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Valve actuator and fuel injection pump driver on Diesel Engine

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ABSTRACT

Marine Diesel engines are converting their fundamental futures, they are compelled to suppress the emissions of CO_2, NO_X, and others maintaining the conference around the thin layer of the earth surface, then these engines are beginning to convert their design concept now. However, it seamed for us that is processing by poor technology and concept, such as the applying computers and electric controls only. The principal reforms of the engines are remove their camshaft, tappets, mechanical push rods, rocker arms and mechanical injection pumps and the tasks are depend to computer and electric control. The engines applied the new concept has some small advantage to traditional engines, easy start and reverse, etc, but facing serious difficulties of its reducing thermal efficiency. This paper describes that the compatibility of suppress the emissions keeping high thermal efficiency of the engine. We are remaking an engine will be changed from conventional engine to the innovative one applying our patent HYDRAULIC SWITCHING TECHNOROGY.

KEY WORDS

Key words, hydraulic switching, CVT, equivalent to electric switching, fuel injection, valve actuator

NOMENCLATURE

D1 : smaller diameter of stepped booster piston
D2 : larger diameter of stepped booster piston
D3 : diameter of pluger
Ph : pressure of hydraulic fluid
Pf : pressure of fuel oil
Qm torque of mortor
Qp : torque of hydraulic pump
I : inertia of rotary part of pump
Es : sauce Voltage
L1 : reactor inductance

INTRODUCTION

We have established hydraulic switching servo control system in 1973, but we have not disclosed it over 30 years. The hydraulic power switching technology has been disclosed in the JFPS spring meeting held in Tokyo on 2002, at first in the world, simultaneously we applied patents and obtained it [1][2][3].

Recently, marine Diesel engines are beginning to undergo a transfiguration by the requirement for suppression of their emissions and smoke.

On uni-flow two-stroke marine Diesel engines exhaust valves are changed to hydraulic push rod already instead of mechanical push rods and rocker arms[4][5].

The hydraulic control systems of the engines reduce its thermal efficiency.

We have made a plan to increase the thermal efficiency of these engines drastically applying the FST, which is a hydraulic transmission applying hydraulic power switching technology equivalent to the electric power switching control, suited for the reciprocate.

CONVENTIONAL FUEL INJECTIN

Figure 1 shows a cross section of the conventional fuel injection pump. An electrically controlled booster pump as fuel oil booster is shown in figure 2.

