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HJ Common Rail Lubrication System

10 - Latest Engine Component Developments - Components & Tribology

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ABSTRACT

A novel lubrication system for large slow-speed two-stroke engines has been developed. The system integrates the lubricator into the HJ SIP injection valve, utilizing a single cylinder oil supply line, as it is known from the fuel oil common rail systems and is patented by Hans Jensen Lubricators A/S. The system is modular, making maintenance and troubleshooting faster and more customer-friendly. This modular system greatly reduces the need for components, piping and cabling, while making the lubrication system much more flexible for custom lubrication strategies. This paper presents the new system, the control algorithms developed and the possibilities of the lubrication strategies, including proposed solutions to the lubrication challenges related to complying with the 2020 sulphur cap regulations. Laboratory test results will be presented, showing quantity range and stability, precision of timing and spray quality. Full scale engine tests to determine optimal lubrication strategies will commence in November 2018 and will be the subject of later published papers.

The system is described in five main parts, the HJ common rail SIP valve, the hydraulic system, the electrical control system, the valve control software and an IoT module. Various solutions to the HJ common rail SIP valve are patented or patent pending by Hans Jensen Lubricators A/S. It consists of a solenoid valve controlling the opening and closing of the valve. The hydraulic system comprises a frequency controlled motor pump unit to build the common rail pressure and a pressure sensor to maintain correct pressure level of the cylinder oil. Safety measures such as over-pressure valves, cut-off valves and redundancy has also been implemented in the hydraulic system. The electrical control system uses an Ethernet protocol for all signal communication, ensuring a thoroughly standardized and robust network with high bandwidth and low latency. The electrical components are modular, so replacing a defective component is easy and can be done in a matter of seconds. All PCB surfaces are in protective casings and all connectors are protected from wrongful mounting to minimize the risk of human error during maintenance. The valve control software contains advanced control algorithms that make the solenoids fast enough to provide very accurate timing and very low quantities per injection, which allows fresh cylinder oil multiple times per engine revolution. These valve control algorithms are patent pending. Included in the new lubrication system is a brand new IoT module with a wide range of new features, such as predictive maintenance algorithms, online surveillance and an intuitive graphical interface. This IoT module is presented along with Hans Jensen Lubricators' vision for the possibilities of such an IoT lubrication system. The IoT module will also be introduced on existing HJ systems.

1 INTRODUCTION

When going from mechanical engine designs to electronically controlled engines, the camshaft driving the mechanical lubricators was no longer available. This development created the necessity for the electronically controlled lubricator. Electronically controlled engines and lubricators have become the norm in new vessels throughout the past three decades. The introduction of electronic lubricators provided much easier control for previously cumbersome operations, such as adjusting the quantity or injection angle and enabling load dependent regulation.

Slight changes have been made to the design of the electronic lubricator since its introduction, but the overall design has remained the same for the vast majority of offered solutions, i.e. one lubricator per cylinder with one piston pump and pipe per injection valve.

The current available technology can sufficiently lubricate the cylinder liner and piston rings, but it cannot test advanced lubrication strategies with the possibility of minimizing cylinder oil use and needed BN while maximizing cylinder liner and piston ring life. In the following subsections some of the shortcomings of the current technology are discussed.

1.1 Precision of timing

Concerns regarding precision of timing, have not been prompted by the introduction of electronic lubricators. Timing the cylinder oil injection in the lubricator and translating this to the injection valves has always created an uncertainty of the realized injection time. In electronic lubricators this has been corrected for, by introducing a delay that accounts for mechanical and hydraulic delays in the system. In most softwares these delays are static constants usually between 30 – 50 ms. In reality the delays are dynamic and dependent on pipe length, pipe diameter, component tolerances, component wear, component temperature, oil pressure, oil quantity, oil viscosity and thus temperature.

Precision of timing has two elements, start of injection and duration of injection.

1.1.1 Correct injection angle and lubrication window

When injecting the cylinder oil into the ring-pack, is must optimally be time to deliver between 1st and 2nd piston ring and satisfactory between 1st and 4th piston ring. With HJ SIP timed lubrication, the injection takes place before the piston passes the lubrication quills, typically at 256º from TDC with valves placed at 1/3 from the top. Tests have shown that HJ SIP has an injection window of approximately ±15º where the oil delivery may take place [1].

A MAN-ES G engine with a stroke length of 3,720 mm operating at 58 RPM, lubricated in the ring-pack, between 1st and 4th ring, with the injection valves positioned 1/3 from the top, will have a window of approximately 4-5º of crankshaft position. This translates to about 14 ms. Injecting at a target of ±1.0º or approximately ±36 mm of piston position, translates to a window of approximately ±2.9 ms. HJ SIP timing in the same example translates to a window of approximately 86 ms. Please see Figure 1.

