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Research Paper

Dynamic performance of suction valve in stepless capacity regulation system for large-scale reciprocating compressor

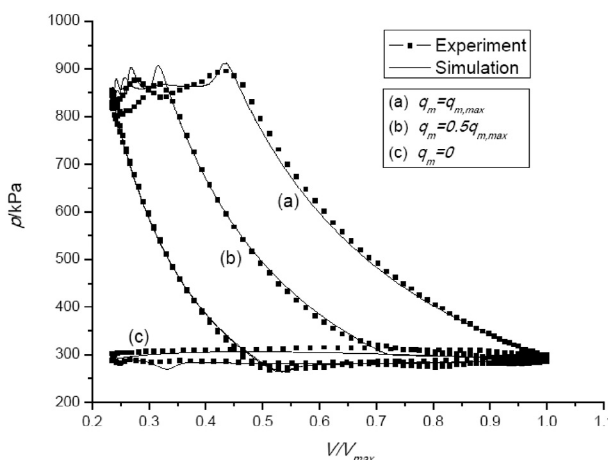
Guangbin Liu *, Yuanyang Zhao, Bin Tang, Liansheng Li

State Key Laboratory of Compressor Technology, Hefei General Machinery Research Institute, Hefei 230031, China

HIGHLIGHTS

- A mathematical model coupled with compressor, actuator and hydraulic system is built.
- The dynamic performance of suction valve influenced by structural and operating parameters is detailed and analyzed.
- The *p-V* diagram and power consumption in the regulation condition are tested.
- The power consumption decreases 21% when the capacity is 70% of the full load based on the experiment.

GRAPHICAL ABSTRACT



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ABSTRACT

Regulating capacity by controlling suction valve has a good application value for the large-scale reciprocating compressor used in the petrochemical industries. A mathematical model coupled with compressor, actuator and hydraulic system is built in this paper, and some performances of the system are tested by the experiment. The results show that the maximum displacement of actuator increases with the oil pressure until it is limited by the lift limiter. The low hydraulic oil pressure leads to the partially opened condition of suction valve, and the valve plate impacts on the actuator at the same time, which influences the accuracy of indicated powers and mass flow rate. The reset response time of valve plate cannot be improved by increasing oil pressure after the actuator is completely opened. The mass flow rate decreases with the hold time after the closing process of suction valve is delayed until nothing is discharged. The reset response time can be improved by increasing the reset spring stiffness and the path diameter of solenoid valve, or decreasing diameter of hydraulic cylinder. All the power consumption and mass flow rate decrease apparently caused by the delayed compression process. The power consumption decreases 21% when the capacity is 70% of the full load based on the experiment.

1. Introduction

Large-scale reciprocating compressor is the indispensable equipment for the petrochemical and metallurgical industries. Usually, it consumes large energy due to its high discharge pressure and mass flow rate. For example, the power consumption of a hydrogen

* Corresponding author. Tel.: +86 0551-65335770; fax: +86 0551-65335770.
E-mail address: guangbin0805@163.com (G. Liu).

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compressor in the hydrocracking device is generally larger than 2000 kW. But most of the large-scale reciprocating compressor is operated in the low efficient condition because the design capacity of compressor is larger than it required in the system. This mismatch of gas flow rate is caused by the inevitable design margin, model selection and various operating condition; therefore, a stepless capacity regulation system is required. Some efficient capacity regulation methods of reciprocating compressor have been applied in the industrial fields [1–3]. For example, the most common method is controlling the redundant gas flows from discharge pipe to the suction one through the bypass throttle, which wastes lots of energy. Another method by adjusting the clearance volume can only regulate partial gas load, and the response time is large. Regulation capacity by opening part of suction valves completely cannot adjust the capacity steplessly. The method adjusting capacity by controlling suction valve can realize the stepless capacity regulation because it controls the valve plate during all the running moments. In addition, the power consumption of compressor is almost proportionally reduced with the gas flow rate due to the delayed compression process.

