradually until a clear low note is obtained. This usually occurs after the valve has been opened between 1/8 and 1/4 of a turn. After desired adjustment has been obtained set screw should be tightened and knurled cap replaced. Unless some foreign matter is carried into valve it should hold its adjustment indefinitely.

The CC, standard F and G diaphones, when operating properly, should produce a full strong and even tone during the entire period of the blast, terminated by a distinctive grunt. The older types of C diaphone and also the type B diaphone signals do not have the distinctive grunt at the end. The two-tone diaphone does not produce the grunt, but both the high and low tones should be full and even without any tendency to throttle.

HEADQUARTERS' COMMENTS.

Lieutenant Holbig's article on the diaphone is interesting and concise. The description of the operation of the unit should be readily followed by reference to the excellent cuts accompanying it.

A few observations taken from operating notes may be of interest and may possibly elicit further discussion on the subject.

The length of grunt is affected by the length and section of the interconnecting tubing between the pilot valve and control valves. It is desirable to keep this short and no longer than 3/8" o.d. as specified.

It has been noted in several instances that more than 1/8 to 1/4 turn, even several turns, have been necessary in setting the bypass valve on F2T diaphones in order to produce a sustained smooth tone on the low note. The adjustment was good when finally accomplished.

The fundamental tone of the diaphone apparently corresponds to the actual reciprocating motion of the piston, which is not in itself an efficient producer of sound since the resonator is not matched to it accoustically. A study of the design makes it apparent that the annular slits CS and PS pass each other twice each stroke, thus giving rise to a series of puffs of compressed air into the resonator which thus generate a tone twice that of the piston, or its second harmonic. A recent frequency analysis made from records obtained at Cape Henry shows the 220 cycle tone (approximate, depending on instrument, air pressure, resonator, etc.) to be the fundamental. If the piston is moving more slowly past the slits in one direction than on the return stroke, the puffs will be of alternately high and low amplitude, thus generating a half-frequency modulation of frequency equal to that of the piston. This low frequency has little energy and rapidly disappears with distance. This may explain the prevalent belief that the fundamental of the diaphone is in the order of 110 cycles. It is commonly noted that the low tone of the F2T diaphone has greater overall sound-in-air energy than the high tone. Anomalously its frequency structure contains a predominance of higher tones and the odd harmonics are accentuated. There has been no complete explanation of this phenomenon. Possibly, with the admission of a small quantity of air to the driving chambers through the bypass valve, the piston tends to synchronize with the natural frequency of the resonator. This might be expected since at thetnatural frequency of the resonator there will be a pressure loop at the base of the resonator, that is on the face of the piston. This might account for the accentuation of odd harmonics in the note and the increased overall amplitude of sound on the "low tone".

Suitable compressors are mentioned. An effort is being made to standardize compressor sizes. With due consideration to manufacturers' standard sizes, type of air signal to be operated, type of prime mover, etc., the majority of our needs can be satisfied by three sizes; namely 50, 125 and 210 c.f.m. (delivered air) at 40# gauge. Exceptions will arise since by the very need for diversity in the strength and characteristics of tone and length of sounding to serve the needs of navigation, a large range in air delivery is required. In many instances the compressors must be capable of furnishing higher pressure air for cargo and anchor hoists.

The diaphone is somewhat more susceptible to freezing than are diaphragm type signals. The Cleveland District has designed a satisfactory electric heating jacket to offset this tendency, installed around the cylinder and thermostatically controlled. Its maximum power consumption is less than one kilowatt.