A T H E S I S

on

THE UTILIZATION OF WASTE HEAT IN INTERNAL COMBUSTION ENGINES

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By

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Within the last few years the internal combustion engine has become quite prominent in engineering and manufacturing work, it's field is very broad, since, on account of it's light weight, simplicity, quick starting, small bulk of fuel consumed and also fuel economy, it can be used in so many places where it would not be practical to try other engines. Its growth has been very great. Consequently the engineer finds that it is now his duty to see how the engine may be run most economically and to the best advantage. The mere invention of an engine is a very small part of the work to be done before the task is completed, the greater part of the work must be done on improvements and devices which will make the engine a success economically.

To this end the writer has been working upon an idea conceived by Prof. C. E. Ferris to improve the efficiency of the internal combustion engine.

The internal combustion engine consists of a cylinder in which a piston works. A mixture of air and gas is drawn into the cylinder, this is then compressed and when the piston is near the end of the stroke, the mixture is ignited, this generates heat and expands the gas to such an extent that the piston is pushed forward. Upon the return stroke the burnt gas is pushed out, upon the next stroke the mixture is again drawn in and the same process is repeated. This engine is called the four cycle engine. In some instances, the mixture is partly compressed in a separate chamber and at the end of expansion this mixture rushes in and pushes out the burnt gas thus doing away with two strokes so that we have a two cycle engine. Some engines are used in which air alone is compressed to a high temperature, and then oil is injected into the cylinder. This ignites, due to the high temperature, and gives the same effect as the results given above.

Most internal combustion engines have cooling water around the cylinder in order to keep the metal from getting too hot. This water carries off a good portion of the heat generated in the cylinder, and a larger portion is wasted at exhaust, due to high exhaust temperature.

For an average efficiency of an internal combustion engine we may assume 21.3 %, this leaves 78.7 % of the heat wasted, and from experiments we have found that about 25.7 % is carried off by the jacket water, and 53 % turned out in the exhaust. If this heat could be utilized in some way it would add greatly to the efficiency of the engine.

The idea carried out in my work was to use this heat to generate steam and to use this steam in the same cylinder in which the gas was used.

The water jacket of the engine was used as a boiler, the steam being collected in a dome especially provided, and by means of specially designed gears and cams the steam was admitted to the cylinder. The exhaust was used in a feed water heater to preheat the water before entering the water jacket. A device was provided by which the water in the steam dome could be kept level. For further explanations see drawing, also page 5.

The average steam engine may be said to have a thermal efficiency of about 8 %. Therefore, since the waste heat of the gas engine was about 78. 7 % (assuming the efficiency of the jacket as a boiler to be about 70 %), the per cent in efficiency that the engine could be improved is .787 x .70 x .08 = 4.4 %. Since the efficiency of the engine was assumed to be 21.3 %, the % that the efficiency of the engine was raised is $\frac{4.4}{21.3}$ = 20.6 %.

When I began experimenting with the engine it was arranged as shown in fig. 16, the work on it having been done by Prof. Ferris. The cams were so arranged that the actions were as follows. At the beginning of the cycle all valves are closed, but when the piston moves forward the pressure inside the cylinder lowers, the gas pressure opens the valve and admits gas and air in the right proportion into the cylinder. On the return stroke the gas is compressed and ignited. It then expands and is on the next return stroke pushed out of the cylinder. At this time, the valve S is opened by means of the cam on the gear G, and admits steam. This steam is allowed to work expansively and then pushed out and gas and air enter again, thus changing the gas engine from four cycle to six cycle using both steam and gas.

The first twenty hours were spent in overhauling the engine, grinding valves, etc. When the engine was in good shape I proceeded to make a run and test the engine. I succeeded in getting a steam pressure of forty pounds per square inch.

When the steam was admitted to the cylinder, the engine stopped. Upon investigation I found that the valve which admitted the steam did not have a spring strong enough to hold a pressure of 40 #. Also there was some dirt and oil which had gathered in the little pocket around the valve. This had been splattered all over the spark plug and prevented ignition. After drying out the pocket containing the muck and reducing the pressure to 25# per sq.inch, I took cards such as are shown in figures 1,2,4 & 5. The engine when running on gas alone carried a load of 2.5 H.P. While running on steam and gas it carried a load of only 1.8 H.P. There was a decided decrease in the strength of explosion, and the steam pressure fell off to 13# where it remained. The cards shown were taken when the engine was running on steam pressure of 25# per sq. inch.

