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A linear resonant compressor model based on a new linearization method of the gas pressure force

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ABSTRACT

In this paper, the resonant compressor is studied and one new method for modeling using the gas pressure force's effects is presented. The gas pressure force is nonlinear and variable throughout the operation. Therefore, it is a very difficult task to calculate the resonance frequency with the necessary accuracy to optimize the compressor efficiency. Thus, the design of a high performance controller for linear compressor drive presents a challenge since the system is highly nonlinear. This new method proposes to deal with this problem through linearization of the gas pressure force. This new approach is based on the effects that this force causes in the compressor operation. From the use of this approach, it is possible to model and to analyze the compressor's behavior as a linear time varying system.

Un modèle linéaire de compresseur résonant basé sur une nouvelle méthode de linéarisation de la force de pression du gaz

Mots clés : Compresseurs ; Systèmes non-linéaires ; Moteurs linéaires ; Machines électriques ; Résonance

1. Introduction

Refrigeration and heating systems are widely used in our society, with many diverse applications, from food conservation to ambient temperature control, enabling life quality and thermal comfort.

One of the principal methods of heat exchange is through a fluid phase change. This kind of system has four main parts: evaporator, compressor, condenser and throttle valve,

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Nomenclature

A_{PT}	piston area [m^2]
d	mobile set's displacement [m]
D_{LIM}	distance between the resting point and the upper limit [m]
f_R	mechanical resonance frequency [Hz]
F_G	gas pressure force [N]
F_{AM}	damping force [N]
F_{MT}	motor force [N]
F_{ML}	resonant spring's force [N]
F_{REq}	equivalent resultant force [N]
F_{MLEq}	equivalent spring force [N]
F_{AMEq}	equivalent damping force [N]
F_{CEq}	equivalent continuous force [N]
i	current in the winding [A]
K_{MLT}	total spring coefficient [N m^{-1}]
K_{ML}	resonant spring's force coefficient [N m^{-1}]
K_{AM}	damping force's coefficient [N s m^{-1}]
K_{MT}	linear actuator coefficient [N A^{-1} or V s m^{-1}]
K_{MLEq}	equivalent spring force's coefficient [N m^{-1}]
K_{AMEq}	equivalent damping force's coefficient [N s m^{-1}]
K_{MLT}	total spring coefficient [N m^{-1}]
K_{AMT}	total damping coefficient [N s m^{-1}]
L	stator winding's inductance [H]
m	mass [kg]
m_G	mass of the gas inside the cylinder [kg]
P_{in}	initial gas pressure inside the cylinder [kPa]
P_{AMT}	power consumed by the total damping force [W]
P_G	gas pressure [kPa]
P_S	refrigeration system's suction pressure [kPa]
R	stator winding's resistance [Ω]
R_G	gas constant [kPa m^3 kg^{-1} K^{-1}]
T_{in}	initial temperature of the gas [K]
V_G	volume within the cylinder [mm^3]
V_{in}	cylinder's initial volume [mm^3]
V_{ENT}	voltage at the entry of the linear actuator [V]
v	mobile set's speed [m s^{-1}]

Greek letters

η	adiabatic expansion coefficient [–]
ρ_{in}	initial gas density [kg m^{-3}]

according to Fig. 1. The refrigerant fluid, while passing through the throttle valve, has its pressure and temperature reduced, entering the evaporator as a liquid in a temperature lower than the environment. Then this fluid evaporates, taking the heat off the place to be refrigerated ($\dot{Q}_E$). In the gaseous condition, the refrigerant is sucked off the evaporator and compressed in the compressor, reaching a raised pressure and a temperature higher than the environment. In the condenser, the refrigerant goes into the liquid condition, releasing the heat to the outside environment ($\dot{Q}_C$), and it returns to the evaporator through the throttle valve. This closed cycle repeats constantly.

The compressor and the throttle valve are responsible for maintaining the pressure difference between the evaporator and the condenser. Given that the compressor is the element that consumes energy ($\dot{W}_C$) to pump and make the fluid flow in the refrigeration system, its efficiency is fundamental for system performance (Navarro et al., 2007).

In crank rod systems, the forces provided from the motor rotary stir transformation, in a piston alternative movement, produce mechanical losses. Thus, using a system that provides energy directly to the piston in the direction of its movement without needing a mechanical bearings system, rod and crank, it is more efficient (Bradshaw et al., 2013a,b).

Therefore, in recent years, the refrigeration industry has shown great interest in the resonant compressor (Kim et al., 2009; Bradshaw et al., 2011; Bradshaw et al., 2013a,b). In these compressors, the piston is activated by a linear agent, resulting in the formation of a resonant mass-spring system, where the moving part's mass is composed of the piston and magnets. A spring, called a resonant spring, connects the moving part to a support structure, composed of a cylinder, plate valve and stator from the linear agent. The moving part and the spring compose the compressor's resonant set, according to Fig. 2.

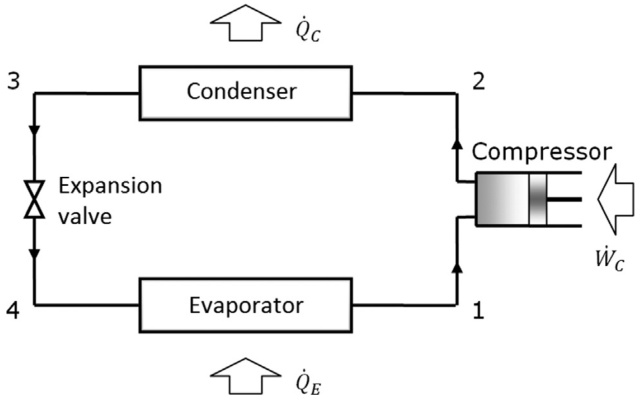

Fig. 1 – Refrigeration cycle by vapor compression.

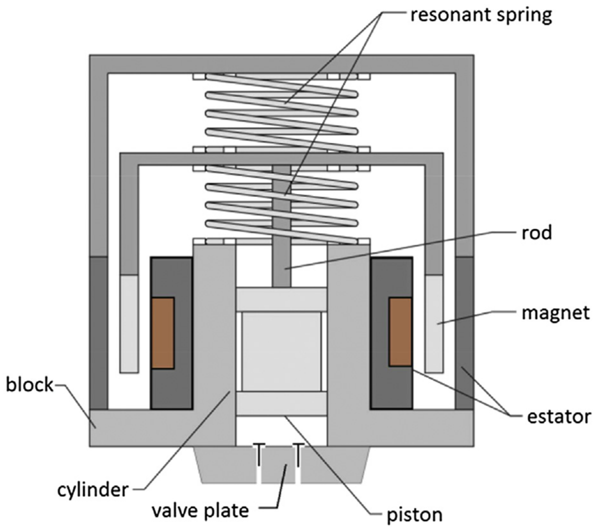

Fig. 2 – Lateral plane of the resonant compressor.