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EXPERIMENTAL STUDY OF OIL INJECTION AND ITS EFFECT ON PERFORMANCE OF TWIN SCREW COMPRESSORS

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ABSTRACT

In this paper some individual processes related to oil injection are investigated experimentally to get a better understanding of oil injection and its effect on performance of twin screw compressors. Firstly, a large number of performance data are obtained from test on several types of oil-injected twin screw compressor at various operating conditions, so as to get some performance characteristics of oil-injected twin screw compressors. Secondly, $p-V$ diagrams of a prototype compressor at various operating conditions are recorded and analyzed with the aid of a measuring system of dynamic pressure, in which a signal collector is used to transfer the pressure signal from the transducer embedded in the female rotor to the data acquisition system. Finally, with the laser measuring system PIV used, atomization effects of the injected oil at different oil-injection parameters are visualized and compared, and observation of oil distribution within the working chamber is made on a model compressor and some valuable phenomena are obtained for further investigation.

INTRODUCTION

Oil injection has a significant influence on performance of twin screw compressors because the injected oil serves the function of cooling, sealing and lubricating. On the other hand, the oil injected into the working chamber will move rapidly with the rotating rotor, thus introducing additional power losses. Therefore, the study of oil injection and its effect on performance of twin screw compressor is very important for those who are engaged in the optimum design of oil-injection parameters in order to obtain the minimal power consumption while maintaining perfect cooling, sealing and lubricating.

There are now many papers about the theoretical studies of oil-injected twin screw compressors for the past twenty years [1-5], mainly by means of simulating the thermodynamic process within the working chamber. Although some experimental investigations have been introduced in these papers for the purpose of verifying the mathematical models, papers specialized in the experimental studies seem to be deficient. Moreover, the existing papers involved in the experimental studies are usually concentrated on one or two aspects of oil injection and its effect [6,7]. Therefore, though very valuable, information provided by them is not enough for us to get a thorough comprehension of the effect of oil injection on performance.
For many a year, the authors have been carrying out a systematic study on oil injection both theoretically and experimentally. In this paper, three aspects about the experimental study are reported, i.e. (1) performance characteristics of twin screw compressors owing to oil injection, (2) analysis based on the record of $p-V$ diagrams, and (3) observation of oil injection and distribution.

**PERFORMANCE CHARACTERISTICS OF TWIN SCREW COMPRESSORS OWING TO OIL INJECTION**

Performance data of several types of oil-injected twin screw compressors at various operating conditions have been tested on a test rig (as shown in Fig.1). These test data are valuable for us to not only obtain an integral impression of performance characteristics of oil-injected twin screw compressors, but also get a deep-going comprehension of the influence of oil injection on performance. What is more, a large number of experimental data, especially obtained from a wide range of operating conditions, are very useful for validating the theoretical models.

Different types of oil-injected twin screw compressors usually represent different performance curves, but these curves have some significant common characteristics, which can be attributed to oil injection, so performance results of one arbitrary type of oil-injected twin screw compressors is taken for example of analysis.

Fig.2 shows changes of the volumetric efficiency of the prototype compressor at various discharge pressure and rotating speed (or tip speed) of the male rotor. It can be seen from this figure that the volumetric efficiency of oil-injected twin screw compressor changes with the rotating speed (or tip speed) much more slowly than that of oil-free twin screw compressor $^{[8]}$. As a matter of fact, changes of the volumetric efficiency in Fig.2 don't exceed 5% in a wide range of rotating speeds (or tip speeds) from 2000 rpm (or 10.996 m/s) to 6000 rpm (or 32.998 m/s), except for a rapid increase at low rotating speeds (or tip speeds) such as below 2000 rpm (or 10.996 m/s).

It can also be seen that the volumetric efficiency will not increase but decrease if the rotating speed (or tip speed) exceeds certain value, e.g. around 6000 rpm (or 32.988 m/s) in Fig.2. Contrary to this characteristic, the volumetric efficiency of oil-free twin screw compressors tends to be constant $^{[8]}$.

The characteristics stated above are meaningful for us to give a deep analysis on the sealing effect of oil injection. Although increase in the rotating speed will bring about decrease in duration for gas leakage, thus raising the volumetric efficiency, higher rotating speed will result in a lower ratio of oil to gas within the working chamber (see Fig. 3), thus weakening the ability for oil to seal the leakage gaps. As a result, the volumetric efficiency can't increase at a ratio as can be seen in an oil-free twin compressor. And moreover, when the rotating speed becomes excessively high, a large proportion of oil will be cast out of the compression chamber by the centrifugal force, thus not only weakening the sealing effect of oil in the leakage gaps between two rotors, but also occupying some space otherwise for the gas to be drawn from the inlet port. Besides these factors, decrease in suction pressure resulting from high speed is much bigger than that in an oil-free compressor, which will also cause decrease of the volumetric
efficiency.

Fig. 4 shows the isentropic efficiency of the prototype compressor at various operating conditions. It can be seen from this figure that, though a maximal isentropic efficiency exists for a given discharge pressure at various rotating speed (or tip speed), the isentropic efficiency at the other speed is considerably approximate to the maximal value, except for at low speed such as below 2000 rpm (or 10.996 m/s). When Fig. 4 compared with Fig. 2, it can be seen that increase in the volumetric efficiency doesn’t definitely mean increase in the isentropic efficiency, which should be attributed to rapid increase in additional power losses of oil injection.

The fact that both the volumetric efficiency and the isentropic efficiency change slowly with the rotating speed provides us a favorable information that performance of oil-injected twin screw compressors at a wide range of variable speed is fairly good.

