INTRODUCTION OF THE COMMON RAIL SYSTEM APPLIED IN MARINE DIESEL ENGINE

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Abstract: *At the present time, together with the development of the digital control technology in various industries, the fuel injection process of marine diesel engine equipped with the electronic common rail (CR) system which creates significant impact to the environment has been researched by numerous engine manufacturers such as Caterpillar, MTU, Cummins, Man, etc. In this paper, authors are going to research thorough and analyse the advantages as well as the disadvantages of the various electronic common rail systems which has been developed for marine diesel engine. In accordance to the result of this research, authors are going to analyse and deliver commentaries as well as summarize the common characteristics of marine diesel engine common rail system which has been developed, in order to give out suggestions of remarks and notices for the exploitation, maintenance and repair processes of these such systems.*

Keywords: *Common Rail, CR, Injector, ECU, Nozzle*

Classification numbers: *2.1*

1. Introduction

Marine diesel engines are nowadays utilized broadly on the world transport vessels due to their efficiencies and economy. However, with the present sustainable development aims which concentrates on the environment protection, marine diesel engines should have become environmental friendly. In some aspect, common rail system could be the answer for this requirement, due to its various advantages, such as reducing the noise, maintain the required high injection pressure despite the engine speed, reducing the NO_x emission, etc. Common rail system was developed in 1913 by Vickers company in England [1] but until 1995, this system had been applied for diesel engine by DENSO in Hino Rising Ranger Truck [2]. Since then, the common rail system has been popular and used largely.

1.1. Principle of operation.

In a common-rail engine, a feed pump delivers the fuel through a filter unit to the high-pressure pump. The high-pressure pump delivers fuel to the high-pressure accumulator (the rail). The injectors are fed from this rail. The injectors inject fuel into the combustion chamber when the solenoid valve is actuated. The fuel volume between the high-pressure pump and the injectors serves as an accumulator. This helps to dampen oscillations initiated by the pulsating delivery of the high-pressure pump. A pressure sensor measures the fuel pressure in the rail. Its value is compared to the desired value stored in the electronic control module (ECM). If the measured value is different from the desired value, an overflow orifice on the high-pressure side of the pressure regulator is opened or closed. The overflow fuel returns to the tank. The injector opening and closing is controlled by the ECM. The duration of injection, fuel pressure in the rail and the flow area of the injector determine the injected fuel quantity. [3]

1.2. Structure of common rail system

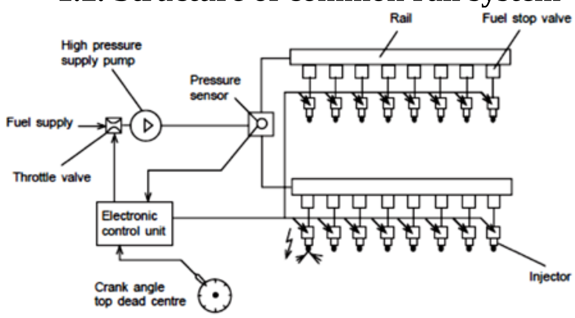

Figure 1. *Common rail injection system of a typical MTU high speed engine.* [4].

1.3. Particular parameters of the system

When researching the common rail system, there are several parameters that should be investigated, such as injection pressure, injection timing and the forming and developing of the injection spray.

Pressure: Fuel injection pressure of a common rail system is always maintained at the set value and not affected by the various speeds of the engine. Global automotive supplier DENSO Corporation has developed a new diesel common rail (DCR) fuel injection system with the world's highest injection pressure of 2,500 bar. Based on DENSO's research, the new system can help increase fuel efficiency by up to 3 percent while also reducing particulate matter (PM) by up to 50 percent and nitrogen oxides (NOx) by up to 8 percent. This is compared to DENSO's previous generation system. [5]

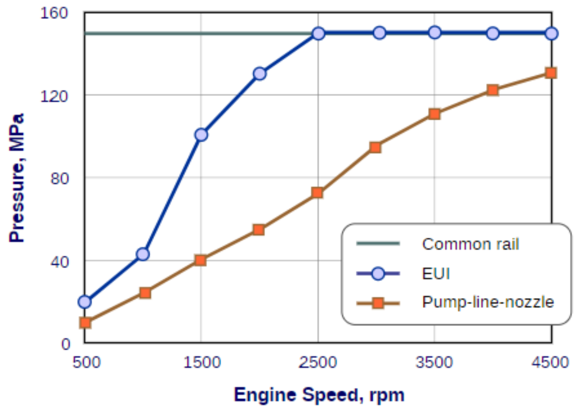

Figure 2. *Injection pressure of common rail system compared with others.*

Injection timing: The injection timing is controlled by the Electronic Control Module (ECM). This ECM controls the piezoelectric fuel injectors in terms of opening or shutting them off. Injection timing can be varied during running of the engine, whereas in conventional system the engine has to be stopped and setting for timing has to be changed.

