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A Study on the Scavenging Air Flow through the Scavenging Ports*

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To examine the characters of the scavenging air flow through the scavenging ports in two-stroke engines, the inlet flow pattern through the model ports has been observed by a high speed motion camera, using a single cycle test apparatus.

In general, the scavenging air flow is not coincident with the designed direction of the scavenging port at comparatively slight opening, and the efflux direction changes with the piston displacement. In a small crankcase-scavenged two-stroke engine cylinder, to keep the scavenging air flow close to the direction of the scavenging port it is effective to make the scavenge air guide long and to incline the scavenge air passage between the crankcase and the cylinder axially along the circular surface of the cylinder. In a large loop scavenged engine cylinder, to make the scavenging air flow coincide with the direction of the scavenging port in the early stage of scavenging, it is effective to set the guide plate inside the scavenging port.

1. Introduction

State of efflux of scavenging air flow is an important factor on the scavenging process, and up to the present to find the direction of air stream into the two-stroke engine cylinder through the scavenging port, the static investigations were carried out under the simplified conditions of steady flow^{(1)~(5)} or theoretically on the assumption of two dimensional potential flow^{(6)~(8)}. On the other hand, the scavenging efficiency was measured by analysis of the contents in an actual engine cylinder, utilizing the gas sampling valve⁽⁹⁾.

According to these papers, the flow pattern of

scavenging air changes with the piston travel.

However, the question arises as to whether the flow pattern under such steady conditions is the same as in a running engine, especially in a high speed engine.

The state of efflux angle could be judged by the studies of the scavenging process in the cylinder having various scavenging port arrangements, which were carried out by utilizing dielectric properties of gases by authors^{(10)~(12)}.

In order to make clear how the efflux angle changes under the condition of moving piston, the authors have devised a new single cycle model apparatus and have taken high speed photographs of scavenging air stream by making the flow visible by SiCl₄ and analysed the scavenging air stream in a small crankcase-scavenged engine cylinder and in a large loop-scavenged engine

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cylinder.

2. Small two-stroke engine with SCHNÜRLE scavenging system

2.1 Apparatus and method

A two-dimensional single cycle model test apparatus was used. The original engine was a small crankcase-scavenged engine having a bore of 52 mm and a stroke of 58 mm, and the model port was constructed similar to that in the actual engine.

Analyses of the scavenging air stream were performed by taking high speed photographs of visible flow of white smoke which was produced by mixing SiCl_4 with NH_3 in the scavenging reservoir.

The test arrangement is shown in Fig. 1. The piston was driven by a cam C, the profile of which was designed such that it caused the same piston movement as that of an actual engine. By supplying a steady current to the magnetic coil A, the collar W is pulled upward against a spring force, thereby permitting the cam shaft to be driven freely. The scavenging port is closed by the piston. At the time when the piston is to be moved, a heavy current is supplied the magnetic coil B instantaneously, then the follower attached to the piston is dropped on to the cam profile by a spring force and the piston moves along the

A: fixed magnetic coil, B: inverse magnetic coil, C: cam, D: disk, K: high speed motion camera, M: plane mirror, O: phototransistor and lamp, P: piston, S: scavenging port, T: scavenge air passage, V: spring, W: collar

Fig. 1 Schematic diagram of test apparatus for small SCHNÜRLE scavenging system

cam profile. When the piston reaches the initial position again after a single cycle the collar W is pulled by magnetic force again, and the piston is stopped. In such a way, the scavenging process can be performed during the piston travel.

A block diagram of control system is shown in Fig. 2. After a free running of cam shaft is set at a desired speed, and the high speed motion camera is started by the manual trigger switch N, the gate G is turned ON by the timer I when the high speed motion camera attains the present speed. A trigger pulse generated at the T.D.C. of the cam profile passes through the gate G, and

D: disk, G: gate, H: discharge circuit, I: timer, J: controller of high speed motion camera, K: high speed motion camera, L: magnetic power supply, M: magnet, N: manual trigger switch, O: photo-transistor, P: lamp, Q: slit, S: scavenging port

Fig. 2 Block diagram of control system

Scavenging port Model piston
L=8 mm, $\theta=0^\circ, 6^\circ, 9^\circ, 12^\circ$
13 0°
18 0°
23 0°

Fig. 3 Model port and piston for small SCHNÜRLE scavenging system

instantaneous current is fed to the reverse magnetic coil by discharging the capacitor of circuit H through a strobo discharge tube, and the magnetic field disappears instantaneously. The trigger pulse for moving the piston was produced by a phototransistor and a lamp set on both sides of rotating disk with a slit, as illustrated in Fig. 2.

The detail of the model scavenging port and

Fig. 4 Piston displacement and opening area of scavenging port

the piston is shown in Fig. 3. The scavenging port opens at $52^{\circ}20'$ before B.D.C. Fig. 4 shows the piston displacement and the opening area of scavenging port. The solid line in the diagram shows the model piston movement which is measured by a high speed motion picture and the dashed line shows that of the actual engine. The model piston movement agrees well with that of the actual engine.

