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ABSTRACT

Based on simulations and experiments, the effects of refrigerant injection on the general performance and inner compression process of scroll compressor has been researched. As a result, it is found that the refrigerant injection process can be considered as a continual parameter-varying “adiabatic throttling + isostatic mixture” time-varying process. The indicated efficiency of the injection scroll compressor will acquire the maximum when the ratio of inner compression ratio and outer compression ratio is a right value. When the compression is an isentropic process, the value is 1. The effects of injection pressure on the power, refrigerant flow rate, p-h diagram, volume efficiency, and indicated efficiency is studied detailedly.

1. INTRODUCTION

The scroll theory was brought forward at the beginning of the previous century and the scroll compressor became more and more popular recently because of its unique advantages, such as low level of noise, high efficiency and high reliability.

Technology of refrigeration injection has been applied in scroll compressor widely in recent years. For low temperature heat pump system and high condensing temperature refrigeration system, refrigerant injection can not only increase capacity and EER/COP of the system but also decrease the discharge temperature. Because of the variation of the inner pressure in injection process, the injection processes of screw and scroll compressors are more complex than that of two/multi-stage compression, such as the injection process of the centrifugal compressor. According to the state of the injected refrigerant, the refrigerant injection system of the scroll compressor can be divided into liquid injection system and gas injection system.

To review the published papers (Beenon and Pham, 2003; Ding et al., 2004; Ma and Chai, 2004; Ma et al., 2003) about refrigerant injection, most researches focuses on the effects of injection parameters, such as injection pressure, on the general performance of heat pump or refrigeration system, such as COP, EER, heating capacity and discharge temperature. The research results can not display the effect of refrigerant injection on the inner compression and are hard to reveal the essence of refrigerant injection, which make it difficult to use those results to direct the optimal design of the injection compressor and injection system.
This paper intends to develop a general model of scroll compressors and setup a test plant, which can measure both the dynamic pressure in working chamber and system performance. Use it and the effects of refrigerant injection on the general performance and inner compression process of scroll compressor has been researched detailedly.

2. RESEARCH METHODS

Measuring the dynamic pressure in the compression pocket is the fundamental and critical work of the experimental research on refrigerant injection system. Because the scroll is rotated in a high frequency (30Hz~100Hz), which lead to the pressure in the measuring pocket fluctuating quickly, the sensor must have a good dynamic performance to follow the variation of the pressure. So every component in the measurement system of the dynamic pressure must be seriously considered, include pressure-leading system, pressure sensor, signal transducer, detecting circuit, filter and so on. Before all of them, the power spectral density (PSD) of the pressure signal must be analyzed to decide the maximum effective frequency of the signal.

The installation position of pressure sensors is effected by both measuring range of the sensor and the installation space. Figure 1 shows the real measuring positions in this test. The measuring system of dynamic pressure is illuminated in Figure 2.

Figure 1 Location of measurement ports

Figure 2 Design of the sensor configuration

Figure 3 shows the schematic of the system experimental bench. Two tube-in-tube heat exchangers are used as evaporator and condenser, respectively. A mass flow meter is installed in the liquid line of injection tube to measure the injection refrigerant flowrate. A plate heat exchanger is equipped between the evaporator and the condenser to reduce the cooling and heating requirement of bench to service system. A lot of static pressure sensors and thermocouples are fixed in the bench to measure the stable system performance.

Figure 3 Schematic of the test bench
A distributed parameter model of an injected scroll compressor is built to research the influence of refrigerant injection on the compressor performance. Compared to the other published models of the scroll compressor (Cho et al., 2003; Dutta et al., 2001; Park et al., 2002), the unique advantage of this model is that this model can be used in the dry or wet compression as well as refrigerant injection or refrigerant release. The detailed information about this numerical model can be found in the further papers.

3. RESULTS AND DISCUSSION

3.1 Characteristics of Refrigerant Injection

In previous researches (Jonsson, 1991; Winandy and Lebrun, 2002), the injection process of the scroll compressor or the screw compressor always is considered as an instantaneous process. Under this assumption, the injection process is treated as an isostatic or isometric mixture.

In actual, for the scroll compressor, the refrigerant injection process can not be finished in a short period in the geometrical viewpoint, it will last $3\pi/2 - 2\pi$. The experiments and simulations also certify this point. Fig.5 presents the experimental results and the numerical results of dynamic pressure in the working pocket of scroll compressor under an injection condition. The evaporating pressure is 0.33 MPa, the condensing pressure is 1.51 MPa and the injection pressure in 0.65 MPa. It can be seen that the effect of the refrigerant injection on the pocket pressure is long-time and the injection does not make sudden change in the inner compression process.

![Figure 4 Pocket pressure VS. rotating angle](image1)

![Figure 5 Influence of refrigerant injection on the pocket parameters](image2)

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Fig. 5 shows the influence of refrigerant injection on the other parameters in working pocket. The temperature and the mass also change slowly in the whole injection process (3π/2~2π).