Injection spray: Currently, it is possible to have up to eight injection pulses - two pilot, four main, and two post-injection pulses during the injection of a common rail system [6]. By using two high-speed video cameras to capture the development of the injection spray, it is stated that by increasing injection pressures and using small injector orifice sizes, the injected diesel droplets reduce in size and penetrate further, hence increasing air utilization, thus leading to faster evaporation rates and reduced ignition delay (figure 3).

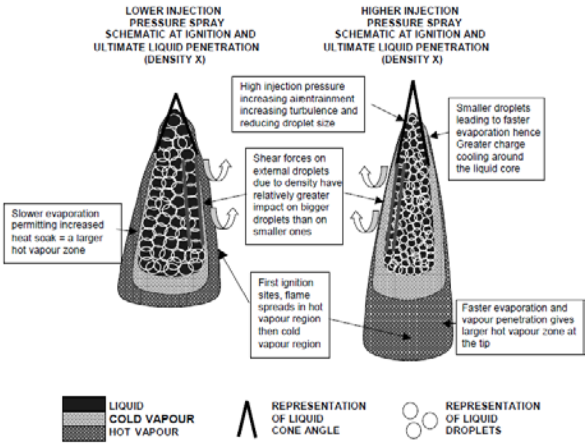

Figure 3. *Summary schematics of two spray developments in similar in-cylinder densities for different injection pressures.*

1.4. Advantages of common rail system

Any injection pressure can be used, at any engine load or speed operation point, with the injection rate control close to the nozzle; this makes it possible to improve performance over the full engine load range.

Injection timing can be varied during engine running to optimize engine performance without the timing range being limited by cam working lengths; this is beneficial for emissions optimization as well.

Camshaft peak torque is smaller; this allows a smaller camshaft to be used and makes possible greater engine power density and smaller engine outlines.

The common rail pumping principle gives higher efficiency (no helix spill) and the potential to reduce mechanical drive losses, underwriting lower fuel consumption.

The design is simpler, allowing the elimination of the one pumper- cylinder principle, the fuel rack control shaft and the mechanical governor; this results in cost reductions for the overall fuel injection system.

Among the potential operational benefits are: lower fuel consumption; lower NOx emissions; no visible smoke at any load (and the possibility to start the engine without visible smoke); load cycling without smoke; and lower maintenance costs.

2. Common rail systems of marine diesel engine

CAT: The key features of the Cat Common Rail technology are: Well adapted injection pressure over the entire engine operating range; Fully flexible fuel injection system enabling optimized emissions and engine performance; Suitable for HFO, MDO and DO; 100% retrofittable system. CAT CR system is equipped with two high pressure pumps to deliver the required amount of fuel to the rail and provide the desired rail pressure in closed loop control. The pump itself is based on a proven design and has been modified for HFO operation. By having two pumps for all in-line engines the amount of HP connections and components is drastic - ally reduced and thus increases reliability. The inlet metering control of the pump ensures a high pump efficiency. The double-walled rails are pressurized and act as an accumulator, with one rail segment feeding fuel to three injectors, i. e. a nine cylinders engine has only three rail segments, an eight cylinders engine has two rail segments, each feeding four injectors. This layout reduces the number of parts and the number of high pressure connections. Flow limiters prevent the cylinders from over-fuelling; a safety valve acts as pressure relief in case of an unwanted over-pressurized rail. [7]

Figure 4.*Rail segment with three injectors of CAT M32C engine.*

MTU: In 1996, with the Series 4000 engine, MTU was the first manufacturer of large diesel engines to introduce common rail fuel injection as a standard feature.

