Thermal Deformation of the Clearance between Cylinder and Piston*

(The Case of an Air-cooled Two-stroke-cycle Engine)

By Yoshio MURAKAMI** and Soichi ISHIHARA***

The clearance between cylinder and piston of the internal combustion engine is expected to be deformed by heating in operation, and its thermal deformation is closely related to lubrication, cooling, friction and blow-by. To measure the thermal deformation of this clearance, an air-cooled two-stroke-cycle engine was chosen as an experimental engine.

The applied measuring method, called " Quick Stopping Method " by the authors, is practical because the thermal deformation can be easily measured by dial gauges. As a result of this series of experiments, it was revealed that local close-fit condition sometimes arose between cylinder and piston even in its normal operation.

(Internal Combustion Engine, Thermal Deformation, Two-stroke-cycle, Cylinder and Piston, Clearance, Dial Gauge, Measuring Method)

1. Introduction

Considerably large thermal deformation is often caused on the inner wall of a cylinder and the outer surface of a piston in the operation of an internal combustion engine. The thermal deformation, of course, causes blow-by, local wear, overheat, fluttering and stick of piston ring, scuffing, and increase of noise, lubricant consumption and friction loss. Therefore, the wall shape must be previously modified with consideration of the thermal deformation; a suitable cooling process must be taken and the lubricant must be circulated well. For this purpose, first of all, the extent of the thermal deformation of cylinder and piston must be measured and its character must be known, but all examples of measurements are either on the cylinder alone or on the piston alone up to this time.

Since the scavenge and exhaust ports of a two-stroke-cycle engine are controlled by the piston, the necessity of researching the thermal deformation in the two-stroke-cycle engine may be greater than that in the four-stroke-cycle engine. Accordingly, the thermal deformation of cylinder and piston was measured simultaneously on a two-stroke-cycle engine, and the authors have investigated how the clearance between cylinder and piston changes due to the thermal deformation. From the results the precautions, which should be taken in the measurement, and the characteristics of the

thermal deformation in this engine were made clear.

Dial gauges have been used for all of the deformation measurements until now, but it is impossible to attach the measuring tips of the dial gauges to the cylinder and the piston in the operating state of the engine for reason of the vibration and high speed movement of the parts to be measured. Therefore, three measuring methods have been developed for convenience, namely methods of reproducing temperature****(1)(2), heating by burner***** (3) and quick stopping of the engine(4).

In the quick stopping method the engine is stopped quickly by braking, the deformation process is measured in the time interval between this moment and the perfectly cooled state, wherein the deformation values immediately after stopping are taken as the values in operation. This method is very convenient for practical application because hardly any tooling and disassembling work is required for measurement, but there is some uncertainty in reliability, because the shapes immediately after stopping are regarded as those in the operating state. Namely, from the beginning of the procedure for engine stopping until the end of reading of the measured values we need 3 to 15 seconds to do different kinds of work. The longer this time interval is, the lower becomes the reliability of the measurement.

**** The deformation is measured on the cylinder or on the piston separately, which is heated by electric heaters and gas burners so that the temperature distributions are the same as those in the engine operation.

***** By installing a gas burner in the combustion space and exhaust ports in the wall of this chamber, the deformation is measured under assumption that the gas burner combustion is similar to the combustion in engine operation.

* Received 2nd October, 1982.

** Assistant,
Faculty of Science and Technology,
Meijyo University,
69-49 Yagoto-Urayama, Tempaku-chyo,
Tempaku-ku, Nagoya-shi, Aichi-ken.

*** Assistant Professor,
Faculty of Science and Technology,
Meijyo University,
69-49 Yagoto-Urayama, Tempaku-chyo,
Tempaku-ku, Nagoya-shi, Aichi-ken.

Therefore, the tolerable length of this time interval has been investigated by another experiment, in which the gas burner heating was applied. In this report, the experiment to investigate this time allowance is called the first experiment and the experiment for the main subject, i.e., the deformation of the clearance between cylinder and piston, is treated as the second experiment.

2. The First Experiment

2.1. Outline

This experiment was done to investigate the reliability of the second experiment and to compare the shape in operation with that immediately after stopping the engine. Namely, the subject of this experiment was to investigate the process of the thermal deformation of engine parts in the time interval from quick stopping after operation to naturally cooled state.

Therefore, a mock engine was made to reproduce the engine operating conditions without heavy vibrations, where by the combustion chamber was heated by a gas burner and the crank shaft was driven by an electric motor. Using this engine, the geometries and the temperatures were measured continuously from the operating state until the end of natural cooling.

