INTERNATIONAL JOURNAL OF REFRIGERATION 47 (2014) 36–45

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ijrefrig

Dynamic behaviors of the crankshafts in single-cylinder and twin-cylinder rotary compressors

Haifeng Zhang [a,b], *Jianhua Wu* [a,*], *Fei Xie* [b], *Ang Chen* [a], *Yanzhong Li* [a]

[a] *School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an 710049, PR China*
[b] *Shanghai Hitachi Electrical Appliances Co., Ltd., Shanghai 201206, PR China*

ARTICLE INFO

Article history:
Received 17 March 2014
Received in revised form
24 June 2014
Accepted 17 July 2014
Available online 1 August 2014

Keywords:
Dynamic behavior analysis
Crankshaft
Rotary compressor

ABSTRACT

Refrigeration rotary compressors are widely used in air-conditioners. A rotary compressor has a special rotor-bearing system, since the elastic cantilevered crankshaft is under dynamic transverse forces on different planes. The large deformation of the crankshaft would affect the thickness of the oil film, wear the bearings down or even induce the rotor-to-stator rubs. It is considered as a non-linear fluid–structure interaction problem. To ensure the compressor operating well, the dynamic behaviors of both single-cylinder and twin-cylinder compressors' crankshafts at various speeds are analyzed. The influence of configuration of balancers on the reliability of rotor system is investigated for the further. Calculation results suggest that the vulnerable sections of crankshaft vary with the rotational speed. It is also found that 80% of the dynamic balance is the optimum design condition to reduce the transverse forces on crankshaft and the wear-out of journal bearings.

Comportements dynamiques des vilebrequins dans des compresseurs rotatifs à cylindre unique et à cylindres jumelés

Mots clés : Analyse du comportement dynamique ; Vilebrequin ; Compresseur rotatif

1. Introduction

In a rotary compressor used in air-conditioners (shown in Fig. 1), the crankshaft driven by the motor is capable of rotating with a large range of speed. The volume of compression cavity changes periodically with the rotation and the refrigerant gas in cylinder is compressed. However, due to the special structure of rotary compressor, crankshaft and motor rotor are made as a cantilever. Besides, the crankshaft is under a large dynamic load including gas force and unbalanced mass forces of comprising mechanical parts (eccentric crank, roller, and balancers on motor rotor). As a result, lubrication conditions at bearings would become severe owing to the deformation of crankshaft, as shown in Fig. 2. What is worse, rotor-to-stator rub would occur if the crankshaft bends

---

* *Corresponding author.*
E-mail address: jhwuxjtu@hotmail.com (J. Wu).

http://dx.doi.org/10.1016/j.ijrefrig.2014.07.014

Nomenclature

C	Radial clearance between crankshaft and bearing(m)
e	Eccentricity (m)
F	Force (N)
F_n, F_t	Normal and tangential force at vane tip(N)
h	Thickness of oil film (m)
H_c	Height of cylinder (m)
K	Dimensionless stiffness coefficient
L	The length of arms of forces(m)
m	Mass quantities (kg)
P	Pressure (Pa)
P_c	Pressure in compression chamber(Pa)
P_d	Discharge pressure(Pa)
P_s	Suction pressure (Pa)
q	Vector of displacement(m)
R	Radius(m)

Greeks

α	Offset angle of roller center (rad)
ε	Eccentricity of journal
θ	Rotational angle of crankshaft (rad)
θ_j	Circumferential angle of bearing (rad)
η	Viscosity of oil(Pa s)
φ	Attitude angle of bearing(rad)
ω	Angular velocity (rad s^{-1})

Subscripts

bal	Balancers
c	Crank
e	Eccentricity of crankshaft
ec	Eccentric mass of roller and crank
g	Gas
j	Journal
mj	Main journal bearing
o	Oil
ro	Roller
sj	Sub journal bearing

more largely. Therefore, to ensure rotary compressor operating well, the dynamic behavior of crankshaft at various speeds should be analyzed.

Classic rotor dynamics is a special branch mainly analyzing the dynamic behavior of structures at overcritical high speed with little transverse loads. Ehrich (Ehrich, 1991) studied the bifurcation of a bearing-rotor system and identified a sub-harmonic vibration phenomenon in the rotor's dynamic behavior. Holmes (Holmes et al., 1978) published a paper dealing with a periodic behavior in journal bearings. Brown et al. (1994) developed a simple model of a rigid, hydrodynamically supported journal bearing using short bearing theory. It was shown that the journal behaved chaotically when the rotating unbalance force exceeded the gravity load. Chang-Jian (2010); Chang-Jian and Chen (2006) discussed about a rotor supported by journal bearings under non-linear suspension and combined with rub-impact effect, turbulent effect and micro-polar lubricant into consideration. Kurka et al. (2012) analyzed the visco-elastic bearing loads in the dynamic model of a reciprocating refrigeration compressor. The Newton–Euler method was used in the analysis, establishing the necessary differential equations that described the movement of the system, leading also to the calculation of orbital displacements of the bearings.

In 1990, Hattori and Kawashima (1990) proposed a method to analyze the rotor-journal bearing system in a twin-rotary compressor. The crankshaft was meshed by one-dimensional beam elements based on finite element method. The short bearing theory was employed to solve the oil film force. The sub bearing was taken as one short bearing while the main bearing was taken as two. Elastic bending deformation of the crankshaft, the bearing loads profiles, and the pressure distributions of the oil film had been obtained. In 1998, Dufour et al. (1998) also took beam element to mesh the crankshaft; the bearings were modeled by one- node elements with two lateral translations, and the main bearing was split into two parts. In his work, the oil film forces were calculated by the stiffness and damping characteristics of the three bearings, which were empirical equations involving bearing clearance and bearing load. In 2003, Dufour (Sève et al., 2003) continued his research on the balancing procedure for variable-speed compressor ignoring the cylinder pressure force. In Xie's study (Xie and et al., 2006),dynamic behaviors of the rotor-journal bearing system for single-rotary compressor at high speed and low speed were analyzed considering both unbalanced mass force and gas force. Wang et al. (2013) applied the finite element model with three-dimensional solid element to study the vibration characteristics of the rotor-journal bearing system in a variable speed rotary compressor. In his work, the dynamic model of the rotor was solved by the finite element software ANSYS.

A variable speed rotary compressor is capable of running from 1200 rpm to 7200 rpm, while the rotation speed of a fixed speed rotary compressor is usually between 2850 rpm and 3650 rpm. Both of them are far below the instability of the lubricant. Besides, unlike the classic rotor dynamics model, the width-diameter ratio of a rotary compressor crankshaft is much larger, and its elastic deformation is mainly caused by transverse forces. Moreover, the height-diameter ratio of the main bearing in rotary compressor is almost 3, so neither the long bearing theory nor the short bearing theory is proper for it. Detailed comparison between is shown in Table 1.

Due to the differences, it is necessary, at the design stage, to use a more suitable model to predict the deformation of crankshaft and the distribution of oil film. In this paper, elasticity of the crankshaft is taken into account, 2-dimensional finite element method is applied to solve the oil film, and the dynamic behaviors of both single-cylinder and twin-cylinder compressor at various speeds are analyzed. The influence of configuration of balancers on the reliability of rotor system is investigated for the further.