

THE REGULATION AND TESTS OF AN
AUTOMATIC CONTROLLING DEVICE

A T H E S I S

SUBMITTED BY
JAMES HICKS NEAL

For
The Degree of
BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

THE UNIVERSITY OF TENNESSEE

1928

TABLE OF CONTENTS

- - - -

1. Introduction.
2. General Survey of the Background.
3. Purpose of Using Automatic Control.
4. General Theory.
5. Description of All Apparatus.
 - (a) Long Distant Recording Gauge.
 - (b) Governor.
 - (c) Automatic Controlling Device.
6. Early Operations.
7. Observations and Results.
8. Conclusions.

INTRODUCTION

The idea of automatic governor control was conceived by Mr. E. V. Gmeiner, General Superintendent of The Knoxville Gas Company, and, up to the present time, no other literature or data dealing with the subject can be found. Therefore, this thesis is based solely on observational and experimental data, the only literature read in connection with it being descriptive matter on governors and long distant gauges and their operating characteristics. This reading was necessary to become familiar with the apparatus in order to find the best operating conditions.

The object of this thesis is to give the reader a clear idea of an automatic governor controlling device, the troubles encountered in searching for the best operating conditions, and the methods used to overcome these difficulties. The device is by no means perfected at this time. However, by continual changes and experiments, the ideal conditions are being approached to a closer degree than ever before when operated by hand. At the outset, the conditions were a great deal worse than previously, but by observing the faults and correcting them as they became apparent, the present operation is more satisfactory.

The device has been used mostly as an experiment to test its possibilities. Therefore, the apparatus used is the simplest possible in design and construction. Since the experiments proved it would do the work desired, plans and schemes are being devised for a more permanent apparatus with

greater possibilities. The scheme is not limited to the controlling of gas pressures, but may be used for controlling the pressure of any fluid. As such a controlling device, the possibilities of a commercial demand are highly probable.

GENERAL SURVEY OF THE BACKGROUND

The controlling of gas pressure at the end of a distribution system, or remote control, has been in vogue several years. There are a number of companies making long distant recording instruments that tell the station operator the pressure at a certain point in the distribution system. It is desirable to keep the pressure at the end of the mains at a minimum and yet high enough for domestic and commercial use. This pressure is usually around four inches of water. In order to maintain such a pressure at the end of the line, the station pressure must be considerably higher and must vary according to the load conditions. The station under consideration is the property of The Knoxville Gas Company, and is situated on Bernard Street adjoining the Southern Railroad. The line or distribution system under consideration is the North Knoxville main extending out Broadway.

The machinery used at the station consists of a booster for raising the pressure, a governor, for regulating the flow of gas, and a long distance recording gauge, that records the pressure at the intersection of Coker Avenue and Broadway. The governor is operated by moving weights back and forth on a lever arm which in turn opens or closes a valve that varies the amount of gas flowing.

Formerly, this operation was done by hand. The station men had to watch the charts and as the pressure gauge varied the weights had to be taken off or put on by hand. There has been, in the past, too much variation of pressure

at the end of the mains. The high and low points varied too much, causing some service trouble and expense to the Company. These situations may be laid to the fact that whenever a machine depends upon man-power for part of its operation, it will always be subject to the common human fallacies.

With automatic control on all the governors at the outlet station, a much better pressure condition would prevail, and at a much cheaper operation expense.

PURPOSE

The purpose of the experiments and tests was to find out whether or not better operating conditions were available, and better charts could be made by using an automatic governor controlling device rather than by hand controlling.

GENERAL THEORY

Figure Number 1 shows a drawing of the Reynolds station governor. This is the same type governor as the one on which the automatic controlling device is mounted. It consists of several parts, the most important ones that were dealt with being the main governor bowl, the valve, and the lever arm. By looking at the drawing it is evident that by placing weights on the lever arm, the balance valve is forced open, allowing more gas to flow through. If these weights could be moved back and forth on the lever automatically, and still keep the pressure within the desired limits, then the idea would be an accomplishment -- the first, so far as is known, of its kind. This is in short the theory: namely, a device that would vary the position of the weights on the lever arm, being operated and controlled automatically by means of a long distant recording gauge, and thus keeping the gas pressure at the end of the line within certain limits.

The Bristol long distant pressure indicating and recording set is operated by means of electricity and a clock, the clock being on the receiving or recording end. It consists essentially of two parts, the indicating or transmitting instrument, located at the corner of Broadway and Coker Avenue, and the recording or receiving end located at the plant station. Induction balance is the principle on which the Bristol long distant electric transmitting system operates. The transmitter actually measures the pressure and electrically transmits it to the receiving instrument which is an electrical

