7. *The Position of the Inlet-valve Lever Set Screw S.*

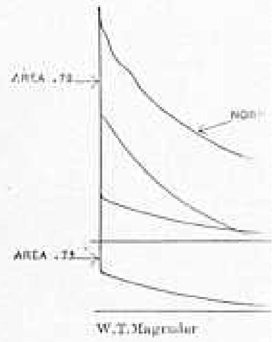
This set screw *S* caused the inlet valve to open at the beginning of the suction stroke. The spiral spring surrounding the spindle of the valve caused the valve to seat itself as soon as the motion of the set screw would permit. By lowering the set screw, it is evident that the valve was opened later and closed earlier, and the result on the engine was a decrease in speed. By raising the screw, thereby preventing the valve from spring-seating, the ignition was made much later and the speed of the engine decreased from 266 revolutions per minute to 200 revolutions per minute. On these cards, the word "normal" refers to the diagram which was taken under normal conditions, either just before or after making the special diagram, and was taken to make the comparison more marked. Figs. 301 and 302, Cards Nos. 7 and 10 of Run 146, show the effect of turning down the inlet-valve lever set screw, while Fig. 303, Card No. 6 of the same run, shows the effect of turning it up on the time of ignition and the areas of the cards. When turned up one turn, the inlet valve was never allowed to tightly close.

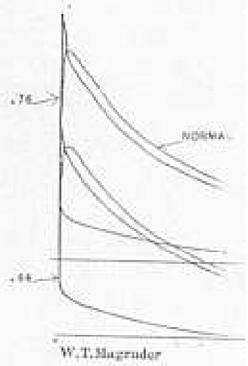
8. *Whether the Exhaust Valve Leaked or Not.*

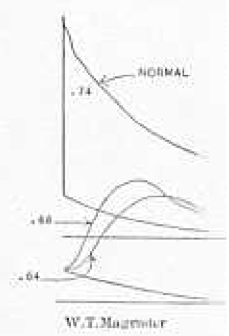
Figs. 304, 305, and 306, Cards Nos. 1, 2, and 4 of Run 150, show that the ignition was later when the handle was horizontal than when it was vertical, and that the effect of causing the exhaust valve to remain open even a slight amount during the entire stroke was to reduce the average mean effective pressure from 72.68 pounds, when the handle was vertical, to 62.175 pounds, when the handle was horizontal. The conclusion therefore is that any leaks about the inlet or outlet valves cause the ignition to take place later.

9. *The Temperature of the Jacket-water Outlet.*

Figs. 307 to 312, the cards of Run 149, would seem to indicate that at constant speed the higher the temperature of the jacket-water outlet the earlier is the ignition; but that with constant and excessive load, so that the governor hit every time and did not miss an ignition, the speed of the engine increased from about 180 revolutions per minute to 280 revolutions per minute as the temperature of the jacket-water outlet increased from 60







degrees Fahr. to 200 degrees Fahr., the inlet temperature being 49 degrees. With this highest outlet temperature, the amount of water circulating was so small and the valves were so nearly closed that any slight change in the water pressure, so as to produce a corresponding change in the quantity of water circulating, caused a marked decrease in speed.

10. *The Temperature of the Mixing and Ignition Chambers.*

Figs. 313, 314, 315, and 316, Cards Nos. 2, 3, 4, and 5 of Run 139 *BBB*, illustrate how the time of ignition gets earlier as the engine gets hotter, the speed and jacket-water temperatures remaining constant.

11. *The Speed of the Engine at Constant Jacket-water Outlet Temperature.*

Fig. 317, Card No. 30 of Run 148, shows that the time of ignition is earlier with the slower speeds, and that above 275 revolutions per minute with this engine, no change in time of ignition could be discovered. This latter result was probably due to a small change of crank circle arc at the dead centre not being easily calculated when measured by its diametral projection.

12. *The Temperature of the Hot Tube.*

It is self-evident that the hotter the hot tube, the more quickly will the gases be heated up and become inflamed, and therefore the earlier will be the ignition, and vice versa. Fig. 318, Card No. — of Run 139*AA*, illustrates the effect of a change in the temperature of the hot tube by a series of diagrams of consecutive ignitions, showing that the cooler the hot tube the later was the ignition. It should also be noted that each ignition curve starts from a different point on the compression line, and that the expansion lines and terminal pressures were higher the later was the ignition.

