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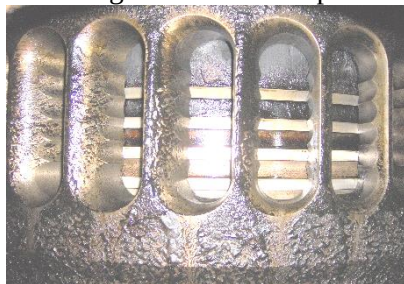
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FEATURES OF OIL SUPPLY TO THE CYLINDERS OF MODERN MARINE DIESEL ENGINES

In recent years, the global maritime fleet has seen a trend towards a significant increase in the rate of construction and commissioning of new large-capacity vessels, with annual growth currently at around 2%.

The reliability and durability of marine diesel engines is to a certain extent determined by the wear rate of the cylinder-piston group (CPG) parts. One of the main issues that plays a primary role in determining the service life of the CPG are the issues of organizing the lubrication of its rubbing surfaces in accordance with the specified operating mode, the type of fuel used and the engine cooling mode.

As demonstrated by the operation of marine diesel engines, excessive oil consumption leads to increased oil waste products, deposits on cylinder-piston group components, in the scavenge ports of the cylinder liner (Fig.1), in the scavenge receiver, and in the exhaust tract. Increased oil discharge into the under-piston cavity is observed.



a)



b)

Fig.1. Deposits on the piston crown (a)
and scuffs on the cylinder liner surface (b)

At the same time, insufficient lubrication leads to a breakdown of the oil film on the cylinder liner's working surface, resulting in dry or semi-dry friction (the appearance of dry surface areas on the piston crown and cylinder bore, or "dry rings"). Mobility is reduced, and piston rings can become pinched and stick.

This is accompanied by intense wear and sometimes scuffing of the friction surfaces, leading to forced shutdowns and reduced reliability and engine life of diesel engines. Blowby gases and sparks occur, as well as the ignition of oil deposits in the piston cavity [1,2].

The forcing of engines, the use of heavy grades of fuel with increased sulfur content and the maintenance of reliability and durability of diesel engines increases the role of the lubrication system of cylinder-piston group parts.

In existing lubricating systems, oil delivery to the nozzles of a single cylinder is staggered over time, with the oil portion size ranging from 2 to 8 mm³. Furthermore, the period between plunger injection strokes, depending on the specific drive design, ranges from two to eight crankshaft revolutions. This, in turn, prevents regular and uniform oil flow to the friction surfaces.

Operating experience has shown that when using high-sulfur fuels, the correct selection of the amount of alkaline oil supplied to the cylinder, necessary to create a stable oil film on the rubbing surfaces, plays a decisive role in the durability and efficiency of a low-speed diesel engine.

The use of turbocharging and heavy fuel on many diesel engines has led to changes in the design of oil supply nipples. As boost increases, liner and gas temperatures rise, leading to the neutralization of the oil's alkaline additives and the deposition of solid particles in the outlet channel, which can disrupt lubrication. To reduce the impact of thermal stress on the oil, nipples have been positioned closer to the point where the oil enters the cylinder, reducing the time the oil spends in the high-temperature zone between the nipple and the outlet port in the cylinder liner.

The oil supply channels behind the check valve vary in length, diameter, and configuration. Individual sections of these channels are located both vertically and horizontally. There are also channels with inclined and offset (relative to the nozzle axis) sections, as well as sections rotated in the vertical and horizontal planes (Fig.2).

The cylinders of modern turbocharged diesel engines running on heavy fuel are lubricated exclusively with oils containing additives. In these diesel engines, the purpose of the oil is not only to ensure fluid friction but also to quickly and evenly distribute the alkaline additive across the cylinder liner surface.

If the oil is distributed slowly and unevenly across the surface, the alkaline additive will react with the acids before the oil has spread over the

entire surface, and the exposed areas of the liner will be subject to corrosive wear to the same degree as with pure oil without additives [3].