ANALYSIS BASED ON THE RECORD OF $p$-$V$ DIAGRAMS

Whether the thermodynamic process is perfect or not can be judged from the $p$-$V$ diagram. For an oil-injected twin screw compressor, not only is the cooling effect of the injected oil able to be identified by comparing the compression in the record of $P$-$V$ diagram with the adiabatic curve, but also the power losses during the suction and discharge processes, especially caused by oil injection, can be estimated. Furthermore, the mechanical power losses, which are mainly caused by friction and churning of the injected oil, can be figured out by combining the record of $p$-$V$ diagram with the measurement of power consumption.

Fig. 5 shows the picture of the measuring system for recording the $p$-$V$ diagram. In this system, a signal collector is used for transferring the pressure signal from the transducer to the dynamic signal analyzer, and the transducer is embedded in the groove of the female rotor at the discharge end (see Fig. 6).

Fig. 7 shows some examples of the record of dynamic pressure change with time within the compression chamber. Fig. 8 and Fig. 9 show the $p$-$V$ diagrams converted from the $P$-$t$ diagrams. From these figures, it can be seen that the beginning of discharge phase is apparently different for different discharge pressure, while the other parts of the pressure curve for different discharge pressures are much alike. The rapid increase of pressure at around the end of discharge phase may be caused by oil-extrusion effect owing to contact of two rotors. A phenomenon worthy of noting is that gas pulsation exists during the suction phase (see Fig. 7).

In order to find out the most possible factors that influence power consumption during discharge process, the authors have carried out a further investigation on the gas pulsation during discharge phase. In general, the power losses during the discharge process are attributed to two sources, i.e. (1) the viscous friction owing to high-speed discharge flow of the gas-oil mixture and (2) the gas pulsation owing to periodic discharge process. In order to distinguish these two sources, the gas pulsation within the discharge cavity in the vicinity of the discharge port is
recorded and the results are shown in Figs. 10～12. It can be seen from these figures that the amplitudes of the gas pulsation at most of operating conditions are considerably large and therefore have an ignorable influence on discharge pressure losses. What is more, Figs. 10～12 present us with two facts: one is that the relative amplitude of pressure pulse increases with the raise of rotating speed, the other is that the farther away the discharge pressure deviates from the internal pressure, which is determined by the built-in volume ratio, the larger the relative amplitude of pressure pulse becomes.

OBSERVATION OF OIL ATOMIZATION AND DISTRIBUTION

Although the effect of oil injection on performance of twin screw compressor is well known, what really happens in the working chamber, especially between gas and oil, has long been a puzzle. Since understanding the oil distribution within the working chamber is the key to analyzing quantitatively the influence of the injected oil, some experimental investigations on oil atomization and distribution have been carried out.

Fig. 13 shows the test rig as well as the laser measuring system PIV for investigating the oil atomization. With the aid of PIV (Particle Image Velocimeter) system, atomization state of the injected oil can be visualized. Fig. 14 shows the examples at some different oil-injection parameters. Some conclusions are obtained from the great number of pictures like those in Fig. 14: (1) an optimum diameter of the oil injection hole exists, which makes the atomization effect most perfect; (2) a large number of bubbles are presented in the column of the injected oil, and the number of these bubbles changes greatly with such oil injection parameters as diameter of the injection hole and injection pressure. Using the PIV system, the authors obtain the velocity field, which can be used to verify the calculation results about the free flight of oil droplets in the space of working chamber.

So far as the oil distribution is concerned, some phenomena obtained from observation are listed as follows.
(1) Owing to the centrifugal force, a large amount of oil exists in the space of the working chamber in the form of oil droplets, which enhances heat transfer between gas and oil.
(2) Oil in the leakage gaps between two rotors are cast out by the centrifugal force and the pressure difference, thus weakening the sealing effect, especially when the ratio of oil to gas is low.
(3) A thin film of oil always exists on the rotor surfaces, which makes the lubricating effect perfect.
(4) A large proportion of oil is foamed after falling onto the rotor surfaces, thus weakening the sealing effect but enhancing the heat transfer.

A model compressor has been established, and its rotors are made of transparent materials. With the PIV system applied, observation of the oil distribution within the leakage gaps is going to be made in the near future.

CONCLUSIONS

Performance of oil-injected twin screw compressor is characterized of smaller changes of
volumetric efficiency and isentropic efficiency in a wider range of operating conditions than that of oil-free twin screw compressor, which is favorable for economic operation at variable conditions.

$p-V$ diagrams at various conditions for a twin screw air compressor have been recorded and analyzed. The beginning of discharge phase is apparently different for different discharge pressure, while the other parts of the pressure curve for different discharge pressures are much alike.

Oil atomization and distribution has been observed with the aid of PIV system. Oil atomization effect has a considerable difference owing to changes in oil-injection parameters. Many oil droplets are observed flying in the working chamber. A thin film of oil always exists on the rotor surfaces, and a large amount of oil is foamed and many bubbles are presented in the working chamber. The authors are now carrying out further experimental investigations to understand oil distribution within the leakage gaps.

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REFERENCES

Fig. 7 Examples of the record of P-t diagrams

Fig. 8 P-V diagrams at n=2000 rpm

Fig. 9 P-V diagrams at n=3000 rpm

Fig. 10 Gas pulsation at n=2000 rpm

Fig. 11 Gas pulsation at n=3000 rpm
Fig. 12 Gas pulsation at n=4000 rpm

Fig. 13 PIV laser measuring system

Fig. 14 Visualization of oil atomization at various oil-injection parameters