Analysis on Flow Characteristic according to change of Working Fluid Temperature and Swash Plate Angle in Swash Plate Piston Pump

CHUNG-HO LEE
Dept. of Mechanical & Aerospace Engineering
Gyeongsang National University
501, Jinju-daero, Jinju-si, Gyeongsangnam-do
KOREA
gnuthermaleng@gmail.com

JEONG-SE SUH
Dept. of Mechanical & Aerospace Engineering, Engineering Research Institute(ERI)
Gyeongsang National University
501, Jinju-daero, Jinju-si, Gyeongsangnam-do
KOREA
jssuh@gnu.ac.kr

Abstract: - Comparison analysis of the flow characteristics inside pump was performed in this study using Computational Fluid Dynamics (CFD) by changing the working fluid temperature and swash plate angle to reduce pulsation and to improve efficiency of pump. Analysis subjects are divided into Notch Applied Model and Notch Unapplied Model, and Swash Plate Angle of 16.3˚ and 8˚. Cylinder revolution speed was set to 1,500 rpm for all cases. Numerical analysis was performed with 40℃ and 100℃ of working fluid temperature. As a result, it was found that average discharge flow rate is high and pulsation amplitude is low for all cases when working fluid temperature is 40℃.

Key-Words: Swash Plate Piston Pump, Working fluid Temperature, Swash Plate Angle, Pulsation, CFD

1 Introduction

Hydraulic system is the device that exchange energy between fluid energy and mechanical energy by moving or changing closed space using fluid pressure. It has been widely used in various industries for a long time because it has high power density, and has advantage for small size and lightweight. Hydraulic pump was invented in early 20th century and has been continuously developed until now. It has the role to change mechanical energy to fluid energy in this hydraulic system. From many types of hydraulic pumps, piston pumps are more widely used because they are suitable for high pressure and have high efficiency. Piston pumps are further categorized into Axial Type and Radial Type in their structure, and Axial type is most widely used because it is easy to apply variable capacity and has good response. Problem of piston pumps can be pulsation due to piston's reciprocating motion. This pulsation is known as the direct cause of noise and vibration. In addition, excessive pulsation is the problem that should be improved because it causes damage inside the pump and shortens its design lifetime, and because it is the factor to lower its performance by disturbing stable power supply to the whole system. Therefore, comparison analysis of the flow characteristics inside pump was performed in this study using CFD by changing the working fluid temperature and swash plate angle to reduce pulsation and to improve efficiency of pump.

2 Analysis Method

2.1 Analysis model

Analysis model used in this study is composed of inlet/outlet port, valve plate and 9 cylinders as shown in Fig. 1. Piston diameter and piston pitch circle's diameter, which are the main dimensions, are 18.5mm, 74mm, respectively. Theoretical volumetric displacement per 1 cylinder revolution calculated with above dimension is 52.3498 cc/rev. We generated grid for numerical analysis using STAR-CCM+ which is commercial flow analysis program. We composed the analysis model with around 500,000 hexahedron grids based on similar type of piston pump numerical analysis study. 3-dimensional, incompressible, unsteady Reynolds Average Navier-Stokes(RANS) equation is used as

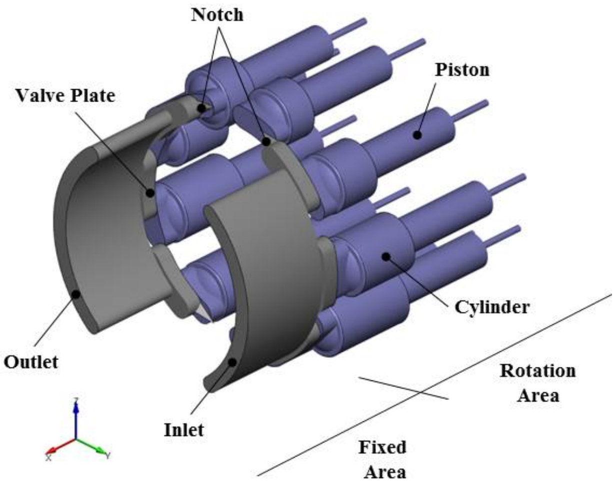


Fig. 1 Geometry of swash plate piston pump

governed equation for numerical analysis. Standard k-ε is applied for turbulence model.

