S3–02

Study on Effects of Structure and Dimension of Fuel Supplying System of CWS Engine on Fuel Supplying

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Summary

A fuel supplying system of CWS–fueled engine usually has either the diaphragm pump or the isolating piston. In order to raise the reliability of the system, we used both of them. We formed the fuel supplying system with the diaphragm pump and the isolating piston, and modeled and simulated it. The reliability and accuracy of the system has been verified by the simulation and experimental research. The density of the CWS used in the research is 0.875g/cm^3 and the power of the testing engine is 8hp. The difference between the characteristics of the fuel supplying of the testing and simulation is below 3%.

Keywords: CWS; Fuel supplying system; coal–fueled engine

1. Introduction

The traditional fuel supplying system which has the high pressure pump and fuel injector is not suitable for CWS–fueled engine. The coal particle size of CWS is within the tolerance of the plunger couple and the delivery valve, so the wear of them increases, and the reliance of working gets decrease, and the lifespan gets short. Because of the high viscosity of the CWS, in the long high pressure pipe with the small diameter, the viscosity resistance of CWS gets high, and the pressure of the high pressure pump is rather higher than in the injector. So the CWS could be injected badly or even not injected at all. In order to remove this effect, the fuel supplying system with the diaphragm pump and one with the isolating piston have been used. [1~3] Lifecycle of them is not long because of the mechanical wear. We suggested the CWS–fuel supplying system with both of hydraulic diaphragm pump and isolating piston to increase lifecycle of the system. The characteristics of such fuel supplying system have not been introduced before.

We studied the effect of the structure and dimension of the fuel supplying system on fuel supplying processes.

2. Mathematical modeling of the CWS fuel supplying process

We formed the fuel supplying system of the CWS–fueled engine as following.

In order to analyze the fuel supplying system easily, it is assumed as below.

First, Sonic speed is constant in the high pressure pump, and not relative to the pressure of fuel and temperature. The flow speed of the fuel is very low than the sonic speed.

Second, the flow of the fuel is 1–demension in the high pressure pipe, and the flow speed is constant through all the section. Third, mechanical and thermal deformations of the parts such as plunger and injection needles are ignored.

Forth, the wear of the wearing couples of the fuel supplying system and the gravity of the fluid and moving part are ignored.

Fifth, leakage through the isolating piston is ignored.

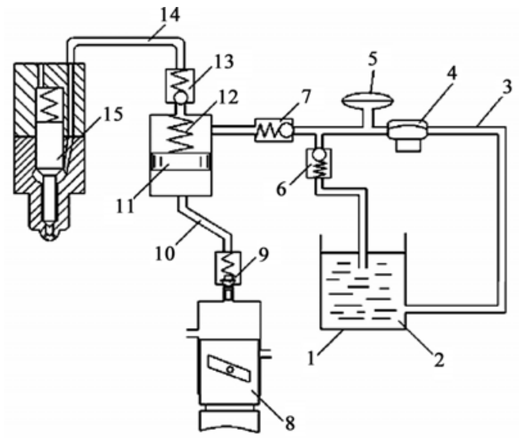

Figure 1. CWS fuel supplying system
1–fuel tank; 2–CWS; 3–fuel pipe; 4–balance space; 5–hydraulic diaphragm pump; 6–relief valve; 7, 13–check valve; 8–plunger, 9–delivery valve; 10, 14–high pressure pipe; 11– isolating piston; 12–spring of the isolating piston; 15–injector

The flow of the CWS is considered as the high viscosity fluid because of its high pulverizing rate. The kinematic equation and continuity equation of the fuel in the high pressure pipe are as follow

$$\left.\begin{aligned} &\frac{\partial u}{\partial t} + \frac{1}{\rho}\cdot\frac{\partial p}{\partial x} + ku = 0 \\ &\frac{\partial \rho}{\partial t} + \frac{\rho \partial u}{\partial x} = 0 \end{aligned}\right\} \tag{1}$$

where u–Flow speed, p–pressure, ρ–density of fuel in the pipe, k–Hydraulic resistance factor

