RESEARCHES ON THE PISTON RING.

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ABSTRACT

With a view of improving the piston ring, the amount of the radial pressure exerted by the piston ring on the cylinder wall was at first ascertained by means of a specially designed apparatus; to which piezo-electricity of quartz was applied so as to get the configuration of the pressure distribution.

Tests of the many sample pieces of commercial rings on markets, show that there is surprisingly a wide range of pressure irregularity which is naturally an undesirable function for the efficiency and maintenance of the engine.

In this paper, a ring which exerts a nearly uniform pressure on the cylinder wall is described and the maximum stress of the ring under working conditions is calculated mathematically, and a 3 HP four cycle horizontal Diesel engine which is in the laboratory in our Institute was used for the experimental researches in connection with the effect of the pressure of rings on gas tightness, as well as for determining the frictional resistance between the piston ring and the cylinder wall.

1. INTRODUCTION

Many papers⁽¹⁾ have been published in regard to the researches on the problem of the piston ring, but none has yet dealt with exact measurement of pressure exerted on the cylinder wall at any given point in the ring. Only the paper we can trace so far in this subject is Mr. Nakagawa's⁽²⁾ report on the determination of the relative distribution of pressure on the cylinder wall, but as the measuring method adopted therein appears, I think, to need further consideration, we have no exact idea obtained yet how the obturation of gas between the piston and cylinder is affected by the distribution of the radial pressure of the ring. Consequently the author of this paper has endeavoured to get an exact measurement of the pressure distribution by employing an apparatus of his own invention, and to investigate the conditions under which the ring exerts uniform pressure on the cylinder wall.

- (1) A. Inokuty, Journ. Soc. of Mech. Eng. Vol. 24, No. 65 (1921) 23~30.
K. Aichi, " " " " Vol. 25, No. 74 (1922) 51~59.
J. Prescott, The Autom. Eng. Sep. (1919) 295~302.
- (2) K. Nakagawa, Proc. Soc. of Nav. Arch. No. 14 (1914).

II. MEASUREMENT OF THE PRESSURE ON THE CYLINDER WALL.

i) Measuring device.

Mechanical methods were first introduced as shown in Fig. 1

Fig. 1

Fig. 2

and Fig. 2. In Fig. 1, a ring was compressed by applying external forces radially by means of levers on its peripheral surface, the diameter of the ring being exactly equal to the inner diameter of the cylinder. The pressure can be calculated from the readings of the weights hanging at the ends of levers. In Fig. 2, a circular hole is made in a cast iron circular disc such that the inner diameter is equal to that of the cylinder. Having put the ring to be measured into the position in the disc, an external force

is applied by a wedge shaped block. Any slight deflection of the ring is observed by rotating a small mirror M it is possible to plot a load-deflection curves of the ring. In case the peripheral surface of the ring exactly coincides with the inner surface of the disc, a discontinuity will distinctly appear on the load-deflection curve, and it shows the load at this point is balanced by the normal pressure exerted by the arc length QR of the ring. Following the similar method in succession by rotating the ring, we can determine the pressure distribution on the cylinder wall. The result is however not satisfactory owing to the inaccuracy of the measurement due to the enormous friction between the ring and the cylinder wall, so that the following conditions must be fulfilled in order to get correct figures.

(a) The pressure measurement of the rings must be entirely free

from the friction between the ring and the cylinder wall.

(b) : The inner surface of the testing apparatus must be so accurately machined as to form an exact right cylindrical surface of a given diameter. If there exists any irregularity of the surface, however slight, the pressure distribution will be affected accordingly.

Considering the mechanical methods may not very well satisfy these conditions, the author has attempted to apply the piezo-electricity on this subject. Plate I represents the apparatus for measuring the piston ring. In place of the cut in the cylinder wall QR , a piezo-electric crystal C is introduced, and the radial pressure exerted on the crystal by the corresponding part of the ring is determined by the amount of electric charge which is to be proportional to the change of the pressure on the crystal. A is a thick steel plate, having its inner surface well machined and finished with a grinder to a diameter identical with the inner diameter of the cylinder in which the ring is to be placed for use. B is a piece taken from the cut QR in the steel plate. C are two quartz crystals, each being 3.5 cm. in diameter & 1.2 cm. in thickness; a thin copper plate is inserted between them as to lead the electric charge produced on their surfaces; D are thin steel discs. B , C , and D are tightly held by four bolts E to the steel plate A , so that the crystals are initially compressed under a certain pressure. Thus the radial pressure on the segment QR exerted by the ring is completely borne by the crystals. The surface of the block B exactly coincides with the circumference of the inner surface of A and measures $2a = 127.08 \text{ mm}, \pm 0.008 \text{ mm}$. F are hemp or copper strips to adjust the

Fig. 3 Calibration curves of electroscope.

position of the ring and one of them is also used to set free the ring

from the block B so as to unload the crystals, and the change of the pressure on the crystals is measured by the amount of electric charge. Plate II shows the general arrangement; A is the testing apparatus shown in Plate I, G is Shimiz's sensitive electroscope⁽³⁾ and K is a group of storage batteries. The silvered quartz fiber of the electroscope is charged with 100~150 volts, one of the poles is earthed and the other is connected with the copper plate between the quartz crystals. To avoid the electro-magnetic induction the apparatus and lead wires are shielded in iron boxes and pipes, L .

ii) Method of observations.

To determine the pressure distribution, the outer surface of the ring is oiled and inserted in the apparatus above explained. The deviation of the ring from the normal central position to either side due to the friction between the ring and the cylinder wall is adjusted by pulling the hemp strips. Next, the zero point of the needle of the electroscope is fixed, the residual charge of the quartz being earthed, and then the ring is separated from the piece B and the deflection of the needle read. It does not matter how the pressure is taken off the quartz crystals, whether suddenly or slowly, the results are always independent of the ways treated. If we know the sensibility of the electroscope, which can be calibrated by loading or unloading a known weight on or off the quartz crystals, the amount of the total force F exerted by a small part of the ring corresponding to the segment may be obtained. It is confirmed by a series of careful examinations that such a simple method as using hemp strips is quite satisfactory for adjusting the deviation of the ring and for fitting it perfectly to the inner surface of the cylinder.

Let a and b be the inner radius of the cylinder and the height of the ring respectively, then the following relation can be obtained, assuming the intensity of radial pressure $p(\theta)$ on the segment $a\varphi$ is constant.

$$F = 2ba \int_0^{\frac{\varphi}{2}} p(\theta) \cos \theta d\theta = 2bap \sin \frac{\varphi}{2} \quad \text{or} \quad p = \frac{F}{2ba \sin \frac{\varphi}{2}}.$$

Then the intensity of pressure along the circumference of the ring is to be calculated from the observed value of F .

iii) Specimens.

Class $A-5'' \times \frac{5}{16}''$ Cast iron piston rings from a famous piston ring

(3) Japanese Journal of Physics. Vol. 1. No. 9, 10 (1923) 107.

manufacturer.

No.

1—Virgin ring.

2—No. 1 annealed at 300°C for 2 hrs.

3—No. 2 „ „ 8 hrs.

4—Virgin ring.

5—No. 4 annealed at 200°C for 3 hrs.

6—No. 5 „ 300°C „ 2 hrs.

7—No. 6 „ 400°C „ „

8—No. 7 „ 550°C „ „

9—Virgin ring.

10—No. 9 annealed at 600°C for 1hrs., the gap being nearly closed ; an external force being then applied and the gap again opened.

11—The ring after being used for half a year at the top of the piston of a Diesel Engine.

12— „ „ „ at the 3rd from the top of the piston.

13— „ „ „ at the 5th „ „

14—Virgin ring of half the height.

15— „ „ „ „

16—The compound ring combining Nos. 14 & 15.

17— $5'' \times \frac{5}{16}''$ Cast iron piston ring from another manufacturer.