2.2 Analysis Condition

ISO VG 46 series values as shown in Table 1 are applied as material property for working fluid inside pump. We applied 1 bar and 100 bar of pressure boundary condition for inlet and outlet boundary, respectively, and no-slip condition for other wall surfaces. Analysis model includes Piston Shoe area, but additional leakage condition is not considered. Cylinder compression and expansion movement is implemented by position function of piston's boundary surface, which is expressed by cylinder block's rotational angle and swash plate angle. Two cases, 16.3˚ and 8˚, are considered for swash plate angle, and cylinder block's revolution speed was 1,500 rpm for both cases. Numerical analysis is performed by setting working fluid temperature to 40℃ and 100℃.

3 Results

Comparison analysis of the flow characteristics were performed by dividing analysis subjects into Notch-Applied Model and Notch-Unapplied Model group. Numerical analysis was performed until cylinder block rotates 7 times. In most cases, pump inside flow showed periodic distribution after 3 revolution. Therefore, we extracted result value at 5th revolution, which is at the range of 1440˚ ~ 1800˚.

3.1 Flow Characteristics according to change of Working Fluid Temperature

Table 1 Working Fluid's Material Property

Material	Density (kg/m^3)	Viscosity (mm^2/s)	
		40℃	100℃
ISO VG 46	861	46	6.8

Table 2 Analysis Model Types

Case	Notch Application	Swash plate angle (α, deg)	Working Fluid Temperature (℃)
1	Not Applied	16.3	100
2			40
3	Applied		100
4			40
5		8	100
6			40

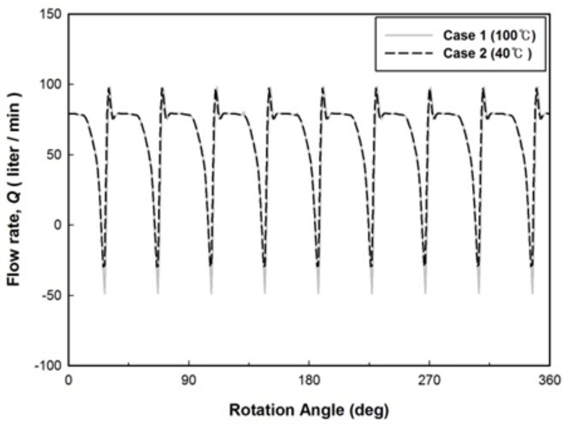
Average discharge flow rates of case 1, 2, 3 and 4 are compared to find out the flow characteristics according to change of working fluid temperature. It showed that relatively low temperature Case 2 and Case 4 has 2.2272 L/min, 1.9558 L/min higher value, respectively, regardless of notch application. In addition, as shown in Fig. 2 (a) & (b), periodic flow rate pulsations are similar for all 4 cases, but low temperature Case 2 & 4 shows bigger difference between max and min value $(Q_{max} - Q_{min})$.