13. *Whether the Previous Stroke had been Missed or Not.*

Figs. 319 and 320, Cards Nos. 1 and 10 of Run 129; Fig. 321, Card No. 7 of Run 131; Fig. 322, Card No. 2 of Run 144; Figs. 323 and 324, Cards Nos. 6 and 7 of Run 155, illustrate the fact that, with a four-cycle engine with a hit-or-miss governor, and taking air every other revolution, the time of ignition is earlier after an ignition has been missed and the burnt gases have been scavenged by fresh air. These cards also show why it is that the gas consumption per indicated horse-power per hour is so much greater with frictional or light loads than with heavy loads.

It is shown in Fig. 325, Card No. 13 of Run 133, that, when using an air-inlet orifice as small as 1 inch in diameter, the diagram obtained after missing, even with the earlier ignition incident thereto, really produces more power on account of its larger supply of air than the succeeding charges with later ignition and a single supply of air.

14. *The Pressure of the Gas.*

Figs. 326 to 330, Cards Nos. 1, 2, 3, 4, and 5 of Run 127*B*, show that, with a constant quantity of air coming through a $1\frac{1}{2}$-inch air-inlet diaphragm, the time of ignition was earlier with 3-inch gas pressure than with either more or less gas pressure—that is, that the mixture so produced was more inflammable; but that the card with 8-inch gas pressure gave the greatest mean effective pressure.

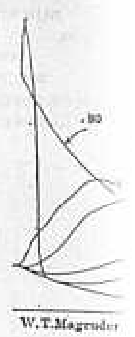
15. *The Position of the Gas-cock Handle.*

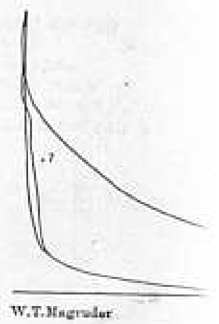
Figs. 331, 332, and 333, Cards Nos. 2, 3, and 8 of Run No. 145, show that, by changing the gas-cock handle from the wide-open position marked "10" to the positions marked "7," "6," and "5," respectively, the ignition was made earlier; that the areas of the diagrams, and therefore the mean effective pressures, decreased correspondingly; and that from a speed of 264 revolutions per minute with the gas cock at 10, the speed of the engine decreased to about 240 if the gas cock was changed to 7.

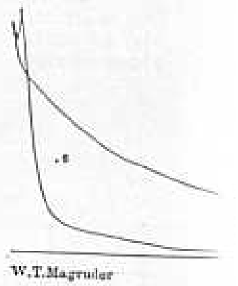
The conclusion therefore is that with less gas, for the given amount of air, the earlier is the ignition, within certain limits. Possibly, if later ignition could be secured—by shortening the hot tube, for example—the engine would give more power per cubic foot of gas used.

16. *The Size of the Air-inlet Diaphragm.*

Figs. 334 to 337, Cards Nos. 9, 10, 12, and 34 of Run 148, show the effect of changing the air-inlet diaphragm from $1\frac{3}{4}$-inch diameter to $1\frac{1}{2}$-inch, to $1\frac{1}{4}$-inch, and finally to 1-inch, as compared with cards obtained when there was no diaphragm in the







2-inch union in the air-inlet pipe, and the gas cock being wide open in all cases. The conclusion therefore is that with the gas cock wide open, to throttle the air supply caused the ignition to be later.

17. *The Pressure, or Suction, with which the Air was Delivered to the Engine.*

In certain of the 25 preliminary tests previously referred to, in order to vary the ratio of air to gas as much as possible, the air was either forced by a pressure-blower, or else sucked by the engine, first through an air meter, and then through a 6-inch galvanized iron pipe, to the 2-inch air-inlet union at the engine. A valve at the inlet to the meter enabled the desired suction or pressure to be obtained. The results then obtained confirm the results recorded in cases Nos. 14, 15, and 16, above, namely, that, within limits, the greater the air pressure the earlier is the ignition, and also that the greater the air suction the later is the ignition; in other words, that if the mixture be a lean one, the ignition is earlier; whereas if the mixture be a rich one, the ignition is later. In either case, the mean effective pressures of the diagrams and therefore the indicated horse-powers are less, and the consumption of gas per indicated horse-power per hour will be greater, than if the ratio is such as to give the proper mixture to insure proper timing of the ignition and the best combustion of the gas. By a "lean mixture" is here meant one in which the volumes of gas and air used are as one to eight; and by a "rich mixture," one in which the ratio is as one to four.