Capacity regulation of reciprocating compressor by controlling suction valve was proposed in the 1970s, but it was not developed with the control technique until 1990s. The HydroCOM system of Hoerbiger and the ISC system of Dresser-rand have been used in the industrial field. Although some reports focus on the dynamic performance of this system, lots of simplification is used in the mathematical model. Hong et al. [4] discuss the relationship between the pressed-off crank shaft angle and compressor capacity, and the obtainable capacity regulation range is 10–100% of full load. Jiangming et al. [5,6] built a mathematical model to describe the dynamic process of suction valve based on L-K real gas state equation, and some dynamic performances under capacity regulation condition are analyzed. Some calculated results are also verified by the experiment on a type 3L-10/8 reciprocating compressor. Dacheng et al. [7] analyzed the advantage of program logic controller used in the stepless capacity adjustment system, and suggested to use it in the industry field. Bin et al. [8,9] simulated the capacity regulation system by AMESim software, and calculated the dynamic performance influenced by hydraulic cylinder and reset spring stiffness. The simulated results agree well with the experiment. But the results cannot reflect the actual working process of this system because the theoretical model ignores the couple rule between actuator and valve plate. Yuanyang et al. [10] tested the dynamic response of capacity control system in reciprocating compressor, and the influence by reset spring stiffness and oil pressure is also analyzed. Zhaolin et al. [11] proposed a capacity control method based on pulse signal concept to reduce the motion frequency of suction valve, but the related experiment is not reported. Because of the high frequency response in the capacity adjusting process, the dynamic performance of the system is very important for sensitivity and accuracy. Therefore, a mathematical model coupled with compressor, actuator and solenoid valve is necessary in order to describe the dynamic process of the system accurately in the capacity regulation condition.

Above all, although some reports focus on the stepless capacity adjustment system and some dynamic performances of suction valve have been discussed, the relationship and influence between elements are not analyzed. In this paper, a mathematical model on stepless capacity system used in large-scale reciprocating compressor is set up, which is coupled with compressor, suction valve, actuator and hydraulic system. The dynamic performance influenced by oil pressure, hold time, diameter of hydraulic cylinder, reset spring stiffness and path diameter of solenoid is analyzed. The p-V diagram and power consumption are also tested in the capacity regulation condition. The results are helpful for the design, analysis and optimization of this system.

2. Theoretical analysis

The capacity adjustment system is mainly composed of monitor, controller, hydraulic system, adjustment device and so on, which are shown in Fig. 1. The adjustment device includes actuator, hydraulic cylinder, hydraulic piston, solenoid valve, reset spring and other accessories. The adjustment device changes the motion rule of suction valve based on the control signal in order to regulate the gas flow rate of compressor. When the adjustment device is started, the

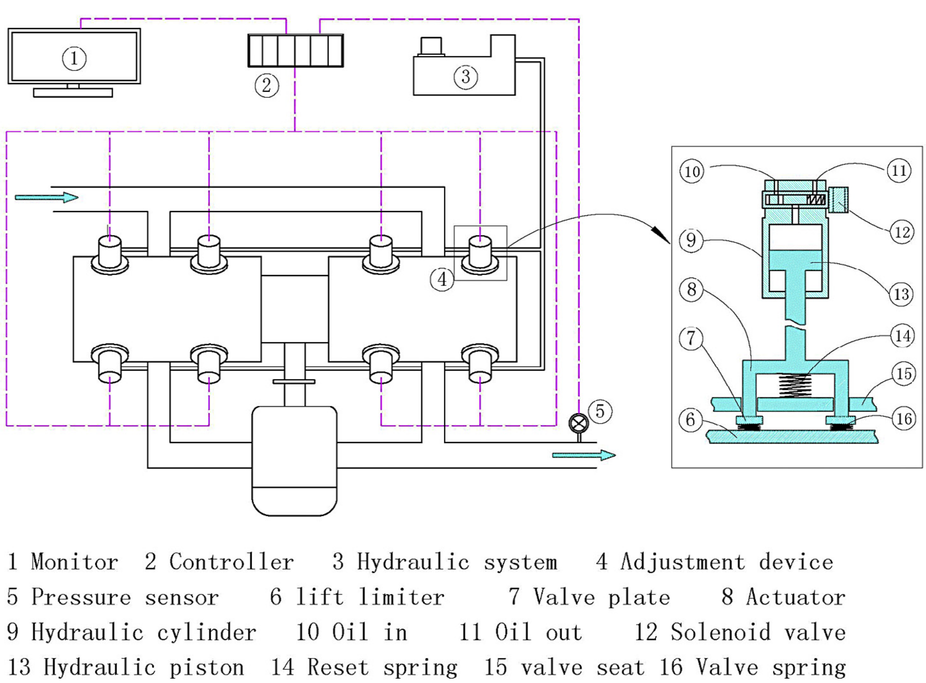

Fig. 1. Schematic diagram of stepless capacity adjustment system.