Class *B*.—Piston rings made in our Institute ; the outer surface is finished by a grinder, the gap being clamped by tangential forces.

18—Virgin ring.

19—No. 18 annealed at 300°C for 2 hrs.

20—No. 19 „ „ 8 hrs.

Class *C*.—The rings were taken from a cast iron hollow cylinder with a larger diameter than that of the engine cylinder, and no other machining was done except slotting a required gap.

21—Variable thickness. (eccentric type).

22—Uniform thickness.

(Annealing process will be explained later).

iv) Results :

The results of measurement of the radial pressure distribution of the rings mentioned above (No. 1~22) are summed up in Talbe I and Plate III, in which we see that the rings (No. 1~16) belonging to the class *A* are subjected to three maximum pressures, namely one at the gap ends and the other two at approximately 120° from the gap ends.

It will also be noted there are three minima nearly opposite to the maxima. The mean pressure of virgin rings is 1.00 kg/cm^2 in round number. The ratio of the maxima to the minima varies as about 10 ~ 50. This irregularity may be avoided to some extent by combining two rings.

For example, rings No. 14 and No. 15 in Plate III have so much irregular distribution as illustrated, while it is considerably improved in the case of the compound ring No. 16, the ratio of the maximum to the minimum being reduced to 2. The rings (No. 18~20) belonging to the class *B* have nearly uniform distribution, the mean pressure being 0.914 kg/cm^2 , and the ratio of the maximum to the minimum is 1.7. On the other hand the rings No. 17, 21 & 22 have much irregularity of pressure as seen from diagrams No. 17, 21 & 22 respectively, having no pressure at all on the cylinder wall at several places.

III. EFFECT OF ANNEALING TEMPERATURE ON THE PRESSURE DISTRIBUTION.

It is not clearly known yet how the pressure distribution of the piston ring changes with the rise of temperature during the running of an internal combustion engine under load. The heat effect on the pressure distribution should surely be noticeable, and it must be taken into consideration when the ring is heated at a high temperature⁽⁴⁾, say 500°C . But it is of course difficult to get the measurement of the ring pressure on the cylinder wall in the hot state, so that the experiment was made on annealed rings with a change of temperature.

The annealing process is as follows. For annealing purposes a cast iron hollow cylinder is prepared, its inner diameter being equal to that of the engine cylinder, and the rings to be annealed are placed within it with graphite powder, and then heated to a required temperature in an electric resistance furnace for several hours.

Fig. 4 and No. 4~8 in Plate III show the effect of annealing, in which the mean pressure gradually decreases with the rise of the annealing temperature, rather rapidly beyond 300°C , and drops down to half the pressure of the virgin ring at about 500°C ; similar case is observed

(4) G. Asakawa, S. Isizuka & U. Hashimoto, Journ. Soc. of Mech. Eng, Vol 24 No. 63 (1921) 7-16; Vol 24, No. 70 (1921) 21-44.

T. Sahara & N. Sato, Journ. Soc. of Mech. Eng, Vol 25 No. 73 (1922) 35-70.

Sulzer, V.D.I. Bd. 70, No. 13, (1926) 429-436.

A.H. Gibson, Inst. of Mech. Eng, No. 2 (1926) 221-249.

in the class *B*. It is interesting that the configuration of the pressure distribution is not much affected by annealing below 400°C. The effect of annealing on the mean pressure is great for one or two hours, after which the time effect becomes weak. The rings were used for half a year in 6 HP four cycle vertical Diesel engine (bore 127 mm. × stroke 191 mm.) and show better distribution of pressure than the virgin ring as described in diagrams No. 11~13 in plate III, in which the

Fig. 4 Annealing temperature °C

maximum pressure at the gap ends is considerably reduced, slight depressions being formed at these ends.

The ratio of maximum and minimum pressures becomes smaller in the old ring and in the case of ring No. 11 it seems that the mean pressure is not reduced to 90 % of its original value. Observing the depression of mean pressure after annealing and comparing it with that of the ring No. 11, the highest temperature to which the old ring was subjected during months' running of the said Diesel engine would probably not exceed 250°C. If there had been considerable wear of rings due to the friction in the cylinder and fatigue of the ring material, this highest temperature might be over estimated. The course of the depression of pressure at the gap ends of the old rings is not very clear, but it may be the result of wear which took place especially at the gap ends owing to the oblique motion of piston in the cylinder during operation.

To ascertain whether these diagrams express the true characteristics

of the ring pressure, or in other words, to prove that the asymmetric distribution of pressures is not due to imperfection on the part of the apparatus; another measurement is taken for the pressure distribution of the ring No. 3 reversed. Here the result No. 3' is same as the former case, and so the diagrams of the pressure distribution shown before may be said to represent the characteristics for each ring. Next when the ring is put in and compressed within the cylinder, it must be under the equilibrium condition of forces, that is to say the pressures distributed as shown in the diagrams are in equilibrium. If so, the resultant of the distributed pressures would be Nil. Applying this consideration to the rings No. 3 & No. 20, the resultant forces are computed to be 1.94 kg. and 1.37 kg. respectively with their directions as indicated by arrows in the diagrams of rings No. 3 & No. 20 in Plate III.

These resultant forces are 5~7 % of the total radial pressure on the periphery, so that it may be said that the pressures distributed are nearly in equilibrium.

IV. STRESS CALCULATION OF THE PISTON RING.

The bending moment at any section of the ring which is placed into the engine cylinder may be calculated from the pressure distribution diagram obtained by the experiment, and the maximum bending stress is estimated as follows.

As a first approximation, the maximum stress in the tension side of the ring No. 3 is 1,997 kg/cm² worked out from the formula for curved beams, where the bending moment at the opposite side of the gap ends is 47.7 kg. cm, the radius of curvature in the unstrained state

Fig. 5

the bending moment of 47.7 kg. cm. calculated from the diagram of No. 3 is an admissible value for the working condition. Then the

6.514 cm, the thickness of the ring and the cross sectional area 0.420 cm and 0.334 sq. cm respectively. The bending test is made on several piston rings having the same dimensions as the ring No. 3 by gripping the opposite side of the gap ends and pulling the thin steel band attached tangentially. Then the maximum bending moment is found to be 110~120 kg. cm. at the breaking point, and it follows that

maximum stress, just determined mathematically, appears to be so excessive that the formula could not be used for the stress calculation of cast iron rings because of its being based on the perfect elastic substances. We have, therefore, to introduce here so called "Potenz Gesetz" $\epsilon = \alpha \sigma^m$, according to Bach, where σ , ϵ are stress and strain respectively and α , m are certain constants.

In Fig. 5

	initial	final
Radius of curvature at the external surface	ρ_0	ρ
Length of arc element	ds_0	ds
Angle subtending the arc element at the center of curvature	$d\varphi$	$d\varphi + \Delta d\varphi$
Half the thickness of the ring	t	
Height of the ring	b	
Distance of the neutral surface from the central surface..	e	
Strain of arc element distant η from the neutral surface ..	ϵ	

Then

$$\epsilon = \frac{ds - ds_0}{ds_0} = \frac{(\rho_0 - \rho - e) \eta}{\rho (\rho_0 - e + \eta)} \quad \dots \dots \dots (1)$$

Introducing the relation $\epsilon_t = \alpha_1 \sigma^{m_1}$ & $\epsilon_c = \alpha_2 \sigma^{m_2}$, in which ϵ_t & ϵ_c are tensile & compressive strain respectively, we obtain the stress for the tension side,

$$\sigma_t = \left[\frac{(\rho_0 - \rho - e) \eta}{\alpha_1 \rho (\rho_0 - e + \eta)} \right]^{\frac{1}{m_1}} \quad \text{or} \quad \sigma_1 (\text{max. stress}) = \left[\frac{(\rho_0 - \rho - e) h_1}{\alpha_1 \rho (\rho_0 - e + h_1)} \right]^{\frac{1}{m_1}} \quad \dots (2)$$

for the compression side,

$$\sigma_c = \left[\frac{(\rho_0 - \rho - e) \eta}{\alpha_2 \rho (\rho_0 - e + \eta)} \right]^{\frac{1}{m_2}} \quad \text{or} \quad \sigma_2 (\text{max. stress}) = \left[\frac{(\rho_0 - \rho - e) h_2}{\alpha_2 \rho (\rho_0 - e + h_2)} \right]^{\frac{1}{m_2}} \quad \dots (3)$$