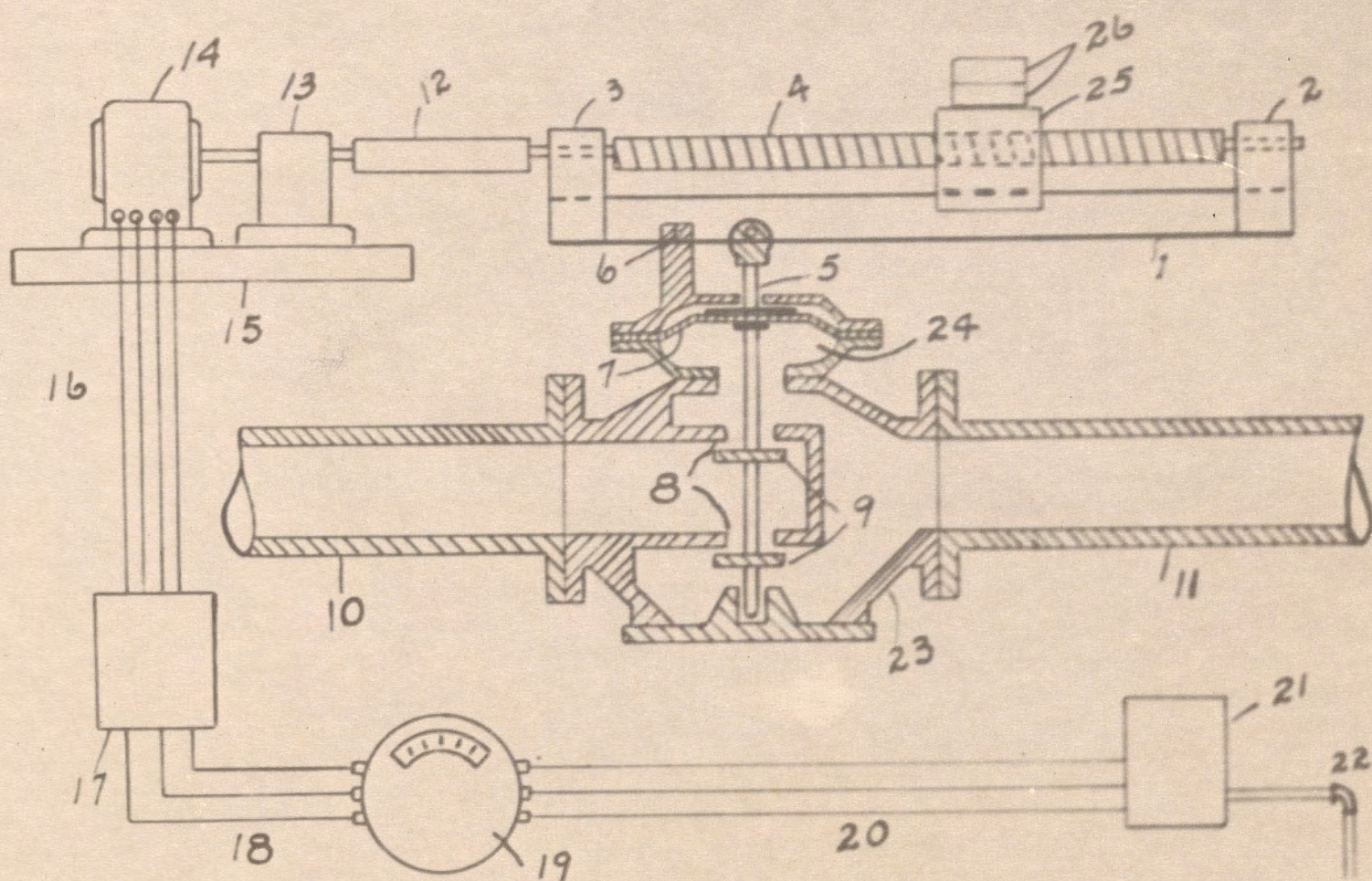


FIGURE 1.