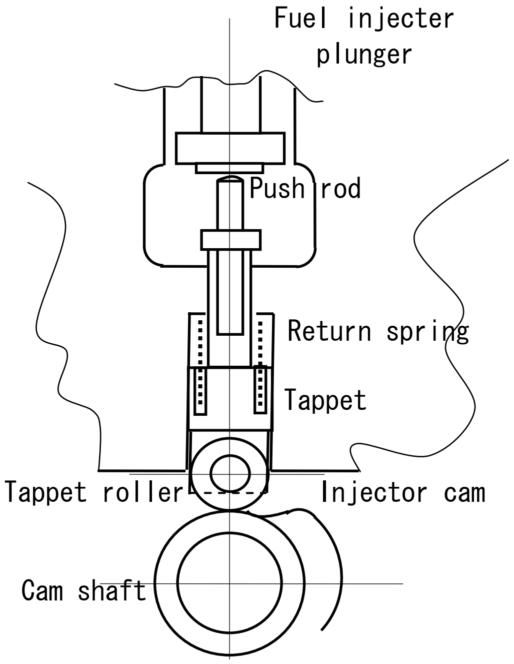

Figure 1　Conventional fuel injection pump

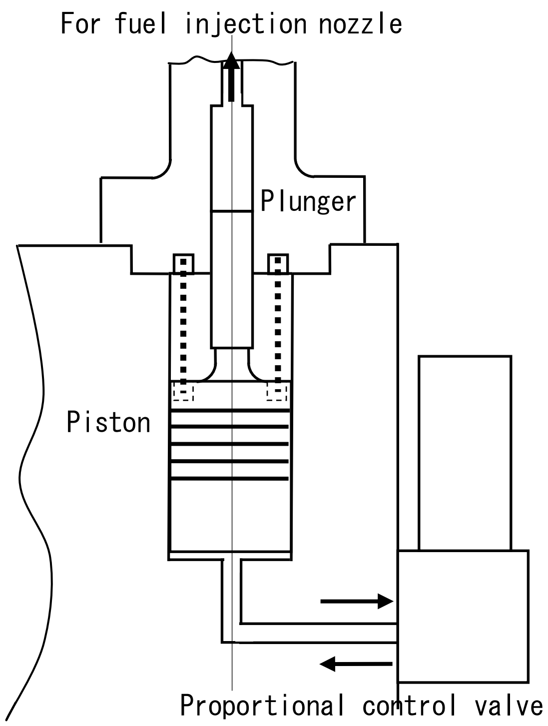

Figure 2　Electrically controlled fuel pressure booster

Figure 3 is an example of fuel oil pressure transition in the boosted fuel oil pipe of the conventional engine. Figure 4 is an example of double injection electrically controlled pressure transition of boosted fuel oil.

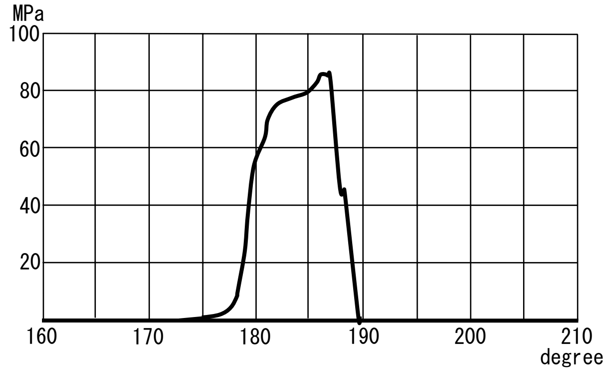

Figure 3　Fuel pressure transition conventional engine

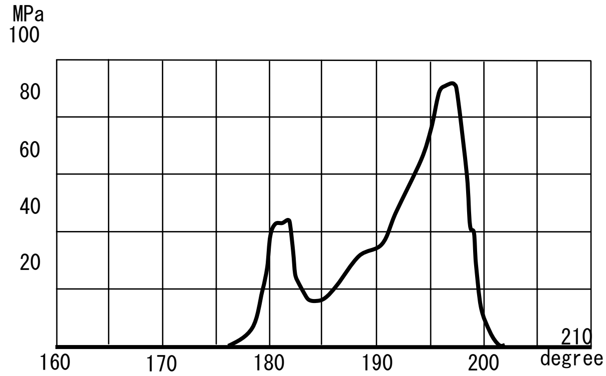

Figure 4　Fuel oil pressure transition hydraulic booster

The boosted fuel oil pressure transition pattern of electrically controlled injection is variable, to have best compromise to improve the relation between thermal efficiency and emission of NOx.

It is well known that high rate fuel injection on TDC, combustion gas generates high density of NOx. The air in cylinder is compressed to a maximum pressure and minimum entropy on the TDC, then high rate fuel injection generates high density of NOx by the combustion of high temperature and high pressure.

Progressive injection or double injection reduces NOx emission, however the injection pattern of this way spoils thermal efficiency of the engine(4)(5).

We continue the experimental simulation of progress the thermal efficiency of a Diesel engine, by means of applying the FST technologies, for fuel oil pressure booster and valve actuators of the engine.

The compatibility between emission and high thermal efficiency of the engines will be cmpleted.

THE REVILUTION ON FUEL INJECTIN

The increase in dissipation of energy on the electrically controlled fuel injection system makes increase in fuel consumption of the engine, and reduces its net thermal efficiency.