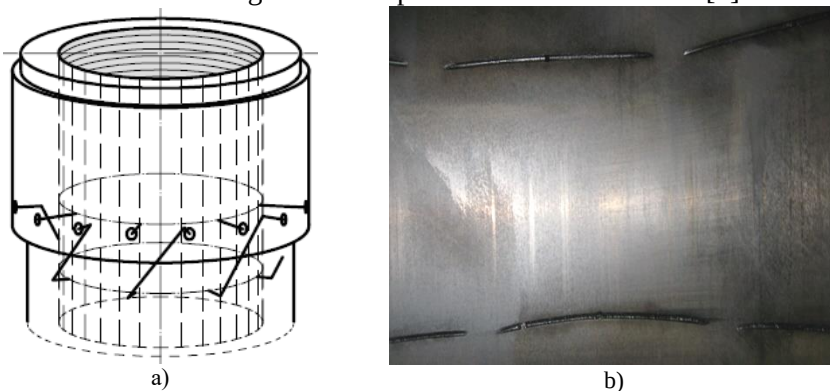


Fig.2. Double-row connection of fittings

In modern diesel engines running on heavy fuel, special attention is paid to the location of lubrication points, their number and the design of the distribution grooves. The presence of grooves on the mirror and their correct geometry ensure a more intensive distribution of oil in the transverse direction (Fig.3).

In modern marine engines, two types of timing grooves are commonly used: individual grooves at each oil supply hole and continuous grooves (common to all holes) located around the entire circumference of the cylinder liner.

According to modern concepts, continuous grooves are preferable. Their continuity ensures a more uniform lateral distribution of lubricant, and the overlap of the groove by two piston rings simultaneously helps distribute the lubricant quickly.

From existing ideas about the operation of lubricating systems, it follows that uncontrolled, uneven and irregular supply of oil to the internal combustion engine cylinders is caused by long oil lines, which make it difficult to pump small portions at the right time.

With the steady trend toward boosting modern low-speed diesel engines, despite a significant increase in specific consumption and the use of high-quality lubricants, the shortcomings of existing oil supply systems are becoming increasingly apparent.

This suggests that the ability of newly developed oils to compensate for the imperfections of oil supply systems is reaching a limit beyond which normal operation of boosted diesel engines is possible only at re-

duced power or with the use of newer oils, such as synthetic oils [3,4], capable of performing under more severe supply conditions than mineral-based oils.

When there is a pulsed change in the back pressure of the gases inside the cylinder, which occurs when the compression ring zone moves through the belt of the lubrication holes, a reciprocating movement of oil occurs in the channel, which leads to intensive mixing of the oil with the gases and, as a consequence, causes an uncontrolled process of oil exiting the channel, causing significant losses due to its supply to the bottom and the side surface of the piston head, where it burns, turning into an additional source of carbon deposits that intensify the wear of the CPG parts.

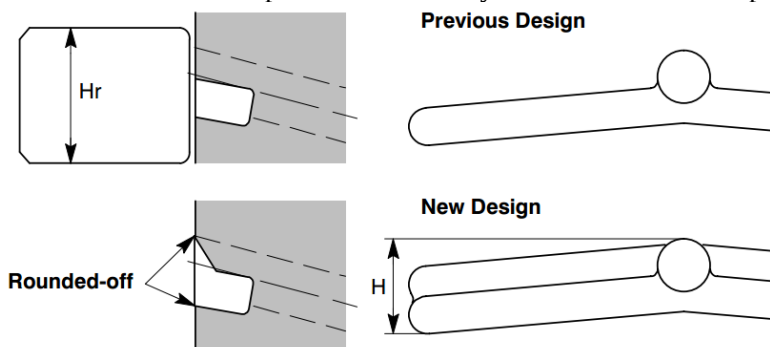


Fig.3. Distribution groove design

Consequently, oil enters the engine cylinder by gravity flow or is supplied by gases. Lubricant typically leaks past the oil inlet opening when the lubricator valve is closed and the lubricator plunger is stationary.

