Research on Four Stroke Diesel Engine Starting Unload Mechanism

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Abstract. In this article, we analysed the principles of starting air system, designed a starting air unload system, installed and tested on a diesel engine. The test result shows that, after applying this system, the starting air pressure is reduced sharply. Air consumption for each start cycle is also reduced.

1. Introduction

Diesel engine is used widely on ships as main propulsion power plant. The diesel engine’s starting mechanism can be classified into the following 3 types: 1. electrical motor starting system, 2. Compressed air starting system, 3 human power driving. There are two types of Compressed air starting system [1-3]. One is driving by air motor which is driven by compressed air, another is driving by means of compressed air directly piloted into the cylinder. On board marine ships, the second type of starting system is broadly in use. In this type of starting system the compressed air is piloted into each cylinder according to the firing order and timing of diesel engine. But classical starting system is mainly composed of mechanical parts. The system’s defects are inaccuracy of starting timing, not easy to adjust the injection timing and air leakage caused by wearing. Much of the defects can be avoided by changing the mechanical starting system to a MCU controlled starting system.[4-7] But there is also another obstacles that affect the staring speed, minimum starting air pressure, and air consumption. In this article we analysed the principle of starting air system, designed a starting air unload system, installed and tested on a diesel engine. This system has good effect on promoting starting speed, reducing both air consumption and minimum starting air pressure.

2. principles of compressed air starting system and unload system

2.1 principles of compressed air starting system

This research is based on 6300ZC type diesel engine. the starting air system is shown as figure 1. air reservoir is used for storing compressed air from air compressor. It is required that there should be enough compressed air both in quality and quantity. When standing by engine, the outlet valve 5 and check valve 8 should be opened, the compressed air is piloted to main starting valve 3 and starting control valve 7. When starting the engine, control handle 4 is switches to “START” position, starting control valve 7 is opened, the control air reached at main starting valve 3 and push its piston move downward so that the main starting valve is opened. Compressed air is divided into two ways. One goes to starting valve directly and “waiting” there. Another goes to starting air distributor 2. The starting air distributor is driven by camshaft of diesel engine. Due to the reason that the cam shaft is
driven by crankshaft. It not only transfer power but also transmit camshaft position to starting air distributor. The starting air distributor distribute the starting air according to diesel engine camshaft position, diesel engine firing order, diesel engine injection of timing, diesel engine valve of timing. When one cylinder is in expansion stroke. The starting air distributor will distribute starting air to the starting valve 1 installed on the cylinder. The air from starting air distributor serves as pilot air and used to open starting valve 1. Then large quantity of compressed air goes to this cylinder. In the cylinder, the air expands and pushes piston moves downward. When the piston move down, crank shaft and cam shaft will rotate and the starting air distributor will rotate at the same time. when the cylinder runs out of its expansion stroke position. The starting air distributor will stop the control air supply. Starting valve will close. In the same time the next cylinder which is in expansion stroke will be distributed starting air to push the piston downward. This mechanism makes the diesel engine from static to run. When the engine speed reach to its minimum starting speed. The air supply will be cut off. And fuel oil supplying system begin to put into service. The starting process is finished.

![Diagram of Starting Air System](image)

1 Starting Valve, 2 starting air distributor, 3 main starting valve, 4 Operating Handle, 5 Outlet valve, 6 Starting air reservoir, 7 starting control valve, 8 Check valve

**Fig 1 Principle of Starting Air System**

### 2.2 Principles of compression unload system

During the starting process, the cylinder in compression stroke will compress the air in cylinders. The compression process will brake the engine to rotate freely. In other words it plays a braking effect. And this effect will prolong starting time, promote start pressure and start air consumption. Which makes the engine hard to start. A way to solve this is trying to unload the compression stroke.

Ways to unload the compression stroke is widely used on human powered starting engines. Usually, it uses a lever to push the end of exhaust valve’s ends to make the engine unload. It is hard to use this mechanism on compressed air started system, because the cylinder must be used to provide starting energy.

A Solutions to this is to unload the cylinder in compression stroke according to its valve timing. It means to open the compression stroke cylinder by pushing open the exhaust valve or open the indicator cock of the cylinder.
3. Designs of the unloading system

![Diagram of unloading system]

1 starting valve solenoid valve, 2 starting valve, 3 unloading solenoid valve, 4 fuel oil control unit, 5 turning gear, 6 absolute encoder, 7 reversing sensors, 8 air pressure solenoid valve, 9 air reservoir, 10 MCU, 11 lubricating oil pressure sensors

Fig 2 Unloading system

This system is consisted of sensors, MCU, actuators. Sensor mainly include absolute encoders 6, reversing sensors 7, lube oil solenoid valve 11, air pressure transducer 8. MCU is based on TMS F2812. The actuators mainly include starting valve 2, starting solenoid valve 1, unloading solenoid valve 3. The sensor is used for measuring crankshaft position, judging the starting conditions. It is shown in Fig 2. In this system the MCU collect the sensors signals judge cylinders stroke state, it will supply compressed air to the expansion stroke cylinder and unload the compression stroke cylinder. The compression stroke cylinder will be unloaded by means of open the solenoid valve installed on the indicating cock.