2.2. Experimental Apparatus

The experimental apparatus is shown in Fig.1. The mock engine was made by modifying an actual engine specified in Table 1. The cylinder head is shown in Fig.2, in which the gas burner with a flame spreader is attached to the center of the chamber using the thread for spark plug and the exhaust ports are installed at a short distance around the burner. A suction blower is set downstream of the exhaust port to let the burned gas flow also to the exhaust port on the cylinder wall when opened by the piston. The piston is driven by a variable speed motor through the crank shaft.

Fig.1 Experimental apparatus (1)

The measuring points of the thermal deformations (displacements) and the temperatures are shown in Fig.3. The measuring points of displacement are situated outside the cylinder on the bottom surface of spot facing located at a distance of 3 mm from the inner wall surface of the cylinder. The displacements were continuously measured by dial gauges with automatic recorders. In this measurement the displacements were first detected as resistance changes in the transducers and then converted into electric current changes. It is necessary to pay attention to various things for exact measuring, but these are the same as in the case of the second experiment (described subsequently).

Table 1 Specifications of experimental engine

Use	General
Type	Two-stroke cycle
Number of cylinder	1
Bore x Stroke	60 x 58 mm
Stroke volume	164 cc
Scavenging type	Schnurle
Precompression	Crank case
Lubrication system	Mixing lubrication (25 : 1)
Cooling system	Forced air cooling
Compression ratio	6.5
Rating power	3.3 kw/4000 rpm
Material	Piston Aluminum alloy
	Cylinder Cast iron

Fig.2 Cylinder head

Fig.3 Measuring points of deformation and temperature (1)

2.3. Measuring Method

After firing the gas burner, the piston, the suction blower and the cooling fan in the apparatus were operated. The crank shaft rotation was set at 33 rpm to maintain the flames of the burner stable. The cooling fan speed was adjusted to keep the same indicated cylinder temperature as in actual engine operation.

The engine was stopped after a pre-fixed operating time, the measuring tips have contacted the cylinder when the engine was still running. The recording began in the running state and continued, until the engine cooled perfectly and no more deformation was detected. The engine stopping was made by either of two processes, namely, (a) after the engine had been stopped at B.D.C., the gas burner, the suction blower and the cooling fan were stopped at the same time; (b) all of the above mentioned stoppings were done at the same time.

2.4. Experimental Results

Examples of experimental results are shown in Fig.4 and Fig.5. Figure 4 is one by process (a) and Fig.5 by (b).

2.5. Consideration

To observe the process of the deformation by heat only with the time, the records by process (a) - Fig.4 - were found easier to examine. It was made clear by exact observation that the temperature began to fall immediately after extinguishing the gas burner; the deformation was kept, however, at nearly constant level until 15 seconds thereafter. Though the vibration caused by piston running appeared in the displacement recording, there was practically no change in the cylinder diameter with the time, which was calculated from the readings of one couple of measuring tips.

Fig.4 Experimental result (gas burner, suction blower and cooling fan stopped after engine stop)

Fig.5 Experimental result (engine, gas burner, suction blower and cooling fan stopped at the same time)

3. The Second Experiment

3.1. Outline

The quick stopping method was tried basing on the fact, that the thermal deformation was maintained steady until 15 seconds after extinguishing the fire in the first experiment.

3.2. Experimental Apparatus

The experimental apparatus is shown in Fig.6 and the specifications of the experimental engine are shown in Table 1. To measure the deformations, 8 dial gauges with a minimum division of 0.01 mm were set for the cylinder measurement and 6 other dial gauges for the piston. To measure the temperature 8 chromel-alumel thermocouples were attached on the inside surface of the cylinder. To prevent thermal deformations in the dial-gauge holding frame (iron pipe), a constant pressure cooling water was supplied through the frame pipe. The measuring tips of the dial gauges were made of invar.

Figure 7 shows the shape of the cylinder. Each measuring point of the cylinder displacement was situated on the surface of spot facing having a 6 mm diameter, which was located at the distance of 3 mm from the inner surface of the cylinder. Each measuring point of the piston displacement was situated on the outer surface of it, and for this purpose a 4 mm diameter hole was drilled through the cylinder wall. Measuring points for the dial gauges and the positions of the thermocouples are shown in Fig.8.

