Internal Leakage Analysis from P_d to P_c Port Direction in ECV Body Used in External Variable Type A/C Compressor

Md. Iqbal Mahmud, Haeng Muk Cho, Seo Hyun Sang, Wang Wen Hai, Chang Heon Yi, Man Ik Hwang, Dae Hoon Kang

***Abstract*—**Solenoid operated electromagnetic control valve (ECV) playing an important role for car's air conditioning control system. ECV is used in external variable displacement swash plate type compressor and controls the entire air conditioning system by means of a pulse width modulation (PWM) input signal supplying from an external source (controller). Complete form of ECV contains number of internal features like valve body, core, valve guide, plunger, guide pin, plunger spring, bellows etc. While designing the ECV; dimensions of different internal items must meet the standard requirements as it is quite challenging. In this research paper, especially the dimensioning of ECV body and its three pressure ports through which the air/refrigerant passes are considered. Here internal leakage test analysis of ECV body is being carried out from its discharge port (P_d) to crankcase port (P_c) when the guide valve is placed inside it. The experiments have made both in ordinary and digital system using different assumptions and thereafter compare the results.

***Keywords*—**Electromagnetic control valve (ECV), Leakage, Pressure port, Valve body, Valve guide.

I. Introduction

To meet the demand for improved comfort, drive ability and fuel economy standard, the compressor for automotive air conditioning system has been developed to get high performance, high reliability, low noise and low vibration. To satisfy these requirements, the variable displacement swash plate type compressor, which can control the compressor displacement by increasing or reducing the swash plate angle, has been developed [1]. Compressor is a high efficiency requiring component and it consumes a lot of engine power to control air conditioning system in automobiles. At present, automotive industries prefer variable capacity compressors instead of fixed capacity compressors because of its low energy consumption and highly efficient characteristics [2], and it is coupled with an ECV that is used for automobile air conditioning control system. Fig. 1 shows the external variable displacement type A/C compressor with ECV.

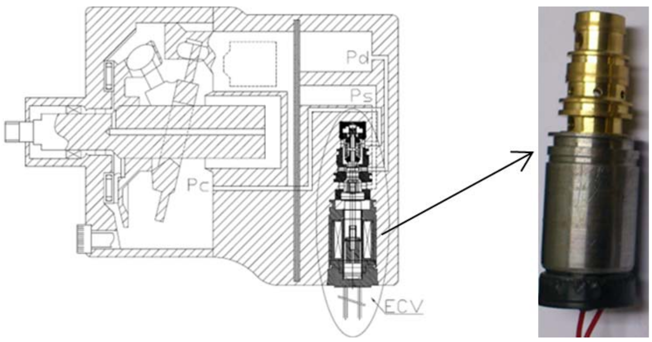

Fig. 1 Variable displacement type A/C compressor with ECV

The air/refrigerant flow controlled by ECV varies the pressure inside the compressor; and this pressure changes the piston movement that changes the angle of swash plate of the compressor. Because of ECV needs to control the pressure at different pressure ports locate on the valve body; the design therefore need to be very precise and accurate. The three pressure ports i.e. suction port, P_s (communicates to compressor suction cavity and senses suction pressure), crankcase port, P_c (delivers discharge gas to the compressor crankcase) and discharge port, P_d (receives gas from the compressor discharge cavity) are mainly connecting passages through the ECV for air/refrigerant flow functions [3]. Fig. 2 shows ECV structure with its different pressure ports.

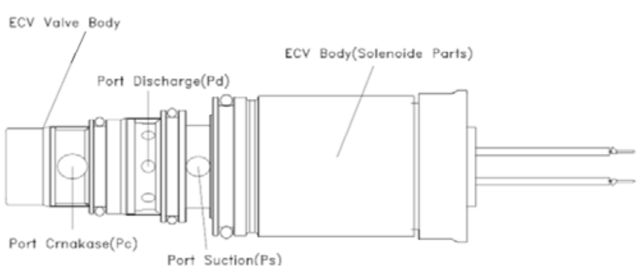

Fig. 2 Different pressure ports in ECV

The pressure sensitivity control mechanism adjusts the flow

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of air/refrigerant from the discharge side (high-pressure side) to the crankcase side of the compressor. Thus, the differential pressure can be controlled [4].