Tests were made at scavenging pressure of 100, 200, 300 mmHg and at engine speed of 600, 1 000 and 2 000 rpm respectively.

2.2 Test result

2.2.1 General characters of scavenging air stream In general, the scavenging air stream is not coincident with the designed direction of the scavenging port at comparatively slight opening. As shown in Fig. 3, the scavenging port has an upward inclination of 25° and an inclination of 38° to the radial direction. The scavenging air efflux angle, however, is not coincident with both angles,

Engine speed=1 200 rpm, Scavenging pressure=200 mmHg, Guide length $L=8$ mm

Fig. 5 Typical photographs

and the efflux angle approaches the designed direction as the port opening increases.

Fig. 5 shows an example of the high speed photographs. The efflux angle changes with the piston movement. From beginning of scavenging until 35° before B.D.C., the upward inclination δ of the scavenging air flow is larger than designed

Fig. 6 Schematic diagram of the flow

Fig. 7 Effect of scavenge air guide length L

Fig. 8 Effect of inclination θ of scavenge air passage

angle 25° as illustrated in the schematic diagram of the flow. Thereafter, it flows out in the nearly designed direction of the scavenging port until the scavenging port is closed. As for the radial angular deviation, the scavenging air flows out radially at the comparatively slight opening, and this radial inclination φ of stream shown in Fig. 6 increases as the port opening increases. The inclination to radial direction, however, is less than designed angle 38° . At larger port opening after 35° before B.D.C. it flows out in almost constant direction.

2.2.2 Influence of the length of scavenging air guide on the efflux angle In a loop scavenging system, the upward flow into the cylinder occurring in the earlier stage of scavenging process may be one of the causes of lowering the scavenging efficiency by short circuiting of the scavenging air. In order to prevent the upward flow, it may be effective to construct the scavenge air guide as long as possible.

To examine the effects of length of the guide on the scavenging flow, tests were made by varying L as shown in Fig. 3. As shown in the test result in Fig. 7, to keep the scavenging air stream close to the direction of the scavenging port, it is effective to make the scavenge air guide long. However, to make the scavenging air flow coincide with the direction of the scavenging port at B.D.C. perfectly, the scavenge air guide length must 23 mm. In a small crankcase scavenged-engine cylinder, however, it is difficult to construct such a long

scavenge air guide by reason of engine construction.

2.2.3 Influence of the axial inclination θ of scavenge air passage between the crankcase and the cylinder The photographs (b) in Fig. 5 are typical photographs showing the air stream under the condition having an inclination of $\theta=9^\circ$ (Fig. 3). Comparing them with the photographs (a) ($\theta=0^\circ$), the former shows a remarkably inclined air stream. The effects of inclination of the scavenge air passage are shown in Fig. 8. From the diagram, it will be noted that to keep the scavenging air stream close to the direction of the scavenging port, it is very effective to give some inclination to the scavenge air passage between the crankcase and the cylinder.

Both the speed and the scavenging pressure exert almost no effects on the characters of the scavenging air flow qualitatively.

3. Large engine of loop scavenging type

3.1 Apparatus and method

A schematic diagram of the model test apparatus is shown in Fig. 9. The principle is the same as that in the previous investigation. The piston movement was taken from the piston motion of an engine E, which had a stroke of 200 mm and a length of connecting rod of 400 mm. Nearly the same piston movement as that in an actual engine can be obtained as shown in Fig. 10, if the

C: cylinder, D: disk, E: engine, F: phototransistor and lamp, M: magnet, P: piston, Q: motor, S: scavenging port, T: scavenging air reservoir, U: manometer, V: pressure gage, W: collar

Fig. 9 Schematic diagram of test apparatus for large loop scavenging system

engine E is driven at a speed 3 times the actual engine. The ports are a two-dimensional model of a center port and a side port of M. A. N. large two-stroke engine having a bore of 840 mm and a stroke of a 1600 mm. Its port timing is;

center scavenging port opening.....
.....41°7' before B.D.C.
side scavenging port opening.....
.....43°1' before B.D.C.

The controlling method of the apparatus and the analyzing method of scavenging air flow were the same as in the previous investigations.

Tests were made at the scavenging pressure of 50, 100, 200, 300 mmHg and at the speed of 60, 75, 90, 105 and 120 rpm respectively.

3.2 Test result

3.2.1 State of efflux from the center scavenging port The model scavenging port is shown in Fig. 11, and the high speed motion photographs are shown in Fig. 12. The direction of efflux changes in accordance with piston displacement

Fig. 10 Piston displacement

Fig. 11 Center port of large loop scavenging system

similarly to that obtained in the small crankcase-scavenged engine. In a large engine of loop scavenging type, however, the efflux angle deviates again from the designed direction of the scavenging port when the piston approaches the end of scavenging.

