



Simulation Model Development to Predict Dynamic Performance of Variable Displacement Axial Piston Type Pump

Sunghun Kim* and Sangkyu Lee** and Jaechan Yoo***

*Doosan Corporation Mottrol BG
184 Yeondeok-ro, Seongsan-gu, Changwon-si, Republic of Korea
sunghun2.kim@doosan.com

** Doosan Corporation Mottrol BG
sangkyu1.lee@doosan.com

*** Doosan Corporation Mottrol BG
jaechan.yoo@doosan.com

Abstract. Electronically controlled hydraulic components are recently required with growing the interest on energy efficiency of mobile hydraulic system. Especially, the pump for electronically controlled hydraulic system should have high dynamic performance to remove pressure peak and flow losses. Therefore in this paper, a simulation model for prediction of pump dynamic performance are introduced, and the influence factors (damping inside of cylinder, and swash moment) to be considered for an accurate simulation are discovered by the verification with tests.

Keywords: Swash moment, Pump dynamic performance, Pump simulation

INTRODUCTION

The world-wide efforts to lower emissions of carbon dioxide and energy consumption are requiring multiple actions. One of the actions is the application of an electronically controlled hydraulic system on excavator. Accordingly, many electronically controlled hydraulic system such as VBO (Virtual Bleed Off), IMV (Independent Metering Valve) and PCA (Pump Controlled Actuation), etc. are developed or being studied. For these electronic control systems, the hydraulic pump and also the main control valve (MCV) should be controllable via electric signal. Especially, the pump is required high dynamic performance to remove pressure peak and flow losses in electronically controlled hydraulic system. Therefore, our company "Doosan Mottrol" has developed a pump controlled by an electric proportional pressure reducing valve (EPPRV). In other words, the flow rate of pump is controlled by an EPPRV with mechanical feedback of swash angle as shown in Fig. 1.

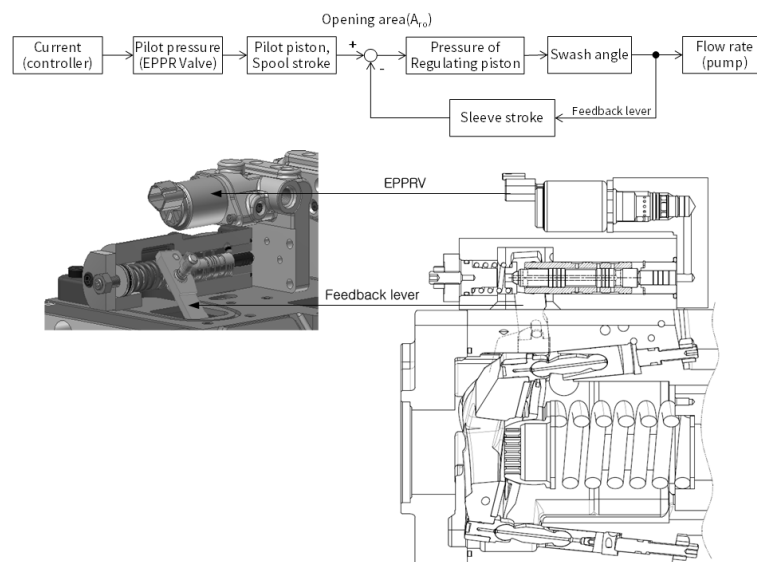


FIGURE 1. Electronically controlled pump of Doosan Mottrol

But in the development of the pump, low dynamic performance in low pressure operating condition as illustrated in Fig. 2 was observed while the swash angle especially changes from maximum position to minimum position. For the analysis of this problem, a simulation model was necessary first of all and then it was developed.

So, this paper shows a simulation model to predict dynamic performance of a swash plate type variable displacement piston pump. Also, the main parameters effecting on pump dynamic performance are determined by sensitivity analysis and the influence factors to be considered for an accurate simulation are discovered by the verification with tests in this study.