The FST(Fluid Switching Transmission / Technology) will make the revolution on technology of suppression of NOx and smoke emission[7][8][9].

FST is the registered trademark of a hydraulic control system that is developed and applied the patent to us, and it means "Fluid Switching Transmission" and "Fluid Switching Technology". [1][2]

Figure 5 shows cross section of injection system driven by the FST, the fuel injection pump has similar structure to the conventional or electrically controlled one.

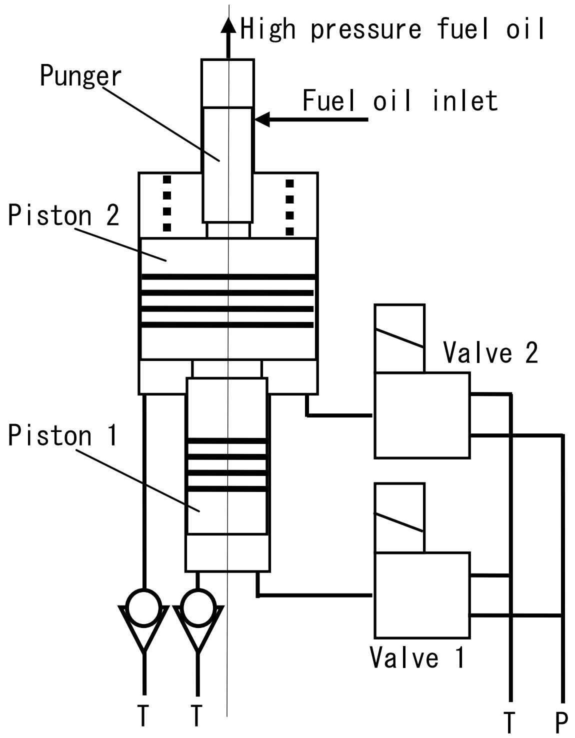

Figure 5 FST fuel pressure booster

The FST fuel injection pump is a mechanism of the hydraulic pressure boosters, and the plunger actuator piston has multiple steps of its diameter coaxially.

Piston 1 generates lower pressure in the fuel oil, and piston 2 makes middle pressure by the differential area on the step of diameter.

The valve 1 is opened, and the valve 2 is closed, plunger makes lowest fuel oil pressure by the hydraulic pressure delivered on the area of small diameter piston.

When the valve 2 is open, and the valve 1 is closed, fuel oil pressure is made by differential area of the piston, middle level of pressure is given to the fuel oil.

The both valves are opened fuel oil pressure rises to the maximum injection pressure.

A simulated transition of fuel oil pressure transition is shown in figure 6.

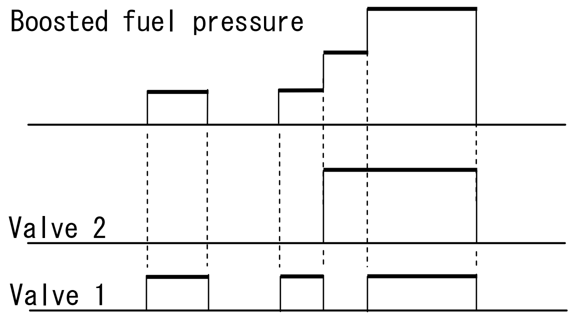

Figure 6 Bit control and boosted pressure

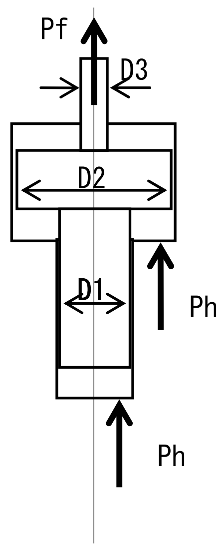

Figure 7 Pressure balance on multiple piston

Figure 7 shows an illustration of fuel oil pressure booster equipped multi diameter pistons D1 and D2.