It is important to consider the issue of selection of ECV material, dimensioning and tolerances. Generally, the tolerance for each component of ECV is ±0.02mm to ±0.05mm, whereas some of the components associated with the leakage performance are assembled within a tolerance of ±0.002mm which is definitely a challenging issue to obtain [5]. The valve body of ECV is made of brass material as it requires precise machining to create complex flow/leakage paths. Moreover, it is non-corrosive and could make minimum friction because of its slip behavior. For brass materials, it is possible to maintain the dimensional tolerances precisely and obtain good surface finishing while using high speed steel (HSS) tools. On the other hand, valve guide is made of stainless steel materials of non-magnetic grade because it is a stationary item in the ECV. Fig. 3 shows the assembly of valve body and valve guide and the pathway to flow of air/refrigerant from discharge port (P_d) to crankcase port (P_c) through the internal leakage (gap) between the two parts.

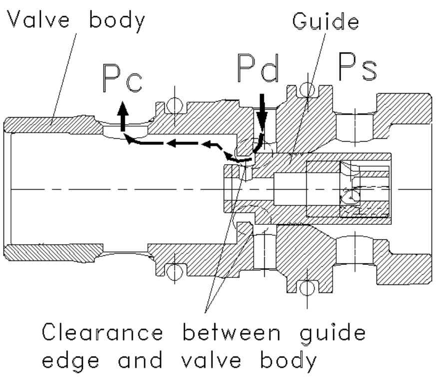

Fig. 3 Flow from P_d to P_c pressure port

In this research, experimental test of internal leakage of ECV body is performed at the discharge port of the valve body that is being adjacent with the valve guide internally. Experiments done both in ordinary and digital system to observe the internal leakage amount and then the results compared.

II. Experimental Assumptions

A. Sampling of Valve Body and Valve Guide

At first random sampling of valve body and valve guide is counted according to the precise tolerance values. For valve body inside (burr) diameter (where the air will passes through making small gap with valve guide) is ϕ6.495±0.003mm and the valve guide diameter is ϕ6.484±0.001mm. Total 24 valve body and 25 valve guide samples were measured with digimatic hollset (model: HTD-8R) and outside micrometer (model: M110-25) respectively to get the exact dimension with respect to the tolerance values. Fig. 4 shows valve body and valve guide sampling according to the specified dimensions.

Finally, 13 samples of both valve body and valve guide are selected at random that maintained the tolerance limit values. Fig. 5 shows the selected valve body and valve guide in graphical presentation that used for body leakage test analysis at discharge pressure port location. It is seen that, valve body samples stay between the tolerance values 6.492mm to 6.498mm and valve guide samples stay between the tolerance values 6.483mm to 6.485mm.

