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# Design of Common Rail Fuel Pipe for High Pressure Direct Injection Natural Gas Engine in Marine Cylinder

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**Abstract.** The natural gas common rail Fuel pipe which is an important component of marine high pressure direct injection natural gas engine is need to optimize. A 1-D dimensional working process model including natural gas common rail pipe and high-pressure natural gas pipe was established in this paper and different common rail pipe schemes was compared and analyzed. The results show that transient pressure fluctuation before the first cylinder injector in the four schemes of short natural gas common rail pipe is little difference, and the cyclic variation coefficient decreases with the increase of the volume. Finally, the short common rail pipe scheme 1 is choose as the best design scheme.

**Keywords.** fuel pipe, high pressure direct injection, pipeline optimization, 1-D model.

## 1. Introduction

Marine high pressure direct injection natural gas engine is a marine dual fuel engine that injects natural gas into cylinders under high pressure near the compression TDC and ignites natural gas using a small amount of diesel fuel pre-injected earlier to achieve diffuse combustion of natural gas. The natural gas common rail pipe is an important component of marine high pressure direct injection natural gas engine used to distribute natural gas evenly among the cylinders and ensure the stability by the natural gas injection pressure, as shown in figure 1. The injection pressure of natural gas varies from 120 to 300 bar at any time with the change of operating conditions. In order to prevent the injection pulse width from being too short which leads to the variation of injection uniformity of each cylinder, a lower injection pressure is used in small load operation and a lower injection pressure is used in large load operation in order to shorten the injection time and improve the combustion rate. In-cylinder high pressure direct injection natural gas engine injection technology belongs to time-pressure common rail technology. The pressure fluctuation at the injector inlet needs to be limited to a certain range to ensure the control of natural gas injection quantity, so the common rail tube needs to be optimized.

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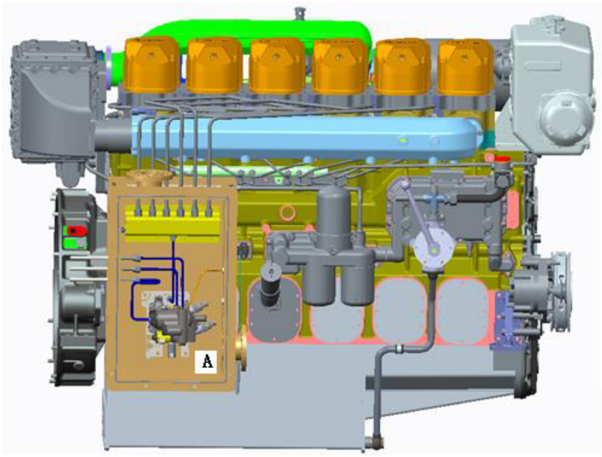



**Figure 1.** Engine Part Piping Diagram.

Yigao Ning, et al. [1-2] studied the processing and optimization of common rail pipe by means of finite element analysis method and proposed reasonable solutions. Xiang Wang et al. [3-5] analyzed the design idea and technical scheme of common rail system by combining performance simulation calculation and test verification. Catania et al. [6] developed a mathematical model to support experiment, layout and control design as well as performance optimization based on Numerical Simulation of common rail injection system dynamics, and verified the accuracy of the mathematical model on a high-performance test bench.

The study is to establish a one-dimensional working process model including natural gas common rail pipe and high-pressure natural gas pipe by using GT-SUITE simulation software for the optimization of fuel common rail pipe of marine high-pressure direct injection natural gas engine. The influence of different inner diameters of natural gas common rail pipe on the pressure fluctuation of common rail pipe and the cyclic variation of natural gas injection volume is studied, and the best scheme of natural gas common rail pipe is determined.

## 2. 1-D model of Fuel Common Rail Tube for Marine High Pressure Direct Injection Natural Gas Engine

### *2.1. Establishment of Model*

The diesel common rail pipe of 15L engine high pressure direct injection natural gas engine follows the structure of the original diesel engine, and the natural gas common rail pipe is designed as shown in figure 2.

The diesel common rail pipe of 15L engine type high pressure direct injection natural gas engine follows the structure of the original diesel engine, and the natural gas common rail pipe is designed as required. The common rail tube of 12L engine type in-cylinder high pressure direct injection natural gas engine has been mature. The 15L engine gas common rail pipe is designed on the basis of the original 12L engine type gas common rail pipe.