Lest the impression should be created that the irregular cards here presented are the usual thing with this engine, Figs. 338 and 339, Cards Ncs. 2 and 5 of Run 160, are added as fair samples of a very regular set of cards, and the following are the average results of the 30-minute run, No. 160:

Revolutions per minute	274.4
Explosions per minute	131.6
Ratio explosions to double strokes	95.92
Mean effective pressure	76.53
Indicated horse-power	8.63
Brake horse-power	6.46
Mechanical efficiency	74.93
Corrected gas per indicated horse-power hour	19.577 cu. ft.
Corrected gas per brake horse-power	26.129 cu. ft.

That these results are not unusual, reference is also made to Fig. 7 and 8, Cards Nos. 4 and 6 of Run 140, previously given, in which the diagrams were repeated or traced 13 times without removing the indicator pencil, and giving 7.50 indicated horse-power, 5.73 brake horse-power, a mechanical efficiency of 76.39, and a corrected gas consumption of 20.44 cubic feet per indicated horse-power per hour, or 26.76 cubic feet per brake horse-power per hour.

In English text-books on the gas engine it is stated that the use of the hot tube as an igniting device is to be preferred to electric ignition chiefly on account of the skill required in keeping up the batteries and keeping the platinum points in working condition. That electric ignition has its individual peculiarities and troubles goes without saying; and, when the proportion of air to gas is not right, that late, but not early, ignition is just as possible with electric methods as with hot-tube methods. It is well, however, to understand just what the internal ailments are which are likely to affect the open hot-tube method of ignition, and hence this study of the subject. It should be said, however, that it does not follow that all hot-tube ignition methods and mechanisms are subject to all of the troubles here isolated and described; or that any one engine is likely to be afflicted with all of these troubles at any time in its life. There are a few external ailments, such as not having the hot tube hot enough, which was mentioned above in case No. 12; not having the proper supplies of gas and air to the Bunsen burner of the hot tube, the asbestos lining of the chimney not being of the right size, the hot tube itself burning out or becoming filled with soot or tarry matter, or being cracked by drafts of air if of porcelain, and the like, which it is not the purpose of this paper to discuss.

It is thought that a fuller knowledge of the possible external and internal organic troubles of the gas engine will remove it further from the realm of uncertainty to a position where it may be more fully depended upon for economical running and continuous service.

DISCUSSION.

Professor Emory.—I would like to ask the name of the generator described in the paper.

Professor Magruder.—The maker prefers that I should not state.

Professor Emory.—At the place where this engine is used, it is greatly to be desired to have electric sparking, on account of the fact that the hot tubes are very liable to burn out, especially it would be one's luck to have them burn out when there is no attendant there. Several times this has happened in our plant, and some one has come in the nick of time to avert trouble. But the electric spark would be very much better in every respect. It seems to me that this special generator could be greatly improved by a very slight change in the cam arrangement, whereby the ignitions could be obtained at a sufficient point in the stroke to start the machine, and also to provide for ignition a little earlier as the machine comes to full speed. A number of the cards that are shown in the paper have been more or less duplicated by a number I have here from another machine, which show very materially the benefits of a slow explosion, that is, late burning rather than by an initial explosion followed by an attempt at adiabatic expansion. The test made was not sufficiently long to warrant the assertion as to the economy, but from a number of cards taken, the planimeters showed some wonderfully near approaches to the ideal card.

In most generators of the size mentioned in the paper, makers provide for both hot-tube and electric ignition. From the cards one sees that the ignition with hot tube is, as a rule, at instant of greatest compression and invariably at the beginning of the stroke. With the electric ignition this is very materially changed. In Card No. 1 (Fig. 340) of this discussion is shown the cycle of operations of a gas engine of $7\frac{1}{2}$ horse-power nominal, recently tested by me, showing the early explosion of a charge with the hot tube. It is not a selected card, but the average of a number of similar ones at full load. Card No. 2 (Fig. 341), is from the same, with all conditions the same, except the hot tube was replaced by electric ignition by turning the torchlight out and switching in the current. With the electric-firing card it is noticeable that ignition is very tardy; in fact, it is a case of "stern chase."