This means that lubricators merely serve as a dispenser and pump, periodically refilling a kind of pre-chamber, a rather complex channel between the lubricator valve and the cylinder bore, under relatively low pressure.

The flow of oil into the cylinder is directly related to the geometry of the part of the discharge tract of the system, which is located between the check valve and the sleeve mirror, as well as with the back pressure of the gases acting in the channel area from inside the cylinder.

Changes in the length, diameters, volumes and other geometric elements of this part as a whole or its individual sections have a direct impact on the mechanism of formation of processes occurring inside the channel, as well as on the values of the parameters of oil flow into the cylinder, in

accordance with the difference in the geometric characteristics of the oil supply channels.

Research into the operation of lubricating systems resulted in solutions aimed at increasing the uniformity (over RPM) of oil flow into engine cylinders, so-called accumulator systems. These are diesel lubricating systems in which pressure accumulators are installed in the discharge tract.

The division of the cyclic portion of oil over the entire period between two injection strokes of the lubricator plunger was achieved in accumulator systems by reducing the oil pressure in front of the check valve of the fitting to a minimum value, which, in the intervals between gas pressure pulses, before the piston rings arrived at the lubrication points, ensured a regular exit of oil into the cylinder on each piston stroke.

Cylinder oil must be delivered to the cylinder at a specific piston position and time to achieve optimal results, which is not always achieved with conventional lubricators today.

Therefore, diesel engine manufacturers have begun to widely utilize new cylinder lubrication systems with electronically controlled lubrication on modern ships (Fig.4).

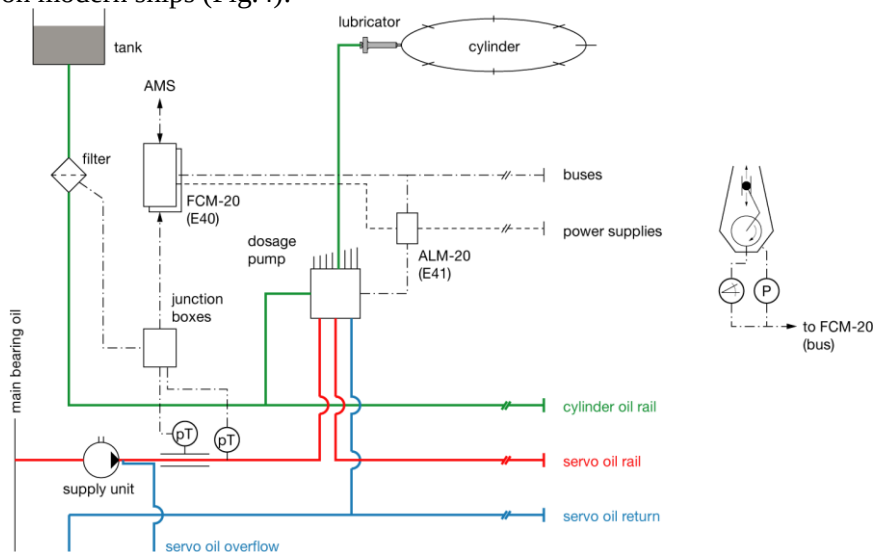


Fig.4. Electronically controlled lubrication system

The new lubrication system is based on the principle of injecting a specific volume of oil into the cylinder every four (five, six, etc.)

revolutions. Furthermore, precise injection timing ensures (according to the company) that all the cylinder oil reaches the piston rings where it's needed.

Analysis of the electronic system design reveals that the following are essentially new: a computer-controlled hydraulic plunger drive (instead of a mechanical one), which has led to a change in the lubricator's appearance (Fig.5); as well as communication with engine load[4] .