The continuity equation in the plunger chamber is as follow.

$$\begin{aligned} \beta V_p \frac{dp_p}{dt} = f_p u_p - \mu_{pi} f_{pi} \sqrt{2\left|p_P - p_{pi}\right|/\rho} - \\ - \mu_{pd} f_{pd} \sqrt{2\left|p_P - p_d\right|)/\rho} - f_d \frac{dh_d}{dt} - \\ - q_{pl}\mu_{po} f_{po} \sqrt{2\left|p_P - p_{po}\right|/\rho} \end{aligned} \tag{2}$$

where β–A factor of compression; V_ρ–A volume of the plunger chamber; p_ρ, p_d–the pressure of the plunger chamber and the space of the delivery valve; p_{pi}, p_{po}–the pressure of the fuel inlet and outlet; f_p, f_d–The section area of the plunger and delivery valve; $\mu_{pi}f_{pi}$, $\mu_{po}f_{po}$–the effective flow section area of the inlet and outlet; $\mu_{pd}f_{pd}$–The effective flow section area between the plunger and delivery valve; h_d–delivery valve lift; q_{pl}–The fuel leakage through the plunger couple every second

Continuity equation in the delivery valve space is as follow.

$$\beta V_d \frac{dp_d}{dt} = f_d \frac{dh_d}{dt} + \mu_{pd} f_{pd} \sqrt{2|(p_P - p_d)|/\rho} - f_{hp1} u^s_{hp1} \quad (3)$$

where f_{hp1}–Section area of the high pressure pipe, u_{hp1}–flow speed of the fuel in the high pressure pipe, u^s_{hp1}–flow speed of the fuel in the start point of the high pressure pipe 10 ($u^s_{hp1} = u_{hp1}(0, t)$)

Kinematic equation of the delivery valve is as follow.

$$m_d \frac{d^2h_d}{dt^2} + c_d \frac{dh_d}{dt} + k_d(h_d + h_{d0}) = f_d(p_p - p_d) \quad (4)$$

where m_d, c_d, k_d–Mass of the delivery valve, damping coefficient, stiffness, h_{d0}–Initial clamping rate of the spring of delivery valve

The continuity equation in the below space of the isolating piston is as follow.

$$\beta V_{ib} \frac{dp_{ib}}{dt} = f_{hp1} u^e_{hp1} - \mu_{il} f_{il} \sqrt{2|p_{ib} - p_{it}|/\rho} - f_i \frac{dh_i}{dt} \quad (5)$$

where V_{ib}–volume of the below space of the isolating piston; p_{ib}, p_{il}–pressure of the below and upper space of the isolating piston; u^e_{hp1}–flow speed of the fuel in the end point of the high pressure pipe 10($u^e_{hp1} = u_{hp1}(l_1, t)$); $\mu_{il}f_{il}$–effective flow section area between below and upper space of the isolating piston; f_i–section area of the isolating piston; h_i–lift of the isolating piston

The continuity equation in the upper space of the isolating piston is as follow.

$$\beta' V_{it} \frac{dp_{it}}{dt} = f_i \frac{dh_i}{dt} + \mu_{il} f_{il} \sqrt{2|p_{ib} - p_{it}|/\rho} - - \mu_{ic} f_{ic} \sqrt{2|p_i - p_c|/\rho} - f_c \frac{dh_c}{dt} \quad (6)$$

where β'–factor of the compression; V_{it}–volume of the upper space of the isolating piston; $\mu_{ic}f_{ic}$–effective flow section area between upper space of the isolating piston and the check valve; p_c–pressure in the check valve; f_c–section area of the check valve; h_c–lift of the spring of the check valve

The kinematic equation of the isolating piston is as follow.

$$m_i \frac{d^2h_i}{dt^2} + c_i \frac{dh_i}{dt} + k_i(h_i + h_{i0}) = f_i(p_{ib} - p_{it}) \quad (7)$$

where m_i, c_i, k_i–mass of the isolating piston, damping coefficient, stiffness; h_{i0}–Initial clamping rate of the spring of delivery valve.