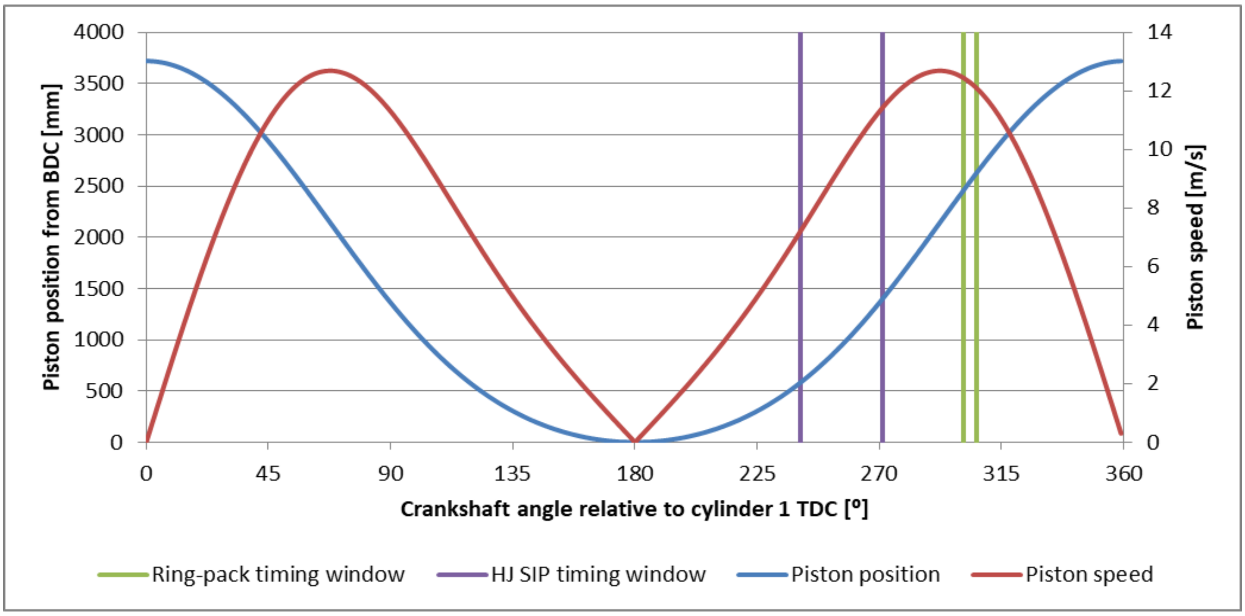

Figure 1. Ring-pack lubrication window and HJ SIP lubrication window.

This means there is a much higher requirement to precision of timing and duration of injection when attempting to lubricate the piston ring pack. Too early timing will lubricate the piston crown, too late timing and/or too long duration will lubricate the piston skirt.

1.1.2 Multiple injection angles

The advantages of HJ SIP lubrication has been well documented in papers [1] and [4], as well as numerous positive case stories found on the HJL website. However traditional ring-pack lubrication may have its own advantages. Mixing HJ SIP timed cylinder oil injections with traditional ring-pack timed injections, may provide the benefits of both lubrication strategies.

Making injections in multiple injection angles in the same engine revolution is patented (e.g. publication no. WO2010149162), but not yet tested by HJL. Implementing multiple injection angles on current systems (regardless of make) will be restricted to dosing the same quantity at each angle. Cylinder lubrication generally has three major functions:

- Neutralize the sulphuric acid formed during combustion.
- Lubricate the running surfaces by creating an oil film between the piston rings and liner surface.
- Keeping the liner, piston rings and –crown clean by preventing or minimizing build-up of deposits and flushing out particles from wear and formed in the combustion process.

The hypothesis is that optimal placement of the cylinder oil is dependent on the function of the oil. For example:

If lubricating to neutralize sulphuric acid, placement in the top according to HJ SIP timing is best, as this is where corrosion wear is seen. Lubricating to create an oil film between running surfaces, a combination of HJ SIP and ring-pack timing may be optimal, as abrasive wear is higher at the top, but a concern on the entire liner surface. Lubricating to clean the liner and ring-pack, ring-pack lubrication may be at a slight advantage, as the oil more effectively will be able to transport the impurities down to the drain.

1.2 Quantity and adjustment

There are two main philosophies regarding quantity adjustment. Some believe intermittent lubrication, altering the frequency of injection is the better approach. Others, including HJL believe injecting fresh cylinder oil in every revolution, altering the quantity per injection is the better approach.

1.2.1 Lubrication frequency and quantity adjustment

It is well known that oil life is directly related to the Oil Stress Factor (OSF) it is exposed to. Higher pressure and higher temperature will increase the OSF primarily due to acidic, thermal and oxidation stress, as well as higher soot loading [5], [6], [7]. According to [8], OSF levels in a two-stroke marine diesel engine "*accumulate in the lubricant only after a few seconds*" and the OSF is increased as the cylinder oil feed rate is reduced. Moreover to achieve higher efficiency, modern engine designs are designed to a higher maximum firing pressure and a higher combustion temperature [9], [10]. The above implies that refreshing the cylinder oil continuously, is important, and becomes even more important in newer engine designs and when reducing the cylinder oil feed rate.

Experience at HJL has shown that going from intermittent to non-intermittent lubrication, adjusting the quantity per injection instead, provides a significant advantage. The cylinder oil consumption may be reduced and the cylinder condition is improved – confirming the statement above.

However there may be some merits to intermittent lubrication. The hypothesis is that optimal quantity per injection at a given average quantity is dependent on the function of the oil. For example:

If lubricating to neutralize sulphuric acid, fresh oil at every revolution is best, as the sulphuric acids are formed, during every combustion cycle. Lubricating to create an oil film between running surfaces, fresh oil at every revolution is best, as the oil degrades rapidly when exposed to high temperature and pressure. Lubricating to clean the liner and ring-pack, a larger dose intermittently may be at a slight better at flushing out impurities.

1.2.2 Precision of quantity

When dosing the cylinder oil using a piston pump certain factor will affect the precision at which the cylinder oil is dosed. Typically less oil is output from the pump, than the volume the piston displaces. This is referred to as volumetric efficiency. E.g. is a piston displaces a volume of V_{disp} = 100 mm^3, but 3 mm^3 of oil leaks over the piston during the activation stroke, the output oil volume V_{out} will only be 97 mm^3. The volumetric efficiency will in this case be:

$$\eta = V_{out}/V_{disp} = 97/100 = 0.97 = 97\ \% \quad (1)$$

The volumetric efficiency is usually accounted for in the algorithm, calculating the required quantity, but as with the hydraulic delay, this is also dynamic and dependent on the same factors, please see section 1.1.

Another factor affecting the precision is when converting the volume to a mass, which the feed rate is given in. This is usually done in the software using a static mass density, but the mass density is temperature dependent. This may give an additional error in the calculations.