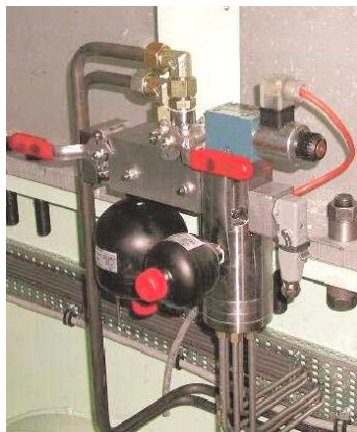
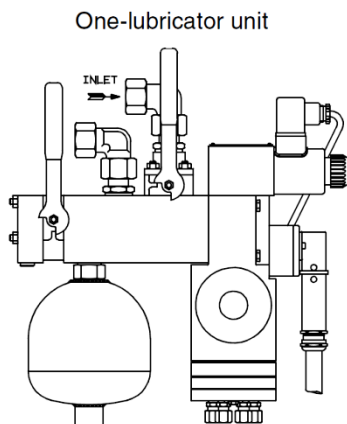


Fig.5. Appearance of the lubricator

The use of a computer in the lubricator's electrical circuit creates the prerequisites for regulating oil portions depending on the sulfur content of the fuel and the base number of the cylinder oil.

Meanwhile, in new MAN-B&W engines, the oil supply channels are located in the upper portion of the cylinder liner, similar to Sulzer engines.

Furthermore, the outlet section of the oil supply channels is either off-set upward or not (Fig.6), which allows gases to enter the channel and consequently disrupts controlled oil flow.

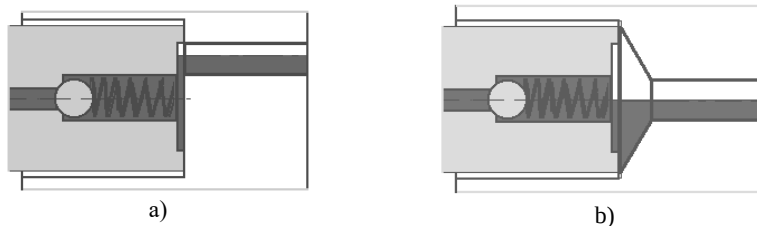


Fig.6. Geometry of channels in the cylinder sleeve

"Alpha" lubricators are installed on each cylinder. A servomotor, via a piston, moves plungers that deliver oil to the fittings. The timing and amount of oil pumped are determined by a microprocessor, which sends control signals to the lubricator's solenoid valve.

The electronic control system has a pump station (Fig.7), including a filter and oil cooler, as well as a working pump, which is activated automatically when the engine is started, and a backup pump. These pumps maintain a pressure of 4.5 MPa at the lubricator inlet.

