Applied Thermal Engineering 29 (2009) 2824–2831

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Experimental investigation on the characteristics of variable displacement swash plate compressor

Changqing Tian [a,*], Hongbo Xu [a,b], Liqin Zhang [a,b], Xianting Li [c]

[a] Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, P.O. Box 2711, Beijing 100190, PR China
[b] Graduate University of Chinese Academy of Sciences, Beijing 100049, PR China
[c] Department of Building Science, Tsinghua University, Beijing 100084, PR China

ARTICLE INFO

Article history:
Received 26 August 2008
Accepted 3 February 2009
Available online 11 February 2009

Keywords:
Variable displacement compressor
Swash plate
Automotive
Air conditioning
Piston stroke length

ABSTRACT

This paper is on a new device developed to measure the piston stroke length (PSL) of the variable displacement swash plate compressor (VDSC), with which the test bench for the VDSC and test system for automotive air conditioner with VDSC is constructed. The volumetric efficiency, PSL and displacement control, and transient behavior along with air conditioning load or compressor rotary speed are investigated experimentally. The experiment results show that the volumetric efficiency of the VDSC is directly proportional to the PSL due to the constant absolute clearance at different piston stroke lengths. When the air conditioning load keeps constant, the PSL and displacement of the VDSC are regulated to meet the air conditioning load at different compressor rotary speeds or vehicle speeds. When the air conditioning load changes gradually, the PSL has a number of small step changes so that the refrigerating capacity of the VDSC can well fit the air conditioning load. When the compressor rotary speed changes abruptly, the piston stroke length, refrigerant mass flow rate, and other parameters change with a very short time delay to ensure a nearly constant refrigerating capacity of compressor.

1. Introduction

The variable displacement compressor has been used popularly in the automotive air conditioning (AAC) system due to its continuous operation, better thermal comfort inside car, and lower petrol consumption [1–3]. Of the variable displacement reciprocating compressors, there are two types: wobble plate and swash plate. The difference between them is that, for the former, the wobble plate and pistons are connected with the piston rods while for the latter, there is no piston rod and the swash plate inserts into the pistons directly, which is used more and more widely due to its simple structure, low noise and excellent performance.

Though it has been widely applied, there are only a few papers published on the variable displacement swash plate compressor (VDSC) due to the competition between companies. Taya et al. [4] introduced the structure, principle, mechanism of variable displacement, and the evaluation results of the VDSC developed by them. Miyagawa and Kayukawa [5] presented the development principles, structures, and special features of their VDSC, which is a swash plate-type continuously variable displacement compressor with one-sided compression. However, in these two papers, only the structure and working principle of the VDSC are introduced and there is no detailed measured steady-state performance or transient behavior included. Yuan [6] investigated experimentally the transient behavior of externally controlled VDSC in an environmental simulation bench, and got the transient response of discharge pressure, suction pressure, evaporating temperature along with the change of input current of control valve and vehicle speed, but there is no measured piston stroke length (PSL). Tian et al. [7] developed a steady-state mathematical model of VDSC combining the sub-models of control mechanism, moving components dynamics and compression process, and simulated the steady-state performance with the verified model.

As for the PSL measurement, Delvaux et al. [8] designed an apparatus to measure the PSL of a variable displacement wobble plate compressor in order to find out how the PSL changed. A position sensor was set in the center of the wobble plate at the end near the discharge cavity, and its displacement signal was obtained outside the compressor so that the PSL could be measured. However, it is difficult to install the position sensor and there is possible refrigerant leakage since the position sensor is fixed at the location with complicated structure. Tian et al. [9,10] developed a new device to measure the PSL for a five-cylinder type variable displacement wobble plate compressor. The PSL could be calculated from measured displacement of journal pivot pin and geometric relation of moving components inside compressor, and this measurement method had been proved simple, reliable, and convenient.

As there is no published paper on the PSL measurement device and experimental investigation with measured PSL on the VDSC,

* Corresponding author. Tel.: +86 10 82543696; fax: +86 10 62554670.
E-mail address: chqtian@mail.ipc.ac.cn (C. Tian).

