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On the Scavenging of Two-Stroke Diesel Engine*

(Scavenging Process in Cross-Scavenging System)

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This paper reports the results of an investigation on the scavenging process in a model cylinder having a cross-scavenging system. The movement of the scavenge front in the cylinder and the short-circuiting of fresh charge were investigated by an electronic method⁽¹⁾.

The profile of the scavenge front was made clear. The port arrangement investigated here gives a flat scavenge and an early short-circuiting occurs at the exhaust ports located near the scavenging ports. A poorly scavenging region exists above the exhaust ports.

Introduction

In the past few years studies of the scavenging process in the cylinder of two-stroke Diesel engines having various scavenging port arrangements have been carried out, and the previous reports have described the scavenging characteristic of the loop—and uniflow—scavenging system⁽¹⁾⁽²⁾.

Up to the present, static investigations to find the flow pattern of air stream inside the model cylinder of a cross-scavenging system under the simplified conditions of steady flow were carried out by many investigators. In actual engines, however, no detailed informations have been obtained as to how the residual gases in the cylinder of the running engine are displaced by a fresh charge.

In the present study, the advance of the fresh charge in the model cylinder of a cross-scavenging system was investigated by means of an electronic technique based on the dielectric properties of gases under the scavenging condition similar to that in an actual Diesel engine. Furthermore, the steady flow pattern of air stream inside the cylinder was observed and it was compared with the advance of the scavenging front.

Apparatus and method

Test equipment

Fig. 1 shows a schematic diagram of the test apparatus. The model cylinder has a bore of 288 mm and a total length of 506 mm, similar to an actual cylinder having a bore-stroke ratio of 1.7. It

has the following port timing :

Exhaust port opening..... $\alpha_e = 59^\circ 30'$ before B.D.C.

Scavenging port opening..... $\alpha_s = 45^\circ$ before B.D.C.

The port arrangement is shown in Fig. 2†.

The piston travel is restricted to the bottom half of the cylinder, at most 144 mm from B.D.C., and controlled by means of the crank and clutch mechanism at any desired moment as mentioned in the previous paper⁽¹⁾.

In order to make clear how the residual gas is replaced by the fresh charge drawn in the cylinder by the depression created in the exhaust pipe, the exhaust control valve G is operated at the same time as the scavenge opening by the cam H driven by chains from the crankshaft.

Test method

To know how the residual gas is replaced by a fresh charge at various portions in the cylinder, it is required to record the instantaneous content of a fresh charge at any point in the cylinder, which varies as the scavenging proceeds. Thus, an electronic method based on dielectric properties of gases was applied, which was almost the same as described in the previous reports⁽¹⁾⁽²⁾, although Freon No. 22-CO₂ mixture was used as a fresh charge instead of NH₃, where Freon No. 22†† content amounted to 30±5%, and CO₂ was used as a residual gas.

† This cylinder has an arrangement similar to that in the engine manufactured by Nordberg Co., illustrated in P.H. Schweitzer's "Scavenging of Two-Stroke Cycle Diesel Engines" published by the Macmillan Co. New York, (1949).

†† In the previous test NH₃ was used, but it had a heavy smell, and moreover reacted on Cu-alloys. Thus, in this experiment, Freon No. 22 gas was used instead of NH₃. Freon No. 22 gas has less dielectric constant than NH₃, therefore gives less sensibility. The dielectric constants are as follows:

1.007 for NH₃ gas at 1 atm, 16°C

1.003 for Freon No. 22 gas at 0.5 atm

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A: eccentric shaft, B: connecting rod, C: driving shaft, D: lever, E: clutch, F: negative pressure vessel, G: exhaust control valve, H: camshaft, I: pressure indicator, J: disk, K: phototransistor, L: lamp, M: fresh charge reservoir, P: piston

Fig. 1 Schematic diagram of model engine

Fig. 2 Model cylinder

α_1	36.5°
α_2	67°
α_3	92°
α_4	113°
β_1	16.5°
β_2	30°
β_3	49°

Developed diagram of scavenging and exhaust port

E: scavenging port, A: exhaust port. Three ports, E₁ have upward inclination of 60°

Six ports, E₂, E₃ have upward inclination of 11°

● Shows measuring points

To indicate the piston movement, an electronic device was applied. A multi-slitted disk was attached to the end of the camshaft H, on one side of which a lamp L was positioned, and on the other side a phototransistor K was positioned. When the piston was driven, the phototransistor was illuminated by the lamp through the slits, thereby producing pulse currents at every 10 mm displacement from B.D.C. The crankshaft was driven by a motor at speed of 290 r. p. m., which corresponds to an actual engine speed n as follows,

$$n = 2\alpha_s / 6t_s \cong 150 \text{ r. p. m.}$$

where t_s indicates an equal total scavenging interval, of the experimental and of the actual engine.

