Some Measurements of the Piston Temperatures
in a Small Type Gasoline Engine*

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The piston temperatures of two 4-stroke agricultural engines and a 2-stroke motor cycle engine were measured accurately by means of the thermocouple method, in which the thermocouple-wires were connected with the moving piston and a fixed point without any joint on the way.

For this purpose we used the following two devices:
(i) The thermocouple-wires were put on a spring which was fixed to the piston skirt at one end and to the crank case wall at the other end.
(ii) A conduit containing the thermocouple-wires was movable with the piston through the combustion chamber.

With the former device, the measurement was carried out at the speed up to 4000 rpm for a 4-stroke engine of stroke 65 mm, and with the latter, at the speed up to 8000 rpm for a 2-stroke engine of 40 mm stroke.

1. Introduction

The abnormal combustion, the ring stick, etc. that were supposed to result from a high piston temperature have been an obstacle to the power up of the practical engine.

It is necessary that the absolute values of the piston temperatures are exactly measured during the engine operation, for the solution of such problems. But as for the high speed engine, there are no reliable values measured before.

For measurement of the piston temperature, the thermocouple method is the most exact and proper of all at present, but it has the following difficulties.

(i) How to connect the standing meter or the cold junction with the reciprocating hot junction.
(ii) How to minimize the effect of the measuring apparatus on the piston temperature and the performance of the engine.

On the item (i), with a low speed engine such as the diesel engine(1) or the kerosene engine(2), the measurement of the piston temperature was successfully made by the link mechanism formerly. But there are several faults even in this method. For instance, the wires are liable to snap on the links under violent bending and the link does not endure the test of time under large inertia. So
the limit of maximum usable crank revolution is about 1000 rpm, moreover it can be utilized only in the engine having a large space in the crankcase.

On the item (ii), in the high speed gasoline engine, the space for equipping the apparatus is small and the piston weight is light, too. Moreover it is necessary to consider the influences on the engine performance.

But it is impossible to do so unless an additional attachment is used, and it becomes necessary to select the measurement method according to the engine construction.

Especially for the 2-cycle small engine, the space in the crank case is narrow and the alteration of the crank case is not admitted, so it is necessary to devise a special measurement.

The principle of measurement in this report is similar to that of the link method, although it has been so improved as to be suitable for the high speed gasoline engine. For instance, a light loop spring was used instead of the solid link mechanism, or the thermocouples were directly led upward of the cylinder head in a conduit through the combustion chamber. By this means, it was made possible to measure the piston temperatures in the 2-cycle motorcycle engine of which an exact measurement so far had been impossible. In this paper, these measuring methods and their results are reported.

2. Methods of leading the thermocouple wire from the piston

2-1 Through the crank case 2-1-1 Outline

Fig. 1 (a) shows a general plan of the link method. A snapping of thermocouple wires happens at the links, for the bending parts are concentrated on them, even if the wires are made in loop lines at the links of A, B and C, and caution is taken to make the bending angles of each part at the loop lines uniform and small. Fig. 1 (b) shows a structure using a spring instead of the link mechanism. In this method, it was so devised as to cause the thermocouple to make uniform bend along the overall length of the moving part, to lighten its weight and to make the construction comparatively simple. Finally the practical limit of the engine revolution was set at 4000 rpm.

2-1-2 Construction Two air cooled 4-cycle farm type single cylinder gasoline engines with side valves were used. One was a GE-13 type having the cylinder bore 55 mm φ and the stroke length 55 mm. The other was a GE-25 type having 70 mm φ and 65 mm respectively.

Both the engine constructions were almost similar, the measuring apparatuses were also similar, but it was necessary to select suitably the form and size of the measuring apparatus, and the position and control of the stoppers according to the construction, size and piston speed of the engine.

Fig. 2 shows the measuring apparatus set up in the engine. The thermocouple wires were led from the measuring points of the piston to the outside of the crank case through the space between the balance weight and the connecting rod. A steel rod 5 was connected with the end of the steel piece 2 that was riveted on the piston skirt, and the spring 3 was fixed on one end of the steel rod and the other end of the spring was fixed on the standing place or the pivot 1; 5 is a control rod that gave the spring an inflexion point and stopped the spring from rolling, but permitted a moving in the direction of the arrow; 7 is the rubber stopper that restrained the increasing ampli-
tude due to the natural frequency of the vibration of the spring.

Five pairs of thermocouples were used at the same time, and they were stuck on the spring and led to the outside of the crank case through the slit ⑥. The spring motion was observed with a stroboscope and controlled.

Fig. 3 (a) shows the photograph of the piston of a GE-13 type engine on which the spring and the thermocouple wires were fixed. The spring was made of steel wire and ten thermocouple wires wrapped up in a small vinyl pipe were bound on it with strong string.

Fig. 3 (b) shows the static positions of the spring ⑤ and the action of the stopper. The stopper ⑥ only was used as the control equipment that pushed lightly the spring in the slits ⑤ by the screws ⑦.