To sum up, the refrigerant injection process of the scroll compressor will last a long time and it has an obvious time-varying characteristic.

For the scroll compressor, the injection ports must be very small to avoid the leakage between adjacent pockets. The injection ports have a very obvious choking effect, which make the injected refrigerant almost has the same pressure when it enters the pocket. After that, the injected refrigerant and the original refrigerant in the pocket will mixed under the equal pressure condition. Because the pressure in the working pocket and the injected refrigerant mass flowrate will vary in the injection process, the injection process of scroll compressor should be considered as a continual parameter-varying “adiabatic throttling + isostatic mixture” process. The schematic thermodynamic process is in Fig. 6: the refrigerant outside of the injected port (A) is adiabatic throttled by the injection port when it passes it and reaches (C), which has a almost same pressure with the refrigerant in the pocket (B) at this time. B and C is mixed at the same pressure condition to get the final station D. After that, the scroll is rotated to compress the D to B1. At this time, the refrigerant A is throttled to C1 and mixed with B1 to get D1. This process will go on until the injection process finishes.

![Figure 6 Schematic of refrigerant injection process](image_url)

Finally, an important conclusion is gotten: the refrigerant injection process is a continual parameter-varying “adiabatic throttling + isostatic mixture” time-varying process.

### 3.2 Effects on the Performance of the Scroll Compressor

The factors effecting refrigerant injection system include injected refrigerant states, parameters of injection ports and compressor characteristics. The injected refrigerant states refer to the injection pressure (intermediate pressure) and injection enthalpy. The parameters of injection ports consist of area of injection ports, position of ports and one-way valve. For a preset compressor, the compressor characteristic mainly refers to the speed of the compressor. To do the research of refrigerant injection on the compressor performance, these factors should be considered one by one. Only the effect of the injection pressure on the performance is introduced here because of the limitation of the paper length, the effects of the other factors will be presents in future publications.

Fig. 7 illuminates the influence of injection pressure on the compressor performance by simulation. Fig. 7(a) presents the p-V curves under different injection pressures when the evaporating temperature is -10 °C. It can be seen that the polytropic factor increases with the increase of the injection pressure and the polytropic factor will decrease when the injection is reverse. Fig. 7(b) shows the relative power of compressor under different injection pressures. The relative power enhances with increase of the intermediate pressure but the speed of increase goes down gradually due to decrease of the injection mass flowrate. When the injection is reverse, the power consumption of the compressor will smaller than uninjected system. The p-h curves is showed in Fig. 7(c). Because the enthalpy of injected refrigerant is smaller than the one in the pocket, the discharge enthalpy decreases with the increase of the
injection pressure, which makes the discharge temperature decrease and keep the compressor in safe working range. Fig. 7(d) is the variation of the volumetric efficiencies of the scroll compressor under different injection pressure. It can be seen that the external leakage increases with the increase of the injection pressure and it reduces the volumetric efficiency. Fig. 7(e) presents the indicated efficiencies of compressor under different injection pressure. For different working conditions, the effects of the injection pressure on the indicated efficiencies is quite different: for low evaporating condition, the indicated efficiency increases following the increase of the injection pressure; for the high evaporating condition, the indicated efficiency will decreases with the increase of the injection pressure. Reorganize the indicated efficiency as a function of the ratio of inner compression ratio and outer compression ratio (Fig. 7(f)), it’s easy to found the indicated efficiency reaches the summit when the ratio of inner compression ratio and outer compression ratio is between 0.78~0.83.

Figure 7 Effects of injection pressure on the compressor performance
Actually, the key point of increase the indicated efficiency is decrease the loss of under- or over- compression. Here, the optimal ratio of inner compression ration and outer compression ratio for injection system is brought forward in Equation (1).

\[
R_{p,\text{opt}} = \frac{P_{\text{dis},i,\text{opt}}}{P_{\text{sec}}} = \frac{P_{\text{dis},i,\text{opt}}}{P_{\text{dis}}} \quad (1)
\]

\(R_{p,\text{opt}}\) stands for the mend situation of refrigerant injection to under- or over- compression and can be used as the index of compressor performance. For the compression process is or is close to an isentropic process, \(R_{p,\text{opt}}\) is 1.

**4. CONCLUSION**

Based on simulations and experiments, the effects of refrigerant injection on the general performance and inner compression process of scroll compressor has been researched. As a result, it is found that the refrigerant injection process can be considered as a continual parameter-varying “adiabatic throttling + isostatic mixture” time-varying process. The indicated efficiency of the injection scroll compressor will acquire the maximum when the ratio of inner compression ratio and outer compression ratio is a right value. When the compression is an isentropic process, the value is 1. The effects of injection pressure on the power, refrigerant flow rate, p-h diagram, volume efficiency, and indicated efficiency is studied detailedly.

**REFERENCE**


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