Assuming the two-dimensional potential flow, the flowing direction was calculated by the following formulas⁽⁶⁾⁻⁽⁸⁾. Referring to Fig. 13,

$$m = -c/b = f_1(\kappa) + \kappa \varphi_1(\alpha)$$

$$n = e/b = f_2(\kappa) + \kappa \varphi_2(\alpha)$$

where κ is the velocity at the infinity point A, and α is the efflux angle of the free stream line; $f_1(\kappa)$, $f_2(\kappa)$ and $\varphi_1(\alpha)$, $\varphi_2(\alpha)$ are the functions of κ and α which vary with the values of β . In the case of $\beta = \pi/2$,

$$f_1(\kappa) = -\frac{2(1-\kappa^2)}{\pi} \tan^{-1} \kappa$$

$$f_2(\kappa) = \frac{1+\kappa^2}{\pi} \ln \frac{1+\kappa}{1-\kappa}$$

$$\varphi_1(\alpha) = \frac{\cos \alpha}{\pi} \ln \frac{1+\cos \alpha}{1-\cos \alpha} - \sin \alpha$$

$$\varphi_2(\alpha) = \cos \alpha - \frac{\sin \alpha}{\pi} \ln \frac{1+\sin \alpha}{1-\sin \alpha}$$

As shown in Fig. 13, the efflux direction of the scavenging air stream is related to only the opening ratios m of the port. To keep the effluent

direction of the scavenging air stream close to the designed direction, it may be effective to divide the port by attaching a guide plate inside the scavenging port, as shown in Fig. 11.

The photographs (b) in Fig. 12 are typical photographs showing the air stream through a port divided by a guide plate, as shown in Fig. 11. Comparing them with the photographs (a), the effects of the guide plate are clear. The effects

Fig. 13 Efflux direction by theoretical calculation on assumption of two dimensional potential flow

(b) Setting position of guide plate
 $D=0$ mm, $H=73$ mm, $L=55$ mm
 Engine speed=62 rpm, Scavenging pressure=50 mmHg
 Fig. 12 Typical photographs

of the guide plate are shown in Fig. 14. As will be expected, the scavenging air flows out in the designed direction in the earlier stage of scavenging if the guide plate is available.

In the case of the scavenging port which was used in these experiments, the coincidence of the

Fig. 14 Effect of setting height of guide plate

Scavenging pressure = 300 mmHg

Fig. 15 Effect of setting position of guide plate

Fig. 16 Effect of setting position of guide plate

scavenging air stream with the scavenging port direction was obtained with the guide plate fixed at the middle of the total port height.

In the above experiments, a guide plate was attached at the cylinder liner. For practical reasons, however, some difficulties may be encountered for such a construction of the cylinder liner. The effects of the guide plate were investigated, when it was fixed at the outside of the scavenging port, as shown in Fig. 11.

Fig. 15 and Fig. 16 show the results. When the guide plate is attached apart from the inner wall of the cylinder liner, the effect of the guide plate is less than that when $D=0$ mm.

Influence of the length of the guide plate is shown in Fig. 17. In the test, the guide plate was set with $D=55$ mm and $H=73$ mm. When the guide plate was set apart from the inside wall of the cylinder liner, no remarkable influences were

Fig. 17 Effect of length of guide plate

Fig. 18 Side port of large loop scavenging system

obtained even if a long guide plate was used. Thus, it is more effective to set the guide plate closer to the inner wall of the cylinder liner.

3.2.2 State of efflux from the side scavenging port Similar tests were made by the side port of a M.A.N. loop scavenged engine as shown in Fig. 18.

The state of efflux is very complicated because it has a complex geometrical form compared with the center port. In this scavenging port, various guide plate are also tested as shown in Fig. 18, but it does not seem that any improvement of the characters of the scavenging air stream is obtained by utilizing the guide plate.

4. Summary

By using the two-dimensional single model port, the characters of the scavenging air stream through the scavenging port in a small crankcase-scavenged engine cylinder and a large loop-scavenged engine cylinder were investigated. The result may be summarized as follows:

(1) In general, the scavenging air does not flow in the designed direction of the scavenging port at comparatively slight opening and the efflux angle changes with the piston movement.

(2) In the small crankcase-scavenged engine cylinder, to keep the scavenging air stream closer to the direction of the scavenging port, it is effective to incline axially the scavenge air passage between the crankcase and the cylinder, and make

the scavenge air guide long.

(3) In the scavenging port located near the center of the large loop scavenged engine cylinder, to make the scavenging air stream coincide with the direction of the scavenging port in the earlier stage of scavenging it is effective to set the guide plate at the middle of the port. In a side port, however, no effect is expected from using a guide plate.

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