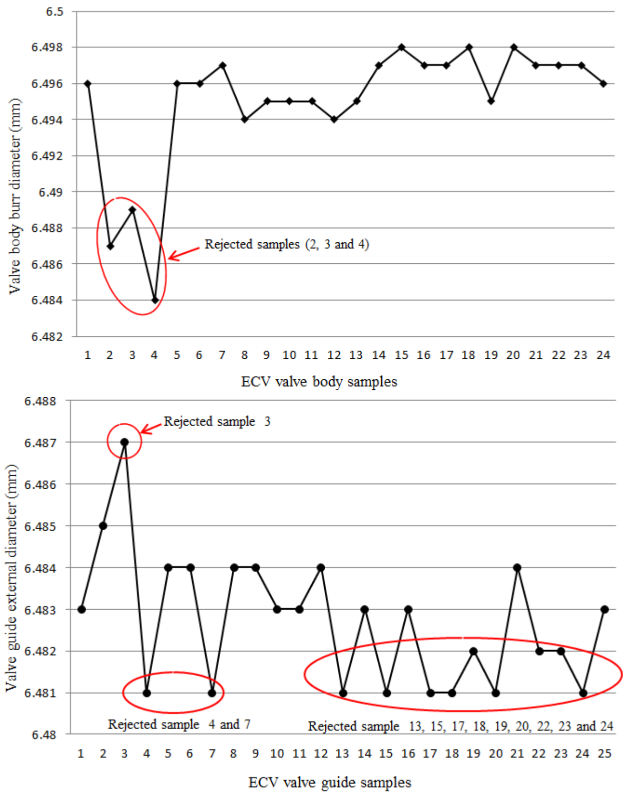

Fig. 4 Sampling of valve body and valve guide

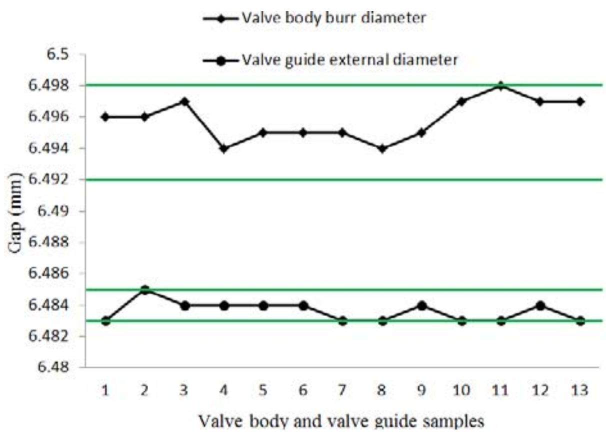

Fig. 5 Representation of valve body and valve guide dimensions

B. Testing Setup

For the P_d to P_c leakage test analysis; an air board tested is developed. Fig. 6 shows the schematic flow diagram of the testing set up.

Before supplying the air to the tester it is important to fix the specifications for the particular test analysis. Table I shows the set up specifications of the test board for internal leakage through P_d to P_c.

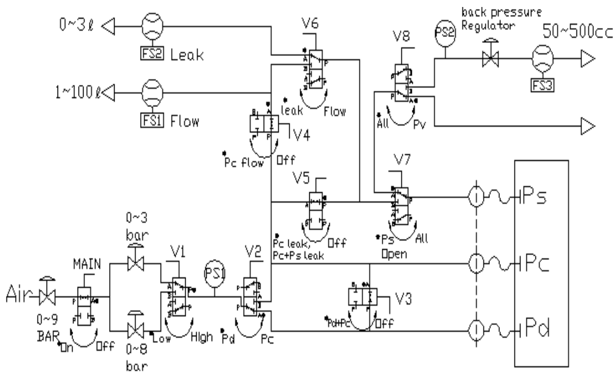

Fig. 6 Schematic diagram of the testing set up

TABLE I
SET UP SPECIFICATIONS

Test Status	Press (bar)	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8
Leak at low press. (P_c+P_s)	P_d=1	Low	P_d	P_d+P_c	Off	Off	Leak	P_s open	All

In the specification table the term *'low'* refers to air/refrigerant flow at low pressure, *'off'* refers to the valve in closing position, *'leak'* refers to measuring the leakage from P_d to P_c and *'all'* refers to the flow of air/refrigerant to all ways except P_s.

III. Experimental Analysis

In the experimental analysis, two systems are used for measuring the body leakage at discharge port location. One in ordinary way and another is in digital system. For conducting ordinary experiment; P_s port hose is disconnected from the valve V_7 and put the hose into the water. After supplying the air from an external source; approximate number of bubbles counted for 13 samples are 200, 180, 160, 240, 150, 240, 160, 120, 160, 110, 120, 280 and 100 in one minute time. It is assumed that the bubbles are spherical shaped and the diameter is 0.50cm. For calculating the volume of the bubbles (1) is used.

$$V = \frac{4}{3}\pi r^3 \qquad (1)$$

where, V= volume and r= radius of the bubble. Using the diameter value, volume of the bubbles= 0.0654cm^3 is obtained. Then leakage is calculated by using the number of bubbles for individual samples and the volume of the bubble. Fig. 7 shows experiment set up in air board tester for counting number bubbles after supply of air.

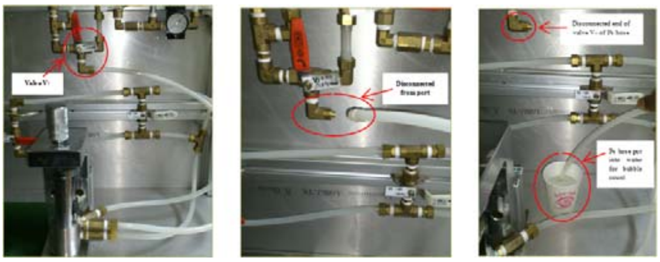

Fig. 7 Experiment set up in air board tester (for bubble count)

Again, the experiment is done by taking the reading from the digital flow meter. In this case the P_s port hose connected to the valve V_7. Now air is supplied and the body leakage values are taken for 13 samples from the flow meter switch on the air board. Fig. 8 shows flow switch on the air board tester.

