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Design optimization of compressor reed valve based on axiomatic design

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ABSTRACT

The reed-type valve is a key component of reciprocating compressors affecting the efficiency and reliability of compressors. The convention design of such valve components focused on the study of the individual elements of the system, which loses the opportunity of reaching the global optima. This paper proposes a scientific guide for the system design, based on which the reed valve system was optimized, in which the reed, the plate, the orifice and valve stop were analyzed systematically, design conflict of valve lift and valve life were indentified in the early design stage. In order to decouple the conflict, the valve lift was formulated into standard parameters. Finally, the design process was simplified. All the design parameters gear to each other. An industrial case is introduced to demonstrate the feasibility of the proposed design approach.

Optimisation de la conception de soupape à lamelles multiples d'un compresseur basée sur la conception axiomatique

Mots clés : Soupape à lamelles multiples ; Conception de soupape ; Conception axiomatique ; Optimisation de conception ; Soupape de compresseur

1. Introduction

The increasing demand by reducing energy consumption promotes a great challenge to the researchers responsible for the development of reciprocating compressors. The reed-type valve is a key component of reciprocating compressors affecting the efficiency and reliability of the machines (Costagiola, 1950; Soedel, 1984). Industry investigations indicate valves afforded more than 40% of the unscheduled compressor

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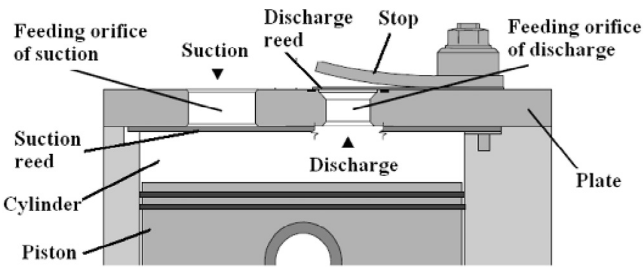

Fig. 1 – The scheme of a reed valve component.

shutdowns (Adolf et al., 2008; Xue Wang et al., 2013). Due to this fact it is important for the compressor designers to pay more attentions to optimize the valve design to improve the overall performance of compressors. Reed-type valves are commonly used in the small reciprocating compressor due to simple structure, low cost and high efficiency. They consist typically of a valve reed, a plate and a stop as shown in Fig. 1. The reed controls the flow of inlet and outlet gas automatically depending on the pressure difference between the cylinder and the suction/discharge chamber. Many approaches have been implemented to investigate reed-type valve mechanism. Costagliola (Costagliola, 1950) established the first mathematical model to describe the valve motion in the form of a single-degree of the freedom system. Soedel (1972) presented a dynamic model for valves to evaluate the performance of compressor. Kim (2006) and Mistry et al. (2012) simulated the valve dynamic behavior. Khalifa and Liu (1998) analyzed the stiction effect on the dynamics of suction valve. Link and Deschamps (2010), Pereira and Deschamps (2010) and Lacerda (2010) investigated the effect of orifice geometry on the effective flow area and fluid behavior. Longo and Gasparella (2003) and Srinivas and Padmanabhan (2002) analyzed the effect of the effective flow area on the valve performance. Matos et al. (2006) and Kim et al. (2008) conducted the fluid structure simulation analysis between valve dynamics and fluid flow. Adolf et al. (2008) and Yu et al. (2014) studied the relationship between the valve lift behavior and the orifice geometry.

Most of present studies mainly focused on the element level of valve, i.e. individual element, such as reed (Kim, 2006; Mistry et al., 2012; Soedel, 1972, 1984), fluid (Boswirth, 1990; Pereira et al., 2012), or two or more elements, such as stop and orifice (Adolf et al., 2008; Yu et al., 2014), reed and fluid (Kim et al., 2008; Matos et al., 2006) and flow area and orifice (Ferreira and Lainor, 1986; Longo and Gasparella, 2003; Srinivas and Padmanabhan, 2002), and lacked a system level model. In fact, the optimization of the element level may lose the opportunity of reaching the global optima. The valve performance is determined by multiple factors. For example, the stop limits the valve lift which affects the reed impact velocity and inclining (Xue Wang et al., 2013), the higher lift may reduce valve loss, and, at the same time may lead to the heavy wear (Altunlu et al., 2010; Tajima et al., 1988); the orifice geometry influences the effective flow area and pressure distribution on the reed (Ferreira and Lainor, 1986; Link and Deschamps, 2010). Bhakta et al. (2012) attempted to propose a valve design methodology in a system level model, where the valve design can be assumed to be a two-step process: the first step to obtain optimal valve parameters and second step to use the parameter values from step one to design the valve geometry, which still mainly emphasized on valve reed.

Based on the above analysis, the design of valve system is a multi-criteria decision making process, and it is essential to present a system level method where the valve was viewed as an integrated system and optimized systematically. Particularly, the modification of any parameter will affect others and trial-and-error method was usually used to make a good balance between different design criteria which leads to increase the design complexity and extend design life-cycle. If the relationships of each element are identified in the early design stage and the key elements are formulated, the process of trial-and-error may be reduced greatly, an optimal valve system will be developed and the failure of final design may be avoided greatly.

In the paper, a synergistic approach is proposed based on axiomatic design (AD) and the key elements of the valve system are analyzed systematically involving the reed, the orifice and the stop, an optimized valve system will be designed eventually. The rest of the paper is organized as in the following. In Section 2, AD and its principles are presented. In Section 3, the working principle of the reed valve is introduced and the design approach based on AD is developed. In Section 4, a suction valve is designed optimistically and the corresponding experiment is done to verify the validation of proposed design method, and Section 5 concludes the paper.

2. Axiomatic design and its principle

Axiomatic design (AD) developed by Suh (2001) is a systematic and scientific design methodology and is widely used to solve many design problems (Chen and Feng, 2004; Coelho and Mouao, 2007; Heo and Lee, 2007; Osman et al., 2010; Suh, 2001; Tang et al., 2009). The AD theory is featured with domains, hierarchies, and design axioms. The activity of design goes through four domains: customer needs (CNs), function requirements (FRs), design parameters (DPs) and process variables (PVs) respectively. It first transfers the CNs to FRs of a product. The FRs are further mapped to DPs. Each DP connects to a PV. Each CN is viewed as a function, which can be further decomposed into subfunctions. Accordingly, every subproblem again decomposes into one or more lower level subproblem until it reaches the “axiomatic” level. Therefore, the problem forms a hierarchical structure. Designers go through a zigzag design process whereby they zigzag between “what we know” specified in FRs and “how we do” defined in DPs. The zigzag design process was used to decompose the system. The design processes zigzag between function domain and process domain as shown in Fig. 2.

Two major axioms of AD are independence axiom and information axiom. The independence axiom maintains the independence of the functional requirements where each functional requirement (FR) is satisfied without affecting the other FRs. The information axiom aims to minimize the information content of the design. Therefore, the definition of FRs depends on the solution with DPs. Formulating acceptable FRs may involve several iterations, which guide the designers to