This proved that the method under the above conditions was unsatisfactory and therefore I decided to change the arrangement and use the exhaust for a superheater instead of a feed water heater. Accordingly the cold water was admitted directly to the jacket, the steam taken from the dome and passed through the superheater. (See fig. 12).

With this arrangement it took two hours to get a steam pressure of 16# per sq. inch and a higher pressure could not be produced, while in the previous experiment I got a pressure of 40# per square inch in about one hour.

Cards taken when running on gas alone are shown in figs. 6,7, the engine at this time (exploding every time) giving about 2.5 H. P., the same as before. Upon admitting steam to the cylinder the power at once lowered to about 1.6 H.P. showing that the superheating had done very little or no good. Furthermore, the cards taken showed no work done by the steam whatever, so that this plan also failed to give satisfactory results. Cards taken, to show steam action were in this case (as in the first experiment) taken with a 16# spring having a collar to prevent the gas pressure from pushing the pencil off the paper.

Further trouble was found with the feed water. When the steam pressure began to raise, the water level in the dome raised to such an extent as not to be visible in the gauge glass and when the engine became cool I was nearly certain to find the level much below the normal.

During the whole work I had much trouble with the gas engine, having to grind the valves three times, replace all packing, some of it several times, and clean the carbon from the piston.

Conclusions.

From the cards taken in the first test it is shown conclusively that steam may be generated in the water jacket and made to do work, but from the size of the card and the expansion curve, it is clearly shown that the amount of steam generated in the first test is entirely too small to be worked in the cylinder. Furthermore from the indications it is shown that the work done when using gas alone is much greater than when using gas and steam. It was thought that the steam being wet might cause a weak explosion; so thinking that the superheating would dry the steam and make the plan satisfactory, it was decided to change the apparatus as in the second test.

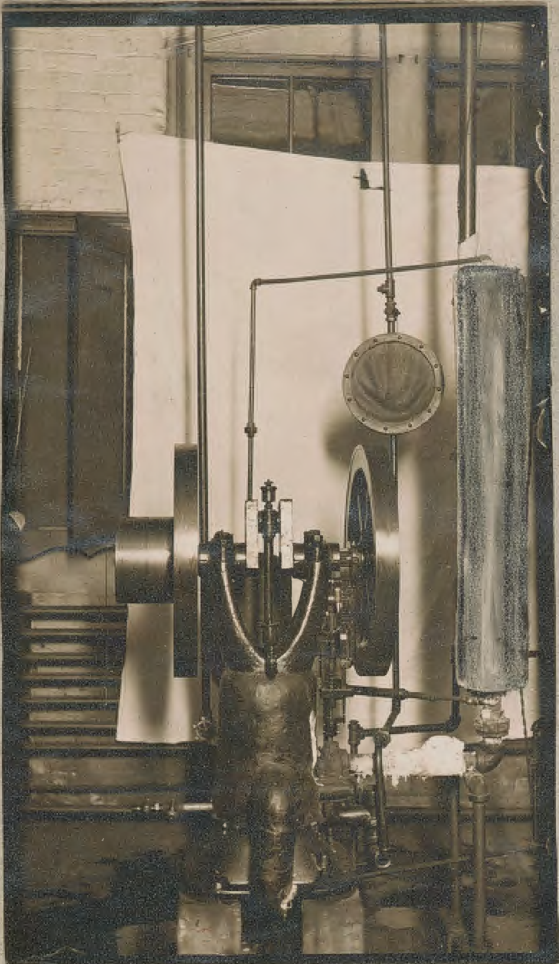
In the second test the cards taken when running on gas alone show that the engine was in very good condition. The cards taken showed that no work was done by the steam. Since in the first test, I got a boiler pressure of 25# and on the card I had a pressure of only 9#, it is evident that there is some wire drawing effect lowering the pressure 17#. Since in the second test I could get a boiler pressure of 16# only, if the wire drawing effect were to act in the same proportions as in the first case, the indicated pressure would be about 5# which would probably not be recorded by the indicator and it may be that the pressure dropped almost to nothing.