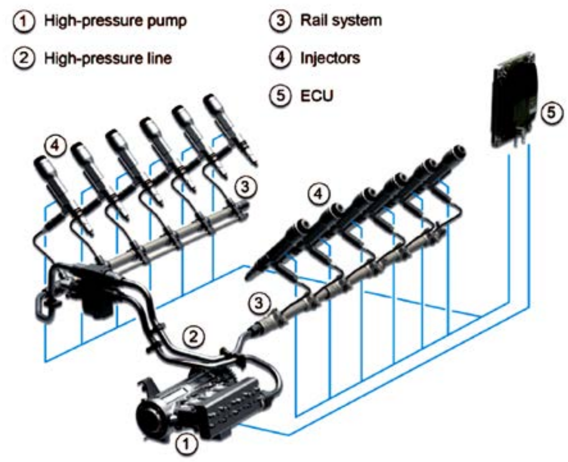

Figure 5. *Common rail system for MTU Series 4000.*

The present evolution stage of the injection system for MTU engines divides the fuel injection sequence into as many as three separate phases. The timing of the start of injection, the duration and amplitude are user-defined in accordance with engine performance map. The main injection phase supplies the fuel for generating the engine's power output. A pre-injection phase initiates advance combustion to provide controlled combustion of the fuel in the main injection phase. This reduces nitrogen oxide emissions, because the abrupt combustion prevents high peak temperatures. A post injection phase shortly after the main injection phase reduces particulate emissions. It improves the mixing of fuel and air during a late phase of combustion to increase temperatures in the combustion chamber, which promote soot oxidation. Depending on the engine's operating point, the main injection phase can be supplemented as required by including pre and/or post injection phases. [8]

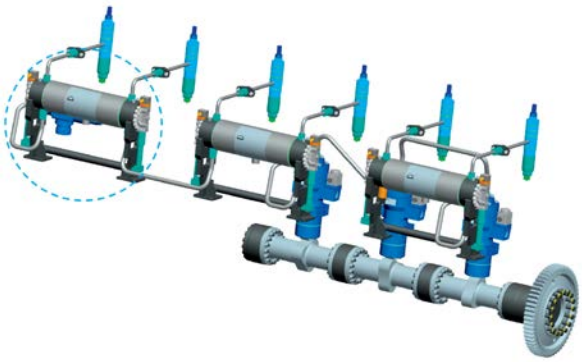

Figure 6*. Common rail injection system of MAN*

MAN: MAN Diesel & Turbo is the world's leading designer and manufacturer of low and medium speed engines – engines from MAN Diesel & Turbo cover an estimated 50% of the power needed for all world trade.

Figure 7 shows the hydraulic layout of the patented heavy fuel oil CR injection system for the MAN 32/44CR engine.

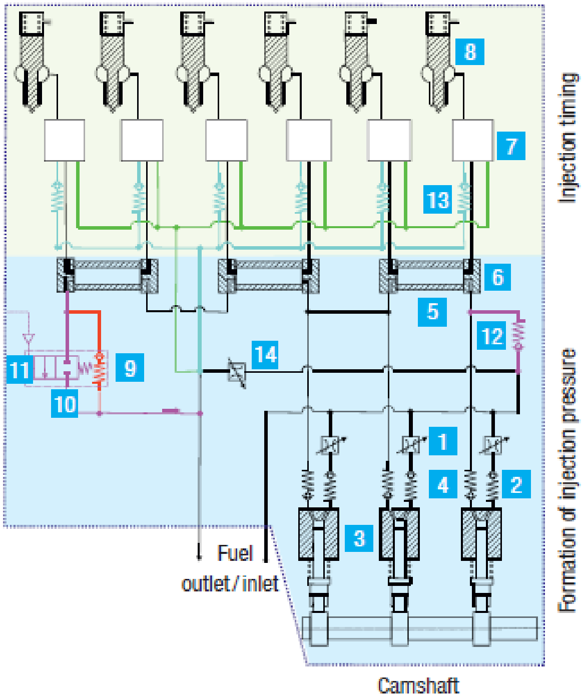

Figure 7. *CR injection system – general layout and functionality of MAN.*

From the fuel system, delivered fuel is led through electromagnetic activated throttle valves (1) and suction valves (2) to the high-pressure pumps (3), which supply the rail units {5) with fuel under high pressure up to 1,600 bar by means of pressure valves (4). The rail units (5), which function as a pressure and volume accumulator for fuel, consist of a high-strength tube closed with end covers in which a control-valve carrier (6) is integrated.