3.3. Measuring Method

3.3.1. Outline

Keeping the measuring tips off the engine in operation the engine was stopped quickly for measurement, and the measuring tips were instantly applied upon the

Fig.6 Experimental apparatus (2)

measuring points. The piston was stopped at a crank angle, at which the measuring points of the piston coincided with the holes on the cylinder, so that the dial gauge tips could contact the measuring points. The displacement was obtained as a difference between the indicated value of the dial gauge at the moment of being applied to the measuring point and that at the time of no deformation after perfect radiation. The displacements of the measuring points on the cylinder were converted into that of inner wall by the ratio of inner radius (30.005 mm) to the measuring point radius (30.005 + 3 mm).

Fig.7 Shape of cylinder

Fig.8 Measuring points of deformation and temperature (2)

3.3.2. Methods for Measurement

Within the period between the quick stopping and the start of measurement, the following work has to be done ; stopping of inertial rotation (quick braking), adjustment of the measuring tips and the measuring points of the piston (setting the crank angle), removing the exhaust pipe and applying the measuring tips upon the measuring points.

Accordingly, 2 methods as shown in Table 2 were employed considering the results of the first experiment and a preliminary experiment for the second experiment.

3.3.3. Inspection for Measurement

The results of inspection before the experiment were as follows.

(1) In the environmental conditions of this experiment no thermal expansion of the measuring tip itself was detected.

(2) In the environmental conditions of this experiment no thermal expansion of the dial-gauge holding apparatus was detected in the axial direction of the measuring tip.

(3) In the case of removing the exhaust pipe after quick stopping, each measuring point of the cylinder moved by 0.010 ~ 0.037 mm. However, the change of the cylinder inner diameter in this case was less than 0.005 mm.

(4) Two different shapes of the inlet pipe were used, so that the experiments could be made without hindrance; the rating power operation was, however, possible with each of both inlet pipes.

Table 2 Measuring methods

Full-circular-measuring method	Couple-measuring method
Using all dial gauges, the conditions at 13 s after the beginning of procedure for quick stopping of engine are measured.	Using 2 couples of dial gauges in one direction, each for cylinder and for piston, the conditions at 3 s after the beginning of procedure for quick stopping of engine are measured. Only for direction ②-⑥ the conditions were measured at 8 s instead of 3 s. To know the conditions on the full circle an engine operation must be done for the measurement for each of 4 directions.

3.3.4. Precautions to Be Taken in Measurement

(1) The city water is adequate as cooling water for the holding frame, but it must be supplied at constant pressure. (In the case of direct connection of the city water pipe with the holding frame, the frame will be deformed by the pressure change of the city water.)

(2) Steel can be used for the dial-gauge holding bar, but it must be set at right angles to the measuring tip, otherwise the cooling water will have to be poured on the holding bar which is wrapped with cloth. (The cloth is useful for softening the impact of water and for uniform cooling.)

(3) The bottom surface of the spot facing at the measuring point of displacement in the cylinder wall must be plane. (When the bottom is conical or rough, the measuring tip will receive lateral force.)

(4) In the case of the dial gauge being in the downstream of cooling air or in the vicinity of the exhaust pipe, it must be shielded with asbestos.

(5) To shorten the time required for various work, which must be finished between quick stop and start of measurement, the construction must be partly modified and special tools must be made available.

3.4. Shape of Profile

The inner diameter of the cylinder at normal temperature was 60.01 mm in all of the directions ① - ⑤, ② - ⑥, ③ - ⑦ and ④ - ⑧ at sections(A), (B) and (C) of Fig.8. The outer diameter of the piston and the clearance (difference between the inner diameter of the cylinder and the outer diameter of the piston) are shown in Table 3.

3.5. Experimental Results

3.5.1. Expression of the Results

The experimental results are given in Fig.9 and the terms and symbols are defined in Table 4, and the meaning of the clearance strain in Table 4 is shown in Table 5.

3.5.2. Experimental Results : Part 1

The engine was operated at rated power, and the thermal deformation in section (B) of the cylinder and in (b) of the piston was

Table 3 Outer diameter of piston and clearance at normal temperature

Radial direction	Section (a)		Section (b)		Section (c)	
	Diameter	Clearance	Diameter	Clearance	Diameter	Clearance
① - ⑤	59.71	0.30	59.81	0.14	59.90	0.11
② - ⑥	59.71	0.30	59.89	0.12	59.91	0.10
③ - ⑦	59.71	0.30	59.87	0.14	59.90	0.11
④ - ⑧	59.71	0.30	59.75	0.26	59.77	0.24

3.5.4. Experimental Results : Part 3

The operation conditions and the measuring sections were set in the same manner as part 2, the thermal deformation in operation (shortly before stopping) was estimated from the results of measurement by the couple-measuring method. An example of the results is shown in Fig.12. The estimation was done by extrapolation (extension of the plotted line) of the recorded curves in natural cooling process shown in Fig.13. Figure 14 shows the values of the strains of each section.

