621.434-242:621.434.016.4

Piston Temperatures of an Automobile Engine*

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The piston temperatures of a Nissan-Automobile E-type 1200 cc gasoline engine were measured by the thermocouples, of which the lead-wires were passed through the combustion chamber and led to the stationary position. The influences of the piston speed, load, cooling water, ignition advance, knocking and mixture ratio upon the piston temperature were examined. The following was worth noticing.

(1) When the engine speed was 4500 rpm under full load, the maximum temperature was about 200°C at the center of the piston head.

(2) When the ignition timing was advanced, the piston temperature proportionally rose. Especially when knocking occurred, its maximum temperature reached 260°C, which was 60°C higher than that in case of the normal operation.

(3) With weak mixture ratio, the temperature of exhaust gas rose, but there was little influence upon the piston temperature.

1. Introduction

Concerning the high speed automobile gasoline engine as well as the other kinds of internal combustion engine, the thermal load of its piston has attracted great attention recently, and it is a foundation of all countermeasures to know the temperature distribution and also its absolute values in the piston of a working engine.

Among the usual techniques of the temperature measurement, the most reliable device is a thermocouple, but it cannot be applied easily to the moving piston. So the metal-hardness-method is also used widely, and it has the following characters:

- (i) It is convenient for knowing the qualitative temperature distribution.
- (ii) absolute value cannot be reliable, and
- (iii) the relation between the indicated temperature and the engine working condition is indistinct.

Therefore it is very important in using the metal-hardness-method, too, to know the accurate temperatures at the representative positions of piston under given engine conditions.

We succeeded in the measurement of the piston temperatures in a small 2-stroke motorcycle engine

by means of the following thermocouple method⁽¹⁾. That is, a conduit rod was fixed on the piston crown and moved reciprocally through the combustion chamber and cylinder head. Some thermocouple wires were led out from the piston to the stationary place, along in the conduit rod and then on the spring band. In this work, also this method is applied to a water cooled automobile engine, and the effect of engine revolution, output, spark advance, mixture ratio and knocking on the piston temperature are investigated.

2. Experimental apparatus and its method

2.1 Test engine Nissan-automobile E-type, water cooled gasoline engine, having 73 mm bore, 71 mm stroke, 4 cylinders and total stroke volume 1200 cm³, is used under the following normal test condition:

- (i) Cooling water temperature: inlet 65°C and outlet 75°C.
- (ii) Lubricating oil temperature: 85°C at the inlet of oil pump.
- (iii) Full load: the throttle valve full open, 1/2 load: half torque of full load at same number of revolutions.
- (iv) Spark advance: $\theta = 8^\circ$ BTDC at 600 rpm, idling.

Since the spark period is changed automatically with the engine speed and the boost pressure, we

* Received 30th November, 1962.

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change it by the amount of θ from the normal advance at 600 rpm, idling.

2.2 Leading out of thermocouple wires In Figs. 1 and 2 the route of the thermocouple wires and its exterior view are shown. The construction of the conduit rod, including its guide, O-ring and oil path, and its exterior view are illustrated in Figs. 3 and 4. In these figures the motion of the conduit rod is guided so closely through the O-ring retainer (1) and (2), that combustion gases are tightened by the O-ring (2), and the inner space formed between the O-ring (1) and (2) acts the part of oil jacket for cooling and lubrication.

A small piston P is fixed on the upper end of the conduit rod and the upper side of P is jointed with circular band B, the end of which C is connected with a bar D to the center of this circle of the stationary point E.

The thermocouple wires are led out from the piston along the inside of the conduit rod, through the route of P, B, C, D and center hole of E to a

stationary place. Therefore, in this route, the wires suffer only a bending on the band B and a torsion in the center of E.

In this test engine the measuring device involves some difficult problems and they are as

Fig. 1 Route of the thermocouples from stationary position to piston

Fig. 2 Assembled view of the apparatus

Fig. 3 Sectional view of guide of conduit rod in which thermocouple wires are contained with insulating material

Fig. 4 Disassembled apparatus

follows:

(i) The cylinder head has a so complex structure that seeking a space for the device is very difficult.

(ii) In order to protect the O-ring (2) from high temperature gases, its position must be high (l =large), but for cooling the conduit rod a lower position is required.

(iii) An electric insulation of the thermocouple wires in the conduit rod is the most important problem because of its very high temperature, so we must use a thermostable binding agent, porcelain clay and glass wool as insulator.

2.3 Other devices (i) The cylinder pressure is measured by a movable anode tube type indicator developed by one of the authors.

(ii) An excess air ratio λ of mixture is

determined by the concentrations of CO_2 and O_2 in the exhaust gases using a combustion triangle chart which is drawn on the assumption that the gases of CO and H_2 are produced due to imperfect combustion.

(iii) Hot junction of thermocouple is formed of a 1 mm dia. silver solder ball, containing each end of the 0.15 mm dia. iron and constantan wire, and it is calked in the taper hole on the piston or cylinder surface.