1.3 HJ SIP spray

In [1] a good spray was defined through modelling and experiments. This work was extended in [2], a Ph.D. study conducted at HJL, finding which parameters have influence on spray formation and to what degree. It was found that cavitation in the nozzle is critical for spray formation when using low viscous fluids like cylinder oils. Figure 2 shows the cavitation formation in an acrylic HJ SIP nozzle during injection.

In Table 1 the equipment and variables of the experiments are shown.

Table 1. Test equipment and variables.

Valve	HJ SIP III
Oil used	ExxonMobil Mobilgard 560 VS
Valve temperature	90º C
HJ SIP closing pressure	60 bar
Spray chamber pressure	Atmospheric
Camera	Olympus i-Speed 2
Shutter speed	1,500 FPS
Lubricator	HJ Lubtronic T155
Piston diameter	Ø6 mm
Stroke length	6 mm

In Figure 3 to Figure 6 a typical spray from a HJ SIP valve can be seen. The images were captured using a high speed camera. Figure 7 shows the spray angle of three experiments. This section serves as a baseline reference to the HJ E-SIP spray tests seen in section 4.1.

Figure 3 shows the valve at rest for reference. The

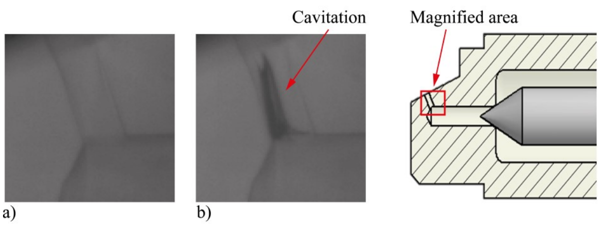

Figure 2. The internal volume of an acrylic nozzle [2].

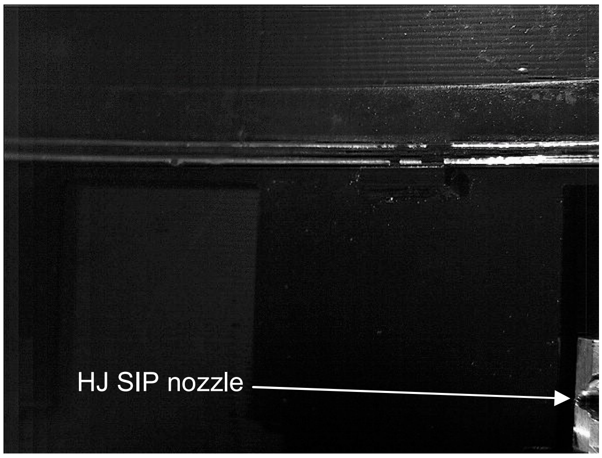

Figure 3. HJ SIP at rest.

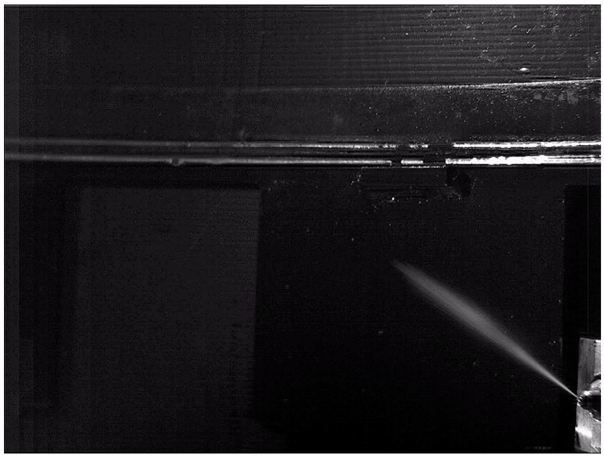

Figure 4. HJ SIP beginning of spray.

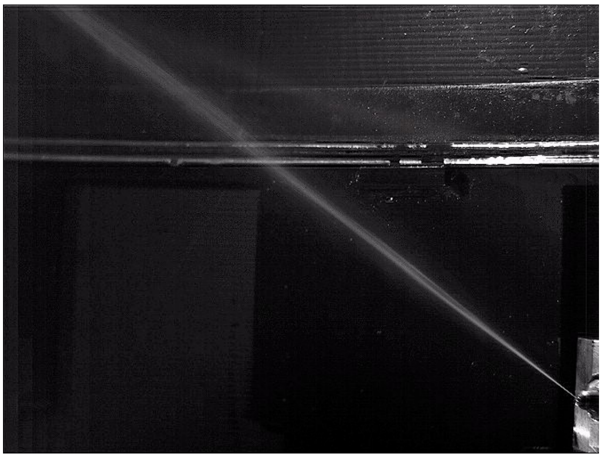

Figure 5. HJ SIP mid spray.

nozzle is at the bottom right corner

Figure 4 shows the beginning of the spray. It shows a spray cone forming at this stage.

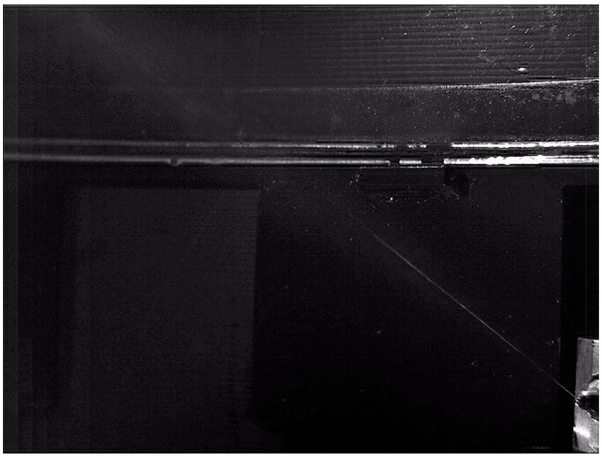

Figure 6. HJ SIP end of spray.