Fig. 4 shows an example on a GE-25 type engine. In this engine, the piston stroke was so long that a flat spring, 0.4×4 mm, was used. The thermocouple wires were stuck on the spring with a bond having the flexibility after drying, and accordingly the fear of the insulation deterioration was decreased. But the spring system had a small natural frequency, so special attention was paid to restraining the extra movement of the spring, and then not only the control rod ③ but also the sponge stoppers ① were used.

2-2 Through the combustion chamber

2-2-1 Outline The method of leading the thermocouple wires along the spring through the crank case had the following faults. (a) It was difficult to select the ideal spring form and movement, because of the existence of the crank arms and the balancing weight near by. (b) Especially in a 2-cycle engine, the gas-tightness of the crank case was necessary and the changing of the crank case volume was not forgiven, therefore it is very hard to get the sufficient space to set up the spring system. In order to overcome such faults, the authors adopted the method of leading the thermocouple wires through the combustion chamber, as shown in Fig.1 (c), and the measurement of piston temperature was successfully made on the 2-cycle engine.

A conduit was fixed on the piston crown and moved together with the piston. The thermocouple wires were passed through the conduit and were led into a hole ⑩ along the spring and the roker arm as shown by dotted line.

The movement of the spring was forced by the circular guide, and ⑤ SRO was right angle and constant always. The gas-tightness of the combustion chamber was ensured by an O-ring. The O-ring and the conduit were cooled and lubricated by a liquid. So, there was little trouble of the wire snapping as happened in Fig.1 (a) and (b). But there were some points to be attended to in this method. That is to say: (i) It was necessary to select the liquid to be forced into circulation. And the positions of the O-ring and the accuracy in the manufacturing of the conduit were also
important factors. (ii) When the cooling of conduit was poor, the temperature of the inner wall of the conduit rose over 500°C, while the bond lost the adhesive power under such high temperature. So it was necessary to improve the method of insulating the wires and cooling of the conduit. (iii) There was a fear of influences of heating or cooling through the conduit on the small type piston.

2-2-2 Construction Fig. 5 (a) shows an example of the apparatus set on the cylinder head, and Fig. 5 (b) shows the engine and the measuring apparatus.

The test engine was a 2-cycle gasoline engine, whose diameter and stroke length were 40 × 40 mm, and the stroke volume was about 30 cm³. On the other hand, the conduit outside diameter was 3 mm, therefore the decrease of the stroke volume was 0.28 cm³ (0.56%) and the increase of the compression ratio was only about 0.02 (0.3%), so they were out of the question. The conduit (2) fixed on the piston crown reciprocated along the guide (3), its upper part was fixed with supporter (6). The gastightness in the combustion chamber was made perfect by the O-ring (4). The cutting oil was used as the cooling liquid and sent forcibly into the jacket (8) to cool the whole guide. Three pairs of thermocouples were passed through the conduit which was filled with the insulating bond. According to the apparatus, a snapping of the wire did not happen even at 8,000 rpm of engine.

Fig. 6 shows a mutual relation of the position of the indicator improved lately by the author. Fig. 7 shows comparisons of the indicator diagrams taken before and after the apparatus setting. From those figures, it was confirmed that the effect of the measurement apparatus set in the engine on the combustion was very small. The life of the thermocouple in this apparatus amounted to several hours at 6,000 rpm and nearly full load at present state, and then measurements were carried out with accuracy though they were painstaking.

3. Thermocouples and their insulation

3-1 Thermocouples The following items were required in using the wires which were led from the moving part: (i) They must be thin and strong wires, (ii) but somewhat thick lines are
needed to make the treatment easy and to get the high accuracy and the rectilinearity of the electromotive force with the temperature, (iii) since it is hard to assure perfect wire insulation, it is necessary to cool the conduit below a certain limit of temperature.

Considering the above items, we used 0.15mm diameter iron-constantan wires and insulated them with enamel and silk thread, but there was a still room for improvement.

3-2 Hot junctions Fig. 8 shows the hot junctions. For measuring the surface and inside temperatures of the piston, the calking of the silver solder used by many people in the past as shown in Fig. 8 (a) and (b) was employed. And for the inner surface temperature of the piston, a pit was made at the measurement point and the hot junction was put in it and the surroundings of it were calked as shown in Fig. 8 (c). Fig. 8 (d) and (e) show the thermocouple set near the inner surface of piston when the gas temperature was lower than about 250°C; it was convenient to set the thermocouple with a metal bond as shown in Fig. 8 (d). Fig. 8 (e) shows the fitting of the wires at a high gas temperature. The insulation of the wires was done also with the metal bond except the calking part.

3-3 Insulation on the way of wires The wires buried in the piston were fixed on some places of the inner surface of piston at a short distance from the wall and were led to the spring. In this case, when the inner wall temperature was comparatively low, the metal bond was used; when it was considerably high, a small screw and two mica pieces were used.