The continuity equation in the check valve is as follow.

$$\beta' V_c \frac{dp_c}{dt} = f_c \frac{dh_c}{dt} + \mu_{ic} f_{ic} \sqrt{2|p_i - p_c|/\rho} - f_{hp2} u^s_{hp2} \quad (8)$$

where V_c–volume of the check valve, f_{hp2}–section area of the check valve; u^s_{hp2}–Flow speed of the fuel in the start point of the high pressure pipe 14

The kinematic equation of the check valve is as follow.

$$m_c \frac{d^2h_c}{dt^2} + c_c \frac{dh_c}{dt} + k_c(h_c + h_{c0}) = f_c(p_{it} - p_c) \quad (9)$$

where m_c, c_c, k_c–mass of the check valve damping coefficient, stiffness; h_{c0}–initial clamping rate of the spring of the delivery valve.

The continuity equation in the injection working volume is as follow.

$$\beta' V_j \frac{dp_j}{dt} = f_{hp2} u^e_{hps} - \mu_{jc} f_{jc} \sqrt{2|p_j - p_c|/\rho} - f_j \frac{dh_j}{dt} - q_{jl} \quad (10)$$

V_j–volume of the injection working volume; p_i, p_c–pressure of the injector working volume and cylinder; u^e_{hp2}–the flow speed of fuel in the end point of the high pressure pipe 14($u^e_{hp2} = u_{hp2}(l_2, t)$); $\mu_{ic}f_{ic}$–effective flow section area between the injector and cylinder; f_i–section area of the injector needle; h_j–Lift of the injector needle; q_{jl}–leakage in the injector every second (m^3/s)

The kinematic equation of the injector needle is as follow.

$$m_j \frac{d^2h_j}{dt^2} + c_j \frac{dh_c}{dt} + k_j(h_j + h_{j0}) = f_j(p_j - p_{jt}) \quad (11)$$

where m_j, c_j, k_j–mass of the injector needle, damping coefficient, stiffness; h_{j0}–initial clamping of the spring of the injector needle; p_{jl}–pressure in the upper space of the injector needle

3. Calculating and simulation

The fuel supplying processes based on the mathmatical modeling expressed in Eq. (1)~(11) have been analyzed by the application AVL/Hydsim.

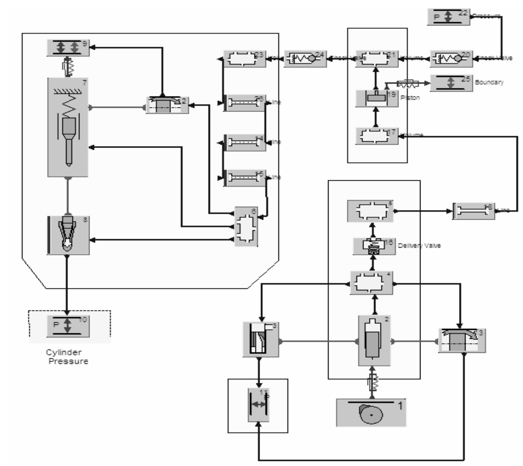

Figure 2. Modeling of the CWS fuel supplying system with AVL/ Hydsim

Main input parameters for calculating are as follow.

Revolution speed of the cam shaft 900r/m

Fuel supplying amount every cycle 80mm^3

Diameter of the plunger 8mm

Diameter of the isolating piston 10mm

Stroke of the plunger 8mm

Stroke of the isolating piston 10mm

Injecting pressure 17MPa

Stiffness of the isolating piston 10 000N/m

The detail structures and managing parameters are input besides upper parameters. The results are as follows.