When Ph is loaded piston diameter D1, boosted pressure Pf is equation (1)

$$Pf1=(D1/D3)^2\, Ph \qquad (1)$$

Next, for middle pressure,

$$Pf2=(D2-D1)^2/D3^2 Ph \qquad (2)$$

And the most pressure is given by area of diameter D1, it is made by the way of feeding pressure Ph both to the area of D1 and D2 of the piston which has a fuel injection plunger and multi diameter piston.

The highest pressure of fuel oil for injection is given as following equation.

$$Pf3=(D2/D1)^2Ph \tag{3}$$

The energy need to fuel injection is the sum of each step of injection pressure transition.
The injection power is increase with boosted fuel oil pressure proportionally, Figure 7 shows a simulated chart of the energy consumption on fuel injection of trendy one and the FST fuel oil booster.
Figure 8 shows injected quantity of the fuel by pressure.

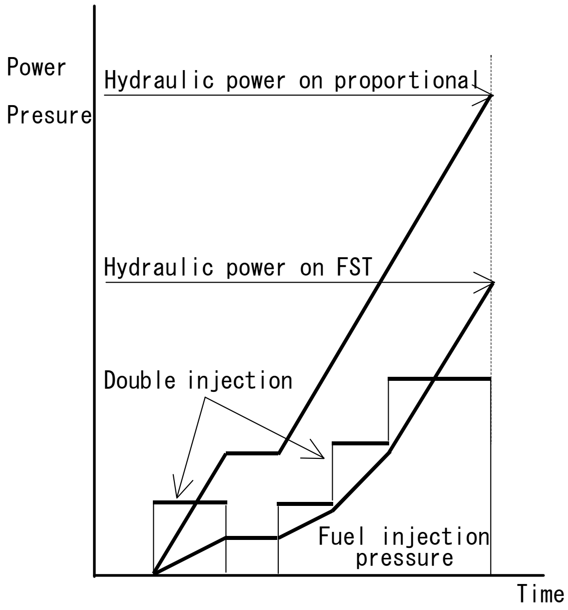

Figure 7 Power consumption on fuel injection

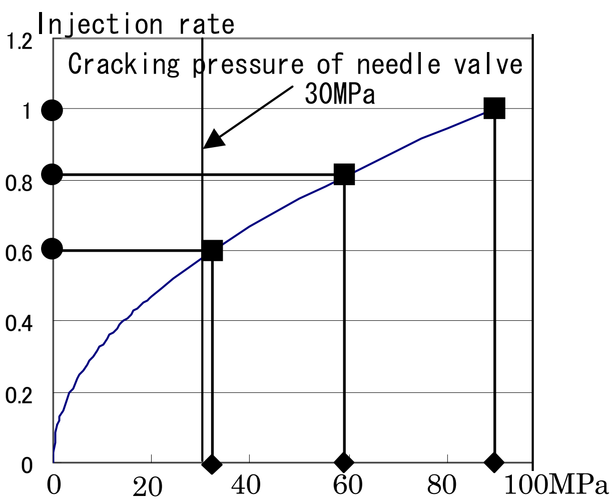

Figure 8 Fuel injection pressure and quantity

REGENERATING VALVE ACTUATORS

We continue the improvement on large scale of Diesel engines applying FST technology for not only their fuel oil pressure booster but also valve actuators.
The hydraulic circuit of the FST is shown in figure 9. Figure 10 is an electric circuit equivalent to the FST.