Fig. 3 shows the piston displacement and the opening area of the scavenging—and exhaust—port at this speed. The dotted line in the diagram shows the piston movement of an actual engine, which has a connecting rod 4 times as long as its crank radius. It will be noted that the piston movement is nearly the same as that in an actual engine.

The concentration of fresh charge was recorded at each point shown in Fig. 2.

Tests were made at scavenging pressures of 100, 200, 300 and 400 mmHg respectively. To investigate the effect of negative pressure of the exhaust port the records were taken at pressures initially adjusted to -100, -200, -300 and -400 mmHg in the back pressure reservoir F.

To prevent a leakage of the fresh charge through the piston clearance, a leather packing was used. Before the beginning of an experiment the piston was at rest at 43 mm above B.D.C., which gave sufficient sealing of the charge.

When the fresh charge is drawn, the pressure in the cylinder decreased because the residual gas expands while the piston moves until the scavenging is taken place. To obtain atmospheric pressure in the cylinder at the beginning of the scavenging port opening, CO₂ was filled in the cylinder at the initial pressure of 200 mmHg.

The test method was same as that applied in previous investigation⁽¹⁾.

Test result

The amount of fresh charge introduced into the cylinder was estimated from the pressure change in the fresh charge reservoir, in the scavenging receiver and in the cylinder. Assume an adiabatic expansion in the fresh charge reservoir, when the fresh charge flows out. Then

$$G_t = G_{t0} \{1 - (p_t/p_{t0})^{1/\kappa}\} \dots\dots\dots (1)$$

where,

G_t : amount of fresh charge from the reservoir

Fig. 3 Piston displacement and opening area of the scavenging—and exhaust—port

G_{t0} : initial amount of fresh charge in the reservoir

p_{t0}, p_t : initial and momentary pressure in the reservoir

κ : adiabatic exponent of the fresh charge, 1.25 ~ 1.26 for the concentration of Freon of 30 $\pm 5\%$ in CO₂

Further, assume that stagnation of fresh charge occurs as soon as the fresh charge has flowed into the scavenging receiver. Then, the following relation may be given :

$$T_t c_p dG_t - T_s c_p dG_s = c_p d(G_s T_s)$$

Applying the state equation, $p_s V_s = G_s R T_s$, the following equation may be given :

$$dG_s = G_s \left[\frac{R}{p_s} \frac{T_{t0}}{V_s} \left(\frac{p_t}{p_{t0}} \right)^{(\kappa-1)/\kappa} \cdot dG_t - \frac{1}{\kappa} \frac{dp_s}{p_s} \right] \dots\dots\dots (2)$$

where

G_s : amount of fresh charge introduced in the cylinder

T_{t0}, T_t : initial and momentary temperature in the fresh charge reservoir

G_s, p_s, T_s : amount of fresh charge, pressure and temperature in the scavenging receiver

V_s : volume of the scavenging receiver

R : gas constant of fresh charge

c_p, c_v : specific heat of fresh charge

Given the initial state, ΔG_s for every 4/1000 sec was calculated from the records of p_t and p_s on

the oscillograph films.

The delivery ratio is defined as follows :

$$L_0 = G_e / (\gamma_0 V_e)$$

where

γ_0 : specific weight of fresh charge at 15°C and 760 mmHg

V_e : total cylinder volume at B.D.C.

Advance of the scavenge front in the cylinder

Fig. 4 and Fig. 5 show examples of the advance of the scavenge front as the scavenging progresses. On the diagram, the dotted lines show the position of the scavenge front at the delivery ratio of 0.3. It will be noted that the fresh charge does not proceed up to the cylinder head, and it takes a short route across the cylinder to the exhaust port, that is, the so-called flat scavenge occurs. Thus, the residual gas at the upper portion of the exhaust port side in the cylinder is replaced very slowly by the fresh charge. This fact is caused by the occurrence of a swirl of residual gas at the upper part of the cylinder as pointed out by Lindner⁽³⁾. To scavenge such a portion sufficiently, a large amount of short-circuiting loss is unavoidable.

Under steady flow conditions, the direction of air stream was observed by means of thin silk

threads in a transparent cylinder having the same size. Fig. 6 shows the flow pattern for each piston position. It will be seen that at 40° before B.D.C., the air stream travels up to the cylinder head along the cylinder wall and a high scavenge is produced. While, with the piston approaching the B.D.C., unstable flow is produced at the middle part above the scavenging port, an air swirl is produced at the upper portion of the cylinder and the air stream takes a short route across the cylinder along the piston surface to the exhaust port, thus turning into a flat scavenge.

Effect of back pressure

Fig. 7 and Fig. 8 show the advance of the scavenge front when the fresh charge is drawn in the cylinder by the negative pressure created in the exhaust pipe.

At the upper part of the cylinder remarkable differences were observed as compared with the former results. In this case the advance of the scavenge front at the upper part of the scavenging port side is very slow. The scavenge front shown by full line in Fig. 8 shows the position of the scavenge front when the scavenging port is closed. Thus, under such a low pressure—for instance at back pressure of -100 mmHg—some part near the cylinder head remains unscavenged.