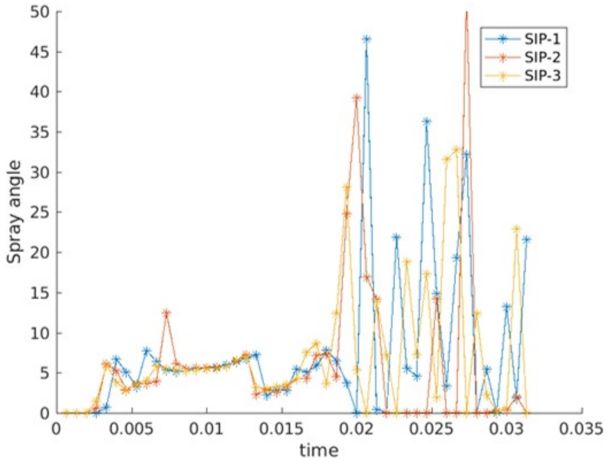

Figure 7. Spray angle for 3 HJ SIP spray tests.

Figure 5 shows the mid spray. It shows that the spray continues to breaks up father from the nozzle, maintaining a constant spray angle.

Figure 6 shows the end of the spray. It shows that during closing of the HJ SIP cavitation stops and a jet forms. Further testing has shown that the quantity delivered in this jet is small compared to the overall quantity delivered in an injection.

Figure 7 shows the spray angle found in three HJ SIP spray tests using an algorithm derived in [2]. The time unit is [s]. The unstable measurements from 20 to 30 ms are the effects of the jet formed as seen on Figure 6.

1.4 2020 IMO sulphur emission requirements

The 2020 IMO sulphur emission requirements hold a number of uncertainties for 2-stroke marine diesel operation no matter the compliance method chosen [3]. Four ways to be 2020 compliant:

- HSFO combined with scrubbers
- LSFO or distillates
- LNG
- Other new compliant fuel types

Possible issues with the various compliance methods pertaining to cylinder condition and lubrication are:

HSFO combined with scrubbers. A lack of availability of HSFO may force bunkering of LSFO at certain times, requiring the ability to operate on both HSFO and LSFO.

LSFO or distillates. The impact of continued operation on LSFO has been proven to be problematic [11]. The sulphur in HSFO have a positive effect on lubrication and the microstructure of the liner wall benefits from minor controlled corrosion to maintain open graphite lamellas that acts as an oil reservoir. Closing these graphite lamellas is called bore-polishing and leads to a high risk of scuffing [12].

LNG. Compared to the experience with HSFO with regard to both operation time and number of vessels, experience with LNG operation is still very limited. As with LSFO the lack of sulphur and minor corrosion may prove problematic.

Other new compliant fuel solutions. The impact on cylinder condition and lubrication is unclear.

1.5 Flexibility

The impacts on cylinder condition, of the 2020 IMO requirements and other future restriction, will require the cylinder lubrication system to be very flexible, to accommodate all known and any unknown issues regarding cylinder condition that may arise.

2 NEW HJL SYSTEM

Through the last years HJL has been developing a new lubrication system based on the same principals know from common rail fuel injectors. As with common rail fuel injectors, the new HJL lubrication system will become the norm for cylinder lubrication.

2.1 Motivation for a new system

As explained above current cylinder lubrication systems perform adequately, but a system that addresses the shortcomings of current systems while maintaining and combining the good characteristics was needed. A list of advantages of the new HJL system can be seen in section 2.3 below.

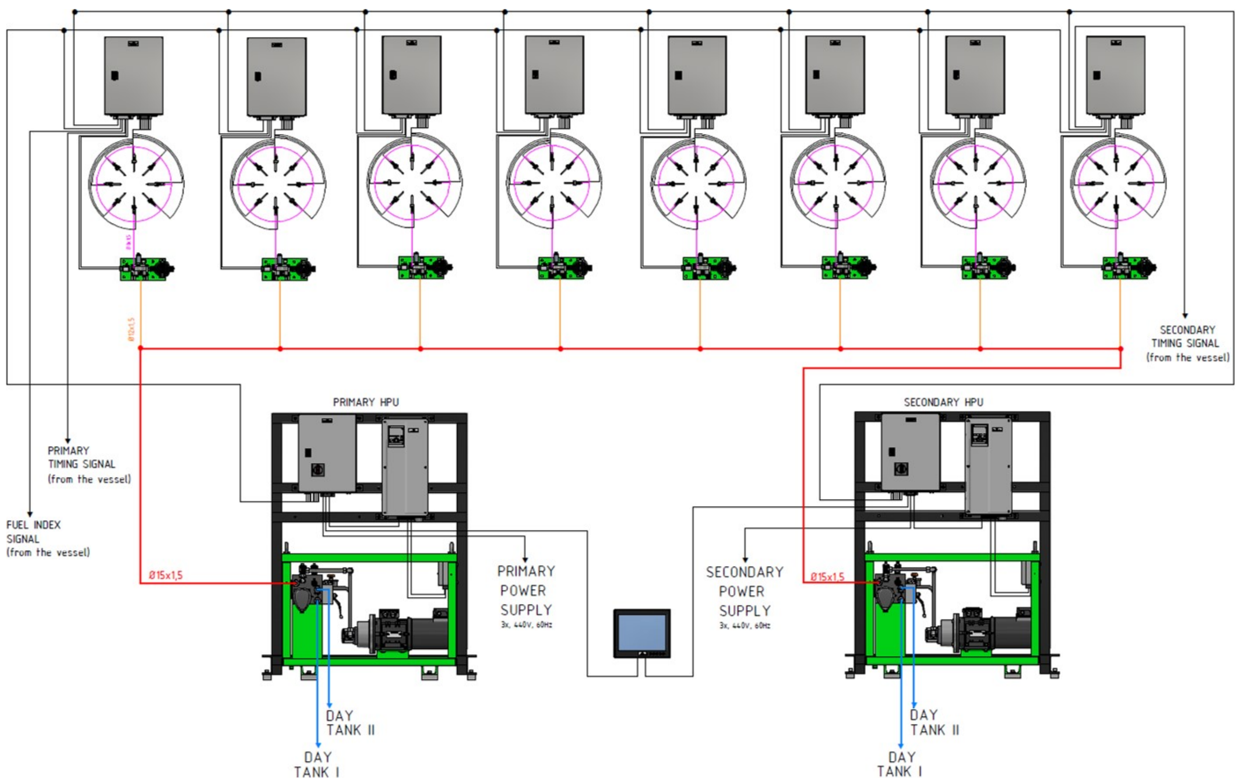

Figure 8. The new HJL system. Blue indicates supply from the day tank, red indicates common rail pipe, orange indicates individual cylinder supply pipes, magenta indicates valve supply pipes, black indicates electrical supply and signals.

