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A new model of screw compressor for refrigeration system simulation

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ABSTRACT

A performance predicting model of screw compressors, for refrigeration system simulation, is developed. The model correlates the running condition and some of the design parameters of a screw compressor. Compared with the experimental data, the errors of the model predictions are about ±2% for the volumetric displacement, less than 3% for the input power at full load condition, about 4% for the input power at part-load displacement condition, and about 2% and less than 4% for vapor injection mass flowrate. This model can also be used to optimize the built-in volumetric ratio of a screw compressor.

Nouveau modèle de compresseur à vis pour la simulation des systèmes frigorifiques

Mots clés : Froid ; Compresseur à vis ; Injection de vapeur ; Performance sous des conditions de charge partielle ; Simulation du système

1. Introduction

Refrigeration system is becoming more important for people's daily lives. For the conventional design method of refrigeration system, a prototype unit must be developed and be tested to verify the design. For getting the satisfactory result, the prototype building process may be repeated several times, which will increase the cost and prolong the design period. In order to make the system design process more efficient and economic, system simulation is widely used to predict the performance and optimize the system design before the equipments are manufactured.

Screw compressor is a kind of positive displacement rotary machine. Due to the advantage of high efficiency, wide operating scope and high reliability, it is widely employed in the refrigeration equipments in both commerce and industry, which have gradually substituted for the reciprocating compressor employed in the small cooling capacity unit and part of centrifugal compressor employed in the large cooling capacity unit.

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Nomenclature

A	area, m^2
C	coefficient
k	polytropic index
P	power, kW
p	pressure
R	radius
T	lead of rotor
V	volume, m^3
V_i	built-in volumetric ratio
η	efficiency
ρ	density, kg m^{-3}
ϕ	helical angle of teeth
h	enthalpy, kJ kg^{-1}
w	specific power, kW
ε	pressure ratio
υ	specific volume, m^3 kg^{-1}
T	temperature, K
m	mass flowrate, kg s^{-1}
α	load percent, %
Z	teeth number
Subscript	
0	Design parameter, theoretical
1	Male rotor, refrigerant state point
2,3	refrigerant state point
υ	volume
m	motor
s	isentropic
b	vapor injection

Compressor is the heart of refrigeration systems. A good compressor model is the key for system simulation. According to the study objectives, the compressor model can be cataloged into steady model and dynamic model. A complicated dynamic compressor model (Wu et al., 2007; Lee et al., 2001; Seshaiah et al., 2006), as well as CFD model (Kovacevic et al., 2000; Vimmr and Fryč, 2006), which is usually used to study the working process and/or to optimize the structure of the compressor, may make the system simulation run too slowly. It is not suitable for refrigeration system simulation. For the compressor model to predict the refrigeration system performance, three parameters including the refrigerant mass flowrate, the input power and the refrigerant temperature at the compressor exit should be calculated accurately and other unimportant parameters can be ignored (Ding, 2007, 2006). Long Fu et al. (2002) employed a very simple model of the screw compressor in his system simulation. The model only correlates the running condition parameters, including the suction pressure and the discharging pressure, not considered any design parameters of the compressor. Some key design parameters have definitely influence on the performance of a screw compressor. For example, the built-in volume ratio has distinctively contribution to the input power for various running conditions. According to the different ratio of discharging and suction pressure, under-compression or over-compression may occur in its working process, which results more power consumption. The built-in volumetric ratio efficiency can theoretically be deduced as (Xing, 2000).

$$\eta_{Vi} = \frac{\frac{k}{k-1}\left(\varepsilon^{\frac{k-1}{k}} - 1\right)}{\frac{k}{k-1}\left(V_{i0}^{k-1} - 1\right) + \frac{\left(\varepsilon - V_{i0}^{k}\right)}{V_{i0}}} \quad (1)$$

Where, k is polytropic exponent. V_{i0} is the built-in volumetric ratio of the compressor for full load condition. ε is the ratio of the discharging pressure and the suction pressure.

For a given built-in volumetric ratio, there is a pressure ratio who has the built-in volumetric ratio efficiency equal to 1.0. Either lower or higher than the pressure ratio makes the efficiency drop, which means more input power to be needed. Therefore, a too simple compressor model, which does not include the compressor design parameters, is not enough to depict the real performance of a screw compressor in a wide running condition scope. It may make the system simulation result not accurate.

Compared with other types of compressor (piston, centrifugal, scroll, etc.), VI (Vapor Injection) is the unique advantage of a screw compressor, which can improve the capacity, as well as COP, of a refrigeration system with economizer cycle. Economizer cycle can easily work with a single-stage screw compressor to realized two-stage compression while two compressors or a two-stage compressor must be used for other types. Few compressor models for system simulation can present the performance of a screw compressor with VI in the referenced articles.

Since cooling capacity requirement varies with climate and work schedule, for most of the time, refrigeration systems run under part-load condition. A slide valve is the most frequently used device to regulate the displacement for screw compressors. With the slide valve moving, the displacement can be changed from 100% to 25%, which results the system capacity change. Among the articles the authors have read, few models for system simulation can calculate the part-load displacement performance of a screw compressor, which is important for estimating the running cost of the refrigeration equipments.

In order to simulate the performance of the screw compressor in a wide running condition scope, with VI and under part-load displacement conditions, some key design parameters of the compressor must be considered. In this article, a new steady model is developed, which correlates both the running parameters and some key design parameters of the compressor. The coefficients used in the model were regressed on the base of experimental data. The model can predict the performance of the screw compressor with and without VI in a comparatively wide running condition scope and under part-load displacement condition with a fast running speed.