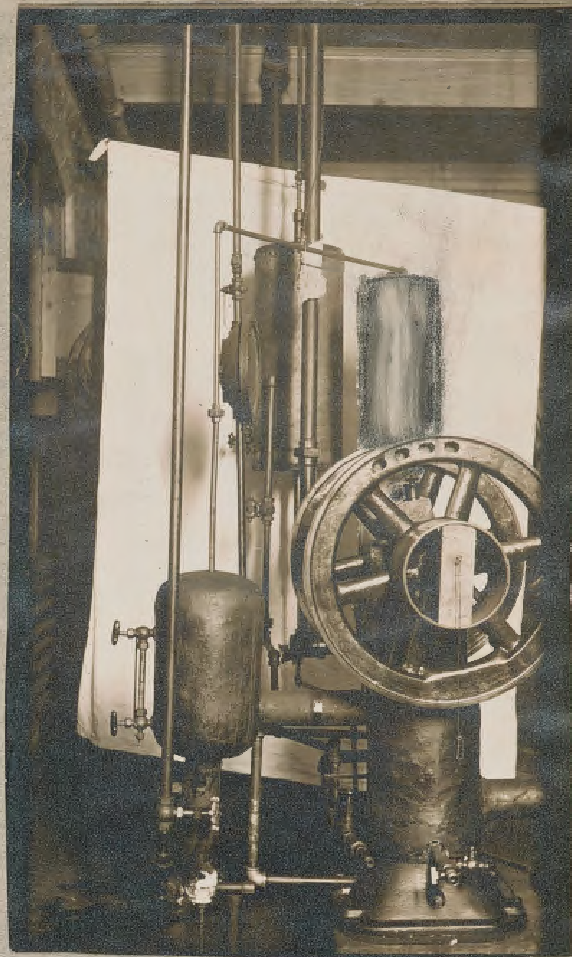
The reason I did not get the steam pressure in the second test that I produced in the first test probably is: The greater part of the waste heat goes off in the exhaust, when using the exhaust as a superheating device, the heat delivered to the steam is very small because the temperature of the steam is high, while in the first case the greater part of the exhaust heat was absorbed by the feed water, this water being at a comparatively low temperature. In the first test it was possible to hold the hand on the exhaust pipe, while in the second test the pipe was very hot, showing that a great deal of heat was wasted in the second test, which had been utilized in the first test. In accounting for the fact that the pressure could not be raised above 16# per sq. inch, I may say that I think it is probably due to the fact that the radiation surface was very great and after the steam reached a certain temperature, the radiation was as great as the supply, thus giving me a constant pressure.

From gas cards taken when the engine was running on gas and steam the ignition seems to occur very slowly, showing that the steam does in some way affect the strength of the explosion.

When comparing these cards with cards given by Mr. Hiscox in his book on Gas, Gasoline and Oil Engines, I find that my cards are very much like the ones which were taken when the cylinder walls were too cool, therefore I inferred that the steam, upon entering the cylinder, cooled the piston and walls to an excessive degree, thus causing a slow ignition. This seems to indicate that the steam must be admitted to the cylinder at a very high pressure and temperature in order to be of any commercial use.

In concluding, it might be well to say that I do not consider the results above as a conclusive proof that the idea worked upon could not be made a commercial success. All that they show is that the steam may be worked alternately in the same cylinder as the gas, but with the conditions under which this test was conducted the method is of no practical value.





Front View of Engine Side View of Engine

as arranged
in the
SECOND EXPERIMENT.

Fig. 1 16# Spring

Fig. 2 16# Spring.

