Journal of Sound and Vibration ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Journal of Sound and Vibration

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

A parameters optimization method for planar joint clearance model and its application for dynamics simulation of reciprocating compressor

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ARTICLE INFO

Article history:
Received 13 October 2014
Received in revised form
23 January 2015
Accepted 25 January 2015
Handling Editor: L.G. Tham

ABSTRACT

In order to improve the accuracy of dynamics response simulation for mechanism with joint clearance, a parameter optimization method for planar joint clearance contact force model was presented in this paper, and the optimized parameters were applied to the dynamics response simulation for mechanism with oversized joint clearance fault. By studying the effect of increased clearance on the parameters of joint clearance contact force model, the relation of model parameters between different clearances was concluded. Then the dynamic equation of a two-stage reciprocating compressor with four joint clearances was developed using Lagrange method, and a multi-body dynamic model built in ADAMS software was used to solve this equation. To obtain a simulated dynamic response much closer to that of experimental tests, the parameters of joint clearance model, instead of using the designed values, were optimized by genetic algorithms approach. Finally, the optimized parameters were applied to simulate the dynamics response of model with oversized joint clearance fault according to the concluded parameter relation. The dynamics response of experimental test verified the effectiveness of this application.

1. Introduction

Reciprocating compressors are one of the most popular machines used in petroleum and chemical production processes, such as gas compression, petroleum transportation and natural gas transportation [1,2]. Some clearances in its joints are inevitable due to tolerances and defects arising from design and manufacturing process or wearing after a certain working period. In the case of oversized joint clearances, contact forces generate impulsive effect, and this situation causes vibratory running condition. Though the existence of vibration is the intrinsic properties of mechanical systems, excessive vibration degrades compressor performances seriously. Thus, the effective and accurate monitoring, diagnosis and prognosis of vibration dynamic response are required to help in both reducing maintenance costs and increasing the plant efficiency [3]. Therefore it is necessary to investigate the effect of joint clearance on vibration dynamic response of compressors.

In the past, several research works have been conducted with the planar joint clearance model and its effect on dynamic response of mechanical systems [4,5]. Dubowsky and Freudenstein [6,7] have formulated an impact pair model to predict

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http://dx.doi.org/10.1016/j.jsv.2015.01.044
0022-460X/

the dynamic response of an elastic mechanical joint with clearance. In their model, springs and dashpots were arranged as Kelvin–Voigt model. Rhee and Akay [8] have studied the response of a revolute joint with clearance in a rigid four bar mechanism. The clearance is modeled as a massless rigid connection requiring a continuous contact. Ravn [9] has presented a method permitting to expect and to characterize the dynamic response of a mechanical system with clearance in the joints by means of a continuous contact analysis. When the contact is detected, a set of opposite forces of contact are applied according to Hertz model. Flores and Ambrosio [10] have presented a computational methodology for dynamic analysis of multibody mechanical systems with joint clearance. Parenti-Castelli and Venanzi [11] have presented a new method based on the principle of virtual work for studying the kinematic influence of clearance affected pairs on the position and orientation of the links of spatial mechanisms. Flores [12] has studied the methodology for the dynamic analysis of mechanical systems considering realistic joint with clearance and lubrication. Khemili [13] has investigated the dynamic behavior of a planar flexible slider-crank mechanism with joint clearance, and they built a model under the software ADAMS and designed an experimental set-up to achieve experimental validations.

In previous research works, the major current focus in joint clearance is to formulate a new model or to improve the existed one, and these models are usually simulated using parameters calculated from geometry characteristics of the surfaces in contact and the designed values of material properties of the colliding bodies. Compared to the designed values of material properties, there may be some deviations of real values for the reasons such as the omissions of lubrication and thermal expansion and contraction of joint pairs in real working condition, so the parameters calculated from designed values may not be ideal for this model. It may be an effective approach to improve the simulation accuracy of joint clearance model by treating the parameters of model as optimization variables and the dynamic response of experimental tests as optimization objective. Several research works have been conducted with the optimization of parameters for mechanical systems with joint clearance. Erkaya and Uzmay [14,15] have given an investigation of joint clearance influences on the mechanism path generation and transmission angle, and genetic algorithm approach was used to optimize the link parameters for minimizing the error between desired and actual paths due to clearance.

A real mechanical system does not have only one joint with clearance, but practically all joints have clearances. This led several researchers such as Flores [16] and Cheriyan [17] to strongly recommend for their work to be extended to include multi-body mechanical systems with multiple joints with clearance. Few recent papers by Erkaya and Uzmay [18,19], and by Flores [20] have considered the dynamic analysis of multi-body systems with two joint clearances. Erkaya and Uzmay [18,19] modeled the clearance in the journal bearing as a massless imaginary link whose length is equal to the clearance size. This assumes that the journal and bearing will be in contact at all times. While in this work, four joints with clearance will be considered in the multi-body model, and the joint was modeled with a three motion modes, that is, the relative displacement of journal and bearing centers is variable.

Furthermore, once the optimized parameters of joint model at one clearance state were obtained using the dynamics response of experimental test as optimization objective, can it be used to simulate dynamics response for this joint model at other clearance state? If so, through the dynamics response of experimental test at one clearance state, the simulation accuracy of this joint model at different clearance states can also be improved, and this will significantly reduce the types of experimental test. While the relation of model parameters between different clearance states in one joint is the basis to implement it, and few references are involved with this relation. So this paper will also discuss the relation of model parameters between different clearance states.

This work focuses on the parameter optimization method of planar joint clearance model and the application of optimized parameters for one joint at different clearance states during the dynamic analysis process of reciprocating compressors. First of all, the revolute joint clearance model is given, and the relation of parameters between different clearance states is discussed. In the subsequent section the dynamic equations of reciprocating compressor with four joint clearances are presented. In Section 4 a multi-body dynamics model of reciprocating compressor was built to solve the dynamic equations. Section 5 describes the parameters optimization approach of joint clearance contact force model using genetic algorithms, and the application of optimized parameters is presented in Section 6. Finally, conclusion is outlined in Section 7.

2. Joint clearance contact model

2.1. Joint clearance model

In the classical analysis a planar revolute joint is considered ideal or perfect, that is, the journal and bearing centers coincide. Indeed, from practical point of view, some amount of clearance is always present in revolute joints in order to allow relative motion between the journal and the bearing. Fig. 1 depicts a typical configuration of planar revolute joint with clearance, in which the radial clearance c is defined as the difference between the bearing and journal radius. The clearance in realistic joint is much smaller than the size of bodies; however, in Fig. 1 it is grossly exaggerated for illustration. The existence of clearance in the revolute joints allows two extra degrees of freedom, that is, the relative displacement vector r between centers of journal and bearing, and the absolute angle γ between the horizontal direction and the displacement vector r, consequently, the journal and bearing can freely move relative to each other.

Three different types of motion between the journal and bearing can be observed during the dynamics of the planar revolute joint clearance, namely, (1) free flight mode, in which the journal moves freely within the bearing boundary, that is,