For comparison of the results by the full-circular-measuring method with those by the couple-measuring method, Fig.15 shows an example of the results indicating the values at 13 seconds after engine stop as picked up from the measured data. Figure 13 shows some examples of such data.

3.6. Consideration

(1) As shown in Fig.10, the thermal deformation data are scattered over a rather wide range. The scatter is especially remarkable in the direction ① - ⑤ . But the dispersion after 60 minutes of operation is comparatively small. After all, the reproducibility of the thermal deformation is not good except at this time.

(2) Comparing Fig.12 with Fig.15, the estimated values just before engine stopping and the measured values at 13 seconds after engine stopping are almost the same. From this fact it can be said that the measured results by the full-circular-measuring method (13 seconds after engine stop) can be considered to indicate the thermal deformation in operation in the case of using the dial gauges with minimum division of 0.01 mm.

(3) As shown in Fig.10 a close fit is seen in some directions at 5, 15 and 30 minutes of operation start. That is, up to about 30 minutes of operation start a partial close fit sometimes arises even if the engine is operated at normal rated power.

Fig.12 Estimated values in operation
(Couple-measuring method)

Fig.13 Example of deformation recording
after quick stopping

Fig.14 Strain in each section

Fig.15 Measured values at 13 s after
stopping (Couple-measuring method)

(4) As observed in Fig.10, the clearances are about the same in each direction at 60 minutes of operation start. It can be said, therefore, that this engine is designed to have the best clearance at about 60 minutes of operation start.

(5) As shown in Fig.14, the diameter strains in the sections (A), (B), and (C) of the cylinder are almost the same, while the diameter strain has the largest value in the section (a) of the piston and smaller values in (b) and (c). After all, the cylinder is deformed uniformly as a whole, but the nearer the position is to the crown, the more the piston is deformed.

(6) The cylinder inclines to the side receiving the cooling air during the operation. That is, as shown in Figs.11 and 12 the cylinder seems to expand to the lower temperature side receiving the cooling air, but from the fact that the cylinder diameter strain in this direction is not always large, it seems that the cylinder inclines.

4. Conclusions

A simultaneous measuring method of the thermal deformation in the cylinder and the piston has been established by using dial gauges. The reliability of this method was controversial because the geometries of the cylinder and the piston immediately after stopping were regarded as those in operation, but the doubt was dissolved by the results of the first experiment and of comparison of the full-circular-measuring method with the couple-measuring method in the second experiment.

The thermal deformation characteristics in rated power operation of a two-stroke-cycle engine were investigated by using this measuring method. As the result, the following was made clear.

(1) Up to about 30 minutes of operation start, a partial close fit sometimes arises.

(2) The clearance between the cylinder and the piston has the best conditions at about 60 minutes of operation start in the case of this engine.

(3) The cylinder inclines to the side receiving the cooling air in operation.

Up to the present the dimensions of the piston clearance have been determined by referring to the conditions and the results of investigations of wear, lubrication and permanent deformation after long operation. From now on, however, the reliability of the data will become higher and the time required for data collection will be shortened by this measuring method.

This experimental investigation was suggested by Professor Emeritus Kiyoshi Tomizuka of Tokyo University and many other people, and assisted by students of every school year of the Traffic Engine Laboratory of Meijyo University. We would like to express our gratitude to all who kindly contributed to our study.

References

- (1) Kazuo, S., Pre-print. Japan Soc. Mech. Engrs. (in Japanese), (Toukai, Hamamatsu) (1962-6), p.32.
- (2) Toshio, T. and Shoichi, F., Pre-print. Japan Soc. Mech. Engrs. (in Japanese), No.730-5 (the 50th General Meeting) (1973-4), p.1.
- (3) Naoji, M., Pre-print. Japan Soc. Mech. Engrs. (in Japanese), No.700-16 (the 48th National Meeting) (1970-10), p.55.
- (4) Kiyoshi, T., et al., Pre-print. Japan Soc. Mech. Engrs. (in Japanese), No.98 (the 41st National Meeting) (1963-10), p.55.