The control valves (7) are fixed on to the control-valve carrier. Connections for high-pressure pipes are radially arranged on the control-valve carrier; these connections lead to the injectors (8), as well as to the next rail unit. This design means the tube itself requires no drilling and is therefore highly pressure-resistant.

To guarantee uniform fuel injection, pressure fluctuations in the system must remain at a very low level. This is achieved by using rail units of optimum volume, several (two to four) high-pressure pumps instead of one single pump, and a camshaft with a carefully arranged triple cam lobe for optimum drive.

The high and uniform delivery volume obtained in this way plays a key role in keeping pressure fluctuations very low. As much fuel as necessary is supplied to the high-pressure pumps, in order to keep the rail pressure at the setpoint. The rail pressure will be calculated by a characteristic map in the injection control, according to the engine load. The electromagnetically activated throttle valve (1) in the low-pressure area will then suitably meter the fuel quantity supplied to the high-pressure pumps.

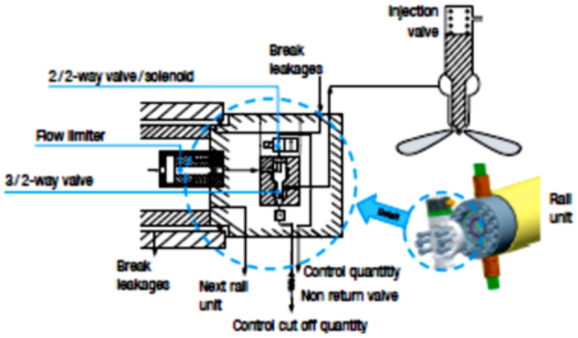

Figure 8. *CR injection system – general layout and functionality of MAN.*

Each rail unit (Fig. 8) contains components for fuel supply and injection timing control.

The fuel flow leads from the interior of the rail unit through a flow limiter to the 3/2-way valve and then to the injector.

The flow limiter consists of a spring-loaded piston which carries out one stroke for each injection, thereby the piston stroke is proportional to the injected fuel quantity. Afterwards the piston returns to its original position.

Should the injection quantity exceed however a specified limit value, the piston will be pressed to a sealing seat at the outlet side at the end of the stroke and will thus avoid permanent injection at the injector.

The 3/2-way valve inside the control valve is operated and controlled without any additional servo fluid by an electromagnetically activated 2/2-way valve.

It can therefore be actuated much more quickly than a servo-controlled valve. It enables the high-pressure fuel to be supplied from the rail unit, via the flow limiter, to the injector.

Fig.9 describes the functional principle of the control valve in the pressure-controlled CR system. Functional leakages arising during the control process of the 3/2-way valve will be discharged back into the low-pressure system via the non-return valve (see Fig.7 and Fig.8).