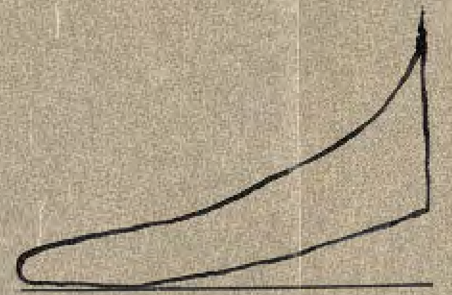


Fig 6 80# Spring

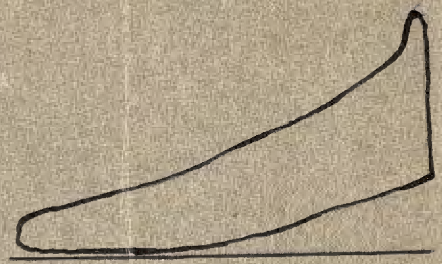


Fig 7 80# Spring

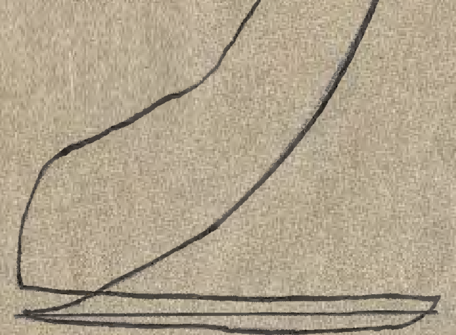


Fig 10 16# Spring

Fig 4 16# Spring.