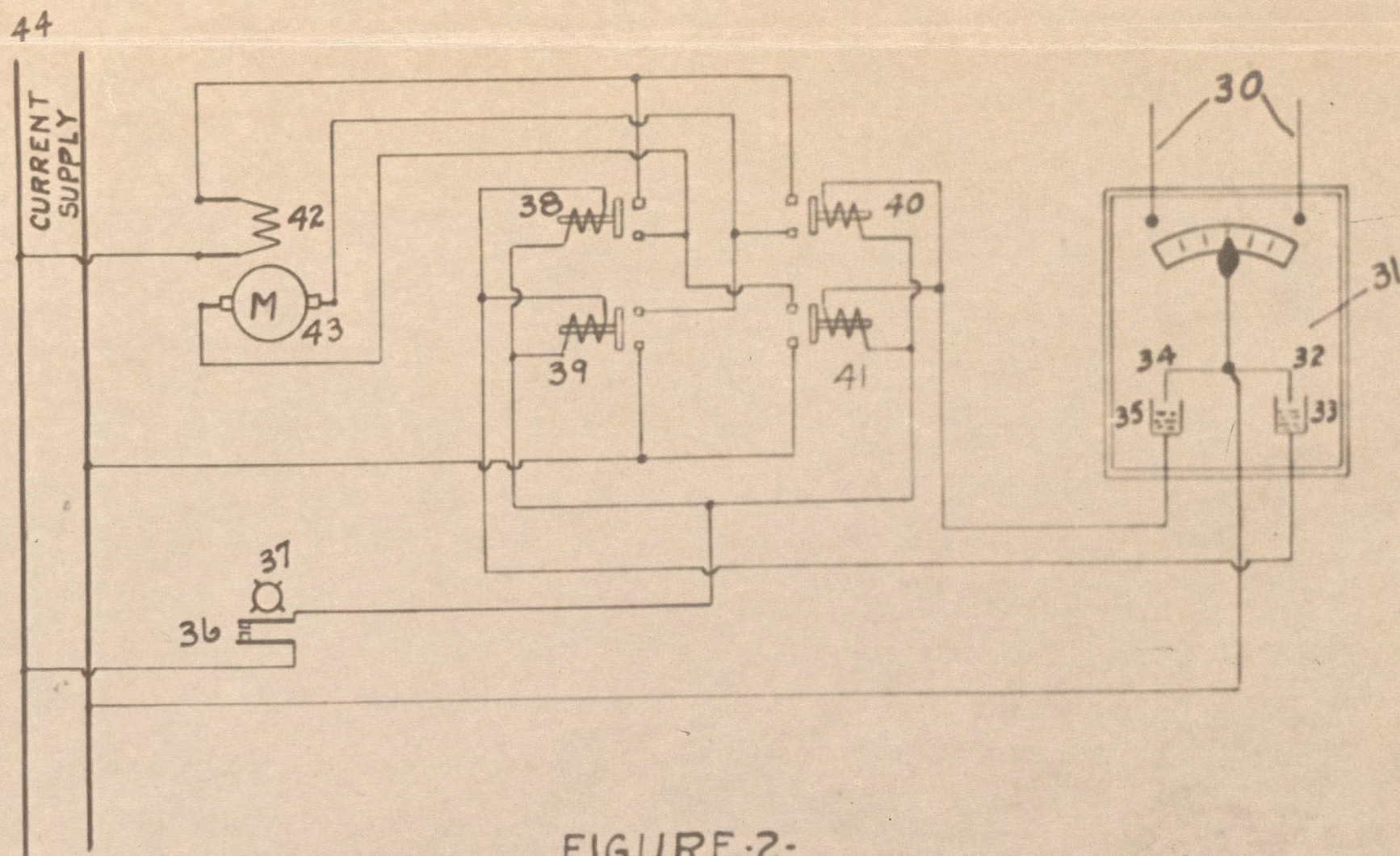


FIGURE 2.

WITNESS

H. G. Bonner
Thos. H. Townsend

Elmer V. Gmeiner
 INVENTOR

duplicate of the transmitter.

In the recording instrument box there were mounted two mercury cups to form electrical contacts at the high and low points on the recording chart. These were formerly used as a bell ringing device to warn the operator of the unusual pressure conditions. This device was used to operate relay switches, which in turn operated a small motor that moved the weights back and forth.

There were several schemes devised by which the weights could be moved back and forth, among them being, by means of a rack connected directly to the lever arm, the motor being mounted on the weight table and traveling back and forth with it. Another method for moving the weights was by means of a weight table mounted on roller bearings and moved back and forth by means of a motor, the two being connected with a chain. Both of these methods were too expensive and a little more complicated than the one finally decided upon. It consisted of a screw mounted directly above and attached to the lever arm and a nut for the screw with the weight table mounted on the nut. The motor, a 1/25 H.P. A.C. G.E. 110 V Single Phase 1750 RPM series motor, was connected to the screw shaft through two gear reduction devices that reduced the speed to about 40 RPM. which was the working speed desired. The speed reducing apparatus consisted of two hand-turned emory grinding machines inverted. The relay switches, G.E. 110 V. solenoid type, were mounted by the motor and operated it in either direction according as the pressure varied and contact was made in the mercury cups.

DESCRIPTION OF APPARATUS

Figure Number 1 shows a drawing of the controlling mechanism complete. 1 is the governor lever arm to which is connected the blocks 2 and 3, which in turn support the screw 4. The weight carrier, 25, is connected to the screw with a nut and moves back and forth as the screw turns. 14 is a one twenty-fifth horse power, alternating current, series motor connected directly to the screw shaft, through the speed reducer, 13, by the universal joint, 12. 6 is the fulcrum of the lever. 5 is the connecting link between the lever, 1, and the governor diaphragm, 7, and the governor valve, 8, and 9. 11 is the inlet pipe and 10 is the outlet pipe.

21 is the transmitting gauge that is controlled by the pressure from the gas main coming through pipe 22. The transmitter affects the recording gauge, 19, which actuates the switches, 17, and causes the motor, 14, to run either direction.

Figure Number 2 is a diagram of the electrical connections at the station. The current supply comes from a 110 volt 60 cycle line, 44. The recording pen of the receiving instrument, 31, assumes the various positions the sending instrument gives it and forms contact in the mercury cups, 33 or 35, closing the relay switch circuits, 38 and 39, or 40 and 41, thus closing the series motor circuit and causing it to run in either direction. 42 represents the field, and 43 the armature of the motor. The interrupter, 36 and 37, is connected in the relay switch circuit. 36 is

an open circuit until forced closed by the projections on the fiber wheel, 37.

This constitutes a description of the controlling device and all the parts it depends upon for its operation.

Figure Number 2A shows a photograph of the device as it now operates.

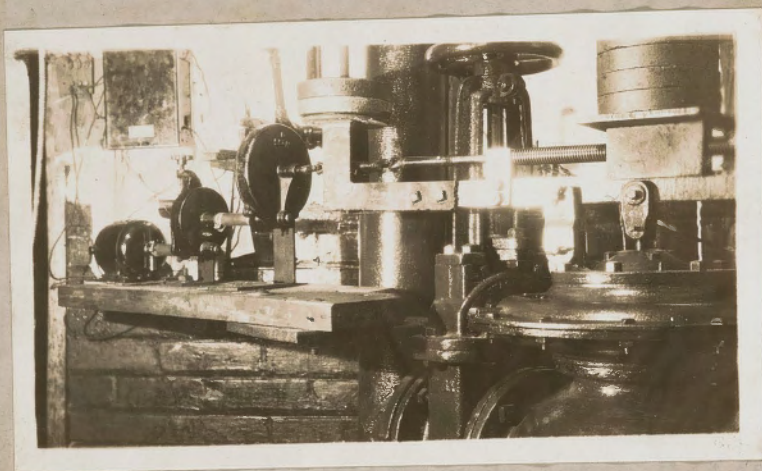


Fig No. 2A

EARLY OPERATIONS

It was in this condition that the device was first put into operation. The mercury cups were set to form contact at four inches of water on the low side, and five inches on the high side. This would cause the weights to move out at the low pressure, and move back at the high pressure. The first charts were very unsatisfactory, as the pressure ranged between three and six inches, instead of four and five inches. By observing the operation over a few peak loads, it was finally decided that the range was too great, and that half of one inch instead of one inch would be used. The mercury cups were set for contact at about 4.2" and 4.8". The charts were much better, but were still far worse than the ones made by hand controlling.