2.2 System description

In Figure 8 the system layout of the new HJL system can be seen. The system comprises a central Human Machine Interface (HMI) connected by Ethernet to two identical Main System Control Units (MSCUs). These MSCUs each supply a pump station comprising a Variable Frequency Drive (VFD) and a motor/pump unit, please see Figure 9. The motor/pump unit comprises an oil selection valve, an inlet and outlet pressure sensor, a temperature sensor, a heater, a filter, a pressure relief valve, and the motor and pump. The VFD adjusts the motor speed to maintain a constant pressure. The MSCUs also supply one Cylinder Control Unit (CCU) per cylinder. These CCUs control the injection valves called HJ E-SIP, please see Figure 10. The pump station supplies pressure to the common rail. The common rail supplies one cylinder manifold per cylinder, please see Figure 11. The cylinder manifold comprises a flowmeter, a non-return valve, a temperature sensor, an accumulator and a cut-off valve. The flowmeter is used for quantity control. Each HJ E-SIP valve is controlled by a solenoid coil that can open and close the valve. A special control algorithm to facilitate the necessary precision has been developed.

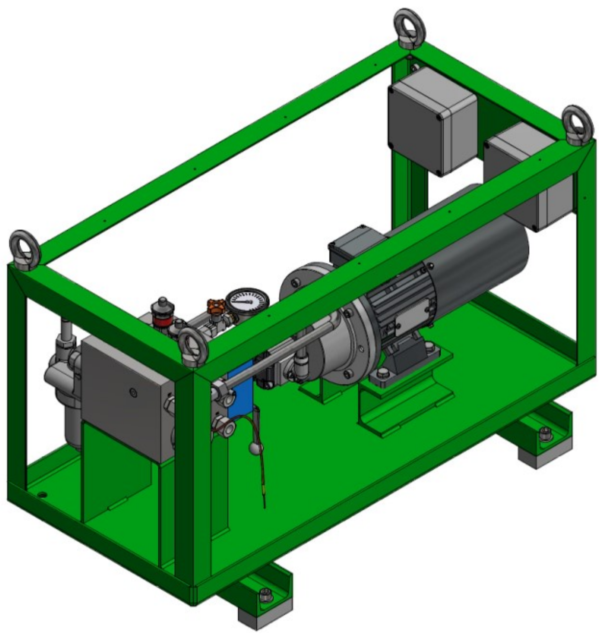

Figure 9. The motor/pump unit.

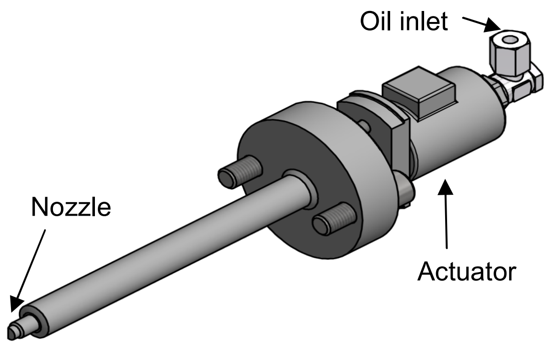

Figure 10. HJ E-SIP.

The algorithm consists of an adaptive feedback control algorithm that continually updates the parameters used to determine quantity and timing delays. It also consists of a valve activation sequence to ensure precise control enabling as fast as possible opening and closing of the HJ E-SIP valve.

The IIoT module is still under development and will be presented later in 2019.

2.3 New HJL system advantages

With the possibilities of advanced control such as multi-timing on individual valves, optimal utilisation of the cylinder oil is achievable, which will lead to less cylinder oil consumption and better cylinder condition.

Most flexible system available, compared to all other current systems making it compatible to all 2020 compliant solutions, no matter what is chosen (scrubbers, LSFO, LNG, other).

Direct control of the valves means more accurately timed injections as there is minimal hydraulic delay from signal to injection. This gets the cylinder oil to the intended target and will lead to a higher utilisation of the cylinder oil.

Very small amounts can be injected while maintaining good spray quality. This makes the system able to deliver oil every revolution, or even multiple times per revolution (multi-timing). Multi-timing (patented) allows cylinder oil to be placed both on the liner surface above the piston and between the piston rings in the same revolution. The quantity can be adjusted between injections, enabling advanced multi-timing control.

The system has regenerative valve control that is able to collect the energy stored in the inductor when it is disconnected. It also has a frequency controlled pump motor to ensure minimum power usage of the pump unit. This makes the new HJL system a very green system.

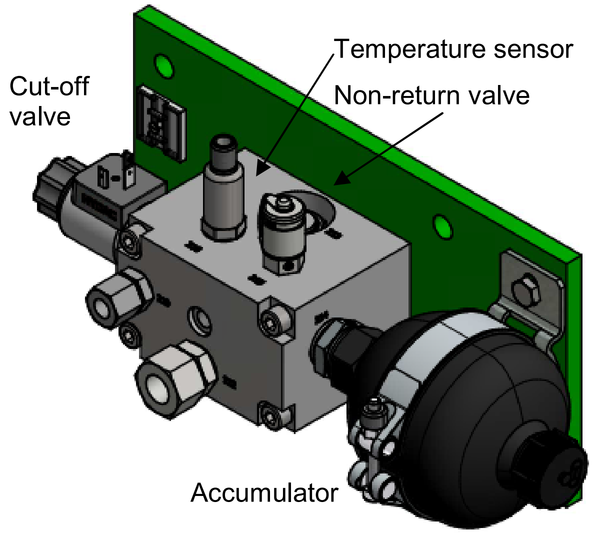

Figure 11.he cylinder manifold without flowmeter.