3. Experimental results

3.1 General temperature distribution of piston and cylinder As preliminary running, the test engine is run for 30 minutes at 2000 rpm, 1/4 load, at the beginning of every experiment, and during this period the temperatures of cooling water and lubricating oil are adjusted to the test condition, thereafter every measurement is begun.

Fig. 5 shows the transition piston temperatures as well as cylinder temperature. It is found that a sufficiently stationary temperature of each point is obtained after the preliminary running.

In Fig. 6, temperature distributions of the piston and cylinder surfaces are shown, where several

Fig. 5 An example of temperature transitions in the preliminary running period

Fig. 6 Temperature distributions of piston and cylinder wall

Fig. 7 The effect of temperature of cooling water

Fig. 8 The effect of engine revolution on the temperatures of piston and cylinder wall

Fig. 9 An engine performance at the full load

Fig. 10 Combustion triangle chart, for determining mixture ratio

measuring points of 1, 2, 3 or I, II and III are arranged to the exhaust manifold side, and both points of I and II indicate the positions of top ring at T.D.C. and B.D.C.

3.2 Effect of various factors on the piston temperature Fig. 7 shows that in the case of changing the water temperature by 20°C , the cylinder temperature also changes by 20°C , but the piston temperature changes by only 15°C .

According to Fig. 8, the temperature of piston or cylinder reach as any saturated value even when the speed is higher than 3500 rpm. This feature depends on the engine performance as shown in Fig. 9 and on the test conditions, that is, ignition advance and mixture ratio are shown in Fig. 10.

Fig. 11 shows the effect of the spark advance angle on the pressure indicator diagrams at every load and speed. Fig. 12 shows the effect of these combustion states on the temperatures of piston,

Fig. 12 Effect of load

Fig. 11 Some pressure indicator diagrams

cylinder and exhaust gas.

From these results, it is seen that the spark ignition advance is the most important factor to the engine performance. Therefore, at several advance angles changed intentionally from the normal angle θ° , we obtain the results as shown in Figs. 13, 14 and 15, and from these features we can find the following:

(i) The earlier the timing of spark ignition, the lower is the temperature of exhaust gas, although the higher temperature of piston and cylinder. That is a effect of ignition advance on the piston temperature is very large.

(ii) The lower the speed and the earlier the spark timing, the more knocking will result and the piston temperature will extremely rise.

(iii) Even if the knocking did not occur, the piston temperature rose in proportion to the earlier advance of spark ignition as shown in Fig. 14. The piston temperature is increased by knocking as well as early spark ignition. So we observed the effect of knocking by using fuels of different Octane numbers (O.N.) under a special condition of 2000 rpm and full load, where knocking is apt to happen easily. Knocking does not appear when a high

Fig. 13 Effect of ignition advance (at full load)

Octane number fuel (O.N.=87.7) is used, however, a low Octane number fuel (O.N.=79.4) generates knocking as shown in Fig. 16, Fig. 17 shows a remarkable influence of knocking on the piston temperatures, that is, the temperature rise caused by knocking reaches about 50 to 60°C.

Furthermore we carried out some experiments changing the mixture ratio by means of regulation of the main nozzle area in carburettor and keeping the spark advance in the normal setting.

Fig. 14 Effect of ignition advance (half load)

Fig. 15 Effect of ignition advance on engine output

Fig. 16 Pressure indicator diagrams when knocking (2000 rpm, full load)

In this case, exhaust gas compositions and excess air ratios are marked on the combustion triangle chart as shown in Fig.18. From these indicator diagrams shown in Fig.19, it is understood that knocking can not occur even with the leanest mixture ($\lambda=1.1$). According to Fig.20, the leaner mixture increases the exhaust-gas temperature because of a decreasing combustion speed, but unexpectedly there is little effect on the piston temperature.

4. Conclusions

In order to study the effects of several main

Fig.17 Effect of knocking on the piston and cylinder temperature

factors on the piston temperature of an automobile gasoline engine, we carried out some experiments considering the practical running condition, and obtained several conclusions as follows;

(i) To measure the piston temperature of

Fig.18 Compositions of exhaust gases, when the mixture ratio is changed

Fig.20 Effect of mixture ratio on piston and cylinder temperature

Fig.19 Effect of mixture ratio on combustion process

a water cooled high speed gasoline engine, our device, called the "combustion chamber across method", is found very useful, its life is several to 10 hours at 4 500 rpm of engine speed.

(ii) Temperature of each point in the test engine settles to a stationary value during 30 to 45 minutes from the engine start.

(iii) Changing the temperature (Δt) of cooling water, the cylinder is smaller than Δt .

(iv) With increase in the number of revolutions and the load, the piston temperature approaches a saturated value.

(v) The influence of the spark ignition

advance on the piston temperature is very large. The temperature increment is proportional to the advance angle.

(vi) The knocking increases the piston temperature by 50 to 60°C, and its maximum value is 250 to 260°C.