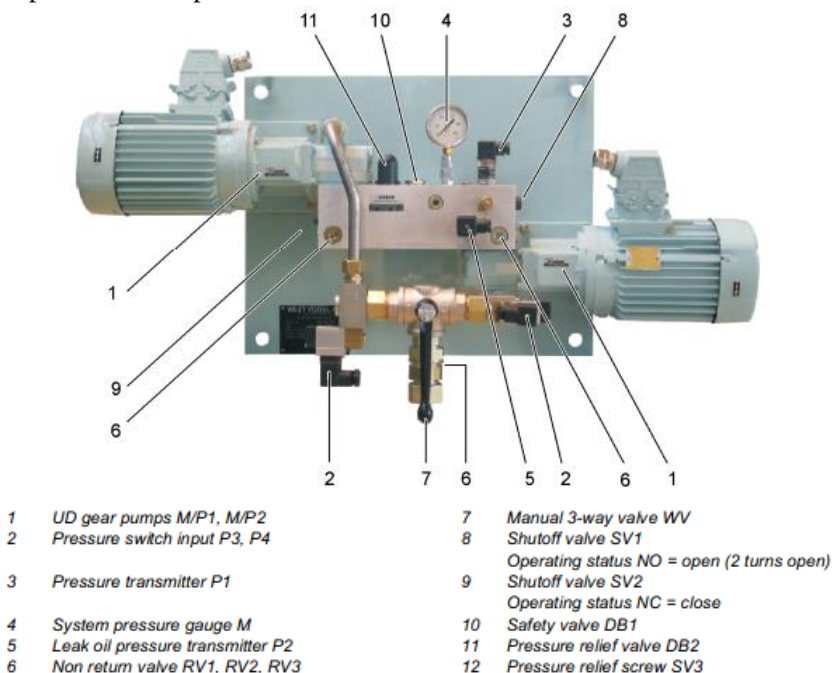


Fig.7. Pumping station

A distinctive feature of the cylinder lubrication system of the engines under consideration is the synchronization of the plunger's oil supply with the piston's position in the cylinder [1,5]. The end of the plunger stroke in this system coincides with the moment when the bridge between the first and second piston rings during the piston's compression stroke is at the outlet openings of the oil supply channels.

The conditions for oil use and the operating conditions of the piston ring-liner friction pair, all other things being equal, must be the same in all cylinders of these diesel engines, unlike engines with non-synchronized

lubricator drives. However, large variations in the length of the discharge pipelines from 1 to 3 meters with equal plunger strokes do not provide the same lubrication conditions for each nozzle, which under certain conditions (incorrect choice of oil grade, its dosage, engine overload, etc.) can cause disruption of the normal operation of the cylinder-piston group.

Tests of the lubrication system with a specific channel (the upper ring of axial channels, see Fig. 2, 6 b) were conducted directly on the engine using a special setup (Fig. 8) with oil supplied by an Alpha lubricator [6].

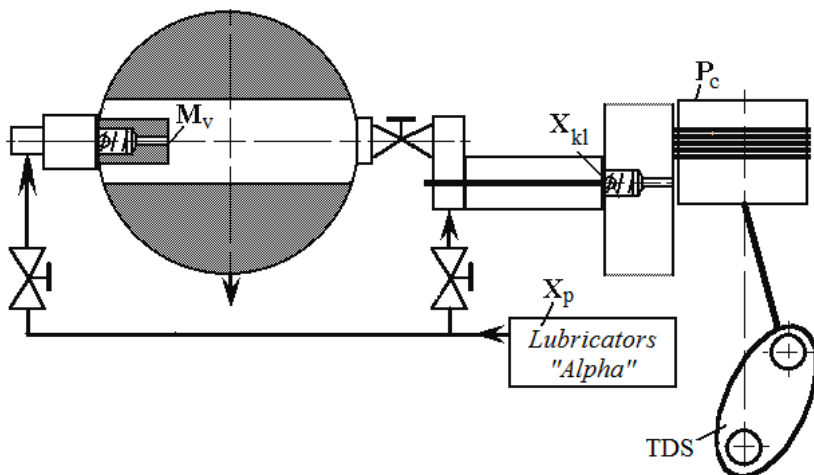


Fig.8. Experimental stand

Visual observations show that the surface of the oil layer in the channel is deformed under the influence of pulsed changes in gas pressure, acquiring a wavy surface and a reciprocating motion. The section of the channel in question (between the end of the nozzle and the cylinder bore) is largely filled with gases. The pulsed change in pressure at the oil supply orifice and the resulting alternating compression and expansion of the gases in the channel causes a reciprocating motion of the oil, accompanied by intensive mixing with the gases.

As the pressure drops at the lubrication holes inside the cylinder, the gas-oil mixture moves along the channel toward the cylinder face, accelerating due to the energy of expanding gas bubbles and chambers enclosed within the channel.

Before the channel exits at the cylinder face, the velocity reaches sufficiently high values that the oil continues to move along the axis of the

outlet channel even beyond its limits (Fig.9,a). Thus, the expanding gases within the channel hurl oil out of the channel.

