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Comparison research on different injection control strategy of CI free piston linear generator in one-time starting process

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Abstract

In one-time starting process of CI free piston linear generator, the starting energy in one cylinder always influence the combustion process in the other cylinder. And the ignition delay has a great influence on the performance of the system running in the process. Based on this influence, two strategies of injection controlling are proposed, which are triggered by displacement signal and velocity signal, respectively. With the strategy of injection triggered by displacement signal, the influence of injection position to MEP, compression radio and other performance parameters of two cylinders are discussed. The velocity injection strategy utilizes the same model and the kinetic energy of piston assembly in different key position is considered as the impact indicator. This parameter and the injection time are interacted with each other, and they can influence the combustion performance of two cylinders. Finally, this paper describes the applicability of two strategies and concludes that the strategy of injection triggered by velocity is more suitable for CI free piston linear generator in process of starting.

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Keywords: Free piston linear generator, injection strategy, starting process, CI

1. Introduction

After the industry revolution[1], energy crisis were becoming increasingly prominent. At the same time many institutes were searching for a low emission and high efficiency system. Free piston linear generator emerged in this situation. Conventional internal combustion engine couples crank-link mechanism and flywheel inertial mechanism. Complex structure contains lots of friction pair and energy storage device, which result in the high friction loss and low efficiency. Compare to the conventional internal combustion engine, free piston linear generator has the advantages of high efficiency, low consumption, simple mechanism, good fuel adaptability and so on. In absence of flywheel or other inertia mechanism, this new type prototype has many unknown characters. The characters contain many potential advantages and

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uncertainties. Especially the compression ignition (CI) prototype has less controlled parameters. Only the injection time can be controlled, the top dead centre (TDC) of the piston is more difficult to predict.

Nomenclature

Abbreviation

LC	Left cylinder
RC	Right cylinder
LDC	Left dead centre
RDC	Right dead centre

Symbols

x	Displacement of piston assembly[m]
m	Mass of piston assembly [kg]
F_e	Electromagnetic force [N]
F_f	Friction [N]
$F_{L,R}$	Resultant of left or right engine [N]
$V_{L,R}$	Volume of left or right cylinder [m^3]
γ	Specific heat ratio
$Q_{Lc,Rc}$	Heat transfer in left or right cylinder [J]

2. Simulation methodology

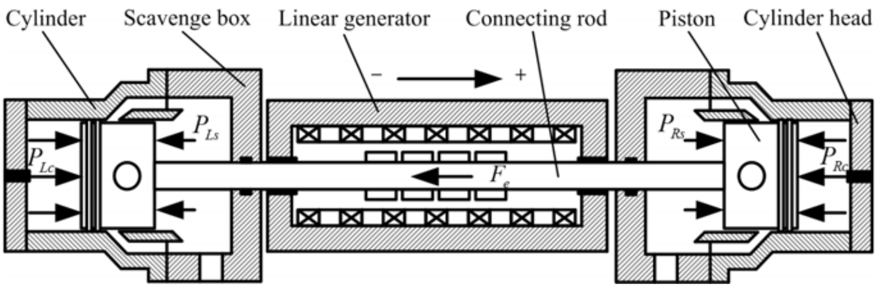

Fig 1 CI free piston linear generator dynamical model

The model contains two diesel engines and a linear motor, it is shown in Fig. 1. When the FPLG system works, the fuel is injected into the compression cylinder of the prototype. In the state of high temperature and high pressure, the gas-oil mixture can burn and release heat. Fuel gas expands to push the piston to work. According to first law of Newton, dynamical equation of piston assembly is shown as:

$$m\frac{\mathrm{d}^2x}{\mathrm{d}t^2} = -F_e + F_f + \left(F_L - F_R\right) \quad (1)$$

In the starting process, substitution and mathematical manipulation yield the following equation which is used to calculate the in-cylinder pressure at each time step[4].

$$\frac{\mathrm{d}p_{Lc}}{\mathrm{d}t} = -\gamma\frac{p_{Lc}}{V_L}\frac{\mathrm{d}V_L}{\mathrm{d}t} + \frac{\gamma-1}{V_L}\frac{\mathrm{d}Q_L}{\mathrm{d}t}, \frac{\mathrm{d}p_{Rc}}{\mathrm{d}t} = \gamma\frac{p_{Rc}}{V_R}\frac{\mathrm{d}V_R}{\mathrm{d}t} + \frac{\gamma-1}{V_R}\frac{\mathrm{d}Q_R}{\mathrm{d}t} \quad (2)$$

According to the working state in cylinders, the process of starting can be divided into 13 stages. These stages contains 4 starting processes and 9 combustion processes as table 1 shows.

Table 1. The 13 stages of the full process

	Stage	State in left cylinder	State in cylinder
Starting compression	1	Adiabatic compression	Adiabatic expansion
	2	Adiabatic compression	Exhaust
	3	Adiabatic compression	Scavenge
	4	Ignition delay	Scavenge
Ignition process	1	Combustion and compression	Scavenge
	2	Combustion and expansion	Scavenge
	3	Expansion without combustion	Exhaust
	4	Expansion without combustion	Adiabatic compression
	5	Exhaust	Adiabatic compression
	6	Scavenge	Adiabatic compression
	7	Scavenge	Ignition delay
	8	Scavenge	Combustion and compression
	9	Scavenge	Combustion and expansion

3. Simulation results

3.1. Injection triggered by displacement signal

This injection controlling strategy means the injection signal is triggered by displacement of the piston assembly. When the piston assembly moves to the default position, the displacement sensor can recognize the position and the signal can be transferred to trigger the injector of the compression cylinder.