The next trouble seemed to be too much see-sawing back and forth on the chart. The pressure stayed within the limits of between four and five inches most of the time, but was continually moving up and down between those extremes. Another thing that was giving a great deal of trouble was the off peak and night load. These curves should have been nearly a straight line for the load was practically all off at that time. Instead of being a straight line, they were always high, and all the weights had to be taken off the arm.

An interrupter was placed in the relay switch circuit in order to correct the first fault. By watching the chart at the plant very closely, it was determined that it required about two minutes for a boost in pressure at the

plant to cause a change in the pressure at Coker and Broadway. So what was happening was that the motor operated too long, and built up too much outlet pressure before it could be noted at the end of the line. When the pressure did reach the end of the line, it would immediately boost the pressure there far too high, then the operation would reverse itself. An interrupter would give the pressure at the end of the line time to adjust itself to a neutral position somewhere around four and one-half inches of water.

The interrupter consisted of two Ford contact points to which the ends of the neutral wire to the relay switches were connected. These were mounted in such a way as to always be open unless forced closed by projection from a fiber wheel that revolved on a slow speed shaft. The wheel made one revolution every ninety-seven seconds, and had four projections spaced equally on it. The projections that made the contact points close were so arranged that they could either be taken out, made longer, or made shorter. It was by means of changing these and varying the length and timing of contact that the curves have improved, and it seems that the interrupter has the key to the situation. Before satisfactory curves can be made automatically, the timing must be regulated and each line or transmission system would be a different problem which would require a little time and observation, especially during the peak loads, in order to determine the best timing.

It was thought that by forming contact about half the time, and using a small number of weights, the faults

would be corrected. This experiment was tried, and even though it improved the curves to some extent, the weights used were not enough to carry over the peak hours. It required seven weights at the end of the lever arm in order to give an outlet pressure of eighteen inches, which is about the maximum required at the peak hours to maintain the pressure at the end of the line. Therefore, seven weights were the minimum number that could be used if the mechanism was to operate automatically. This necessitated the use of counter weights to be mounted on the lever arm back of the fulcrum. This would give the valve a chance to close, or very nearly so, during the off peak and night periods, and make a very nearly smooth curve on the recording chart.

By following the load conditions and changing the timing on the interrupter, the charts for May, 1928, have been very satisfactory. The outlet recording chart builds up in stages for the peak loads, and likewise falls off in gradual stages. Only once in the twenty-four hour period did the pressure get without the limits and that happened just as the peak was passed. At that time, the pressure went nearly to six inches, due in all probability to a sudden change in load conditions. If a big majority of customers quit using gas at about the same time, then the pressure will build up before the controlling device has time to close the governor valve to meet the condition. This situation occurred only during the morning peak and is a unique feature of the load condition. The noon and night peaks have a more gradual rise, and fall, and no trouble or unusual features

have been encountered so far. Occasionally during a peak load the high point will come early, then the load falls off for a few minutes only to build back up to the same high point. These conditions have been taken care of by the controller without any trouble.