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doi:10.1016/j.applthermaleng.2009.02.002

Nomenclature

C constant
l_{op} distance of origin O and P (m)
M_r mass flow rate (kg/h)
N_c compressor rotary speed (r/min)
p pressure (MPa)
Q_e refrigerating capacity (kW)
r_t radius of the cylinder distributing round (m)
S_p piston stroke length (m)
$\bar{S}_p$ relative piston stroke length
t time (s)
V_r real displacement (m^3/r)
V_h theoretical displacement (m^3/r)
v_s refrigerant specific volume at suction end (m^3/kg)
x position on X axis (m)
y position on Y axis (m)
z position on Z axis (m)
α swash plate angle (°)
ε compression ratio
θ rotation angle (°)
θ_n azimuth angle of No. n piston (°)
η_v volumetric efficiency
λ_l seal coefficient
λ_p throttling coefficient
λ_t preheating coefficient
λ_v clearance coefficient

Subscripts
d discharge
n No. n piston
s suction
sc swash plate case
t central point of the connection between piston and sliding shoe
α coordinate system X_α–Y_α–Z_α
θ coordinate system X_θ–Y_θ–Z_θ

this paper explores a new device to measure the PSL of VDSC, and constructs the test bench for VDSC and test system for automotive air conditioner with VDSC, with which the steady-state performance and transient behavior are investigated experimentally.

2. PSL measurement device

2.1. Measurement principle

The VDSC for AAC system consists of the following main moving components: a main shaft, a drive rotor, a swash plate, and seven pistons. The drive rotor is fixed in the main shaft and drives the swash plate rotating along with the main shaft. The swash plate converts its rotary motion into linear reciprocation of the pistons through the sliding shoes inside the pistons (Fig. 1). The control mechanism is composed of a throttling orifice and a mass flow compensation control valve (MFCV). The refrigerant vapor is introduced from the discharge chamber to swash plate case through the throttling orifice, and then into the suction chamber through MFCV. When the automotive air conditioning load decreases, the suction pressure falls down, then the opening of MFCV decreases, and the swash plate case pressure increases. The decrease of suction pressure and increase of swash plate case pressure cause the force moments acting on the swash plate great enough to make the swash plate angle (or PSL) decrease, and the displacement falls down to match the decrease of the air conditioning load. In the similar way, the PSL and displacement will increase when the air conditioning load rises. The absolute clearance of cylinder keeps constant at different PSLs for the VDSC.

The distinct difference between the variable displacement compressor and the fixed displacement compressor is that the PSL of the variable displacement compressor is variable. Thus the changing rule of PSL is the most important for the characteristics of VDSC. It is difficult to ascertain how the PSL changes by force analysis because of the complicated mechanism of the VDSC, so the PSL measurement turns out to be an indispensable way. However, the swash plate and pistons are all inside the closed and opaque shell of compressor, so the PSL cannot be measured by optical means such as laser interferometry, and the ultrasonic measurement is complex and very expensive. Therefore, we try to find out the simple and reliable PSL measurement method according to the structure of VDSC.

Three coordinate systems are set-up in order to analyze the relative geometric relations among the moving components (Fig. 2). The static coordinate system X–Y–Z is defined on the swash plate case, where the origin O is located on the intersecting point of the main shaft center and distal end face of the drive rotor to the cylinders; the Y axis is vertically upward, and the Z axis coincides

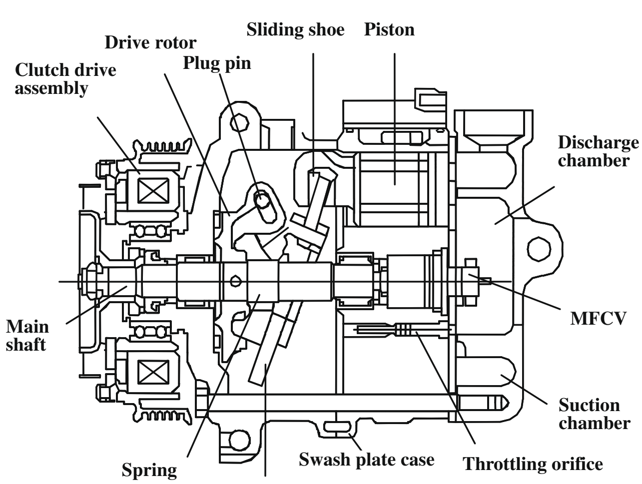

Fig. 1. Variable displacement swash plate compressor.

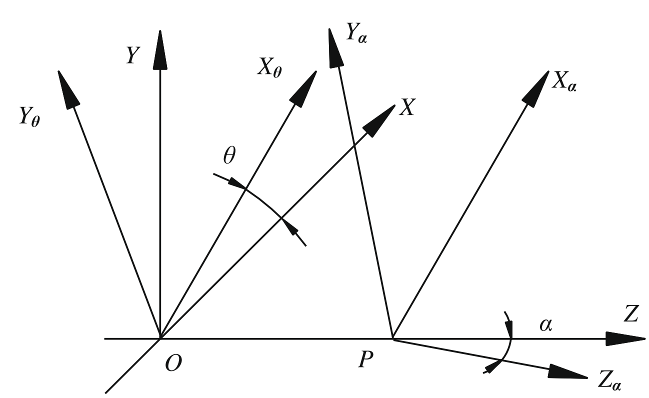

Fig. 2. Three coordinate systems.