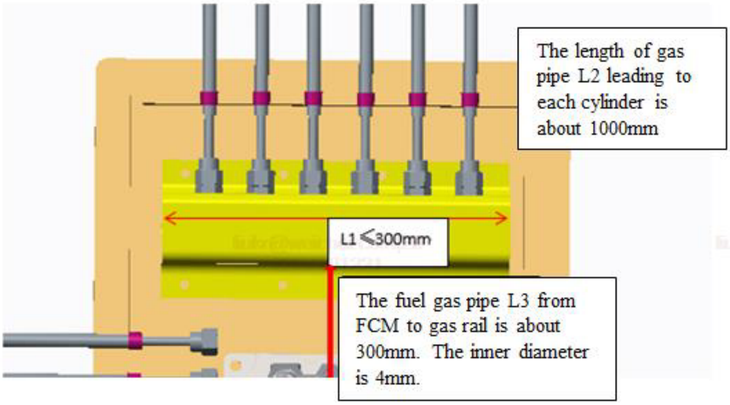



**Figure 2.** Long Natural Gas High Pressure Pipe Model with Short Common Rail Pipe.

Due to the restriction of ship regulations, the common rail pipe and the pipeline through which natural gas flows must be protected, and some of them need double-wall pipe structure. Therefore, the newly designed short common rail pipe adds a natural gas high-pressure pipe between the common rail pipe and the cylinder head. High-pressure natural gas flows back through the gas pipe in the cylinder head and enters the injector. The design method of short common rail pipe is adopted. Four new common rail tubes with different volumes are designed for single cylinder injection of 15L engines and compared.

Introduce the old common rail pipe and the newly designed common rail pipe into the mesh generation software for pretreatment. Divide 2D mesh of pipe inner diameter and import GT-GEM3D discrete processing. The established calculation model is shown in figure 3.

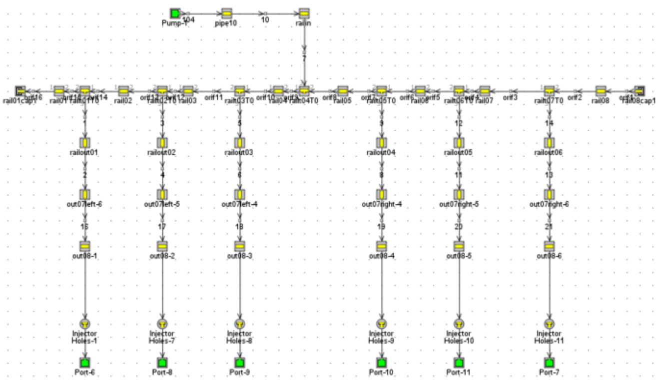


**Figure 3.** 1-D model of short common rail tube.

## 2.2. Input and Calculation Scheme of Model Parameters

The calculation model consists of 1 inlet, 6 simulated injection valves, 6 outlets and piping sections. The total length of M26 natural gas common rail pipe is 290mm, and 4 common rail pipes with different inner diameters are designed. The main parameters are shown in table 1. The calculation can be divided into steady state and transient state. The steady state calculation is that the pressure of natural gas common rail pipe maintains a certain distribution uniformity of each cylinder and pressure fluctuation in common rail pipe. Transient calculation analyses the response of the common rail tube when the inlet pressure increases from 120 bar to 298 bar.

**Table 1.** Calculation scheme of 15L engine type natural gas common rail pipe.

| | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 4 |
|---|---|---|---|---|
| Total common rail tube volume /$mm^3$ | 43000 | 48150 | 52990 | 56580 |

## 3. Simulated Calculation Results and Analysis

### *3.1. Analysis of Steady-state Calculation Results*

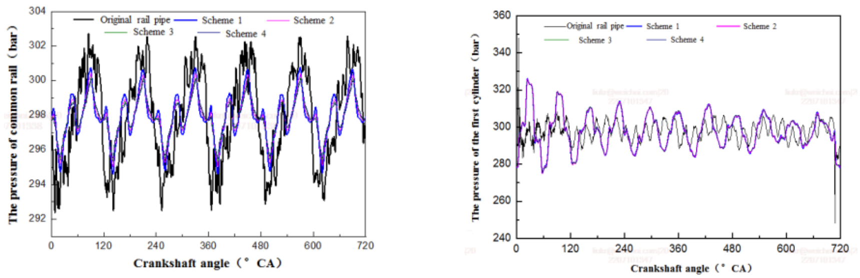
The steady-state calculation is carried out at the engine calibrated speed and the supply pressure of natural gas common rail pipe is 298 bar. The natural gas pressure fluctuations in the inner part of natural gas common rail pipe main pipe and the natural gas supply branch pipe in front of each injector are compared with different calculation schemes.