3.2 Influence of Work Fluid Temperature according to change in Swash Plate Angle

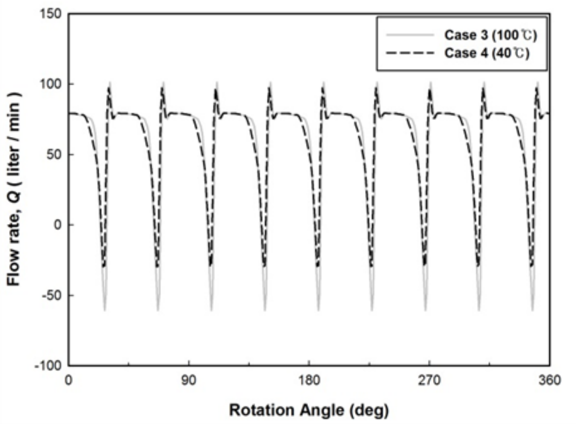
Fig. 2 (c) shows the change of discharge flow rate according to working fluid temperature when swash plate angle is 8˚. Average discharge flow rate difference between case 3, 4 $(Q_{mean,4} - Q_{mean,3})$ and case 5, 6 $(Q_{mean,6} - Q_{mean,5})$ are almost same value of 1.9558 L/min & 1.96063 L/min, respectively. However, efficiency comparison for theoretical volume displacement (78.5245 L/min at α=16.3 ˚, 37.7399 L/min at α=8˚) shows that case 4 is 2.49% higher than case 3, and case 6 is 5.20% higher than case 5. This indicates that efficiency is more influenced by temperature when there is less volume displacement.

4 Conclusion

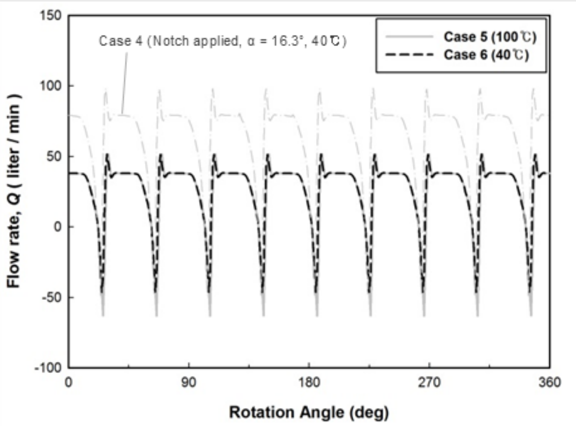
Comparison analysis of the flow characteristics for swash plate piston pump was performed in this



(a) Notch not applied case (α = 16.3°)



(b) Notch applied case (α = 16.3°)



(c) Notch applied case (α = 8°)

Fig. 2 Discharge flow rate according to working fluid temperature

study using CFD according to change in working fluid temperature and swash plate angle. It was found that it has higher average discharge flow rate and smaller pulsation amplitude when temperature of working fluid is relatively low. Also, it was found that efficiency is influenced more by working fluid temperature change when swash plate angle is smaller, from the view of efficiency for theoretical volume displacement. These analysis results can be utilized as basic data when selecting, maintaining and managing the working fluid for swash plate piston pump to improve efficiency and to reduce pulsation.

Acknowledgements

This study has been performed by supporting from National Research Foundation of Korea's "Local Innovative Manpower Cultivation Project" and Brain Korea 21 Plus (BK21+) Project.

References:

[1] J. K. Kim, "Performance Characteristics with Valve Plate Shapes in Swash Plate Type Oil Piston Pumps", Ph. D. Dissertation, Chonbuk National University, Jeonju, Korea, 2003
[2] S. Kim, "A Study on Characteristics of a Compensator System for Swash Plate Type Axial Piston Pump", Master's Dissertation, Chonbuk National University, Jeonju, Korea, 1995
[3] J. H. Lee, "Numerical Study on the Presence of Notch on the Valve Plate in the Swash-plate Piston Pump", Proc. of KSME Spring Conference 2015, Jeju, Korea, February 25-27, 2015, pp. 89
[4] D. M. Noah, S. M. Viral, E. N. Bryan, J. G. Kevin, L. K. Jeff, "Increasing the Power Density for Axial-Piston Swash-Plate Type Hydrostatic Machines", Journal of Mechanical Design, Vol. 135, No. 7, 2013, pp. 071002-071002-6
[5] J. H. Jeong, J. K. Kim, Y. K. Suh, "Numerical study on hydraulic fluid flows within axial piston pumps", Trans. of the KSME, Vol. 34, No. 2, 2010, pp. 129~136
[6] J. H. Jang, "A Study on Pressure and Flux Pulse about the Swash Plate Type Piston Pump of design valve plate notch", Master's Dissertation, Changwon National University, Changwon, Korea, 2014