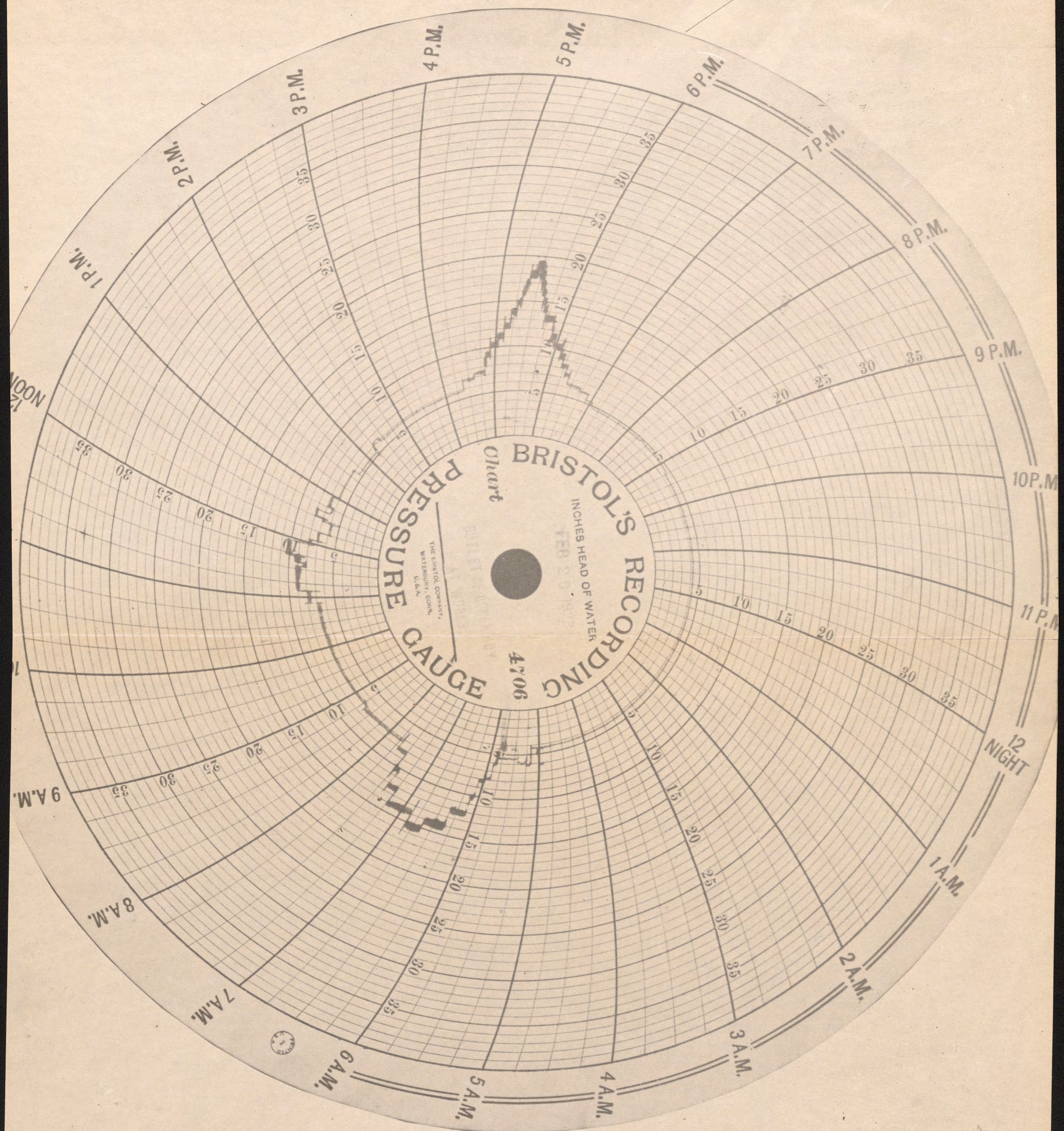


Figure No. 3

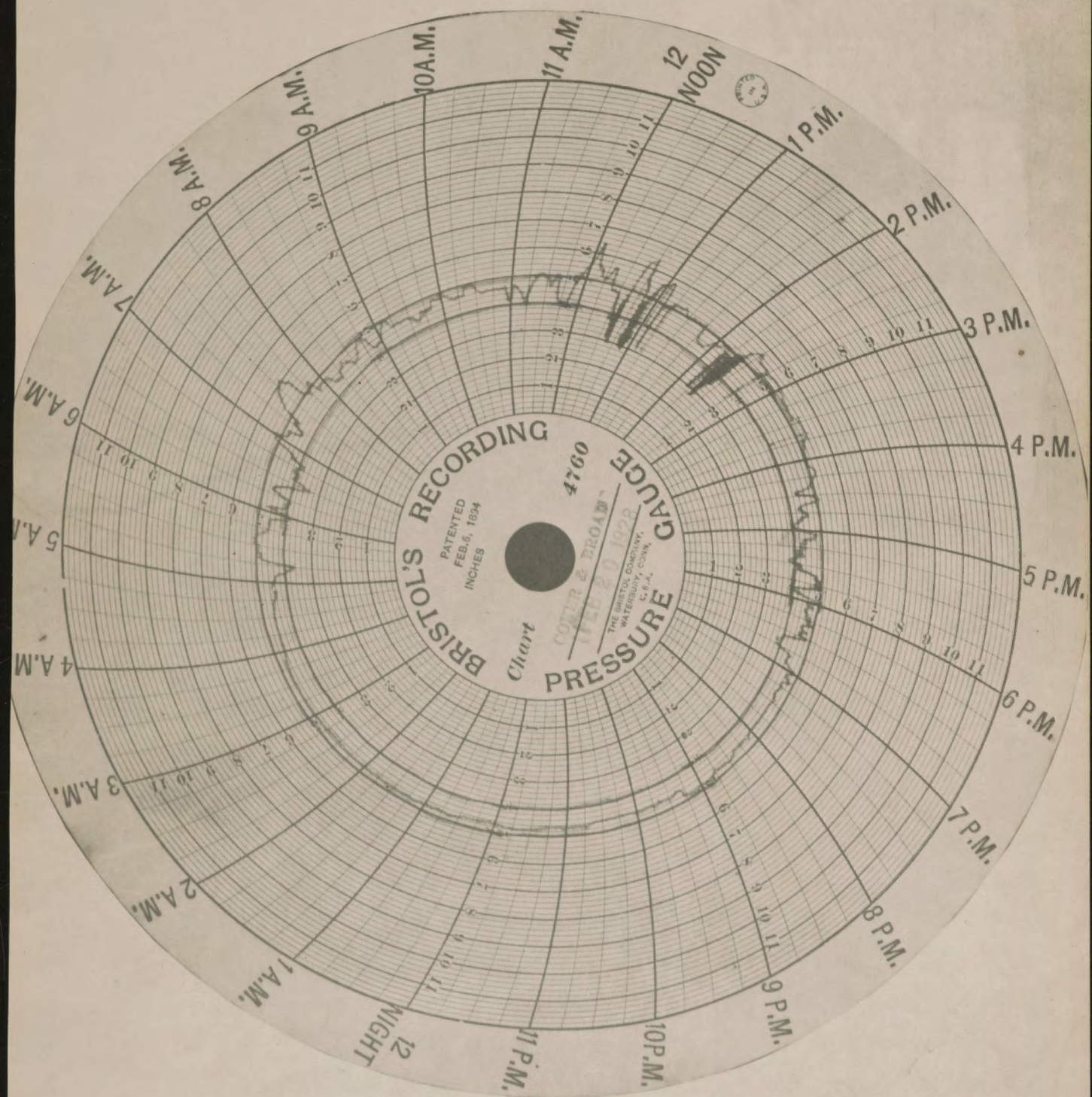


Figure No. 4

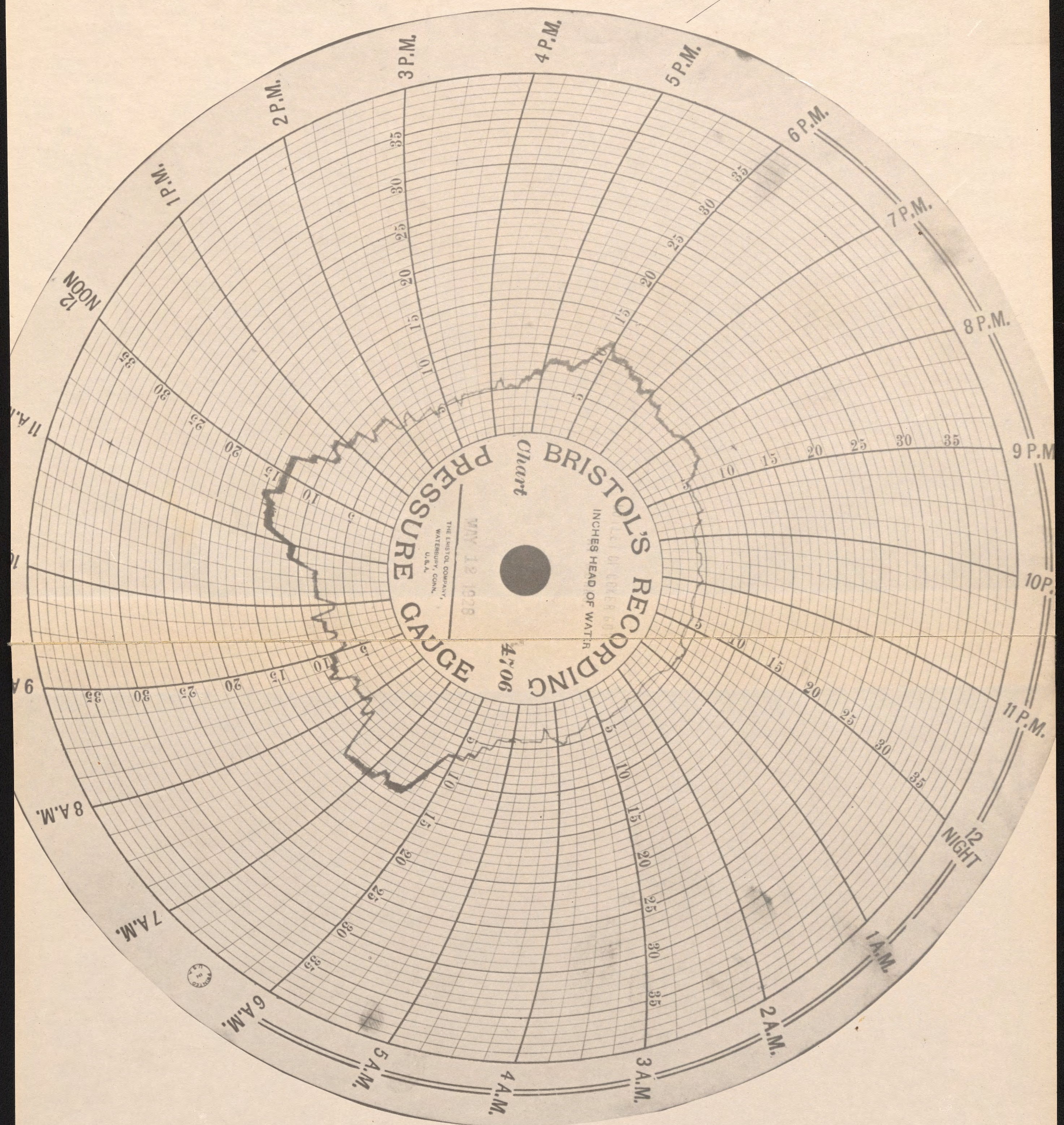


Figure No. 5

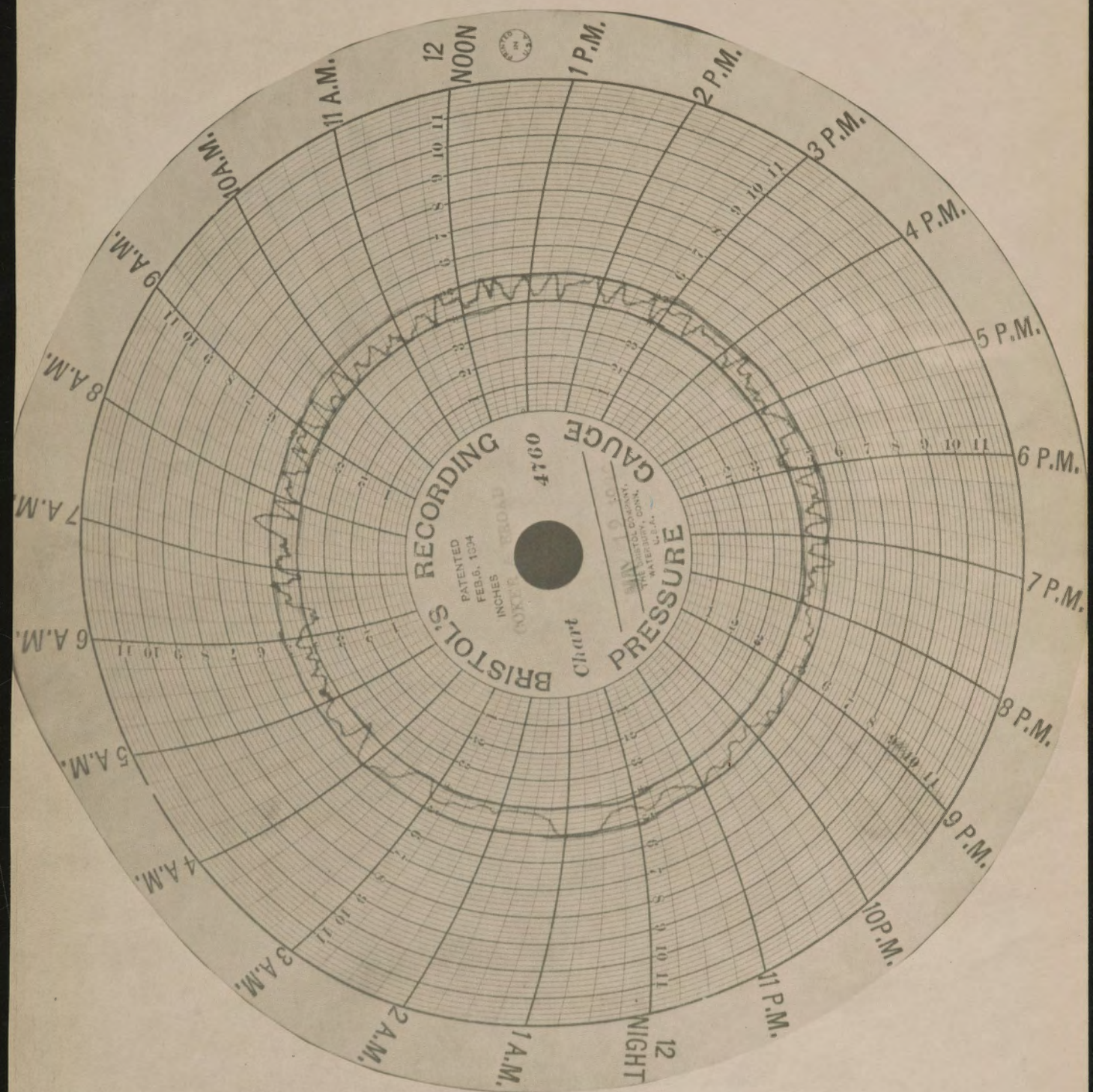


Figure No. 6

OBSERVATIONS AND RESULTS

Figure Number 3 shows a log of the outlet pressure at the station for an average day while the pressure was regulated by hand control. Figure Number 4 shows a log of the pressure at the end of the line for the corresponding date as Figure Number 3. This chart shows that there was too much variation of pressure especially during the peak loads when the pressure was as high as six and one-half inches of water, and low as three inches of water. This is very likely due to changes in load conditions that could not be handled by the operator. There is one good feature about these charts, and that is the night load which is almost a smooth curve on both.

Figures 5 and 6 show the logs of the pressures since the automatic governor controller has been in operation and tested. On figure 5 it can be noted that the peaks are not as pronounced