Fewer parts than current systems and a modular, means less complexity. This ensures higher reliability and makes the system easier to use. It also means faster, simpler and cheaper installation and maintenance.

No volumetric efficiency to consider in neither lubricator nor injection valve, as all oil going through the flowmeter will be injected into the cylinder.

Pipe usage greatly reduced. One common rail supplies all valves, instead of one pipe per valve. This leads to fewer connection/fittings and in turn fewer potential leaks. Fewer pipes also means less oil contained in the pipes. This will allow a faster changeover when changing cylinder oil BN. The changeover can be done between 2 and 3 times faster, even accounting for less oil consumption with the new HJL system.

As an example a 7 cylinder engine with 8 lubrication quills per cylinder is used. Assuming 15 m of 18 x 1.5 mm supply pipe from cylinder oil selection valve to the lubricator/cylinder manifold and an average of 10 m 8 x 1.5 mm valve pipe from the lubricator/cylinder manifold to the injection valves. With the current technology there will be one pipe to each injection valve. This means that the volume in this example will be 8 times greater than the new HJL system. Please see Eq. (2) and (3).

$$V_1 = ((D - d)/2 \cdot 10^{-3})^2 \cdot \pi \cdot l \quad (2)$$

$$V_2 = n_{cyl} \cdot n_{quill} \cdot ((D - d)/2 \cdot 10^{-3})^2 \cdot \pi \cdot l \quad (3)$$

$$V_3 = n_{cyl} \cdot ((D - d)/2 \cdot 10^{-3})^2 \cdot \pi \cdot l \quad (4)$$

Where:

V_1	is the volume of the supply pipe	[m^3]
V_2	is the volume of the current valve pipe	[m^3]
V_3	is the volume of the new valve pipe	[m^3]
D	is the outer pipe diameter	[mm]
d	is the 2 times the pipe wall thickness	[mm]
l	is the pipe length	[m]
n_{cyl}	is the number of cylinders	[-]
n_{quill}	is the number of quills per cylinder	[-]

This results in a total volume of the current technology of:

$$V_1 = ((18 – 3)/2 \cdot 10^{-3})^2 \cdot \pi \cdot 15 \quad (5)$$

$$V_2 = 7 \cdot 8 \cdot ((8 – 3)/2 \cdot 10^{-3})^2 \cdot \pi \cdot 10 \quad (6)$$

$$V_3 = 7 \cdot ((8 – 3)/2 \cdot 10^{-3})^2 \cdot \pi \cdot 10 \quad (7)$$

$$V_{current} = V_1 + V_2 \quad (8)$$

$$V_{current} = 0.00265 + 0.0110 = 0.0137 \text{ m}^3 \quad (9)$$

$$V_{new} = V_1 + V_3 \quad (10)$$

$$V_{new} = 0.00265 + 0.00137 = 0.00403 \text{ m}^3 \quad (11)$$

Where:

$V_{current}$	is the total volume of the current system	[m^3]
V_{new}	is the total volume of the new system	[m^3]

Further assuming a cylinder oil saving potential of 40 % when using the new HJL system, will make changing cylinder oil 2.4 times faster than the current technology, please see Eq. (10)

$$(V_{current} / V_{new}) / 1.4 = 2.42 \quad (12)$$

IIoT-ready system. The system can be brought online, depending on the on-board availability of internet. Remote access for owner/fleet manager/superintendent will be possible. Single-user login shared on the entire fleet will ensure complete traceability. Remote access for HJL after sales for remote service and software updates. Any instance of remote access cannot happen without the prior consent of the crew. Online capability is not a requirement; the system will also be fully functional offline.

Ready for the future, 2020 and beyond – great potential for even further development.

2.3.1 Possible lubrication strategies

This new HJL system presents a large number of possibilities for testing of lubrication strategies. Individually controlled valves with the possibility to vary quantity between injections at a very high precision provide maximum flexibility. Mounting the valves in different levels to further increase the variance is also a possibility as the valves are individually controlled. This means that one valve has unique injection angles, oil quantity distribution relative to these angles and oil quantity relative to the other valves. All issues raised in sections 1.1 and 1.2 can be addressed with the new HJL system.

This will be a mix of existing and new strategies. The overall purpose is, to be able to adapt to any fuel oil operating scenario and any cylinder oil make and BN while:

- Minimize the cylinder oil consumption. In [4] it can be seen that a cylinder oil feed rate of 0.3 g/kWh is achievable while maintaining excellent cylinder condition.
- Improving cylinder condition, maximizing the cylinder liner and piston ring life.

This may require different strategies for different engine type, fuel types, operating scenarios, etc.

Details on these strategies and the results will be divulged in a later paper when vessel tests have been conducted.

3 CONDUCTED AND PLANED TESTING

A series of laboratory tests have been conducted on the new HJL system and the E-SIP valve especially.

In the following sections the tests conducted are described.

3.1 Laboratory tests

To ensure that the system would perform at least as well as HJ Lubtronic SIP a series of laboratory test were conducted. These tests were divided into:

- Spray test to verify the spray quality.
- Quantity test – both stability in quantity over time and ability to adjust quantity.
- Timing test – precision of timing.

3.2 Vessel test

At the submission of this paper no vessel test results are available. The system will be installed on a vessel in the very near future and results of a vessel test are expected to be presented at the CIMAC conference in Vancouver.