(vii) The effect of mixture ratio on the piston temperature is very small.

Reference

- (1) S. Furuham, T. Tada, and T. Nakamura: *Bulletin of JSME*, Vol. 7, No. 26 (1964), p. 422.

Discussion

O. HIRAO: I hold in high esteem the authors' efforts in measuring piston temperatures by thermocouple, but I would like to ask:

(1) What is the accuracy of getting air consumption by measuring the fuel consumption and the mixture ratio which is obtained from the exhaust gas analysis from exhaust?

Did you measure the air consumption separately?

(2) What is the reproducibility of the measured values of piston temperatures?

(3) I think the piston temperature of each cylinder will distribute in some range in a multi-cylinder engine. Have you any examples for a multi-cylinder engine?

T. MASUDA: This paper gives a valuable technique for the measurement of piston head temperature that will be influenced by the heat transferred from the cylinder gases to piston head. Especially, I was very much interested in the fact that the experiment has been made with a high speed automobile gasoline engine for practical use.

(4) It is generally known that the temperature of piston head is affected extremely by engine speed and brake horsepower. In Fig. 10, in proportion as the engine revolution increases, the temperature of piston head shows a saturation trend. This problem is discussed by the authors. Namely, according to their study, in proportion as the engine revolution increases, the engine brake horsepower is saturated because of this engine character. So do I think. However, I think the amount of splashing oil being thrown off from the crankpin is a major factor in the saturation trend of temperature. Because, as the engine revolution becomes higher, the amount of splashing oil on the piston is increased by centrifugal force.

M. YOSHIDA: I appreciate that the authors have measured the piston temperature at 4 000 rpm, using a special device. I want to ask the following:

(5) In Fig. 19, max. pressure decreases in accordance with knocking. What is the reason for this?

And knocking can not be observed in 37° spark advance.

What is the natural frequency of the indicator used?

(6) The relative position of ignition plug to temperature measuring is not clear. Is there not any relation between the temperature and the knocking zone?

(7) How about the fluctuation of the temperature at 2 and 3 under the constant condition of operation?

(8) Referring to Fig. 18, even in the range without knocking, the piston temperature with high O.N. is lower than that with low O.N. fuel. What is the reason for this?

M. MINAMI: I congratulate the authors on their new excellent measuring method of this complex subject. I have a few questions concerning the results given.

(9) I agree with the authors' result that ignition advance affects the piston temperatures seriously, because I have measured the relation between piston temperature and injection time of a low speed diesel engine. How were the cylinder gas pressures (or $dp/d\theta$) in the cases of Figs. 15, 16 and 18, especially in the case of Fig. 16 which shows no knocking?

Concerning the piston temperature, it seems, from those figures, that later ignition makes lower temperature.

How do the piston temperatures relate with the

gas temperature and fuel consumption?

(10) Fig. 22 indicates, it seems, temperature variation of cycle gas hardly affects the piston temperatures.

If so, may we understand that the piston temperature of gasoline engine is affected more sharply by the gas pressure (P_g) than by the gas temperature (T_g)?

Authors' closure

(1) The air consumption is not measured directly. The measurement of air consumption by means of exhaust-gas analysis is an informal method of course, but we can analyze accurately the exhaust-gases with careful sampling and procedure. On the other hand, if we attempt to use the orifice method, the carburettor must be taken in the buffer tank, otherwise the engine performances will be influenced by the measuring apparatus itself. So we believe that use of the gas analysis method for measuring the air consumption is justifiable within the limits of this study.

(2) The maximum difference is about 3 to 5°C practically.

(3) Regretfully, one piston only was measured, but in the case of cylinder wall, we found several degrees of temperature difference between cylinders.

(4) We concur with your opinion that the cooling effect of the splashing oil is not small, so we wish to have more study on this problem in the future.

(5) In this case, really, it is not full throttle running because knocking happens before the full open throttle valve when the spark advance is large.

When spark advance is 37°, also knocking appears in the indicator diagram though it is masked by the time-mark line. And natural frequency of this indicator is about 6 000 to 7 000 c/sec.

(6) The influences of the position of the spark plug and the knocking zone on the temperature distribution are regarded as very interesting themes, and we hope to study them in future.

(7) In this test, these fluctuations of the temperature did not happen.

(8) Using different O.N. fuels, even if in non-knocking combustion, also it is believed that the combustion process is changed in a certain amount.

Append-Fig. 1

(9) These indicator diagrams are shown in Append-Fig. 1.

The effect of spark advance is, just as you say, within the limits of this engine. Please refer to Fig. 13.

(10) If the mixture is leaned, the combustion phase is delayed just as the delaying of the spark timing, so that the gas temperature is decreased in the near T.D.C. and increased in the near B.D.C. And the heat transfer coefficient of the piston crown in the near T.D.C. is very large. Finally, the piston temperature with the leaner mixture is not high in spite of the rising exhaust gas temperature.