From the equilibrium of the stress and the bending moment, the following two equations will be obtained,

$$\begin{aligned} b \sigma_1 \left\{ \frac{\rho_0 - e + h_1}{h_1} \right\}^{n_1} \int_0^{h_1} \frac{\eta^{n_1}}{(\rho_0 - e + \eta)^{n_1}} d\eta - b \sigma_2 \left\{ \frac{\rho_0 - e + h_2}{h_2} \right\}^{n_2} \int_0^{h_2} \frac{\eta^{n_2}}{(\rho_0 - e + \eta)^{n_2}} d\eta \\ = 0 \quad \dots \dots \dots (4) \end{aligned}$$

$$b\sigma_1 \left\{ \int_0^{h_1} \frac{\eta^{n_1+1}}{(\rho_0 - e + \eta)^{n_1}} d\eta - b\sigma_2 \left\{ \int_0^{h_2} \frac{\eta^{n_2+1}}{(\rho_0 - e + \eta)^{n_2}} d\eta \right. \right. \\ \left. \left. = M \dots \dots \dots (5) \right. \right.$$

where M is the bending moment at the section just considered, $n_1 = 1/m_1$ and $n_2 = 1/m_2$.

Then integrating the equation (4) and (5) and combining them we get,

$$b \left(\frac{\alpha_2}{\alpha_1} \right)^{\frac{n_1 n_2}{n_2 - n_1}} \left[\left(\frac{I_{s1}}{I_{s2}} \right)^{\frac{n_2}{n_2 - n_1}} I_{m1} + \left(\frac{I_{s1}}{I_{s2}} \right)^{\frac{n_2}{n_2 - n_1}} I_{m2} \right] = M \dots \dots \dots (6)$$

and

$$\sigma_1 = \left(\frac{\alpha_2}{\alpha_1} \right)^{\frac{n_1 n_2}{n_2 - n_1}} \left(\frac{h_1}{\rho_0 + t} \right)^{n_1} \left(\frac{I_{s1}}{I_{s2}} \right)^{\frac{n_1}{n_2 - n_1}} \dots \dots \dots (5)$$

$$\sigma_2 = \sigma_1^{\frac{n_2}{n_1}} \left[\frac{\alpha_1 h_2 (\rho_0 + t)}{\alpha_2 h_1 (\rho_0 + 2h_2 - t)} \right]^{n_2} \dots \dots \dots (8)$$

where

$$I_{s1} = \frac{1}{(\rho_0 - h_1 + t)^{n_1}} \left[\frac{h_1^{n_1+1}}{n_1 + 1} - \frac{n_1}{(\rho_0 - h_1 + t)} \cdot \frac{h_1^{n_1+2}}{n_1 + 2} \right. \\ \left. + \frac{n_1 (n_1 + 1)}{2 (\rho_0 - h_1 + t)^2} \cdot \frac{h_1^{n_1+3}}{n_1 + 3} - \dots \dots \dots \right]$$

$$I_{s2} = \frac{1}{(\rho_0 - h_1 + t)^{n_2}} \left[\frac{h_2^{n_2+1}}{n_2 + 1} - \frac{n_2}{(\rho_0 - h_1 + t)} \cdot \frac{h_2^{n_2+2}}{n_2 + 2} \right. \\ \left. + \frac{n_2 (n_2 + 1)}{2 (\rho_0 - h_1 + t)^2} \cdot \frac{h_2^{n_2+3}}{n_2 + 3} - \dots \dots \dots \right]$$

$$I_{m1} = \frac{1}{(\rho_0 - h_1 + t)^{n_1}} \left[\frac{h_1^{n_1+2}}{n_1 + 2} - \frac{n_1}{(\rho_0 - h_1 + t)^2} \cdot \frac{h_1^{n_1+3}}{n_1 + 3} \right. \\ \left. + \frac{n_1 (n_1 + 1)}{2 (\rho_0 - h_1 + t)^2} \cdot \frac{h_1^{n_1+4}}{n_1 + 4} - \dots \dots \dots \right]$$

$$I_{m2} = \frac{1}{(\rho_0 - h_1 + t)^{n_2}} \left[\frac{h_2^{n_2+2}}{n_2 + 2} - \frac{n_2}{(\rho_0 - h_1 + t)} \cdot \frac{h_2^{n_2+3}}{n_2 + 3} \right. \\ \left. + \frac{n_2 (n_2 + 1)}{2 (\rho_0 - h_1 + t)^2} \cdot \frac{h_2^{n_2+4}}{n_2 + 4} - \dots \dots \dots \right]$$

With these formulae we can determine the maximum stress in the

ring No. 3, assuming $\alpha_1 = \frac{1}{24,956,000,000}$, $\alpha_2 = \frac{1}{20,000,000}$, $m_1 = 2.623$ and $m_2 = 1.491$, and the results is $\sigma_1 = 1,200$ kg/cm². and $e/2t = 0.065$. (In the above calculation the effect of the normal compressive force on the cross section is neglected as it is very small.)

It may be seen that this value of σ_1 is still too large for working conditions and we shall try later to find α_1 , α_2 , m_1 and m_2 for the calculation of the maximum stress and to determine the position of the neutral surface.

V. ON THE GAS TIGHTNESS AND THE FRICTIONAL RESISTANCE BETWEEN THE RING AND THE CYLINDER WALL.

The pressure distribution of the piston ring on the cylinder wall having been ascertained, we now proceed to examine the relation between the gas tightness and the pressure of the ring on the wall. For this experiment, two kinds of piston rings are used, one made abroad and the other in our Institute, and the engine is a 3 HP four cycle Diesel engine having 89 mm. bore and 140 mm. stroke.

a_1 —Virgin rings, same kind as those of class *A* before explained.

a_2 —Same kind as a_1 but old having been used for a month; its outer surface was self ground and well fitted to the cylinder wall.

b_1 & b_2 —Virgin rings specially made in our Institute to produce uniform distribution of pressures but their outer surfaces were rough.

The amount of mean pressures was measured by compressing the ring with a thin steel band until the gap becomes just the same as when the ring was put into the cylinder. To reduce the amount of mean pressure the rings are annealed in a hollow cylinder, as explained before. The engine is driven with an electric motor and the maximum pressure at the end of compression stroke is measured by means of Dobbie McInnes spring indicator. The maximum pressure thus measured is plotted in Fig. 6 & Table II with regard to the number of revolutions, in which we see that this maximum pressure decreases with the number of revolutions. It will be noted that no distinct rise of pressure is recognized even if the number of rings be increased up to 3, 4 & 7. In order to compare the merits of rings for gas tightness more accurately, slow revolutions of the engine are preferable, and so the number of revolutions is kept to about 130~135 per minute, which is attained by hand starting. The inner surface of the cylinder and the piston rings are carefully washed with petrol to remove the lubricant ever used, and only one ring is placed at the top

Fig. 6.

of piston. The maximum compression pressure thus measured is seen in Fig. 7 & Table III, in which we see that the exact fitting of the ring to the cylinder wall is very necessary for gas tightness in the case where no lubricant oil is used. Next the ring is removed i.e. the piston

Fig. 7.

Fig. 8.

works in the cylinder with no ring and the maximum pressure is considerably reduced, this showing that even with one ring there is an abrupt increase of the pressure as we can see from Fig. 8 & Table IV. From this experiment it seems that the number of rings has not much effect on the gastightness and in the case of sufficient lubricant the pressure is about 20 % higher than that of the poor lubricant; the circulation of lubricant oil is very important.