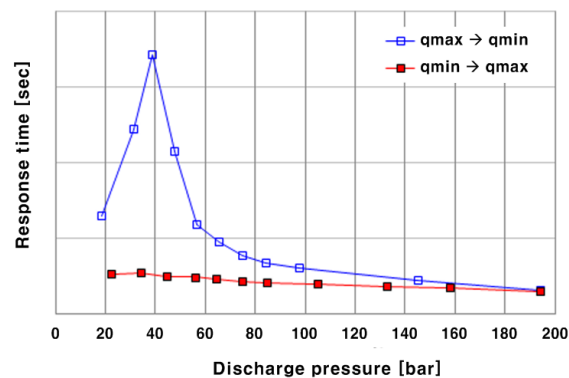


FIGURE 2. Response time of prototype pump depending on discharge pressure

SIMULATION MODEL

A simulation model to predict the dynamic performance of a pump is built using a 1D simulation program (LMS AMESim) as shown in Fig. 3. It includes a regulator controlled by EPPRV, regulating pistons, a swash plate and a simple hydraulic circuit with a pump. Each of the moving part such as spool, sleeve and swash plate has friction model calculated depending on pressure, and the hysteresis of springs is included in this simulation model. Especially, swash moment are considered through look-up table because the swash moment is a function of swash angle and discharge pressure. The swash moment is the resultant torque by pistons force toward swash plate.

By the sensitivity analysis on response time using this simulation model, it is determined that swash moment and swash plate friction are the main influence factors on the dynamic performance of pump. Especially, the swash moment is the most influence factor occurred the problem as shown Fig. 2. The swash moment effects on just one of the rising($q_{min} \rightarrow q_{max}$) and the falling($q_{max} \rightarrow q_{min}$) response time, while both of them increase with the increase of swash plate friction.

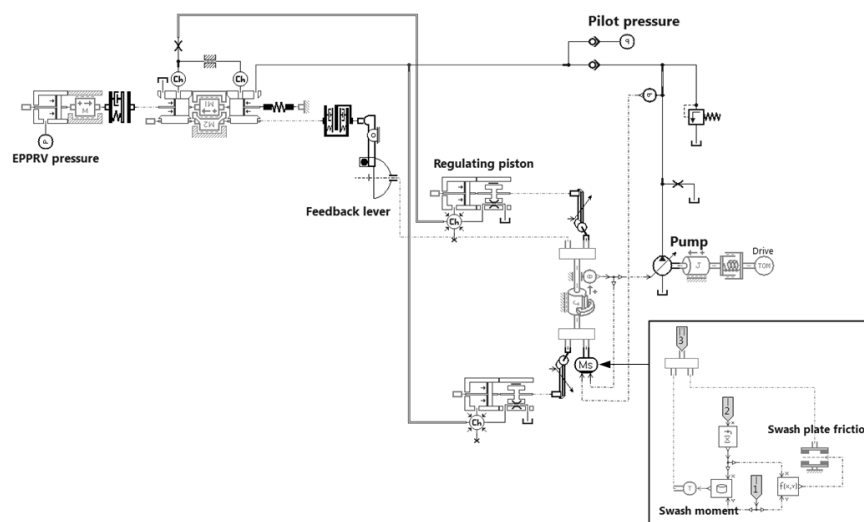


FIGURE 3. Simulation model for pump dynamics

EXPERIMENTAL VERIFICATION

As mentioned above, to simulate the dynamic performance of an electronically controlled hydraulic pump swash moment should be simulated first of all. So, the swash moment are simulated using LMS AMESim pump model considering the inertia of pistons and the friction on tribology parts as illustrated in Fig.4. The inertia of

pistons is a major calculation factor of the swash moment if the pump has enough large displacement as shown in Fig. 5.