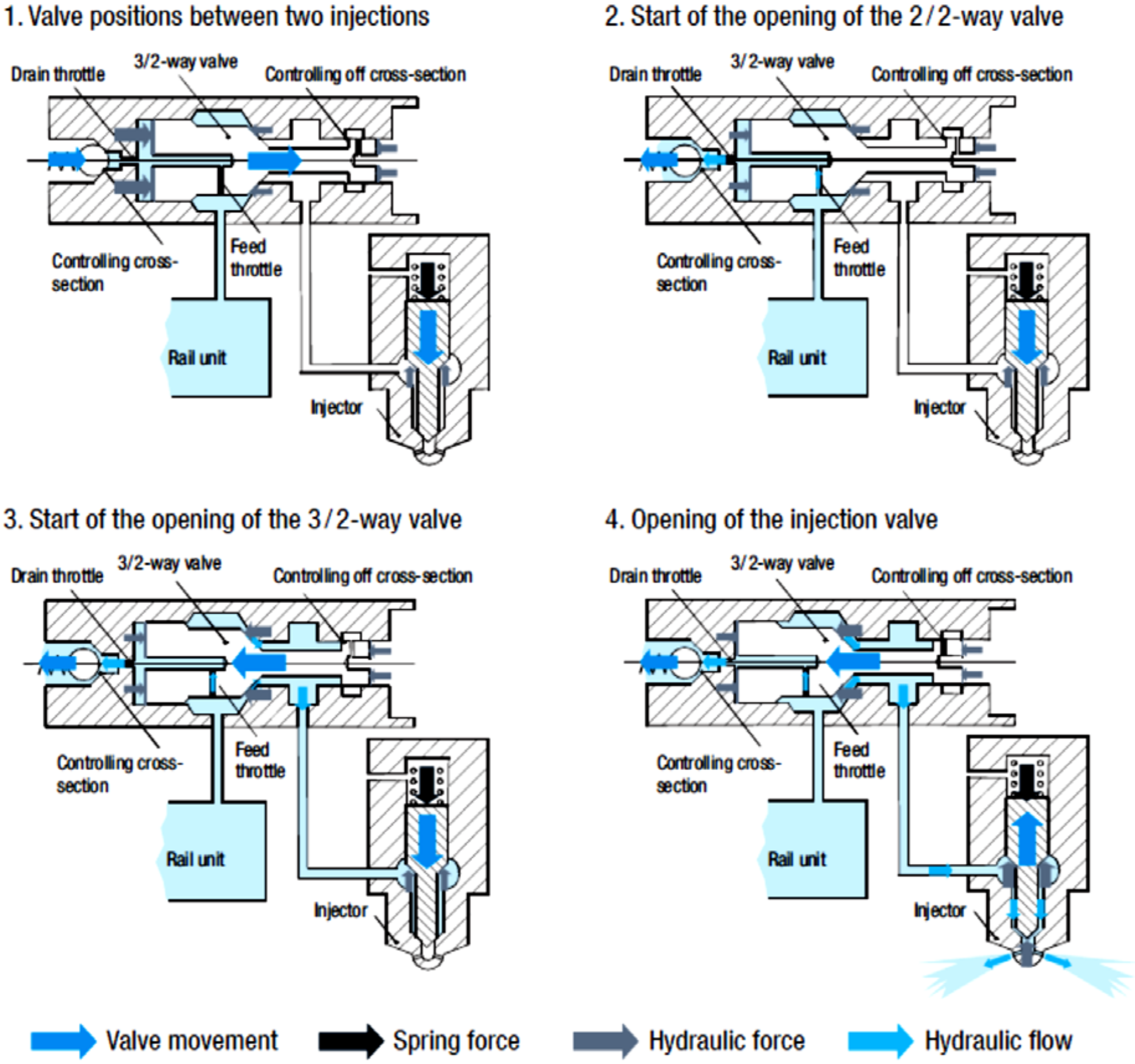

Figure 9. *Positions of control valve during injection.*

The non-return valve (13) (Fig.7) also prevents backflow from the low-pressure system into the cylinder, e.g. in case of nozzle needle seizure. A pressure-limiting valve (9) arranged on the valve block (10) protects the high-pressure system against overload (Fig. 7).

The fuel supply system is provided with an HFO preheating system that allows the engine to be started and stopped during HFO operation.

To start the cold engine running with HFO, the high-pressure part of the CR system is flushed by circulating preheated HFO from the low-pressure fuel system. For this purpose, the flushing valve (11), located on the valve block (10) at the end of the rail units will be opened pneumatically. Any residual high pressure in the system is thereby reduced and the fuel passes via high-pressure pumps (3) through the rail units (5); it also passes via the flushing non-return valve (12) (a bypass to ensure a higher flow rate), through the rail units (5) and back to the day tank. The necessary differential pressure for flushing the system is adjusted with the throttle valve (14).

In the event of an emergency stop, maintenance, or a regular engine stop, the flushing valve (11) provides pressure relief for the whole high-pressure rail system.

The high-pressure components (accumulators and high-pressure pipes) are double-walled; the resulting hollow spaces are connected and form, together with the capacitive sensors and detection screws, an effective leakage detection system, enabling the rapid and specific detection of any leaks that may occur.