Figure 4(a) shows the pressure comparison of the natural gas common rail header. It can be seen from the data in the analysis diagram that the maximum and minimum internal pressure of 12L engine common rail tube is 302.7 bar and 292.5 bar respectively, and its pressure fluctuation range is -1.84%-1.58%. The volume of 15L engine type short common rail pipe is larger than 12L engine, and the length and diameter of the common rail pipe are small, and the pressure fluctuation in the rail is low. Table 2 provides comparison data of pressure fluctuations in rails for four different schemes. As the volume of common rail tube increases, the value of pressure fluctuation decreases, but the trend of decrease decreases.

**Table 2.** Calculation scheme of 15L engine common rail pipe.

| | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 4 |
|---|---|---|---|---|
| Maximum pressure value/bar | 300.76 | 300.44 | 300.21 | 300.11 |
| Minimum pressure value/bar | 294.61 | 295.03 | 295.35 | 295.53 |
| Fluctuation range/% | -1.14—0.93 | -1.00—0.82 | -0.89—0.74 | -0.83—0.71 |

Figure 4(b) shows a comparison of pressure fluctuations before injector of the first cylinder of the natural gas common rail tube. As shown in the figure, the pressure fluctuation of the original common rail pipe is higher than that of the four schemes of the M26 common rail pipe, but due to the short passage in the cylinder head and the connection of the M26 common rail pipe to the injector, the pressure drop before the injector of the first cylinder is lower during the natural gas injection process. As the diameter of the short common rail tube increases, the pressure fluctuation before the injector tends to decrease, but the difference is small. After the injection of the first cylinder, the pressure fluctuation before the injector gradually decreases, so other cylinder injection has little effect on the injector of the first cylinder. The root cause of the pressure fluctuation is the large length of the gas high-pressure pipe.




(a) Header pressure (b) Pressure in front of CYLINDER-1 injector

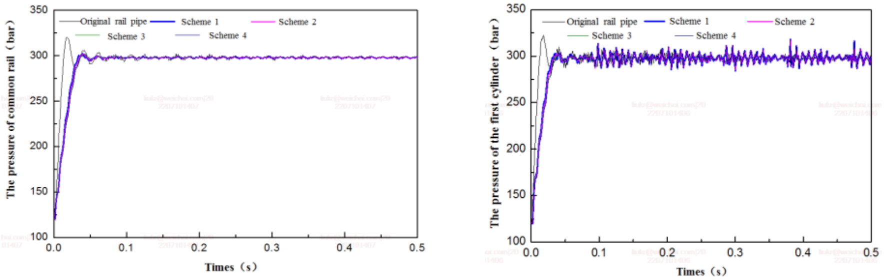
**Figure 4.** Pressure comparison of natural gas common rail pipe.

### *3.2. Analysis of Response Results of Variable Pressure*

When the cylinder high-pressure direct injection natural gas engine operates under low load conditions, its natural gas injection pressure is 120 bar. In order to improve the combustion effect under high-speed and high load operation, its injection pressure is about 298bar. Calculate the time when the natural gas common rail pipe reaches the required injection pressure under variable working conditions, and evaluate its responsiveness. Set the gas pressure in the natural gas common rail pipe, natural gas high-pressure gas pipe and other parts of the pipeline to 120bar, calculate the transient response when the natural gas supply pressure increases from 120bar to 298bar, and analyze the pressure fluctuation inside the natural gas common rail pipe main pipe and the natural gas supply branch pipe in front of each ejector.

Figure 5(a) shows the responsiveness comparison of the pressure in the natural gas common rail pipe from 120bar to the maximum pressure. As shown in the figure, the response time of 12L engine common rail pipe is 0.019s, and the response time of the four schemes of 15L engine are 0.037s, 0.041s, 0.042s and 0.043s respectively, which is about twice that of 12L engine common rail pipe. The main reason why the responsiveness of 12L engine is lower than that of 12L engine is that the volume of natural gas high-pressure gas pipe is large, and the pressure establishment takes a long time.