We have examined the simplest case of gastightness by compressing the air when no explosion takes place in the cylinder and it will be more interesting if the action of rings is carefully studied in the working conditions, but the experiment is very complicated.

The frictional resistance of the piston rings of Diesel engine is generally large owing to the high compression maintained at the end of the compression stroke, and it will be interesting to examine how the frictional resistance of rings would compare in relation to the other frictional and mechanical loss. The 3 HP Diesel engine with the a_2 rings is driven by an electric motor, the cylinder cover being removed to prevent compression. The driving belt is suddenly taken off when the revolution of the engine becomes steady and the reduction of the rotation is recorded in relation to the time of running.

Now if w be the revolution of the engine at the time t from the beginning of the retardation, then we have $w = k'f(t)$ in which k' is constant. The relation between w and t is observed with the aid of a tuning fork and a drum by the well known process and is expressed in a very simple form thus $\sqrt{w} = \sqrt{w_0} - kt$ or $w = (w_0^{\frac{1}{2}} - kt)^2$, where w_0 is the initial rotation of the engine, 455 r.p.m. in our case. The results are plotted in Fig. 9 and Tables V & VI.

Table VI. Value of k

oil	no. of rings			piston only (k_p)	bearing only (k_b)	$\frac{k_7 - k_p}{k_7}(\%)$	$\frac{k_7 - k_{2,3}}{k_7}(\%)$
	7 (k_7)	3 (k_3)	2 (k_2)				
rich	0.192	—	0.150	—	0.050	—	21.8
poor	0.262	0.194	—	0.0974	—	62.8	26.0
none	0.281	—	0.199	0.0998	—	64.4	29.2

From this experiment the frictional resistance of rings is so large as about 60% of the total resistance. Nearly the same results on the

Fig. 9. Time elapsed when the retardation takes place (sec.)

car engines were reported in the Autom. Eng. Feb. 1925. pp. 48~50, thus the number of rings has a great effect on the mechanical efficiency of the engine. If the number of rings is reduced to three the total frictional resistance will be diminished about 25 %, and if the mean pressure of rings is reduced to one half, there will be considerable increase of mechanical efficiency of the engine.

VI. SUMMARY AND CONCLUSION.

(1) The absolute value of the pressure of the piston ring on the cylinder wall has been measured by the specially invented apparatus in

which piezo-electricity was used.

(2) The mean pressure is less than about 1.00 kg/cm^2 for the piston rings examined in our experiments.

(3) The pressure distribution becomes better after the actual use in the engine for a long period of time, even though it was irregular in the virgin ring.

(4) A new process of manufacture has been discovered for piston rings, and it is now a practical possibility to have a piston ring exerting a nearly uniform pressure on the cylinder wall.

(5) The configuration of the pressure distribution is not much altered by annealing in the cylinder below 400°C , while the mean pressure is very much reduced.

(6) The frictional resistance of the piston ring in the cylinder is pretty large, being about 60 % of the total frictional resistance.

(7) The amount of mean pressure and the number of rings, provided the ring is properly finished, have not much effect on the gas tightness, so far as our experiment was concerned.

In conclusion, I wish to express my cordial thanks to Dr. M. Ôkôchi under whose suggestion and constant guidance the present investigation was carried out.

Table I. Amount of pressure exerted by rings on the cylinder wall.

θAngular distance from one of the gap ends in degrees.

dDeflection of needle of the electroscope in cm.

FTotal force exerted on the quartz crystals by the piston ring in kg.

pIntensity of normal pressure per sq. cm.

bHeight of the ring.

tHalf thickness of the ring.

$$b = 0.793 \text{ cm}$$

$$2t = 0.406 \text{ " (mean)}$$

$$(0.379 \text{ " } \sim 0.423 \text{ "})$$

No. 1

No. 2

θ°	d (cm)	F (kg)	p (kg/cm ²)	d (cm)	F (kg)	p (kg/cm ²)	
0	4.27	4.48	1.84	4.00	4.20	1.72	
20	3.15	3.27	1.34	3.00	3.12	1.28	
40	1.47	1.48	0.61	1.18	1.19	0.49	
60	0.58	0.58	0.24	0.30	0.30	0.12	
80	0.30	0.30	0.12	0.40	0.40	0.16	
100	3.06	3.18	1.30	2.98	3.10	1.27	
120	4.40	4.62	1.89	3.70	3.87	1.59	
140	2.33	2.38	0.98	2.24	2.28	0.89	
160	1.54	1.56	0.64	1.96	2.00	0.82	
180	2.74	2.82	1.15	1.51	1.53	0.63	
200	2.83	2.93	1.20	2.58	2.66	1.09	
220	2.58	2.66	1.09	2.68	2.77	1.13	
240	3.09	3.20	1.31	2.80	2.90	1.19	
260	3.00	3.12	1.28	2.63	2.71	1.11	
280	0.90	0.90	0.37	1.00	1.00	0.41	
300	0.59	0.59	0.24	0.85	0.85	0.35	
320	1.52	1.54	0.63	1.23	1.23	0.50	
340	2.60	2.67	1.09	1.99	2.02	0.83	
p_{mean}			0.964	p_{mean}			0.865

No. 3

No. 3'

θ°	d (cm)	F (kg)	p (kg/cm ²)	d (cm)	F (kg)	p (kg/cm)	
0	3.50	3.54	1.45	3.68	3.61	1.48	
20	2.97	2.93	1.20	3.20	3.10	1.27	
40	2.18	2.14	0.88	2.05	1.94	0.80	
60	0.35	0.35	0.14	0.54	0.51	0.21	
80	0.35	0.35	0.14	0.47	0.42	0.17	
100	2.18	2.14	0.88	1.70	1.60	0.66	
120	4.00	4.10	1.68	4.51	4.52	1.85	
140	2.20	2.16	0.89	2.50	2.38	0.98	
160	2.05	2.01	0.82	2.14	2.02	0.83	
180	2.04	2.00	0.82	2.15	2.04	0.84	
200	2.43	2.42	0.99	2.70	2.58	1.06	
220	2.23	2.19	0.90	2.40	2.29	0.94	
240	2.64	2.61	1.07	2.70	2.58	1.06	
260	2.85	2.83	1.16	3.15	3.05	1.25	
280	1.08	1.05	0.43	1.06	0.98	0.40	
300	0.88	0.86	0.35	0.83	0.75	0.31	
320	1.32	1.29	0.53	1.42	1.30	0.53	
340	2.30	2.24	0.93	2.15	2.04	0.84	
p_{mean}			0.848	p_{mean}			0.857

RESEARCHES ON THE PISTON RING

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$$b = 0.793 \text{ cm}$$

$$2t = 0.417 \text{ " (mean)}$$

No. 4

No. 5

θ°	d (cm)	F (kg)	p (kg/cm ²)	d (cm)	F (kg)	p (kg/cm ²)	
0	4.21	4.56	1.87	3.40	3.59	1.47	
20	1.70	1.78	0.73	1.70	1.73	0.71	
40	1.43	1.49	0.61	1.31	1.33	0.55	
60	2.01	2.13	0.87	1.86	1.90	0.78	
80	1.50	1.57	0.64	1.78	1.81	0.74	
100	1.40	1.46	0.60	1.51	1.54	0.63	
120	4.70	5.10	2.09	4.49	4.76	1.95	
140	3.20	3.44	1.41	3.17	3.30	1.35	
160	0.71	0.73	0.30	0.41	0.41	0.17	
180	0.48	0.49	0.20	0.38	0.38	0.16	
200	1.35	1.40	0.57	0.75	0.75	0.31	
220	3.32	3.57	1.46	3.44	3.62	1.48	
240	4.07	4.39	1.78	3.54	3.74	1.53	
260	2.57	2.74	1.12	2.65	2.76	1.13	
280	2.23	2.37	0.97	2.10	2.16	0.89	
300	1.12	1.18	0.48	1.27	1.28	0.52	
320	2.10	2.22	0.87	1.70	1.73	0.71	
340	2.52	2.68	1.10	2.14	2.20	0.90	
p_{mean}			0.980	p_{mean}			0.888