4 RESULTS

4.1 Spray test

To verify the spray of the new HJ E-SIP valve a high speed camera was used set up identical to the HJ SIP spray tests shown above. As there is 20 years of experience with the HJ SIP valve, the HJ SIP spray test in section 1.3 serves as a reference.

In Table 2 the equipment and variables of the experiments are shown.

Table 2. Test equipment and variables.

Valve	HJ E-SIP
Oil used	ExxonMobil Mobilgard 560 VS
Valve temperature	90º C
Common rail pressure	60 bar
Spray chamber pressure	Atmospheric
Camera	Olympus i-Speed 2
Shutter speed	1,500 FPS

The results of the HJ E-SIP spray test can be seen in Figure 12 to Figure 15.

Figure 12 shows the HJ E-SIP valve at rest for reference.

Figure 13 shows the HJ E-SIP at the beginning of the spray. The spray cone is slightly larger than on the HJ SIP reference at the same stage.

Figure 14 shows the HJ E-SIP at mid spray. The spray cone is smaller than at the beginning resembling the HJ SIP spray more.

Figure 15 shows the HJ E-SIP at end of spray. The HJ E-SIP valve closes much more abruptly than the HJ SIP valve. No trailing jet is present.

Figure 16 shows the spray angle found in three HJ E-SIP spray tests using an algorithm derived in [2]. The time unit is [s]. The measured angle of the

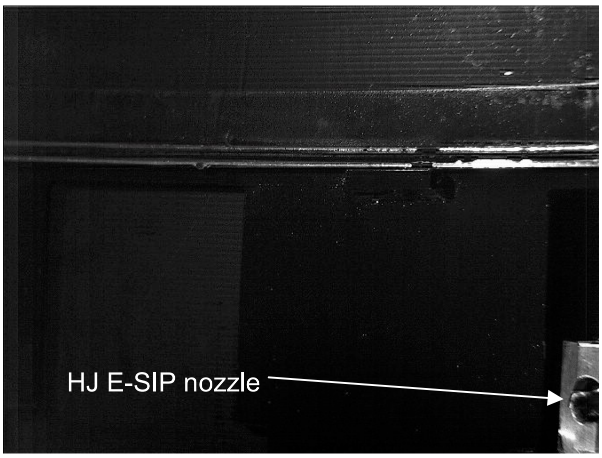

Figure 12. HJ E-SIP at rest.

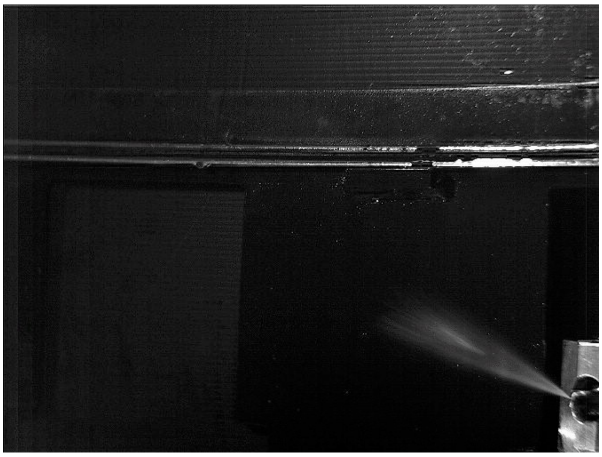

Figure 13. HJ E-SIP beginning of spray.

Figure 14. HJ E-SIP mid spray.

Figure 15. HJ E-SIP end of spray.

HJ E-SIP valves is more stable than the HJ SIP valve. The time of instability at the end of the spray is shorter for the HJ E-SIP valve.

The spray from the HJ E-SIP valve is very similar to the HJ SIP valve. The more stable spray angle and the more abrupt closing of the HJ E-SIP valve

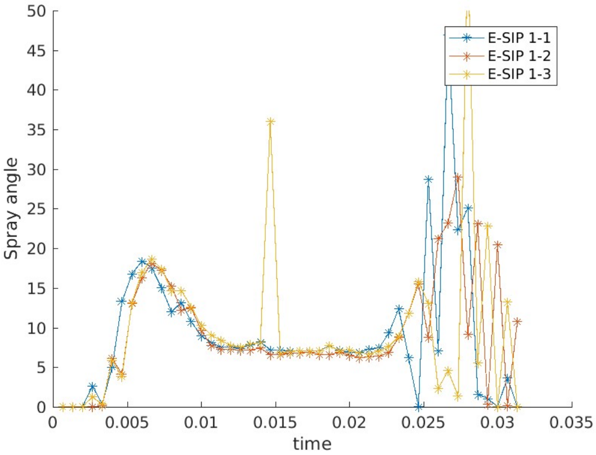

Figure 16. Spray angle for 3 HJ E-SIP spray tests.

may give the HJ E-SIP valve a slight advantage over the HJ SIP valve.

4.2 Quantity test

Several quantity tests have been made to show both the stability over time and the ability to adjust quantity. Figure 17 shows an example of one such test. The data is shown by square marks and a straight curve fitting has been laid on top each valve. It shows that there is stability over time and correlation between time the valve is held open and quantity. The quantity does not converge to 0 mg/injection at “Hold time” 0 ms. This is because of the advanced algorithm. The valve has an open cycle and actually opens before the “Hold time” starts. Adjusting the open cycle can bring the quantity further down. Tests have shown that the quantity can be brought down to 1 mg/injection with the oil breaking away from the nozzle tip during injection. At very low quantities of <1 mg/injection the delivered oil will build up as a droplet on the nozzle tip.