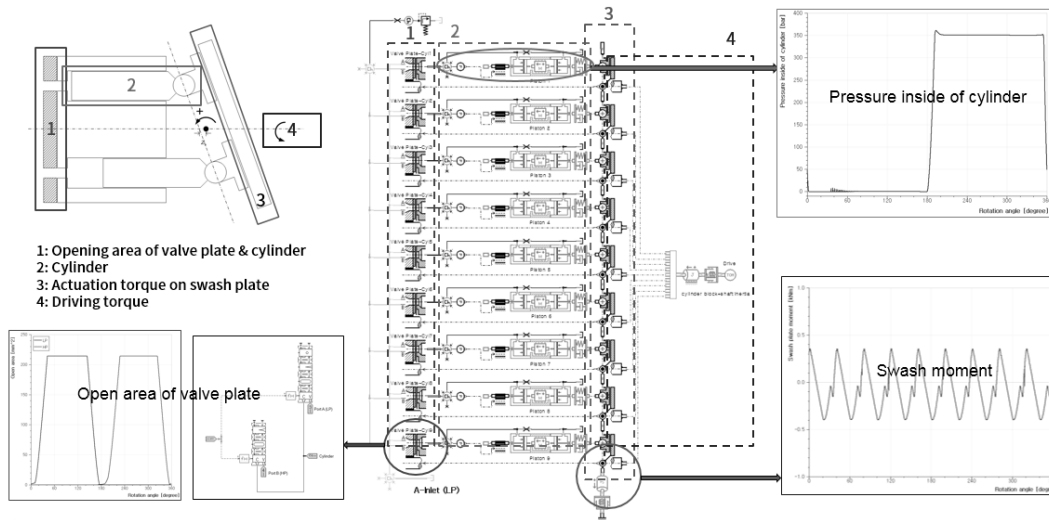


FIGURE 4. LMS AMESim pump model to simulate swash moment

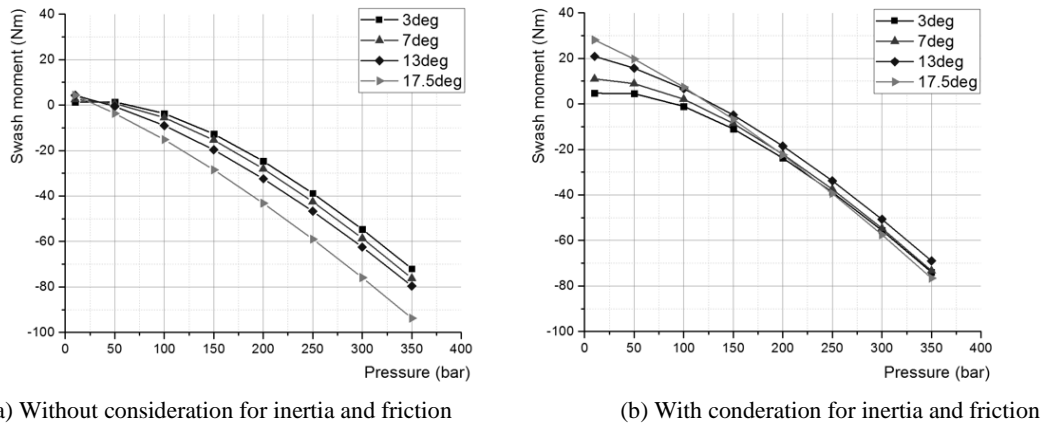


FIGURE 5. Mean value of simulated swash moment depending on swash angle and discharge pressure

Fig. 6 shows the simulation results of the pump response time with the empirically assumed coulomb friction of 50 Nm at 350 bar and viscous friction of 2 Nm/rpm and the simulated swash moment. Unfortunately, the low dynamic performance in low pressure operating condition is not appeared in this simulation. There could be unexpected influence factors on the pump dynamic performance in real condition. However, they would be relevant to swash moment or swash plate friction.