No. 6

No. 7

θ°	F (cm)	F (kg)	p (kg/cm ²)	d (cm)	F (kg)	p (kg/cm ²)	
0	3.28	3.44	1.41	2.68	2.75	1.13	
20	1.88	1.94	0.80	1.83	1.84	0.76	
40	1.23	1.26	0.52	1.33	1.32	0.54	
60	1.70	1.75	0.72	1.19	1.18	0.48	
80	1.70	1.75	0.72	1.24	1.22	0.50	
100	1.72	1.76	0.72	1.53	1.53	0.63	
120	4.10	4.32	1.77	3.71	3.82	1.57	
140	2.90	3.04	1.25	2.93	3.00	1.23	
160	0.40	0.40	0.16	0.40	0.40	0.16	
180	0.33	0.33	0.14	0.34	0.34	0.14	
200	0.90	0.91	0.37	0.53	0.53	0.22	
220	3.30	3.46	1.42	2.87	2.94	1.21	
240	3.43	3.60	1.48	2.85	2.93	1.20	
260	2.40	2.49	1.02	2.01	2.04	0.84	
280	1.45	1.48	0.61	1.36	1.36	0.56	
300	1.20	1.22	0.50	1.23	1.22	0.50	
320	1.70	1.75	0.72	1.80	1.80	0.73	
340	2.25	2.36	0.97	2.20	2.23	0.92	
p_{mean}			0.847	p_{mean}			0.740

$b=0.793$ cm
 $2t=0.407$ " (mean)

No. 8

No. 9

θ°	d (cm)	F (kg)	p (kg/cm ²)	d (cm)	F (kg)	p (kg/cm ²)	
0	1.30	1.30	0.53	6.50	6.63	2.71	
20	0.80	0.80	0.33	2.53	2.60	1.07	
40	0.73	0.73	0.30	0.78	0.77	0.32	
60	0.60	0.60	0.25	0.65	0.64	0.26	
80	0.70	0.70	0.29	1.50	1.50	0.62	
100	0.75	0.75	0.31	2.50	2.56	1.05	
120	1.68	1.68	0.69	6.20	6.32	2.59	
140	1.29	1.29	0.53	2.61	2.68	1.10	
160	0.80	0.80	0.33	0.71	0.70	0.29	
180	0.33	0.33	0.14	0.22	0.21	0.09	
200	0.30	0.30	0.12	0.68	0.68	0.28	
220	1.33	1.33	0.55	3.16	3.25	1.33	
240	1.30	1.30	0.53	6.15	6.27	2.57	
260	0.42	0.42	0.17	1.90	1.92	0.79	
280	0.72	0.72	0.29	0.53	0.52	0.21	
300	0.60	0.62	0.25	0.88	0.87	0.36	
326	1.10	1.10	0.45	1.50	1.50	0.62	
340	0.80	0.80	0.33	3.00	3.08	1.26	
p_{mean}			0.355	p_{mean}			0.924

$b=0.795$ cm
 $2t=0.414$ " (mean)

No. 10

No. 11

θ°	d (cm)	F (kg)	p (kg/cm ²)	d (cm)	F (kg)	p (kg/cm ²)	
0	2.63	2.77	1.13	1.30	1.31	0.54	
20	2.53	2.66	1.09	3.00	3.17	1.30	
40	1.46	1.49	0.61	2.15	2.22	0.91	
60	1.11	1.14	0.47	1.10	1.10	0.45	
80	2.00	2.08	0.85	1.31	1.32	0.54	
100	2.02	2.10	0.86	2.30	2.38	0.98	
120	4.35	4.60	1.89	3.75	4.00	1.64	
140	2.78	2.92	1.20	3.68	3.92	1.61	
160	0.40	0.40	0.16	2.33	2.42	0.99	
180	0.10	0.10	0.04	1.65	1.68	0.67	
200	0.31	0.31	0.13	1.53	1.57	0.64	
220	2.05	2.14	0.88	2.35	2.43	0.99	
240	3.65	3.86	1.58	3.27	3.46	1.42	
260	2.30	2.41	0.99	2.00	2.06	0.84	
280	1.67	1.72	0.71	1.30	1.31	0.54	
300	1.67	1.72	0.71	1.10	1.10	0.45	
320	2.63	2.76	1.13	3.10	3.29	1.35	
340	2.18	2.28	0.93	1.97	2.02	0.83	
p_{mean}			0.854	p_{mean}			0.927

RESEARCHES ON THE PISTON RING

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$b=0.793$ cm
 $2t=0.420$ " mean
 No. 12

$b=0.793$ cm
 $2t=0.418$ " (mean)
 No. 13

θ°	d (cm)	F (kg)	p (kg/cm ²)	d (cm)	F (kg)	p (kg/cm ²)	
0	2.70	2.76	1.13	2.65	2.51	1.03	
20	4.01	4.18	1.71	2.97	2.83	1.16	
40	2.10	2.12	0.87	2.18	2.12	0.87	
60	1.40	1.39	0.57	1.80	1.67	0.68	
80	1.50	1.51	0.62	2.14	1.99	0.81	
100	3.48	3.61	1.48	3.00	2.86	1.17	
120	4.40	4.50	1.84	3.63	3.49	1.43	
140	2.43	2.46	1.01	3.20	3.05	1.25	
160	0.94	0.92	0.38	3.04	2.90	1.19	
180	0.75	0.74	0.30	2.49	2.34	0.96	
200	1.95	1.97	0.81	1.80	1.67	0.68	
220	4.75	4.86	1.99	2.38	2.24	0.92	
240	4.10	4.20	1.72	2.61	2.56	1.05	
260	1.48	1.47	0.60	2.57	2.43	1.00	
280	0.90	0.89	0.36	2.48	2.33	0.96	
300	1.30	1.29	0.53	1.60	1.47	0.60	
320	3.00	3.09	1.27	2.43	2.28	0.93	
340	3.50	3.60	1.47	3.78	3.64	1.49	
p_{mean}			1.03	p_{mean}			1.01

$b=0.397$ cm
 $2t=0.432$ " (mean)
 No. 14

$b=0.397$ cm
 $2t=0.389$ " (mean)
 No. 15

θ°	d (cm)	F (kg)	p (kg/cm ²)	d (cm)	F (kg)	p (kg/cm ²)	
0	2.20	2.07	0.85	2.39	2.67	1.09	
20	1.00	0.90	0.37	1.30	1.40	0.57	
40	0.85	0.77	0.31	0.65	0.67	0.27	
60	1.12	1.02	0.42	0.95	0.99	0.41	
80	2.05	1.92	0.79	1.51	1.62	0.66	
100	1.64	1.52	0.62	1.70	1.85	0.76	
120	1.60	1.49	0.61	2.20	2.44	1.00	
140	0.91	0.83	0.34	1.17	1.24	0.51	
160	0.31	0.28	0.12	0.05	0.05	0.02	
180	0.99	0.89	0.36	0.05	0.05	0.02	
200	2.43	2.29	0.94	0.65	0.67	0.27	
220	2.19	2.06	0.85	2.47	2.76	1.13	
240	1.35	1.24	0.51	2.05	2.26	0.93	
260	1.09	0.99	0.40	1.18	1.26	0.52	
280	0.78	0.70	0.29	0.78	0.81	0.33	
300	0.65	0.59	0.24	0.66	0.68	0.28	
320	1.30	1.20	0.49	0.89	0.92	0.38	
340	1.65	1.53	0.63	1.53	1.66	0.68	
p_{mean}			0.507	p_{mean}			0.502

$b = 0.600$ cm $t = 0.440$ " (mean)