and high as in figure 3. This is due to the greater load for the date on which figure 3 was taken. The pressure on figure 5 built up and changed according to the load conditions and kept the pressure at the end of the line between 4 and 5 inches of water at all times with the exception of a short period between 7:00 and 8:00 o'clock when the load was dropping off. This, as has been said, was probably due to the fact that a majority of the customers are working people who use gas at the same time in the mornings and about all the load goes off at once. This situation would cause a high pressure to be built up suddenly and the controller took care of it as quick as possible.

The night curve, on figure 6, is not as smooth as it should be, but there is nothing very objectionable to it. The main object is to keep the pressure within the prescribed limits, and that end has just about been accomplished.

A comparison of these tests proves without a doubt that the charts made when operated automatically are better than those made when operated by hand.

In order to get the actual effects of the weights on the outlet pressure, a test was made during a peak load. The weights were weighed so the downward force would be known. The distance from the center of the weights to the fulcrum was measured and the outlet pressure was noted at the start. At the end of each period of movement the distance of the weights from the fulcrum and the outlet pressure were noted. This gave a series of points from which curve (a), figure 8, was drawn. This gives the average range for a normal peak load. The pressure ranged from five inches of water to thirteen inches of water, a difference of eight inches of water, while the weights traveled from six and one-half inches from the fulcrum to twenty-two inches from the fulcrum, a distance of fifteen and one-half inches. The weights, neglecting the weight of the lever arm and screw, weighed fifty pounds.

This data shows that an inch of travel by the weight carriage, carrying fifty pounds, has the effect of raising the outlet pressure one-half of an inch of water. The above data is identical for both raising and lowering the pressure.