This appears as a defect in the electric-ignition apparatus which the manufacturers have overlooked, or, at least, failed to remedy. Its cause arises from the fact that the electric ignition is produced by a spark from electrodes which are brought together by the recoil of a helical spring actuating a hammer, which is released from a cam connected to shaft operated from the crank shaft. The cam is ordinarily set to release the spring just before the end of compression. The card above was taken with the cam set to do this when the wheel was run by hand at starting. When full speed is reached it is evident that the periodicity of the spring is too slow for the speed of piston, and the result is that with a position of cam which will start the engine there is too great a delay at full speed. Many attempts were made to start the motor with the cam set far enough back to give ignition spark at the beginning of the stroke, but the result was that a first explosion was obtained followed by one before the end of compression and reversing the motor and stopping the generator. Of course, with a starter of compressed air, the cam could be set so as to give an ignition at a desired point at full speed, but with small powers there is usually no starters considered necessary. In this case, however, its installation would be a great improvement. In many respects the electric ignition is to be desired.

Mr. Rudolph G. Schneble.—I have a few words to say on the hot tube, and that is that the hot tube depends on the amount of compression and on the reliability of the mixture which reaches the hot tubes. The hot tube must be so located that the mixture of gas and air which reaches it will be a good mixture every time—that is, one not contaminated with burnt gas and air, of which a certain amount always remains in the cylinder.

My experience with a hot tube has been mostly with an engine, where it was impossible to locate the hot tube to secure such a mixture to it. To lengthen, shorten, or to heat to a white heat would not help matters. The engine would not give over 75 per cent. of the power with a hot tube that it would develop with an electric igniting device.

I afterwards was consulted on the design of an engine, in which I suggested placing the hot tube directly over the top of the mixture valve (more often called the air valve), which would be over the chamber marked *B* in Mr. Magruder's paper, which entirely does away with the passage *D*. It gave a new and clean mixture to the hot tube each and every time. With such a mixture the tube need be heated but little over black hot, and I have known of tubes of common black iron pipe to last for six months, which is as long as composition tubes will last on some engines where the tube is not so well located.

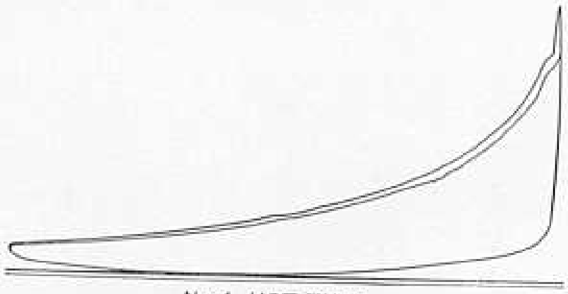
Then again, as to the electric device spoken of by Mr. Emory. I have designed different devices for changing the time of ignition for starting and running the engine, just by simply turning an eccentric or flipper up or down to give an early or late ignition, as we call it—an early ignition for the regular running, a late ignition for starting the engine. The late ignition gives a card like No. 2, shown by Mr. Emory. An early ignition would give a card not nearly so round at the ignition point, and give possibly a much higher initial pressure than Mr. Emory's No. 1 card.

Mr. E. W. Roberts.—I should like to make a few remarks on the subject of electric ignition. I have seen a great many electrically ignited engines in which the ignition was not at the time at which it should be according to the design or according to the timing device. That is what has been the greatest stumbling block to the gas-engine designer, and is known as back firing or premature ignition. It is due to a great many causes, the principal one of which is projections in the cylinder, within the compression space, and one of the principal causes of this trouble is the location of the igniter points, so that they become highly heated and act in the same way as ignition tubes. That is a point which does not seem to have been grasped by a great many gas-engine designers, and I have seen many gas engines in which the electric current could be turned off and the gas engine keep on running. Premature ignition is also caused by using a poor quality of oil, from which carbon is deposited either in flakes or in small cones. These become very highly heated and also act as ignition devices. The misunderstanding of these matters has been the cause of a great deal of objection to electric ignition.

Professor Magruder.—I would like to ask Mr. Emory if he has noticed any difference in the mean effective pressure and the indicated horse-power, if the upper card was slightly rounded and the ignition was slightly later?

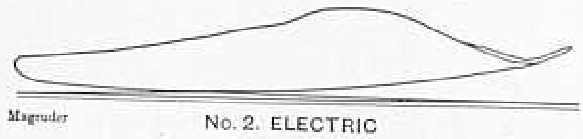
Professor Emory.—The tests of the engine have not yet been worked up, so I cannot speak positively about that. One thing was especially noticeable in those two cards: with the first card, with the hot tube, the speed was more fluctuating; there was apparently less gas used. With Card No. 2 (Fig. 341) the engine immediately began a labored effort, took more gas, and the explosions were not so violent. In every way there seemed to be a greater consumption of gas for less work done. In fact, the regular speed could not be obtained. The speed was not sufficient to work the governor. I think when giving Card

No. 2 (Fig. 341) no more than possibly 1 in 22 to 30 explosions were missed—about 22 to 30 explosions being required before reaching the desired speed. When giving Card No. 1 (Fig. 340) it would miss, on the load that we had, at least 1 in every 6 or 1 in 8. The late ignition gave a smoother performance, because the speed was more regular, and especially to be desired as it was used direct-connected by belt to a dynamo. It is not a very satisfactory type of electric connection. The engine mentioned has been put on the market to meet all conditions, but could be remedied in a very simple way, and so



No. 1. HOT TUBE

Fig. 340.