No. 16

No. 17

θ°	d (cm)	F (kg)	p (kg/cm ²)	d (cm)	F (kg)	p (kg/cm ²)
0	2.28	2.54	1.04	4.98	5.92	3.00
20	2.27	2.53	1.03	0.02	0.02	0.00
40	2.90	3.32	1.36	0.15	0.15	0.08
60	2.27	2.53	1.03	1.25	1.39	0.71
80	2.12	2.34	0.96	2.02	2.30	1.17
100	2.17	2.40	0.98	1.18	1.13	0.57
120	2.55	2.88	1.18	1.73	1.96	1.00
140	2.55	2.88	1.18	1.86	2.12	1.08
160	2.65	3.00	1.23	0.87	0.94	0.48
180	2.33	2.60	1.06	1.22	1.35	0.68
200	2.13	2.36	0.97	3.29	3.98	2.02
220	2.03	2.24	0.92	1.35	1.50	0.76
240	2.00	2.20	0.90	1.70	1.92	0.98
260	3.28	3.89	1.55	1.77	2.01	1.02
280	2.63	2.97	1.22	1.17	1.30	0.66
300	1.89	2.06	0.84	1.57	1.76	0.89
320	2.05	2.26	0.93	0.80	0.94	0.48
340	1.03	2.12	0.87	0	0	0
p_{mean}			1.05	p_{mean}		
				0.914		

 $b = 0.793$ cm $2t = 0.392$ " (mean)(0.352 " $\sim$ 0.427 ")

No. 18

θ°	d (cm)	F (kg)	p (kg/cm ²)
0	1.64	1.67	0.74*
20	2.03	2.10	0.86
40	2.19	2.27	0.93
60	2.19	2.27	0.93
80	2.22	2.31	0.95
100	2.12	2.20	0.90
120	2.35	2.46	1.01
140	1.78	1.82	0.75
160	1.84	1.88	0.77
180	2.47	2.58	1.06
200	2.52	2.65	1.08
220	2.91	3.08	1.26
240	1.94	1.98	0.81
260	1.83	1.87	0.77
280	2.11	2.20	0.90
300	2.33	2.44	1.00
320	2.50	2.63	1.08
340	1.77	1.80	0.74
p_{mean}			0.822

(* These are corrected values for the excess clearance of the gap ends of this ring within the cylinder.)

RESEARCHES ON THE PISTON RING

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No. 19

No. 20

θ°	d (cm)	F (kg)	p (kg/cm ²)	d (cm)	F (kg)	p (kg/cm ²)	
0	1.30	1.36	0.61*	1.40	1.22	0.54*	
20	1.75	1.86	0.76	2.01	1.78	0.73	
40	1.86	1.98	0.81	2.15	1.91	0.78	
60	1.84	1.96	0.80	2.28	2.03	0.83	
80	2.01	2.16	0.89	2.24	1.99	0.82	
100	1.95	1.95	0.80	2.30	2.05	0.84	
120	1.68	1.78	0.73	2.00	1.78	0.73	
140	1.44	1.51	0.62	1.80	1.59	0.65	
160	1.66	1.76	0.72	1.75	1.55	0.64	
180	1.83	1.95	0.80	2.28	2.03	0.83	
200	2.04	2.19	0.90	2.63	2.36	0.97	
220	2.16	2.34	0.96	2.58	2.32	0.95	
240	1.45	1.53	0.63	1.96	1.74	0.71	
260	1.43	1.50	0.61	1.64	1.44	0.59	
280	1.65	1.75	0.72	1.91	1.67	0.69	
300	2.20	2.37	0.97	2.45	2.18	0.90	
320	2.20	2.25	0.88	2.55	2.28	0.94	
340	1.51	1.60	0.66	1.48	1.29	0.53	
p_{mean}			0.823	p_{mean}			0.756

 $b=0.798$ cm $2t=0.220$ " (min.)

0.503 " (max.)

No. 21

 $b=0.798$ cm $2t=0.460$ " (mean)

No. 22

θ°	d (cm)	F (kg)	p (kg/cm ²)	d (cm)	F (kg)	p (kg/cm ²)
0	1.32	3.84	1.57	5.82	13.2	5.40
20	0	0	0	0	0	0
40	0	0	0	0	0	0
60	0.42	1.24	0.51	0	0	0
80	3.14	9.23	3.78	0	0	0
100	0.36	1.06	0.43	0.08	0.26	0.11
120	0	0	0	1.77	4.08	1.67
140	0	0	0	0.29	0.56	0.23
160	0.53	1.58	0.65	0.45	0.94	0.39
180	0.90	2.66	1.09	3.19	7.21	2.95
200	1.35	3.95	1.62	1.93	4.46	1.83
220	1.20	3.47	1.42	0.59	1.28	0.52
240	0.44	1.28	0.52	0.80	1.80	0.74
260	0.84	2.48	1.02	0.93	2.10	0.86
280	2.41	7.08	2.90	0.05	0.18	0.07
300	0.46	1.36	0.56	0	0	0
320	0	0	0	0	0	0
340	0	0	0	0	0	0
p_{mean}			0.892	p_{mean} 0.820		

Table II.

Relation between the maximum pressure at the end of the compression stroke and the number of revolutions of engine.

No. of rings 3		No. of rings 4		No. of rings 7		Remarks
r.p.m.	max. press. kg/cm ²	r.p.m.	max. press. kg/cm ²	r.p.m.	max. press. kg/cm ²	
140	30.2	140	29.9	141	30.2	In all cases lubricant oil is poor
190	32.8	182	32.4	203	32.8	
236	33.4	247	33.4	247	34.3	
267	34.6	261	34.3	292	34.5	
308	35.4	300	34.5	324	35.5	
333	35.6	324	35.6	364	36.2	
353	36.1	365	36.2	390	37.1	
400	36.9	393	36.9	429	37.6	
414	37.4	414	37.3	455	38.2	
428	37.7	444	37.7	490	38.8	
462	38.0	462	38.1	521	39.0	
500	38.3	490	38.4			
521	38.6	510	38.7			
		522	39.0			

Table III.

Relation between the maximum pressure at the end of the compression stroke and the intensity of pressure of the rings.

kind of rings.	p_{mean} (kg/cm ²)	max. press (kg/cm ²)	r.p.m.	Remarks
a_1	0.948	25.9	130	In all cases lubricant oil is none
	0.912	26.0	"	
	0.604	25.2	132	
	0.257	25.4	134	
a_2	0.840	26.9	131	
	0.768	26.7	132	
	0.527	26.9	"	
b_1	0.619	35.8	132	
	0.562	35.9	"	
	0.413	35.8	"	
b_2	0.675	25.9	132	
	0.604	25.9	"	
	0.461	25.8	133	
	0.210	25.8	135	

Table IV.

Relation between the maximum pressure at the end of the compression stroke and the number of rings.