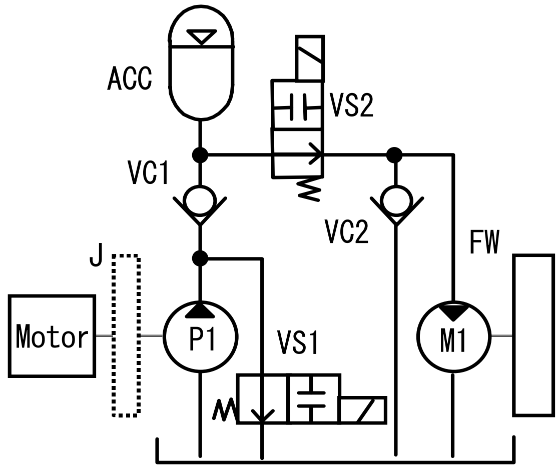

Figure 9. Schematics of the FST

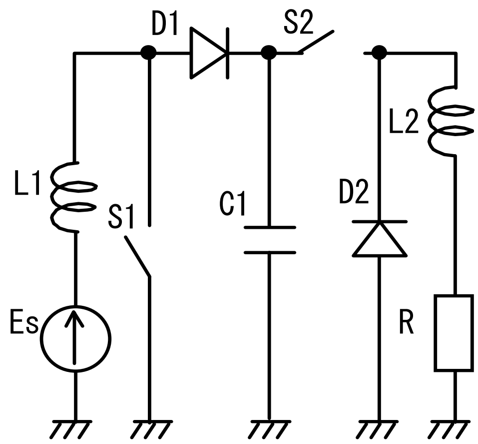

Figure 10 An equivalent circuit to the FST

The FST(Fluid Switching Transmission) is a newly proposed technology on hydraulic transmission.
The principle of FST is the hydraulic power switching technology equivalent to electric power switching control technology.
The principal movement is shown differential equation (4), and (5) is the equation of Figure 10, as a reference.

$$Qm\text{-}Qp\text{-}Id\,\omega/dt=0 \tag{4}$$

$$Es\text{-}EC1\text{-}L1di/dt=0 \tag{5}$$

On the electric switching power control, electric energy is stored in inductors converted to magnetic energy and on the next timing, return to electric energy alternately, synchronized with the electric current chopping.
On the hydraulic switching control, we have newly proposed, hydraulic energy is converted to kinetic energy in inertia like as by flywheels, and return to hydraulic energy on next timing as like as the process of electric power switching on electronic controllers.
So the FST makes converter of hydraulic pressure, and its efficiency for transmission is 100% on theoretically as same to the electric switching converters, and its capability of converting ratio to transfer is more than range of 30, in the area of high efficient operating.
Figure 11,12,13 show cross section hydraulic valve actuators.
Fig 11 shows conventional valve actuator that replaced mechanical push rod to the hydraulic push rod, Figure 12 shows electrically controlled exhaust valve actuator developed by marine engine sellers in Europe recently, and Figure 13 shows a model of valve actuators consist of newly developed FST power control technology.
The FST marine Diesel engines will save much deal of fuel consumption up to 4% of fuel consumption of trendy marine Diesel engines.
Figure 14 shows comparison of energy consumption on hydraulic valve actuator of traditional, trendy and FST.