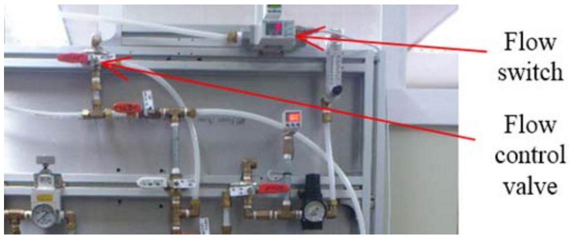

Fig. 8 Experiment set for leakage value from flow meter switch

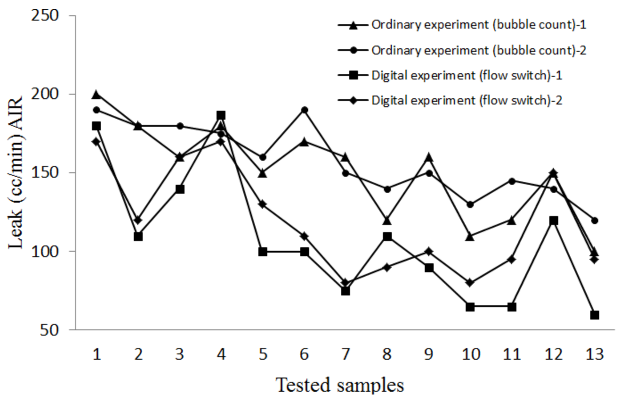

Fig. 9 Comparison of internal leakages at discharge port

In both cases, very limited amount of lubrication oil is used inside the valve body and over the valve guide for reduction of friction if there is any.

IV. Result and Discussion

Fig. 9 represents graphically the valve body internal leakage of 13 individual samples for both types of experimental tests. Each test is carried out 2 times (total 4 times for both type tests) with the similar samples. It is seen that, in case of experimental analysis with bubble count the internal leakage is higher than the digital system. Important issue is the internal leakage at pressure port P_d location is maximum for the respective samples as it operates in switched off condition; therefore no supply of current from external controller. In the case of valve body internal leakage at discharge (P_d) port (then flow through P_c); 50cc/min AIR to 200cc/min AIR leak value is considered as viable option because below or more than the values may cause fluctuation in leakage when the supply current from external controller is introduced. Therefore, all the samples experimented through ordinary system and digital system is observed viable for considering the further steps of ECV development.

V. CONCLUSION

Design and dimensioning with critical tolerances of different internal features of ECV is very important consideration for proper operation. Internal leakage through pressure ports have to be consider very carefully because air/refrigerant flow through the ports need to control efficiently and effectively. The experimental analysis of internal leakage of valve body and valve guide is examined here by both ordinary and digital procedure while the air/refrigerant flow from discharge port (P_d) to crankcase port (P_c) is passed. The experimental results have shown that the standard assumptions for this case follow the acceptable range of value. It will help for further development of other internal features of ECV and attach together with the valve body and valve guide for improving the complete ECV used for external variable displacement type compressor for air conditioning control system.

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REFERENCES

[1] G. H. Lee and T. J. Lee, “A study on the variable displacement mechanism of Swash plate type compressor for automotive air Conditioning system” *International Compressor Engineering Conference*, Purdue University, Illinois, USA, 2004, pp. 1~6.
[2] Y. J. Lee, G.H. Lee and B.E. Lim, “Design for Improving the Performance of a Control Valve in a Variable Compressor”, *4th International Conference on Sustainable Automotive Technologies*, RMIT University, Melbourne, Australia, 2012, pp. 343~348.
[3] M. I. Mahmud and H. M. Cho, “Analysis of forces in an automobile ECV using in external variable displacement swash plate type compressor for air conditioning control system”, *Journal of Mechanical Science and Technology, Vol. 28, No. 5, 2014, pp.* 1979~1984.
[4] F. Toshiro, M. Kazuo, N. Yoshiyuki and Y. Naoya, “Electromagnetic control valve”, *U. S. Patent US6102668A*, 2000.
[5] M. I. Mahmud, Y. J. Yoon and H. M. Cho, “Leakage Analysis of ECV in Variable Displacement Swash Plate Type Compressor”, *International Journal of Applied Engineering Research*, Vol. 9, No. 11, 2014, pp. 1691~1700.