The success or failure of the measurement depended wholly on the quality of the insulation inside the conduit. The wires in the conduit were insulated with glass wool and the space between the wires and the conduit inside wall was filled up with.
the kaolin dissolved in silicone oil, and they were dried. When the inside wall temperature of the conduit was lower than 350~400°C, sufficient insulation was kept by this method. However, when the temperature was higher than 500°C, the adhesive power of the kaolin decreased extremely and the wires moved relatively, and then a deterioration of insulation or snapping of the wires happened. If the conduit was cooled more than needed, the fear would arise that the piston temperature might be decreased.

Fig. 9 shows the influences of the conduit position and the conduit cooling on the temperature of the tested piston of the 2-cycle motorcycle engine.

From the above result, it was proved that the influence of the existence or cooling of the conduit might be disregarded.

There was no heat trouble with the spring, for the temperature was always less than 100°C.

3-4 Method of leading the thermocouple from the piston rings Fig. 10 shows an example of the thermocouples set in the piston ring and the method of drawing them. Needless to say, there were the following problems in this method. (i) Wire snapping and insufficient insulation happened at the place between the ring and the ring groove. (ii) The high pressure gas leaked through the hole ① in the piston. The former was settled by shifting slightly the positions of the holes in the ring and the piston, and as for the latter, the diameter of the hole was made small enough and the bond was used to fill it up.

4. Examples of the measurements and discussion on them

4-1 Examples of measurement in the 4-cycle air cooled engines Fig. 11 shows an example of the measured results of the temperatures of
piston, cylinder wall and gas in the crank case that were yielded by the method of leading out thermocouple wires with the spring through the crank case of a GE-13 type engine.

The hot junction in the piston was located on the exhaust valve side, and its temperature was nearly the maximum value on the same circuit. From this result the following were known.

(i) At the lower speed, the temperature drop on the ring land was specially large but at the higher speed, it was very little. One of the reasons for such a fact was insufficient cooling of piston by the rings only and the other was decreasing in heat transfer between the rings and the cylinder wall; because according to a theory of piston ring lubrication, when the speed increases, the oil film thickness increases.

(ii) As the crown inner surface temperature was fairly high, it was supposed that the heat flow from the inner surface of piston was small.

(iii) The temperature of the upper cylinder wall was slightly higher than that of the piston. This showed that heat flow from the piston to the cylinder wall did not occur when the piston was situated near the T.D.C.

(iv) The oil film temperature on the first ring was estimated at 200~220°C.

Fig.12 shows an example of the measurements obtained with a GE-25 type engine. Comparing with Fig.11, we know the following.

(i) Both characteristics of the temperature distributions were almost similar, and the temperature rose remarkably as the output or revolution of the engine increased.

(ii) The heat flow from the ring was large.

(iii) The temperatures of piston and cylinder in a GE-25 type engine were fairly higher than those of a GE-13 type engine.

Fig.13 shows the temperature distributions of a piston ring and its surrounding wall in a GE-25 type engine. From the figure, the following were known.

(i) The ring temperature lay nearly between

![Diagram of piston temperatures and cylinder temperatures](image)

**Fig. 12** Piston temperatures and cylinder temperatures

![Diagram of ring temperatures and piston temperatures](image)

(a) 1/2 load
(b) 4/4 load

**Fig. 13** Ring temperatures and piston temperatures

![Diagram of piston crown temperature distribution](image)

**Fig. 14**
the piston temperature and the cylinder one.

(ii) In the ring, the temperature distributions of the upper surface and the lower surface were nearly the same and the value near the inner side was slightly higher than the other parts of the ring; that is, the value at the sliding surface was the lowest.

4.2 Examples of measurement in the 2-cycle motorcycle engine Fig. 14 shows the temperature distributions of piston obtained in the 2-cycle motorcycle engine by means of the thermocouple passed through the combustion chamber.

In the temperature distribution on the piston head, Fig. 14 (b), the temperature of the exhaust port was the highest. The whole characteristic of temperature was similar to that of the 4-cycle air cooled engine. However, the piston temperature was very high in spite of the smallness of the size of piston and the cylinder temperature was much higher than that of the 4-cycle engine, too.

5. Conclusion

(1) For the method of leading out the thermocouples along the free spring through the crank case, ample space is necessary in the crank case. The question is how to prevent the wire snapping, and the solution lies in controlling the spring motion adequately by using the stopper and cushion.

(2) When the method of passing through the combustion chamber is used, there is no fear of wire snapping, but the cooling, lubricating and electrical insulating of the conduit decide the limit of the usable engine speed.

For the measurements, however, there exists no invariably good method and the most suitable one should be devised to fit for all the conditions of the engine.

Lastly, the special features of piston temperatures measured by means of the methods mentioned above were as follows.

(a) The course of the heat flow from the piston is nearly the same as the results obtained already with a low speed large engine.

(b) The piston temperatures are much influenced by the revolution and output of engine.

(c) The piston ring is considered as the largest passage of heat flow and the heat flow from the inner surface of piston is small.

(d) The piston temperature in a 2-cycle engine is much higher than that in a 4-cycle one.

References

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