No. 2. ELECTRIC

Fig. 341.

make it an engine that can be started with less difficulty. The great difficulty in starting the engine is its chief fault. We hardly thought it was large enough to put in a pump and compressor to start. We thought we could start it by hand, and the manufacturers claim that we can, which is all true and all very well, if we are satisfied with so late an explosion as almost one-fifth or a quarter.

Mr. Roberts.—I think I can answer Professor Magruder's question. I recently had a talk with Mr. Burger, of the Woolley Manufacturing Company, at Anderson, Indiana, in which he claimed that he could do that; that from a round-top card he got a larger area than from one in which it was pointed.

Mr. Willis.—Can I ask the two gentlemen who have preceded, if they can give me information about the time of explosion in those engines, like the Hornsby-Akroyd, which have neither hot-tube nor electric ignition? Is that regulated by the distance through which the hot gases have to pass? Possibly Mr. Emory might answer the question.

Professor Emory.—I could not give any information on that which would be of any value at all.

Professor Magruder.—What I particularly referred to in my question you can see in Fig. 307, page 981. We have there two diagrams, one showing a sharp, instantaneous ignition and the other with a rounded top. I was desirous of knowing if others had had the same experience. Answering Mr. Willis, I would say that the Hornsby-Akroyd is an oil engine. The oil is injected into a large pot placed outside of the cylinder, and where it is gasified and ignited; and is quite different from a gas engine using a fuel already gasified.

Mr. Willis.—Those engines work with gas just as they do with the oil. They will make them to work on gas without the oil.

Mr. James A. Charter.—The paper treats very intelligently on the internal action of the engine, as well as the various causes which would have to do with the time of ignition when the hot tube is used. A timing valve in connection with a hot tube would, to a certain degree, make the point of ignition more positive, but the valves themselves are subject to wear, corrosion, and warping from heat, and have been found to be very unsatisfactory in practice, so much so that the Fairbanks-Morse engine has been fitted with a mechanically operated electric igniter.

The igniter is operated from an incline cam on the large gear, and by suitable mechanical connections motion is conveyed to a spring catch which is attached to an oscillating electrode. The construction of the igniter is simple, and therefore not likely to get out of order, and as it is strongly built it is not soon affected by wear. Platinum points are provided on the movable as well as the insulated electrode, therefore corrosion does not quickly affect the sparking points, and these igniters have been used on our engines, kept in constant service for a period of ninety days and nights without attention or adjusting.

It will be clearly seen that as the igniter is mechanically operated, the time of separating the points is the same at all times under all conditions; therefore, the charge in the cylinder is always ignited at a pre-determined time. The variation in the charge or the heat of the engine would only slightly effect the perpendicular explosion line. The point of ignition always remaining the same with an over-charged mixture (one having too much gas, for instance), the line would divert from a straight perpendicular on account of the slow burning of the charge, but the indicator card would clearly show the point of ignition having been kept practically constant, the same as when the mixture was an ideal one. The same might be said of the heat of the cylinder caused by the changing of the flow of water through the jackets.

The above described igniter receives its current from a primary battery of either the Edison-La Lande type, or a bank of standard carbon batteries used in connection with the spark coil for intensifying the spark. The above batteries are good for an ordinary run of six to twelve months without recharging, and the satisfaction which this igniter is giving to both the purchaser and the manufacturer is universal.

*Professor Magruder.**—Replying to Professor Emory, I would state that on most gas engines using electric ignition there is a starting cam whereby the ignition is made purposely late until the requisite momentum has been obtained, and then the cam is advanced so as to give an earlier and more effective ignition, so that compressed air for starting is not necessary—this is well shown in Fig. 304. If hot tubes are made of nickel-steel, the chances of their burning out are reduced to a minimum.

The troubles due to electric ignition do not form part of the subject matter of this paper, and further discussion of them should be postponed.

* Author's closure, under the Rules.