$p_{t0} = 300 \text{ mmHg}$

Unit of the numerals is 1/1000 sec

Fig. 4 Advance of scavenge front

$p_{t0} = 100 \text{ mmHg}$

Unit of the numerals is 1/1000 sec

Fig. 5 Advance of scavenge front

Further, when the fresh charge is drawn, it will be noted that the advance of scavenge front at L_0 of 0.3 is slow as compared with that when the fresh charge is pushed out into the cylinder. This may take place due to less mixing action between the fresh charge and the residual gas when it is drawn in the exhaust port. These circumstances were confirmed by the records of concentration change of fresh charge behind scavenge front.

Short-circuiting of the fresh charge

Fig. 9 shows the amount of fresh charge delivered till the fresh charge begins to escape from the cylinder through each exhaust port, L_{op} . It will be noted that

the values of L_{op} are smaller than in M.A.N. loop scavenging system⁽¹⁾. This fact shows that a large amount of fresh charge is lost by short-circuiting.

On the other hand, when the residual gas is drawn by the negative back pressure, the beginning of short-circuiting is delayed.

Further, as shown in the diagram, early beginning of short-circuiting occurs through the exhaust port located near the scavenging port.

Summary

By means of an electronic method the scavenging characteristic of a cross-scavenging system was

Fig. 6 Air stream in the cylinder

Back pressure = -300 mmHg
Unit of the numerals is 1/1000 sec
Fig. 7 Advance of scavenge front

Back pressure = -100 mmHg
Unit of the numerals is 1/1000 sec
Fig. 8 Advance of scavenge front

Fig. 9 Beginning of short-circuiting through each exhaust port

investigated under the dynamic condition similar to that in a running engine. It may be summarized as follows :

(1) The fresh charge does not proceed up to the cylinder head. It takes a short route across the cylinder to the exhaust ports and the so called flat scavenge occurs.

(2) Short-circuiting occurs through the exhaust ports located near the scavenging ports.

(3) Short-circuiting occurs sooner than that in M. A. N. loop-scavenging system, and the amount of short-circuiting loss is larger than the latter.

(4) The state of flat scavenge can be observed by the static experiment carried out under the simplified steady air stream in the cylinder.

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Discussion

A. KIMURA : Generally in cross-scavenging, a high scavenge occurs, at high piston position with small uncovered port height, while the flow pattern turns into a flat scavenge, when the piston approaches the bottom center.

In your experiment the transition point from high scavenge to flat scavenge is comparatively high. Such a flow pattern depends largely on the ratio of length to sectional area of the inlet ports. In my experience a thick port belt, suitable belt guide either outside of the port or in the port gave a stable, high scavenge. How thick is your port belt?

H. FUJITA : I have no question to ask you regarding these experimental results, but wish to know

the measuring method in further detail. For example, I wish to know about the velocity measurement by means of the electrical conductivity of gases. Since it is presumed that condensers are provided in various parts of the cylinder, flow conditions should naturally be different. Therefore, we consider that with this measuring method there is some effect upon the instantaneous change of flow. Also, we wish to know what accuracy can be obtained when Freon gas is used.

Authors' closure

The thickness of the port belt of the cylinder used in this experiment was 13.5 mm. Each

scavenging port had an upward inclination, and a comparatively long guide was given in this direction as shown in append-Fig. 1.

The authors have the same opinion as to the effect of the shape and dimension of scavenging port on the scavenging flow pattern.

Flow pattern may be largely influenced by the ratio between the length of the ducts and its sectional area. Some fundamental investigations as to these problems are being carried out at present in our laboratory.

The probe applied to the recording of concentration of fresh charge was a condenser having 8 plates. It may be considered that the scavenging flow will be obstructed by these plates of the condenser.

As the result of the preliminary test, however, it was confirmed that the probe was so small that it had little influence. Each test was made by fixing one probe in the cylinder. Therefore, the flow condition are not disturbed before the scavenge front reached the measuring point. When the change of concentration is too rapid, some delay occurs in measuring of concentration if the circuits have an insufficient frequency response. In this experiment, however, only the advance of fresh charge was investigated, which was indicated without any delay.

To check this delay, another condenser was connected parallel to the probe and the change of capacity was recorded by cutting the condenser abruptly. From these records the time delay was estimated.

In this model test, the test conditions are different

Append-Fig. 1

from those in an actual engine. At present, however, no measuring methods may be applied to investigate the advance of the fresh charge in an actual engine cylinder correctly. Thus, it is difficult to determine the accuracy of this method.

In the previous report, NH_3 was used as fresh charge. By a preliminary test, it was confirmed that the results obtained by using Freon were almost the same as those obtained using NH_3 .

The other points as to the measuring method were reported in the previous paper⁽¹⁾.