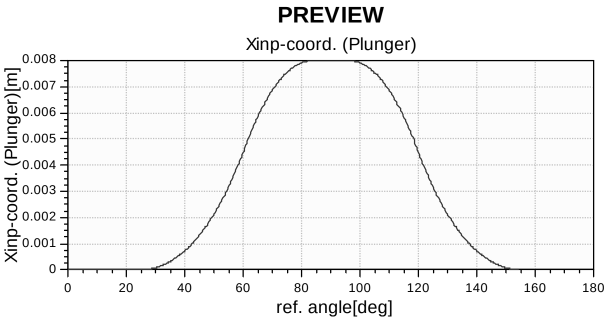

Figure 3. Lift of plunger (cam profile)

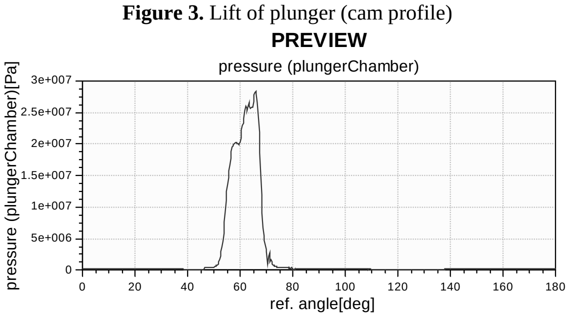

Figure 4. Pressure of plunger chamber

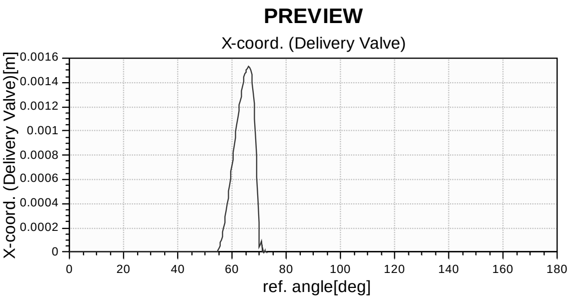

Figure 5. Lift of the delivery valve

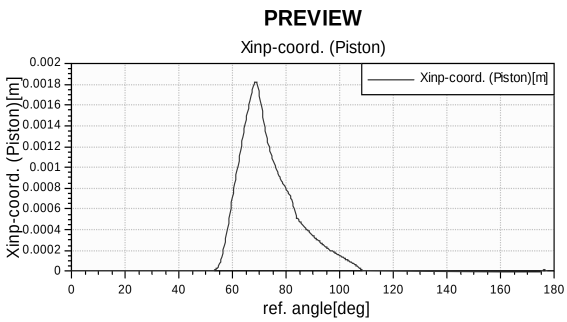

Figure 6. Lift of the isolating piston

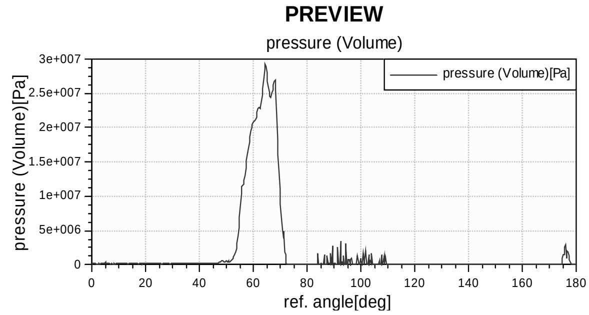

Figure 7. Pressure of the below space of isolating piston

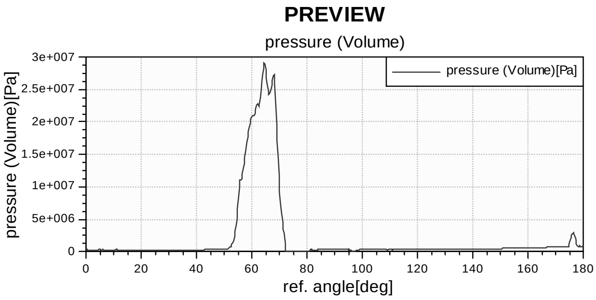

Figure 8. Pressure of the upper space of isolating piston

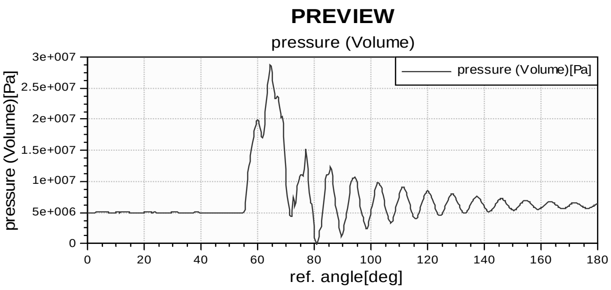

Figure 9. Pressure in the high pressure pipe

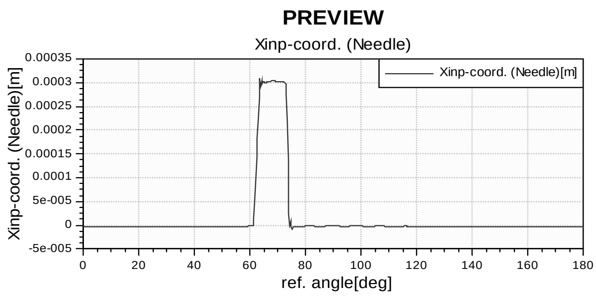

Figure 10. Lift of needle

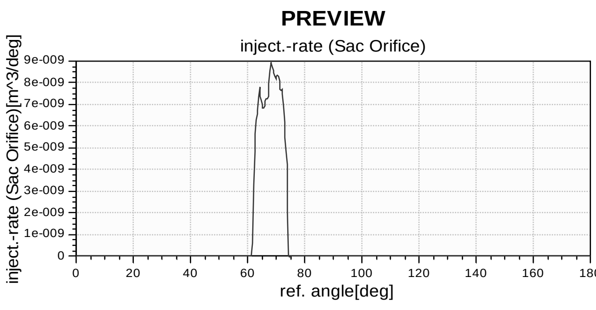

Figure 11. Inject–rate

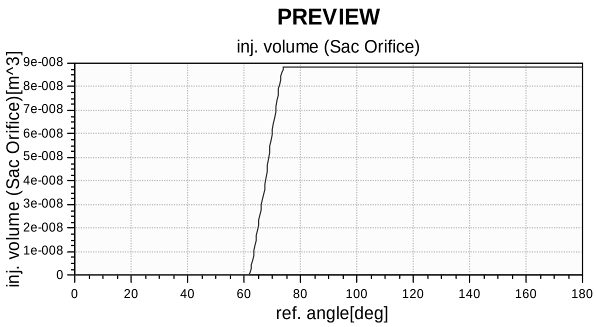

Figure 12. Injecting volume (88.3mm3)

The injecting characteristics were tested in the 8hp engine. The density of the CWS used in testing is 0.875g/cm3. The injecting characteristics measured on the testing engine are very similar to the results of simulation. The injecting volume for every cycle is 86mm3, so the error is as following.

$$e\% = \frac{88.3-86}{88}\times 100(\%) = 2.6(\%)$$

From result of simulation and experimental analysis, it is clear that the mathematical modeling is correct and analysis of the CWS fuel supplying system was done exactly. In order to make the fuel supplying system with suitable characteristics for working process of the engine, we have to select the adaptable design parameters by analyzing the injecting characteristics according to the profile of the cam and deciding the main structural parameters on the model formed by AVL/ Hydsim.

4. Conclusions

We established and modeled fuel supplying system of the testing CWS engine with the diaphragm pump and isolating piston. The effectiveness of structure and dimension of the system is verified on the fuel injection by simulation and testing.

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