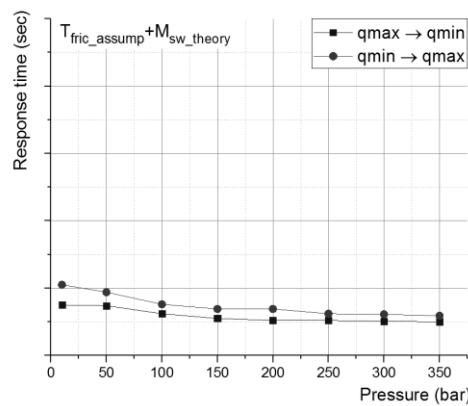


FIGURE 6. Simulation results of pump dynamic performance with simulated swash moment and empirically assumed friction

One of the unexpected influence factors on swash moment could be found in a paper about piston shoe dynamics studied by Böinghoff, O., 1977. The position of resultant force on piston shoe could be eccentric by piston shoe tilting on swash plate as illustrated in Fig. 7. The eccentricity of the resultant force on piston shoe causes the change of swash moment. Deformation of rotary parts could also change the position of resultant force on piston shoe

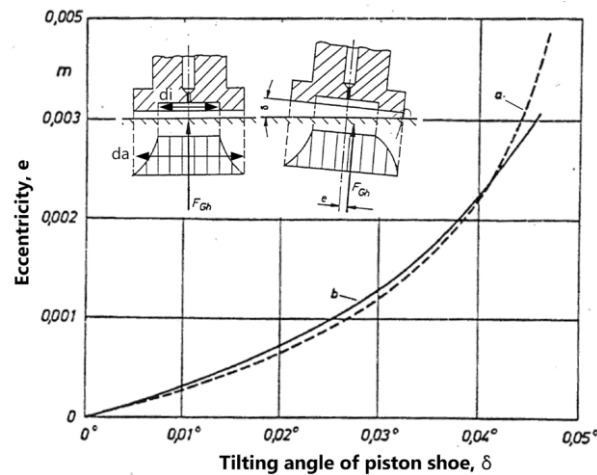


FIGURE 7. Eccentricity of piston shoe rotation circle depending on piston shoe tilting (Böinghoff, O., 1977)
(a) simulation, (b) measurement
(d_a : 0.22m and d_i : 0.17m)

So, the swash moment was verified experimentally. As show in Fig. 8, the swash moment was indirectly calculated using static performance test results because of the limited space to directly install a force sensor on swash plate. The difference between discharge pressure and regulating pressure means the subtraction of coulomb friction from swash moment in case of this test pump when the swash angle increases. On the other hand, the coulomb friction is added to the swash moment if the swash plate changes from maximum angle to minimum angle. Therefore, the swash moment and the coulomb friction could be calculated by the comparison of regulating pressure when the swash angle increases and decreases as illustrated in Fig. 8.

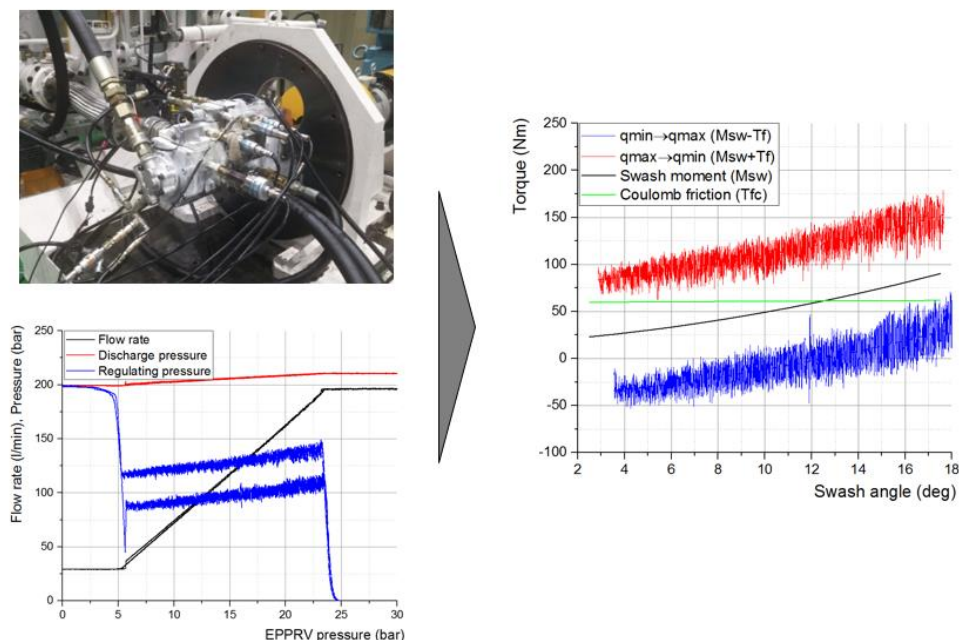


FIGURE 8. Measurement of swash moment and coulomb friction at discharge pressure of 200 bar