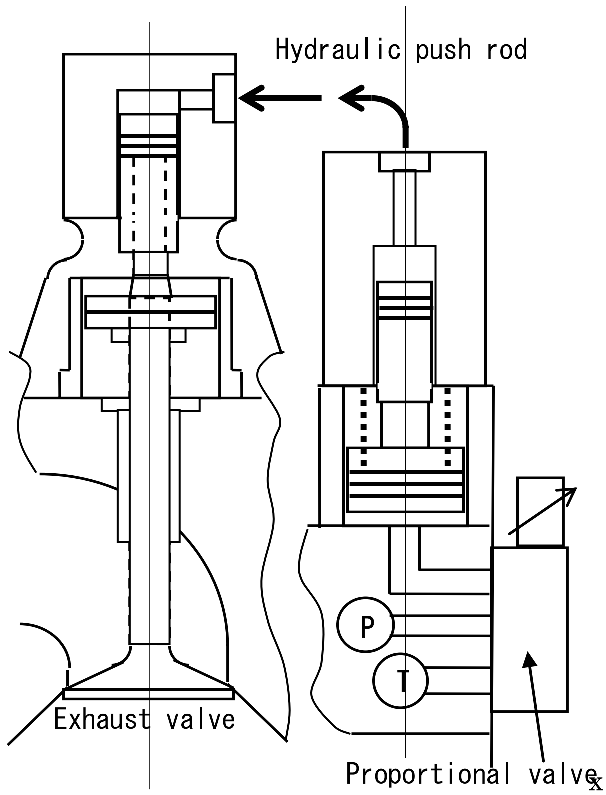

Figure 12 Controllable hydraulic valve system

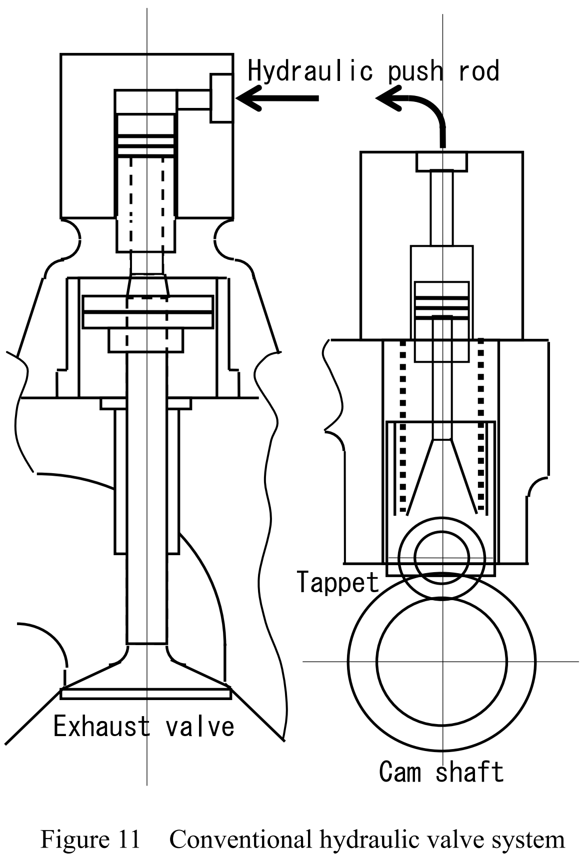

Figure 11 Conventional hydraulic valve system

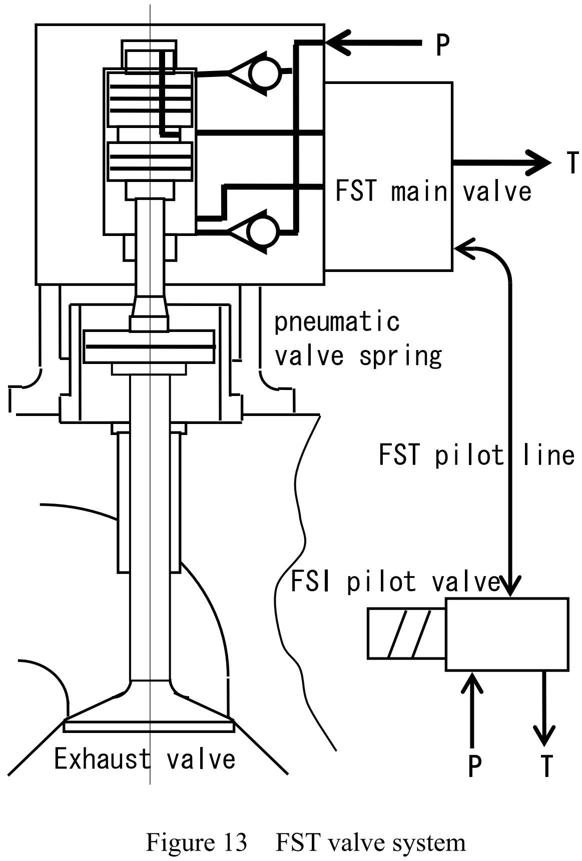

Figure 13 FST valve system

The FST valve actuator and trendy one which has a cam shaft and tappets, regenerates energy that is consumed on the way of opening valves. However the trendy engines regenerates no energy.