Special measurements revealed that in the engines studied, up to 80% of the oil is hurled out of the channel by hurling, with this amount varying depending on the engine and system operating parameters (Fig.9,b).

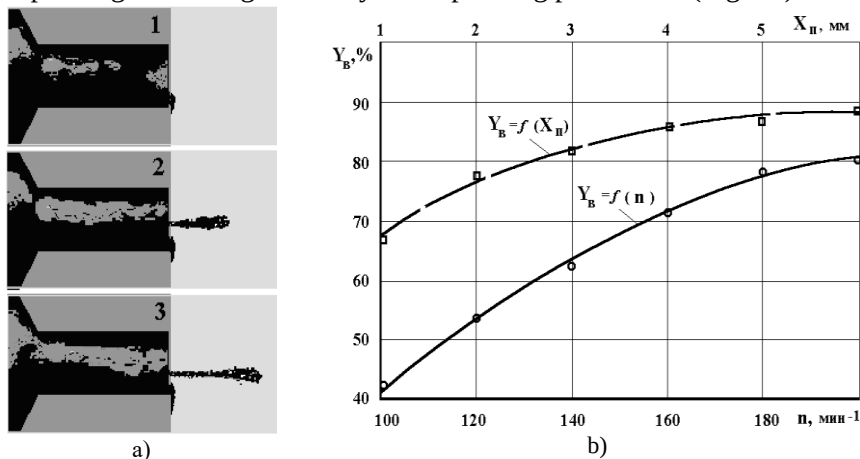


Fig.9. Film footage of the movement of grease through the channel (a), lubricant movement characteristics (b)

Between each stroke of the lubricator plunger, the oil is ejected in several stages. It may be a jet, as in the film frames shown in Fig.9,a, which is typical primarily for the first revolution of the oil supply cycle. Subsequently, the ejection appears as a group or individual droplets. The root of the jet, which does not break away from the surface, causes the oil to slide under the hole and flow vertically down the surface. For several revolutions (2...4), no oil flows from the hole.

It should be noted that the described phenomena occur in all oil supply channels simultaneously, due to the common rise and fall times of gas pressure pulses from within the cylinder for all channels.

Different periods of oil refilling in other cylinders, corresponding to their operating sequence, only determine the alternation of the "ejection" patterns or the conditional order of oil flow from the holes. The above-described alternation of the "ejection" forms, the intervals between them and the breaks in the flow of oil from the holes indicate the emptying of the channel as a result of the "ejection".

Oscillographic recording of the process (Fig.10) revealed that the choke valve opens in 2...3 stages during one revolution, following the plunger's delivery stroke.

Most of the oil enters the cylinder on the first revolution, and a small amount on the second revolution, followed by a pause in oil supply until the next plunger stroke (2...4 revolutions).

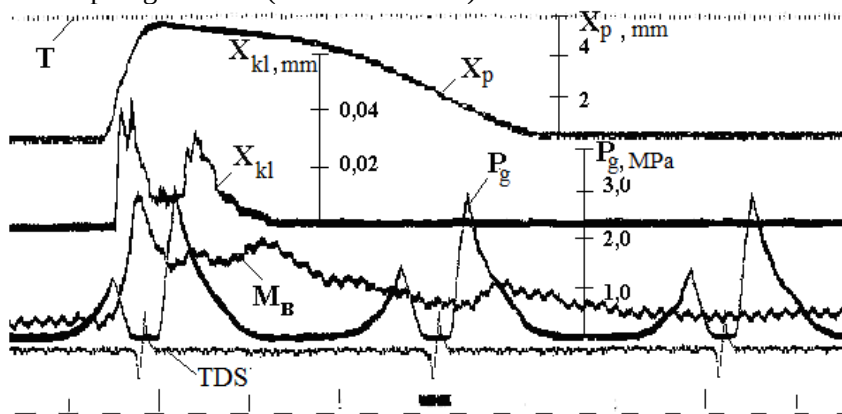


Fig.10. Lubricant supply oscillogram

Moreover, up to 50% of the oil (line M_v) enters with the valve closed (line X_{kl}) and no delivery stroke of the plunger (line X_p).