Fig 5 16# Spring

Fig 8 80# Spring

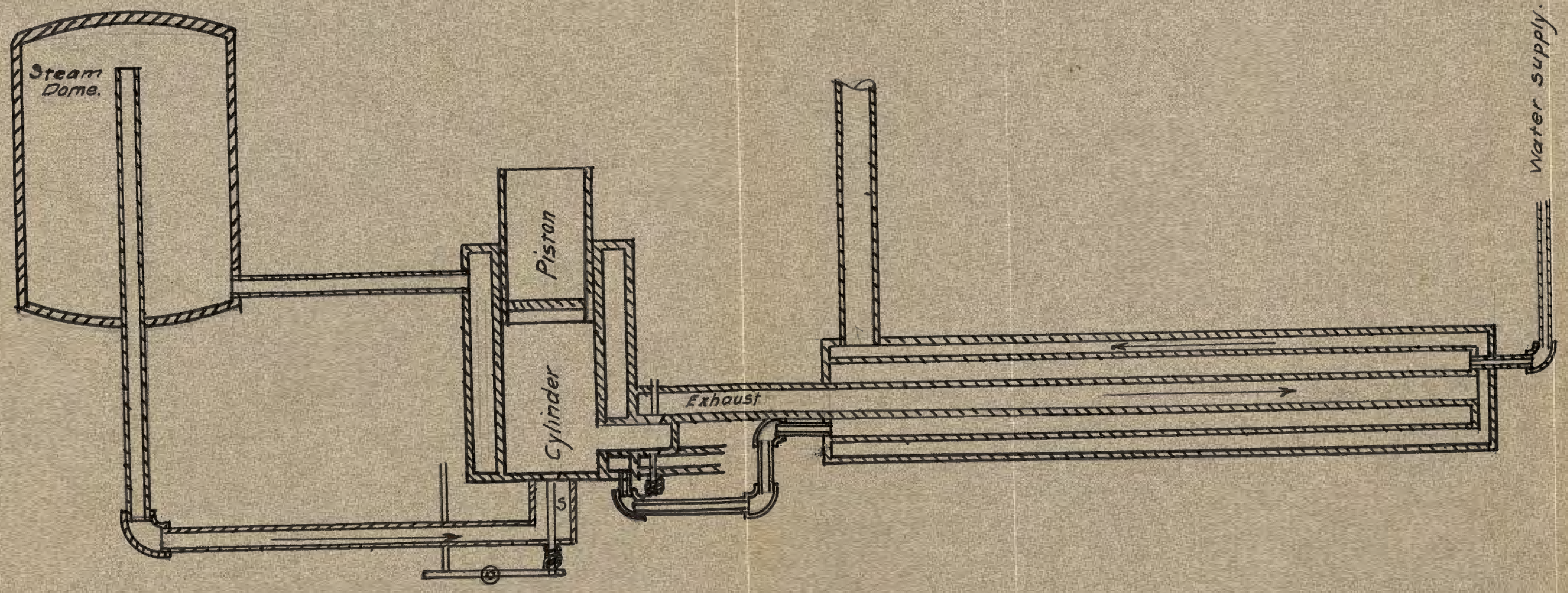
Fig 9 80# Spring

Fig 11 Spring 16#

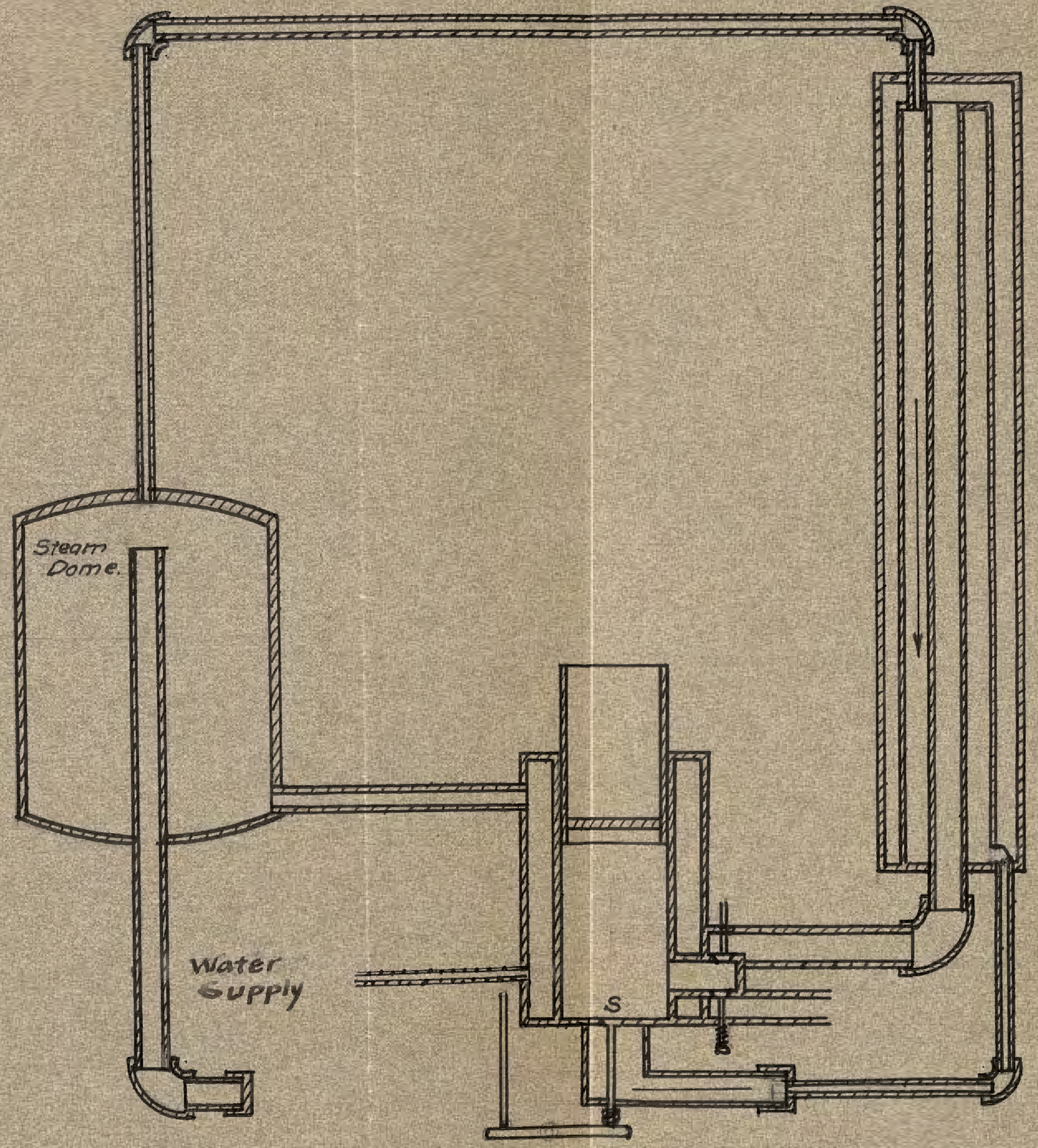
Figs. 1, 2, 4, 5. Steam card in first test.

Figs. 6+7 are normal gas cards.
Figs. 8+9 are gas cards taken when running on gas and steam.