Figure 5 (b) shows the response time comparison of the pressure establishment in front of the injector of the first cylinder. As shown in the data in the figure, the response time of the highest pressure in front of the injector of the first cylinder of 12L engine common rail pipe is 0.018s, which is basically consistent with the time of pressure establishment in the common rail pipe. The four schemes of 15L engine natural gas common rail pipe have little difference, and the pressure establishment time is 0.036s-0.038s. During transient operation, the fluctuation of the pressure in front of the 15L engine first cylinder injector is also significantly higher than that of the 12L engine common rail system.



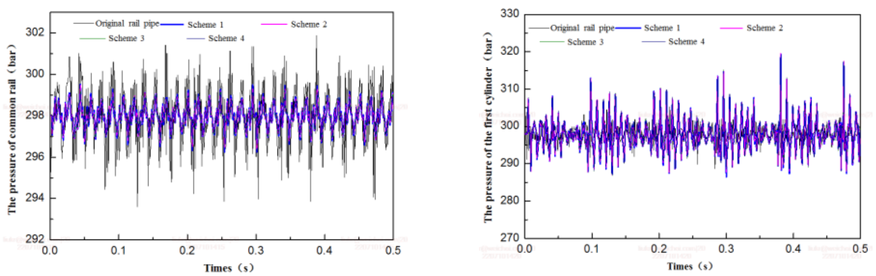

(a) Header pressure (b) Pressure in front of CYLINDER-1 injector

**Figure 5.** Pressure comparison of natural gas common rail pipe.

### 3.3. Analysis of Injection Cycle Variation

Due to the fluctuation of natural gas in the common rail pipe, it will inevitably cause the difference between the pressure in the injector and the pressure ratio in the cylinder during the injection process, which will affect the injection rate of natural gas, and then affect the injection uniformity of each cylinder. Set the initial pressure and air supply pressure in the pipeline to 298bar, and calculate the transient working condition. The calculation step is set to 0.0001s, and the total calculation time is 1.5s. Take the data of the first 0.5s to analyze the influence of the common rail pipe on the cyclic variation of the injection process.

Figure 6 (a) and figure 6 (b) respectively show the comparison of the pressure in the common rail header of natural gas in different schemes and the pressure in front of the first cylinder injector. As shown in the data in the figure, the pressure changes periodically. The value of pressure fluctuation in different schemes is consistent with the trend in the steady-state calculation process. The fluctuation value of 12L engine original common rail is the largest, and 15L engine fluctuation decreases with the increase of common rail volume.




(a) Header pressure (b) Pressure in front of CYLINDER-1 injector

**Figure 6.** Pressure comparison of natural gas common rail pipe (transient).

The cycle variation of natural gas injection process will lead to different work capacity of the engine in each cycle, which will affect the emission and operation stability of the engine. The cyclic changes of the original common rail tube and the newly designed common rail tube injected for 15 times are counted. The original 12L engine scheme is 1.54%, the short common rail tube scheme 1 is 0.85%, the short common rail tube scheme 2 is 0.82%, the short common rail tube scheme 3 is 0.78%, and the short common rail tube scheme 4 is 0.80%.

## 4. Conclusions

In this study, a one-dimensional working process model including natural gas common rail pipe and high-pressure natural gas pipe was established, and the performance of different common rail pipe schemes was compared and analyzed. The conclusions of the study are as follows:

(1) The response time of the pressure in the rail rising from 120bar to 298bar shows that the response time of the short gas common rail pipe is slower than 12L engine due to the increase of the total volume. In the four schemes of the short gas common rail pipe, the response time also increases with the increase of the volume.

(2) There is little difference in the transient pressure fluctuation before the first cylinder injector in the four schemes of short natural gas common rail pipe. The length of natural gas high-pressure gas pipe is long, which makes its pressure fluctuation value 12L engine common rail pipe much larger.

(3) The statistical results of the cyclic variation coefficient of the 15 cycle injection volume of the first cylinder show that the cyclic variation of the natural gas injection volume of the scheme in the short common rail pipe 4 is lower than that of the original 12L engine common rail pipe, and the cyclic variation coefficient decreases with the increase of the volume.

(4) Considering the pressure fluctuation in the common rail pipe, the pressure fluctuation in front of the first cylinder injector and the cyclic variation of the natural gas injection volume, the short common rail pipe scheme 1 is determined as the best design scheme.

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