3.1 Timing of unload

This system is design for 6300ZC-2 (counter clockwise) diesel engine. the basic parameters is shown as the following table

| Tab 1 6300ZC Diesel engine parameters |
|---------------------------------------|
| Type | 4 stroke, direct injection, turbo charged marine diesel engine. |
| Rated output | 600hp |
| Rated speed | 400rpm |
| Maximum output cylinders | 6 |
| Firing order(forward) | 1-4-2-6-3-5 |
| Firing order(reversal) forward | 1-5-3-6-2-4 |
| Maximum speed clockwise | 160rpm |
| Minimum speed counter clockwise | |

The unload cylinder starts from Bottom dead center(BDC) of the engine end in the Top Dead center (TDC) of the engine

| Tab 2 unload sequence of each cylinder |
|---------------------------------------|
| Camshaft Angle | 0~120° | 120~240° | 240~360° | 360~480° | 480~600° | 600~720° |
| Unload V/V Open | 6 | 4 | 5 | 2 | 3 | 1 |
3.2 MCU of Unload Start Control System

![Diagram of MCU of Unload Start Control System](image)

1 starting air pressure, 2 Emergency Stop, 3 Start, 4 Reversing, 5 Turning gear, 6 Lube oil pressure, 7 fuel oil pressure, 8 absolute encoders, 9 input photoelectric coupling circuit, 10 starting valve, 11 unload solenoid valve, 12 fuel oil unit, 13 output photoelectric coupling circuit, 14 reset, 15 power supply

Fig 3 MCU of Unload Start Control System

4. Hardware selection
Camshaft angle is measured by absolute encoder. This type of sensor is featured with low wearing, high precision especially it will not lost data when it is power down. We applied Koyo TRD-NA1024NW absolute encoder. The optocoupler uses PC817 type. The unload solenoid valve STNC UH-20. It maximum pressure is 20MPa. The MCU for this system uses TMS320F2812 DSP.

5. Software design
The main program flow chart is shown as Fig 4
6. Experiment and Result

The system is installed on a 6300ZC-2 diesel engine in China Coast Guard Academy’s marine engineering laboratory. We designed a comparative experiment. The experiment condition is based on <Classification Code for Sea Going Vessels>, experiment conditions:

| Load       | Air temperature | Cooling water temperature | Lubricating oil temperature | Diesel oil band | Diesel oil temperature | injection advance angle |
|------------|-----------------|---------------------------|----------------------------|-----------------|------------------------|-------------------------|
| No load    | 23°C            | 20°C                      | 20°C                       | 0#              | 20°C                   | 15° before TDC          |

Experimental Result:

|                  | Tab 4 experiment result |
|------------------|--------------------------|
| Starting time(s) | 1.2 1.4 1.5 1.6 1.7 1.8 2 2.1 |
| Air pressure(MPa)| 2.0 1.9 1.8 1.7 1.6 1.5 1.4 |
| Starting time(s)| 2.2 2.4 2.6 2.8 3 3.5 3.8 fail |
| Air pressure(MPa)| 1.4 1.3 1.2 1.1 0.9 0.85 0.8 0.6 |

Fig 4 Program flow chart.
7. Conclusion
According to the engine running data and experiences, the minimum starting air pressure is 1.6MPa before application of this system. Due to the leakage and wearing of mechanical starting system, two air reservoirs (0.5m³ for each one) can start the engine for 8 times. When the air pressure is 2.3MPa the starting time is more than 2 seconds. The test results show that, after applying this system, the starting air pressure is reduced sharply. Air consumption for each start cycle is also reduced.

For long term research, there are two research point to be improve. The first one is that the control system should develop a more adaptable system that could be used to more types of diesel engine. The second one is that the unload of timing should be dynamically calculated according to engine speed.

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References
[1] Hu YW Research on Electrical Controlled Starting Air Distributor of Four-stroke Diesel Engine. (2016) Mechanical and Electrical Equipment, 1420: 16-19.
[2] Ying LC. (2013)Marine Diesel Engine. Beijing National Defense University Press. Beijing
[3] China Classification Society. (2012) Classification Code for Sea Going Vessels. China Communications Press. Beijing.
[4] T. Radil, P. M. Ramos, and A. C. Serra, “Impedance measurement with sine-fitting algorithms implemented in a DSP portable device,” IEEE Trans.Instrum. Meas, 2008, 57(1): 197-204.
[5] Wang ZY, Chen QG. (2012)TMS320F2812 Principal and application technology(2 edition): Electronics industry Press. Beijing.
[6] Dang CL, e.t.c. (2008)Hard Ware Design of Diesel Generating Set Digital Control System Based on DSP: Electrical Automation 267:70-72
[7] Chen Y. e.t.c. Design of Driving Circuit for Injector Solenoid Valve Based on DSP 2012, 20(4): 1054-1057.