The theoretical downward pressure exerted by the weights is shown by curve (b), figure 8. This curve was

calculated and plotted for a weight of fifty pounds. The data was calculated by taking moments about the end or fulcrum of the lever, thus giving the downward force in pounds exerted on the governor diaphragm. From these curves the downward force in pounds needed to maintain a certain outlet pressure can be read directly.

The interrupter was tested by a stop watch, and the contact timing recorded.

DATA FOR CURVES

Distance from Fulcrum. Inches	Outlet Pressure Inches of Water	Downward Force Pounds
6.5	5.0	100
9.5	6.5	130
12.0	8.0	160
15.0	9.0	180
18.5	11.0	220
21.5	12.5	250
22.5	13.0	260

INTERRUPTER

Point No. 1 - 6 Seconds

Point No. 2 - 5 Seconds

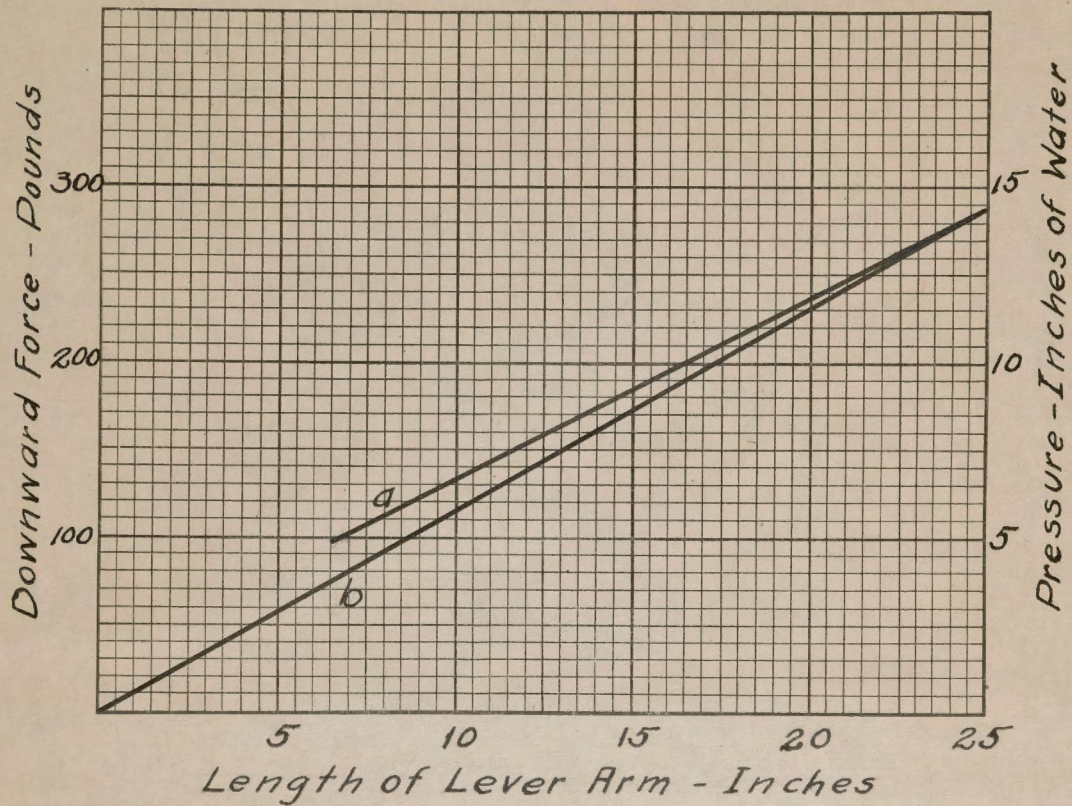
Point No. 3 - 6 Seconds

Point No. 4 - 6 Seconds

Total Time --23 Seconds

Time for One Revolution -- 97 Seconds.

Per Cent Time in Contact, $23/97 = 24\%$

FIG. NO. 8

TITLE:-

INTERPRETATION OF CURVES

Curve (a) shows the relation between the governor outlet pressure in inches of water and any position of 50# on the lever arm.

Curve (b) shows the theoretical downward force in pounds caused by a 50# weight for any position on the lever arm.

CONCLUSION

Automatic controlling of pressures for any fluid distribution system should have a place in the modern plants of our country. There are thousands of automatic devices doing the work that formerly was done by many more thousands of men. These devices are doing the work much better and, in most cases, cut the operating expense more than half.

The expense of hand operating the governors at The Knoxville Gas Company plant varies from \$2,400.00 to \$3,000.00 per year for labor alone. The cost of operating by automatic control would be \$1,000.00 per year at a maximum figure. This would render a saving of 150% to 200% a year over the present condition. Therefore, there would be a marked saving in favor of automatic control.

As was shown by the charts, the pressure condition on the automatically controlled chart was better than the one that was hand controlled. Therefore, the automatic controller is doing the job better than it has been done by hand, even though it was a rough set up, with only the idea of experiment.

There are several bad features in the present operation which are gradually being eliminated, and plans are being devised for a more nearly perfect mechanism to apply on one of the other governors. If a means of forming contact that will prove more satisfactory than mercury cups can be found, then a closer range can be secured and a better regulated log of the pressures obtained.

The field of an automatically controlled device for regulating fluid pressures, such as the one treated in this thesis, has wonderful possibilities, and some day may have a wide use throughout the country.

There are three cardinal points in favor of the automatic controlling device rather than hand control, namely: first, cheaper operating expense; second, better pressure conditions prevail; and third, more dependable service is rendered.

APPROVAL.

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

Name W. R. Woodrich

Title Prof. Mech. Eng.