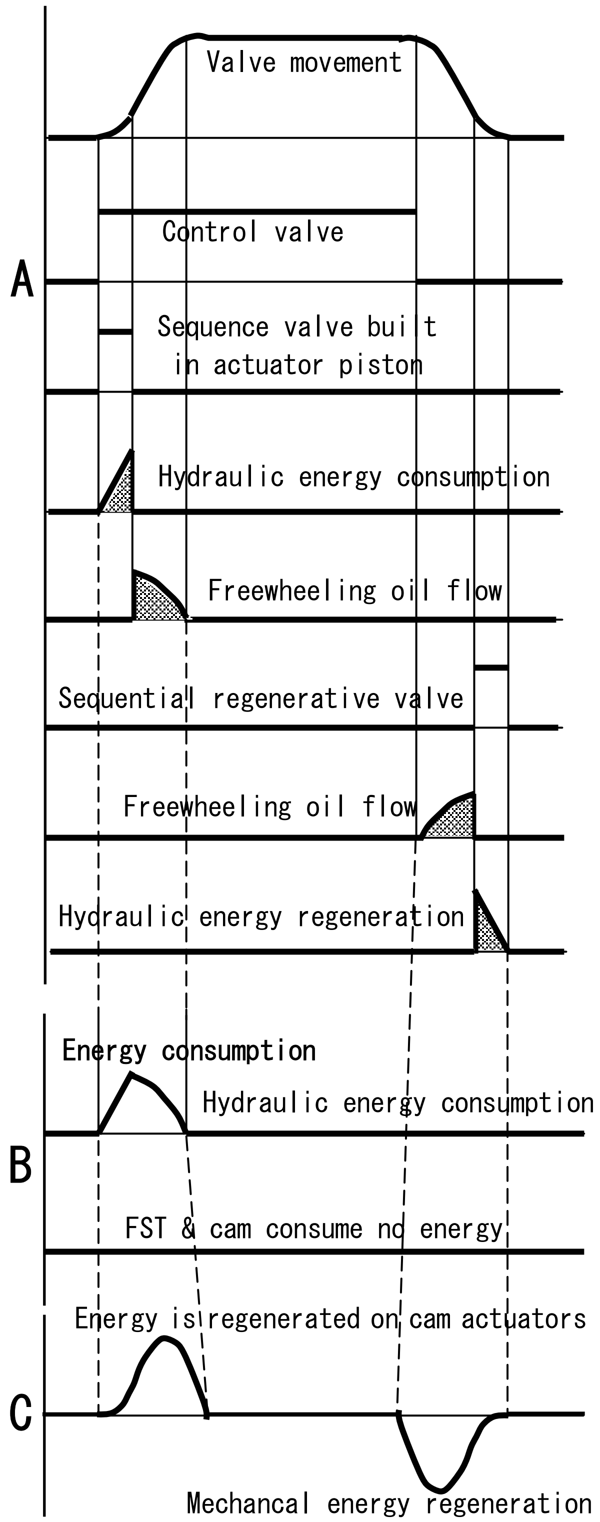

Figure 14 Valve movement and hydraulic flow

EXPERIMENT OF THE ENGINE APPLIED FST

Now, we are converting a conventional marine Diesel engine into the FST controlled one, in order to present the effect of FST on Diesel engines.
FST involves the concept of dynamics, on the rotary inertia in transmission, on the reciprocate machines FST makes most efficient hydraulic system.
The FST engine will complete in September 2005, and it will begin the test run. The full detail of the experiment is will be disclosed in near future.
We have chose 4-stroke cycle Diesel engine in this project in order to prove the performance of FST.
The difficulties applying to 4-stroke will be solved by the FST engine control system.

CONCLUSION

We proofed that the FST is one of best way to keep the compatibility with emission and thermal efficiency of Diesel engine and other thermal engines.
The FST will make some compatibility with thermal efficiency and emissions for thermal engines on Reciprocate.

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