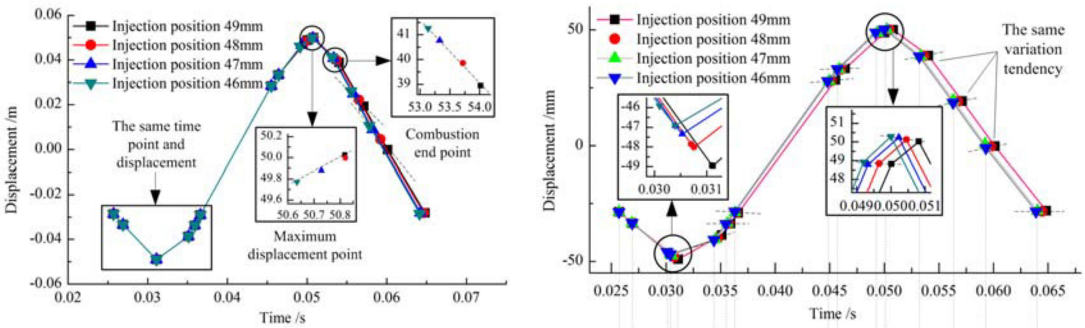

Fig. 2. (a) Motion characteristic in different right injection position; (b) Motion characteristic in different left injection position

The injection position on the right side is set various, and the motion and pressure characteristic profile is shown in Fig. 2. (a). The key position of the piston assembly on the left side increases as the injection position changes from 46mm to 49mm, as a result, the maximum pressure in left cylinder increases from 4MPa to 8MPa. But when the piston moves to the right side, there is little variation of the key position because of the same injection position on this side. Obviously, the hysteresis of the position can be seen.

As a contrast, the injection position on the left side is set various and the results are shown in Fig. 2. (b), the variation trend of motion characteristic after position of RDC is opposite to the Fig. 2. (a).

3.2. Injection triggered by velocity signal

Comparing to the displacement feedback, this injection controlling strategy means the injection signal is triggered by velocity of the piston assembly. In Fig. 3. (a), the displacement and pressure of the key point are shown. With the velocity of injection time decreases, the hysteresis of position of LDC and RDC is not obvious. But the maximum pressure in cylinder in position of LDC rises remarkably. Driven by the gas pressure, the maximum pressure in right cylinder reduces. This indicates that we can adjust the injection velocity of the two sides to control the combustion performance in cylinders. Then the different injection velocity values are set in the simulation model, and the IMEP map of the LC and RC is shown in Fig. 3. (b). The overall trend of the IMEP in LC is that it increases follow the increasing of the injection velocity of LC, but the IMEP of RC increases with the decrease of the injection velocity of the right side. The injection velocity of one side also influences the IMEP in another cylinder, but not the dominant factor.

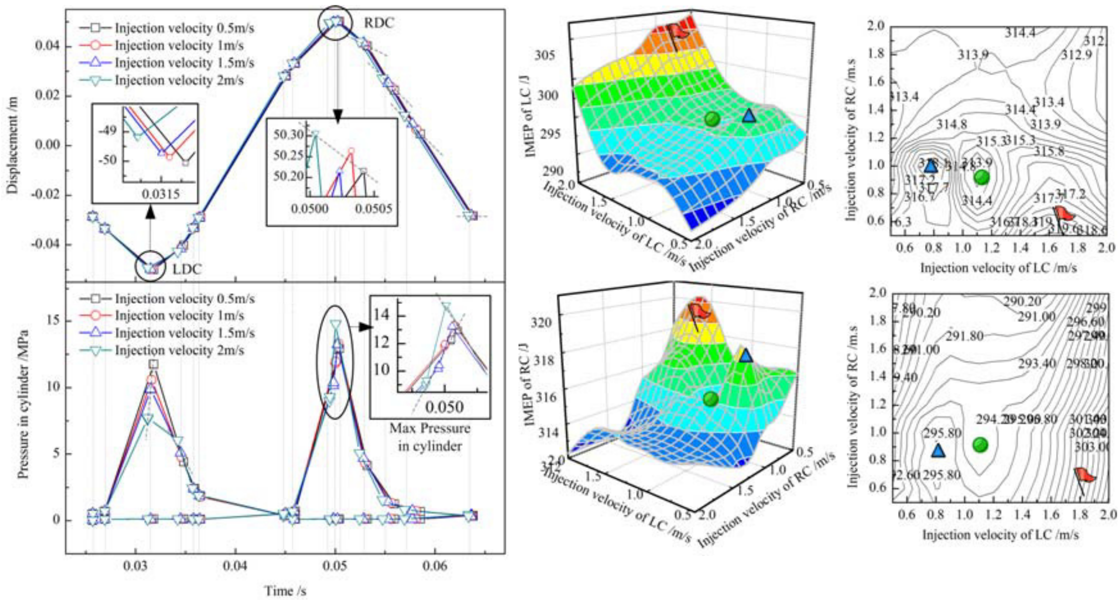

Fig. 3. (a) Motion characteristic and cylinder pressure in same injection velocity; (b) IMEP map in different injection velocity

4. Conclusion

This paper establishes the numerical simulation model based on the first law of Newton, the second law of thermodynamics, and the law of conservation of energy. Aimed at the starting process of CI free piston linear generator, two injection controlling strategy are provided and analysed.

- With the increase of the LC injection position, the position of key points on right side postpones and decreases. But the RC injection position has the opposite influence.
- When injection is triggered by velocity, the maximum pressure in LC (starting cylinder) decrease with the enlargement of injection velocity of piston assembly. But the maximum pressure in RC (driven cylinder) increase.
- The IMEP of LC increases with the injection velocity of left side. But the IMEP of RC increases with the decrease of the injection velocity of right side.

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