No. of rings	max. press (kg/cm ²)	r.p.m.	condition of oil
0	8.9	134	none
1	27.2	131	
2	27.2	130	
4	27.3	126	
6	27.2	120	
0	10.2	137	poor
1	28.8	134	
2	29.7	132	
4	29.9	131	
1	31.6	133	rich
2	33.2	133	
4	33.7	132	

Table V. (B)

Retardation of the angular velocity of the engine after the driving belt has been removed.

time(sec)	w (rad/sec) oil poor				w (red/sec) oil none	
	ring 3	ring 3	ring 7	ring 7	ring 3	ring 7
0	57.1	57.1	57.1	57.1	57.1	57.1
1	57.1	57.1	57.1	57.1	57.1	57.1
2	52.4	53.7	54.6	53.1	54.6	54.6
3	48.4	49.4	50.4	49.0	51.3	50.3
4	44.8	46.5	45.5	45.5	48.4	46.5
5	41.8	44.8	41.8	43.3	45.5	42.4
6	39.2	41.8	37.0	39.2	43.3	38.0
7	35.9	40.0	34.9	35.3	40.6	34.4
8	34.9	37.0	32.2	33.1	38.1	32.2
9	32.2	35.5	29.9	29.5	36.4	28.6
10	29.9	33.6	27.3	27.3	33.1	25.1
11	27.7	29.9	24.2	24.6	30.6	22.4
12	25.6	29.2	20.9	21.6	28.6	19.6
13	24.2	27.3	18.5	19.3	26.7	17.9
14	21.3	25.1	16.5	17.2	25.1	—
15	19.6	23.2	—	—	21.6	—
k	$k_3=0.194$		$k_7=0.262$		$k_3=0.199$	$k_7=0.281$

Table V. (A)

time(sec)	w (rad/sec) oil rich			
	ring 2	ring 2	ring 7	ring 7
0	57.1	57.1	57.1	57.1
1	57.1	57.1	57.1	57.1
2	54.6	54.6	54.6	55.7
3	52.4	52.4	52.4	52.4
4	50.4	51.3	49.0	50.4
5	48.4	48.4	46.5	48.4
6	46.5	47.4	43.5	44.8
7	44.1	44.8	41.8	41.8
8	42.4	43.3	39.2	39.2
9	40.6	40.6	37.0	37.0
10	39.2	39.2	34.9	34.9
11	37.0	38.0	32.2	32.2
12	34.0	34.9	30.6	30.6
13	33.1	33.1	28.2	28.6
14	31.4	31.4	26.2	26.2
15	—	—	24.6	24.2
k	$k_2=0.150$		$k_7=0.190$	

Table V. (C)

time(sec)	w (rad/sec)		
	besring only	without ring	
		oil poor	oil none
0	57.1	57.1	57.1
2	57.1	57.1	57.1
4	54.6	52.4	54.6
6	53.1	49.0	50.6
8	52.4	46.5	48.6
10	50.4	44.8	44.8
12	48.4	41.8	41.8
14	47.4	39.2	39.6
16	46.5	37.0	38.0
18	44.8	34.9	35.5
20	43.3	32.2	32.2
22	42.4	30.6	29.7
24	40.6	27.3	28.0
26	39.2	25.3	25.3
28	39.2	23.7	24.2
30	37.0		
32	35.5		
34	34.9		
36	34.0		
38	33.1		
40	31.4		
k	$k_b=0.050$	$k_p=0.0974$	$k_p=0.0998$

Plate I. Measuring apparatus

Plate II.. General arrangement

Plate III. Diagrams of the pressure distribution of piston rings.

$\begin{cases} p_{mn} = \text{mean pressure in kg/cm}^2 \\ r = \text{ratio of the maximum and minimum pressures.} \end{cases}$

	p_{mn}	r
○.....No. 2	0.865	14.4
●.....No. 1	0.964	15.7

	p_{mn}	r
●.....No. 3	0.348	12.0
○.....No. 3'	0.857	10.9

	p_{mn}	r
○.....No. 4	0.980	10.5
●.....No. 6	0.847	12.6
⊙.....No. 7	0.740	11.2
⊖.....No. 8	0.355	5.8

	p_{mn}	r
○.....No. 9	0.924	30.1
●.....No. 10	0.854	47.3

P_{mn} r
No. 11 0.927 3.7

P_{mn} r
No. 12 1.03 6.6

P_{mn} r
No. 13 1.01 2.4

P_{mn} r
●....No. 14 0.507 7.8
○....No. 15 0.502 56.5
⊙....No. 16 1.05 1.9

P_{mn}
No. 17 0.914

	P_{mn}	r
○.....No. 18	0.822	1.7
●.....No. 20	0.756	1.8

No. 22 P_{mn} 0.820

No. 21 P_{mn} 0.892

質 疑 討 論

會長(新波忠三部君) 此の御講演につきどうぞ御質問討論を御出し下さることを望みます。斯る問題に付きましては、一方ラボラトリーに於てなされた研究の結果と、又實地に日常御携りになつて居る方々の御意見と色々戦はし合ふと云ふのが、我々學會の目的であります。又御経験になつたことなり、御意見なりを御提出さるることが講演者に對して敬意を表する所以であると思ひますから、どうぞ御提出を願ひます。

平田君 プレシユアを一定にする爲に何か加工すると云ふことですが、どう云ふ風にやりますか。

海老原敬吉君 それは井口先生が數年前に機械學會の會誌に發表せられた論文中にあるプリンスプルを實際に應用するに際しまして井口先生の考案せられた工作方法とは全く異つた方法に依つて製作を試みたものであります。即ちギャップを閉ぢますのにフランヂを用ゐずにピンジョイントを用ゐまして共に其の外側のみなクラインダーによつて仕上げたのです。

朝倉希一君 ユニフォーム シツクネスになつて居りますか。

海老原敬吉君 殆どユニフォームです、實際は計算の場合に肉厚が這入つて居りませぬ、本當に委しく計算しますれば御承知の通り肉厚が這入つて來る譯であります、肉厚の不均一の割合は直徑に比して極めて僅かなものですから、出來上つたリングが多少肉厚に不同が有りましては壓力分布の上に及ぼす影響は殆んど無いのであります。

繩野君 リングをアンニール致します時に自然の状態ではおやりになりませんでしたか。

海老原敬吉君 總てシリンダーと同一の内徑を有する圓筒の中に入れて、焼鈍いたしました。

菱田錦吾君 アンニールする場合の時間の影響は....

海老原敬吉君 先刻申落しましたが時間は始めの一、二時間位が有效でありましてそれから後は餘り影響がない様に考へられます。實驗は八時間までしかやつてありませんが。

仲谷新治君 ちよつと御伺ひ致しますが、御實驗になりました外國品は、亞米利加製のものです。

海老原敬吉君 理研で製作いたしました以外のものは總て米國製のリングで内側は鑄放しの儘で粗いものですが材質は組織細く非常に強力です。

仲谷新治君 ハンマードリングに就いての御實驗は....

海老原敬吉君 それは各種の直徑のリングに對する裝置を作りまして追々にやつて見る考へです。

仲谷新治君 それからディーゼルエンジンのピストンリングの数が七個と云ふのは多過ぎるから、四個にした方が宜からうと云ふ御話がありました。私は新潟鐵工所に居りますのですが、私の所で十時位のピストンへ矢張り四個位のピストンリングを入れて作つて居りますが、大變成績が良いやうに思ひます。私が英吉利に居ります時に、或るエンジニアとの話の時に、どうも從來のピストンリングの数が多いやうに思ふ、それで先程御話のやうにリングの数を一、二個減らした方が確かに良い成績が得られ、それに依つて燃料の消費量を減ずることも出来る、今までの所謂ディーゼルエンジンの燃料の消費量を 〇・四六と云ふやうに云つて居りましたものを、ピストンリングを減らすことに依つて、〇・四三にする、或は〇・四二まで下げることが出来ないかも知れませぬが、兎に角可なり下げることが出来る、と云ふので約二年前からそれを實行して居り

ますが、唯今御話下さいましたことと非常に能く一致して居りますので大變結構に感じました。それからピストンリングを製造しますのに、先程のと同様の方法によりまして英國及丁抹の大きなディーゼルメーカーに於て製作して居りましたが、今の御話を伺ひまして、私の見、或は考へて居たことと同じでありまして、大いに共鳴した次第であります。

・海老原敬吉君 唯今の御話に依りまして、ピストンリングの数を減らした方が宜いと云ふ御話は、丁度私のやりましたのと大變能く似て居りますが、之に付きましては更に實際の場合に就いて永い間試験して見たいと考へてゐます。

加藤君 幅に付ては....