Figs. 10+11 are steam cards in second test.

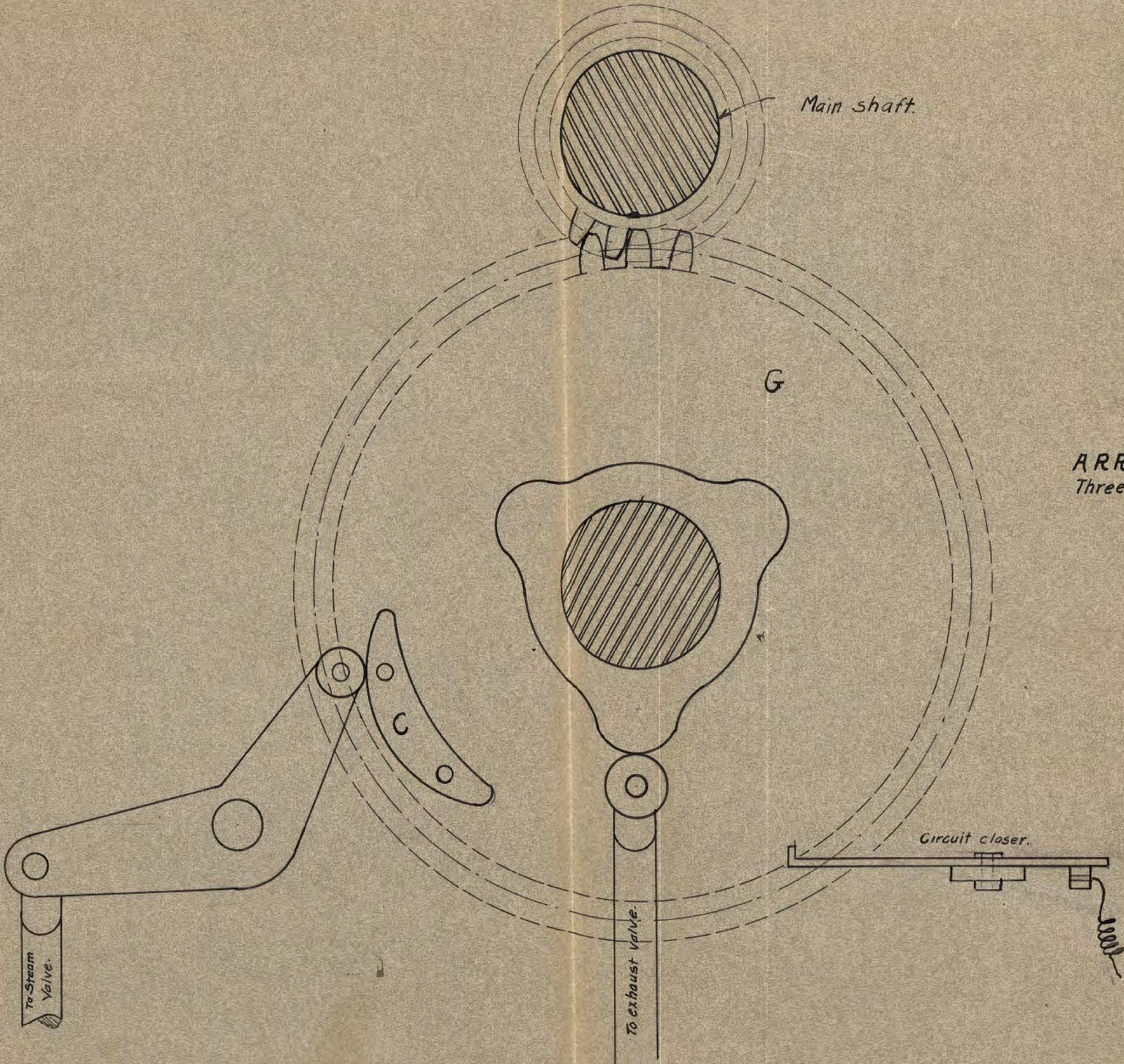


First Experiment. Fig 16



Second Experiment. Fig 12

ELEVATION SHOWING ARRANGEMENT OF ENGINE.



ARRANGEMENT OF VALVE MECHANISM
Three to one gear reduction.