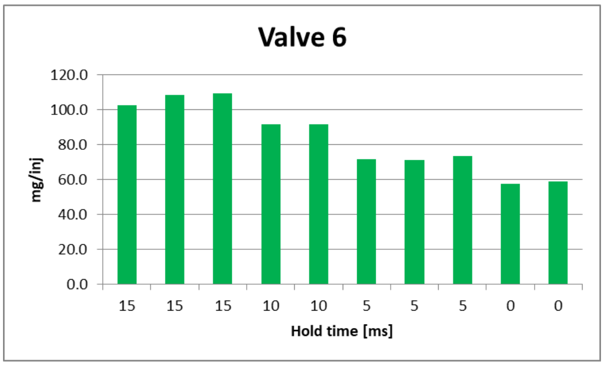

Figure 18. Test results for HJ E-SIP valve 6.

In Figure 18 an example of the data from valve 6 can be seen.

This test was done by forcing the valves to operate at certain parameters. When in service the valves will tune themselves using continually tuned adaptive feedback control algorithms to ensure uniform performance and stability over time.

4.3 Timing test

To test the accuracy of timing a load cell with a strain gauge was mounted in front of the valve nozzle, to register the oil output from the nozzle.

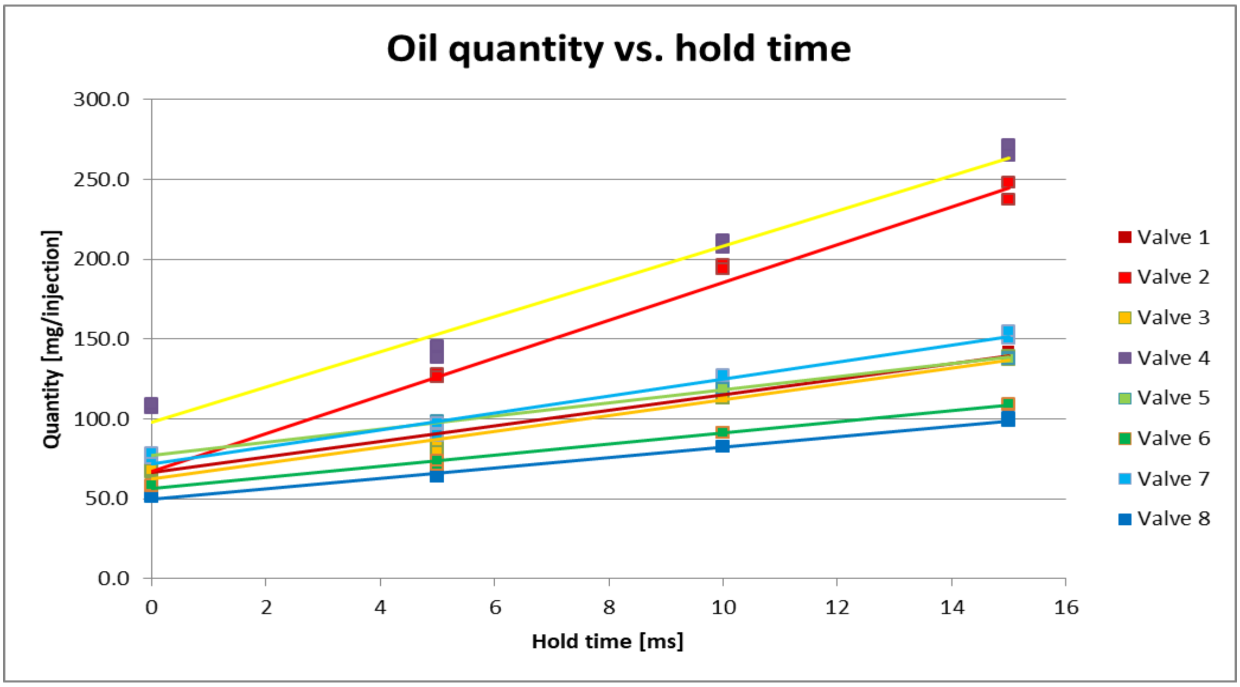

Figure 17. HJ E-SIP quantity test.

An oscilloscope registered the valve activation signal along with the strain gauge output. Three times from the open cycle of the valve algorithm started, to the strain gauge registered a signal, for three valves is recorded in Table 3. This delay will be accounted for in the algorithm. The delay is much smaller than the hydraulic delay used today, please see section 1.1. It can be seen that even if compensating using a static delay of 3.6 ms, the largest deviation would be -1.2 to +0.5 ms, well within the target window of ±2.9 ms found in section 1.1.1.

Table 3. Results from timing test.

Valve	Time 1 [ms]	Time 2 [ms]	Time 3 [ms]	Avg. time [ms]
1	4.1	3.6	3.6	3.8
2	2.4	3.8	4.0	3.4
3	3.7	3.6	3.9	3.7
Avg. all				3.6

The duration of timing will be adjusted according to quantity. This will be restricted to certain lubrication windows ensuring the cylinder oil delivery is restricted to predefined desired crankshaft angles.

5 CONCLUSIONS

The laboratory tests show that the new HJL system performs as well as HJ Lubtronic SIP did in laboratory tests. Moreover the new HJL system provides the possibility for a number of lubrication strategies to be tested for optimal cylinder condition and minimal cylinder oil use. All this is achieved with advanced algorithms and a minimum of components.

The next step is the vessel tests where the new HJL system will be proven in service. Results from these tests may be presented at the CIMAC conference in Vancouver.

Along with the vessel tests, laboratory testing will continue at HJL to gain further knowledge on the performance of the system and optimize the algorithms.

6 DEFINITIONS, ACRONYMS, ABBREVIATIONS

BN: Base Number

CCU: Cylinder Control Unit

HJL: Hans Jensen Lubricators A/S

HJ SIP: Hans Jensen’s Swirl Injection Principle

HJ E-SIP: Hans Jensen’s Electronic SIP

HMI: Human Machine Interface

HSFO: High Sulphur Fuel Oil

IIoT: Industrial Internet of Things

IMO: International Maritime Organization

LNG: Liquid Natural Gas

LSFO: Low Sulphur Fuel Oil

MSCU: Main System Control Unit

OSF: Oil Stress Factor

RPM: Rounds Per Minute

VFD: Variable Frequency Drive

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