Moreover, oil flows into the cylinder in uneven portions. The periods of oil flow to the cylinder wall correspond to $340-35^\circ$ CV and $60-310^\circ$ CV. Based on an estimate of the oil flow rate based on the area under the M_v curve, it was determined that 40-65% of the oil enters the cylinder when the piston rings are above the bores, and 35-60% when the rings are below the oil supply bores.

From the oscillograms, it follows that the moment oil appears at the bore exit is not directly related to the pumping stroke of the lubricator plunger or the opening of the check valve.

Oil flow (line M_v) into the engine cylinder occurs both with the plunger stationary (line X_p) and with the valve closed (line X_{kl}). This provides further evidence that the process of oil flow into the cylinder is controlled not by the lubricator, but by the combination of conditions of gas interaction with the oil contained in the valved portion of the system.

Considering the role of the piston surface in distributing oil across the piston surface, we can assume that the "ejection" phase under consideration carries a certain amount of oil, which is used for its intended purpose. However, some of the oil in this phase will undoubtedly enter the ports, the under-piston space, and the scavenge air receiver, and may be one of the factors predisposing to a fire there.

The second, main, and most wasteful "ejection" phase occurs after the second, more powerful pulse, when the piston crown is located below the lubrication holes at approximately $55...60^\circ$ crankshaft angle.

Based on the processing of high-speed film footage of the "ejection" process (a fragment of which is shown in Figure 10), the oil flight velocities beyond the lubrication holes were determined by graphic differentiation (Fig.11).

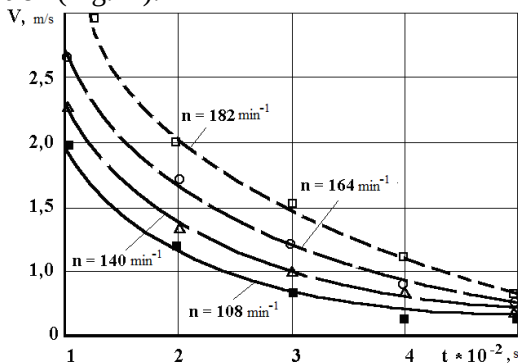


Fig.11. Oil flow rates through lubrication holes

As can be seen from the figure, these velocities range from 0.45 to 2.5 m/s. Depending on the phases and forms of the "ejection," the oil's trajectory within the cylinder can reach several centimeters.

Moreover, small portions of oil (individual drops and bunches of them) are "ejected" from

the channels at a lower speed and travel a shorter distance from the oil hole edges.

The jet-like "ejection" pattern is characterized by a velocity of up to 2...2.5 m/s and the greatest range. Consequently, the bulk of the oil (excluding the root of the jet) entering the cylinder after the second pulse breaks away from the piston face, landing directly on the piston crown, where it subsequently burns.

The root of the jet, which occurs after the larger pressure pulse, and the incomparably small amount that flows out of the oil hole during this phase without separating from the face, are captured by the first compression ring during compression.

Conclusions

The experimental studies revealed the following:

1. Oil enters the cylinder from the channel behind the choke valve due to gas-oil interaction in this channel, accompanied by the release of some oil onto the non-working surfaces of the cylinder-piston group components, leading to direct oil loss;

2. The "release" occurring in the expansion line occurs within the working cylinder volume when the piston is below the lubrication chan-

nels and constitutes the bulk of the oil, which is inefficiently used in the cylinder, increases carbon deposits, deteriorates the cylinder's condition, and reduces engine performance;

3. Oil delivery during compression is partially to the lower rings and primarily to the piston trunk. Uneven oil delivery occurs across revolutions and is disproportionately distributed between the upper and lower piston rings.

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