海老原敬吉君 自分の唯今の考へと致しましては、幅は廣い方がスタビリティがよくピストンの溝とリングの間にガタが出来てもリングはよく汽笛壁に密着してゐられる様に考へますが餘り判然とは申上げ兼ねます。

朝倉希一君 私は機關車の方から申上げますが、南獨逸では幅の廣いのを使つて居りまして大變自慢を云つて居りますが、北獨逸でそれを使ひまして、段々調べた結果、矢張り細い方が宜いと云ふ議論になつて居ると云ふことであります。どうぞ實驗をなさるなら、さう云ふことを一つ御研究を願ひたいと思ひます。結局細い方が宜いと云ふので、我々は細いのをやつて居ります。

浅川權八君 ピストンリングの數に付きまして、色々の御話がありまして、又デイスカツションの内にもピストンリングの數は四個が宜いとかと云ふ風な斷定的な御話もあつたやうに承りますが、此數と云ふものは、中々重大な問題でありまして、さう一遍に定るべき性質のものではなからうと私は設計上思つて居ります。それは先程斯波博士からも御話がありましたが、此ピストンリングは、一つのピストンが完全にパッキングの作用をするものでなく、それから續いて段々と瓦斯の漏洩を防ぐものであるから、或る數が必要だと云ふことは分る譯ですが、エンジンの實際に於ては、どうしても一番上のピストンリングは附着いて仕舞つて用を爲さなくなり、第二、第三、第四が追々に役立つて来る。後にはオイルリングがある。是はピストンとシリンダーとの間に餘り油が餘計供給されると云ふことは、エンジンの實際に於て非常に悪い、出来るだけ少量にすべきものであると云ふので、殊にディーゼルエンジンの如きは、其シリンダーオイルでも完全に燃焼せしめ得るやうな機關でありますから、シリンダー内に於けるルブリケーションと云ふことに付ては、非常に注意するのであります。其爲に實際使ふ油の量が少く計算されたと云ふ例もあるのであります(一概にさうも云へませぬが)、そんな風な次第でありますから、一番下のピストンリングなどは、ピストンヘッドの方には餘り油が行かない爲に、或る程度に油を搔落す寧ろ瓦斯の漏洩を止めると云ふことよりも油を或る程度以上に上げないやうにする、といふ風にして行きますと、まあ四本では到底間に合はない、少くとも四本以上六本位はあつても差支へないかと考へて居ります。で御議論の根據と云ふものは、ピストンリングが汽笛壁との摩擦によつて非常にメカニカルロスを増くするといふので是は御説の通りでありまして、ピストンリングの張りの強いものを使ふ時に著しいものでありますから、此ピストンリングの張りと言ふものが適當に選ばれ各部分へ壓力が出来るだけ平等に配布されると云ふことでありましたならば、ピストンリングはそれ程強いものを使はなくてもよい。實際に於ては〇・二キロ位のものを使ふことは稀でないでありますから、リングの張りを成るべく少くして汽笛壁に對してユニフォームプレシユアを與へるやうに作ると云ふことが、エンジン設計の要諦ではないかと考へて居ります。さう云ふ風な工合に平等に配布するやうな方法を講じまして、ピストンリングを作つたならば、比較

的弱いしなやかなリンクでも随分タイトネスが得られると云ふことは、先程の御研究の結果にもありました様に思ひますが、之は大變に結構な要領を得た御實驗と考へます。リンクの張がそれ程強くなくとも、タイトネスは可なり得られる。殊に一本のピストンリンクでも一樣に良く當つて居ればリーケージは或る程度まで防げると云ふことでありまして、此ピストンリンクの各部分が機關の運轉中十分によく當つて居るか居ないかと云ふことに依つてリンクの數といふ事も自然に決まつて來るのではないかと考へます。それから次に井口先生のピストンリンクの御講演がありました以來、池貝鐵工所では種々研究の結果、先生の論文の通りのピストンリンクを作りました、十時内外のやうなものを作りましたが非常に能く立派なものが出來ました。次に壓力分布の測定に就いては今まで實際測る方法が不完全でありまして、私共今から十年ばかり前に外國のインターナル、コムバツション、メーカーを英吉利、亞米利加邊りを見物いたしました、何處も其時分には不完全でありまして、何れもスプリングで測るとか、レバーで測るとかと云ふことが、最も良い方法と考へられて居りまして、今日承りますと、ピエゾエレキの應用によつて、各部分の壓力の強さを測ることが出來ると云ふことは、内燃機關の會社、及び實地の方面に對して、如何に大なる知識を與へたことであらうと、公益を廣めたことと云ふことに付きまして、私は感謝すると同時に、其意味に於きまして、自分の經驗を附加へた次第であります。

仲谷新治君 先程私がピストンリンクの數に付て四個が宜いと云ふことの斷定を下したやうに御話のやうでしたが、それは唯私の所で十時の四個のものを作つて居ると云ふことであつて、それが總ての種類の方にさうであることが宜いと云ふ積りで申上げたものではございませぬ。それからピストンリンクの位置即ピストンリンクがコムバツションチエムバーと何の位離れてゐるのが一番良いかといふ事が問題になると思ひます。これは又先程のリンクの數といふ問題に對しても重大な關係を持つてゐる様に考へられますので、その方面に對しても御研究を進められる様に切望致す次第です。先程の言葉が足りませぬでしたから一言附加へて置きます。

海老原敬吉君 ピストンリンクの張りの強さ及數の問題に就きましては、先程申上げました様に本日御話し致したのは基礎的の實驗でありまして、更に立派な機關を以つて充分永い間試験を行ふ必要があると信じます。淺川先生及び仲谷技師から色々有益なことを伺ひまして、益々其感を深くした次第であります。

會長(斯波忠三郎君) まだ或は御説を御述べになる方も御有りになるかも知れませぬけれども實驗の裝置が彼處に陳列してあるさうでありますから、それを御覽になる爲に、幾らか時間の餘裕があつた方が宜いと思ひます、尙ほ此上に御討論なり御説の御有りの方は御寄稿下さることも宜からうかと思ひますので、先づ今日は此程度で止めたいと存じますが、散會に先だちまして例に依りまして一言いたしたいと思ひます。海老原君は私の承知して居る所に依りますれば、七八年前でありましたか、藏前の機械科を御卒業になり、後更に東北大學に御入學になつて本多博士の下に御研究になつて居つたやうに記憶いたして居ります。又昨今理化學研究所に於て、工學的研究に従事されて居るのであります。此工學的研究と云ふことは、我々工學者に取りまして、最も必要なことであります。從來此方面はどうかすると閑却されて居つた。研究者も随分ございしますが、研究に従事されて居る方は、どちらかと云ふと、純理科に屬するやうな研究をやる方が多い。工學的研究、即ち實地と親密な關係を有つて居る工學的研究をやる人は比較的少いのを遺憾として居つたのであります。幸に海老原君の如き、殊に機械工學出身であり、其の上理科を修業されて、現在理化學研究所に於て、工學方面の研究に従事されて居ると云ふやうな方の如き

は、我々の最も理想とする研究者の一人であると考へます。其人に依つて最も面白いインジェニアスな方式で、ピストンリングの汽筒壁に及ぶ壓力分布のメジユアメントが實行され、其結果を今日我々機械學會の會員の前に御披露下さいまして、洵に一同非常な利益を得たことと存じます。之に付きまして又新潟鐵工所の技師であり且此ことに携つて居られる主仕技師たる中谷新治君から、實際方面に關する最も面白い御報告がございましたことに付きまして、承りますれば、外國のディーゼル機關のメーカーに於て井口先生の豫れて機械學會に御發表になつたのと同じプリンシプルに依つて作つて居ると云ふことは、我々機械學會員として多大の趣味を以て拜聴したのであります。又淺川博士は從來此方面にける深い御研究の方で、又有益なる御説を御發表のあつたことに付きましては、講演者と共に深く感謝する次第であります。今日の御講演は洵に有益に我々感じたのでありまして、一同拍手して講演者に謝したいと思ひます(一同拍手)

(附記。本講演に對する討論は非常に多くありましたが都合によりまして大分省きました。

御諒承を乞ふ。)