3. Analyzing and Comparing the Advantages and Disadvantages of different systems

The principal advantage of CR injection is the flexibility gained by separating pressure generation and injection control. MAN Diesel & Turbo has kept its CR technology as simple as possible. For example, there is no separate servo circuit to activate the injection valves. Conventional pressure controlled injectors are used and solenoid valves are integrated into the rail units away from the heat of the cylinder heads, resulting in greater system reliability and easy maintenance. Different MAN Diesel & Turbo engine types use a very similar CR system design: for instance, the same basic design of 2/2- and 3/2-way valves is used for the control-valve unit. The use of the separate 3/2-way valves ensures that the injectors are only pressurized during injection. This avoids uncontrolled injection, even if a control valve or injection valve is leaking. The CR system is released for ships with single propulsion systems. Modular division of the rail units and their assignment to individual cylinder units reduces material costs and assembly effort and allows for short lengths of high-pressure injection pipes. The MAN Diesel & Turbo specific CR system design avoids pressure waves in the high-pressure pipes between the rail unit and the injector – a problem that occurs in some other CR systems, especially at the end of injection. Engines equipped with this CR technology, and thus an optimized combustion process, are also sure to meet more stringent emission regulations (IMO, World Bank) that may be imposed in future. The design ensures that smoke emissions from the funnel stay below the visibility limit.

Besides, MAN also points out that the common rail system equipped only one high pressure pump (like MTU engine) may have problems, such as:

- The different fuels that the engine can run on is reflected in the required fuel temperature (25°C to 150°C), and this in turn causes significant differences in the linear thermal expansion of the rail.
- A long rail requires radial drillings for the connection to each cylinder unit. Very high material stresses caused by these drillings are unavoidable. The problems and the scope of countermeasures therefore increase proportionally to the increased inner diameter of the rail in larger engines.
- In the case of reduced accumulator volumes, it would hardly be possible to achieve identical injection ratios for all engine cylinders, and excessive pressure fluctuations in the system could not be ruled out.
- Different numbers of cylinders would lead to various common rails, too.
- Supplying a pressure accumulator of excessive length by connecting it to the high-pressure pump at one point only will result in deviations in injection quality.

In general, all common rail systems have several disadvantages such as:

- Expensive vehicle – Vehicles with a common rail diesel engine are going to be more expensive than those with the traditional diesel engine.
- Expensive Parts – Since the common rail vehicles are more expensive, the replacement parts are going to be expensive as well.
- More Maintenance – Common rail diesel engines will need more maintenance than a traditional diesel engine.

4. Conclusion

Basing on this paper, many kinds of

common rail systems on marine diesel engine have been investigated. The advantages and disadvantages of each systems have been studied. However, the most important component of the common rail system-the nozzle (injector)-has not been researched much. The further research should be carried out about the impact of the pressure and the nozzle geometry to the forming and developing of the spray as well as the spray quality, in order to evaluate the operation quality of the injectors and the engine also. Therefore, the authors are going to carry out the research on this issue by utilizing the method of numerical simulation in order to analyze and evaluate the working condition of common rail injectors❑

References:

[1] P.G.Burgman and F. Deluca (1962), “*Fuel Injection and Controls: for Internal Combustion Engines*”, Technical Press, London.

[2] Miyaki, M. et al (1988), “*Fuel Injection System*”, US Patent 4,777,921

[3] Stumpp and Ricco, (1996). “*Common Rail-An attractive fuel injection system for passenger car DI Diesel Engines*”, SAE Paper 960870.

[4] Dough, W. (2004), “*Pounder’s Marine Diesel Engines and Gas Turbines*”, 8th edition, Elsevier UK.

[5] *DENSO Develops a New Diesel Common Rail System With the World's Highest Injection Pressure* | News | DENSO Global Website". DENSO Global Website.

[6] Mohamad R. H. et al (2016), “*Characteristics of pressure wave in common rail fuel injection system of high-speed direct injection diesel engines*” – Advances in Mechanical Engineering 2016, Vol. 8(5) 1-8. SAGE

[7] Caterpillar Marine Power Systems (2011) “*CAT Common Rail*” – CAT Website

[8] Dr. Johannes Kech et al (2011), “*Common Rail Fuel Injection: Key technology for clean and economical combustion*” – MTU General White paper 2011.

[8]http://www.ecgcorp.com/velav/mainbar.html

[9] MAN Diesel & Turbo Technical papers, “*Common rail – Design and Maturi*

Ngày nhận bài: 6/3/2018
Ngày chuyển phản biện: 9/3/2018
Ngày hoàn thành sửa bài: 29/3/2018
Ngày chấp nhận đăng: 5/4/2018