Fig. 9 shows the swash moment and the coulomb friction calculated from the static performance test results at discharge pressure of 80bar, 200bar and 300bar depending on swash angle. But the coulomb friction is just plotted depending on discharge pressure because it has nearly constant value although swash angle changes.

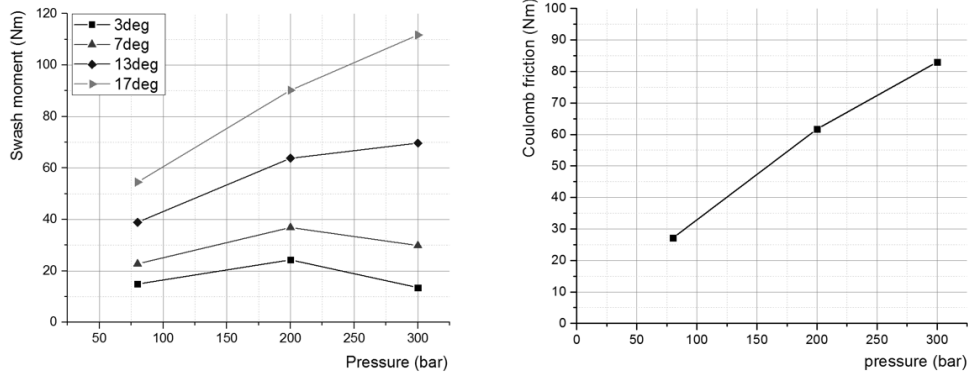


FIGURE 9. Swash moment and coulomb friction calculated from static performance test results

The eccentricity of piston shoes rotation circle by piston shoe tilting and deformation of rotary parts is calculated by the comparison of simulation and test results as shown in Fig. 10. Fig. 10 shows that the eccentricity of piston shoes rotation circle changes depending on swash angle and discharge pressure, and the effect of swash angle is greater than discharge pressure.

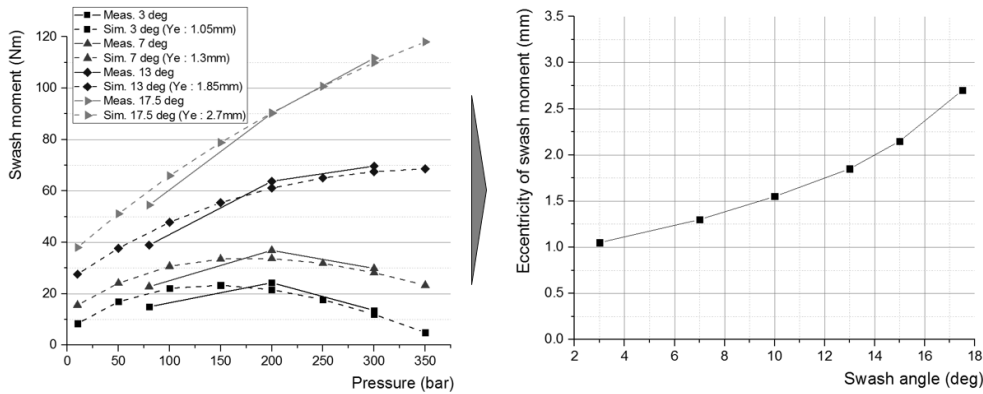


FIGURE 10. Calculated swash plate moment and eccentricity of swash plate moment

Another reason for the difference of the simulation and test results on the dynamic performance of pump is the assumption of friction. The coulomb friction of swash plate is calculated from measurements with swash moment. So, the assumed viscous friction of swash plate should be finally verified. Viscous friction could be calculated by comparison of static performance test and dynamic performance test of pump as shown in Fig. 11.

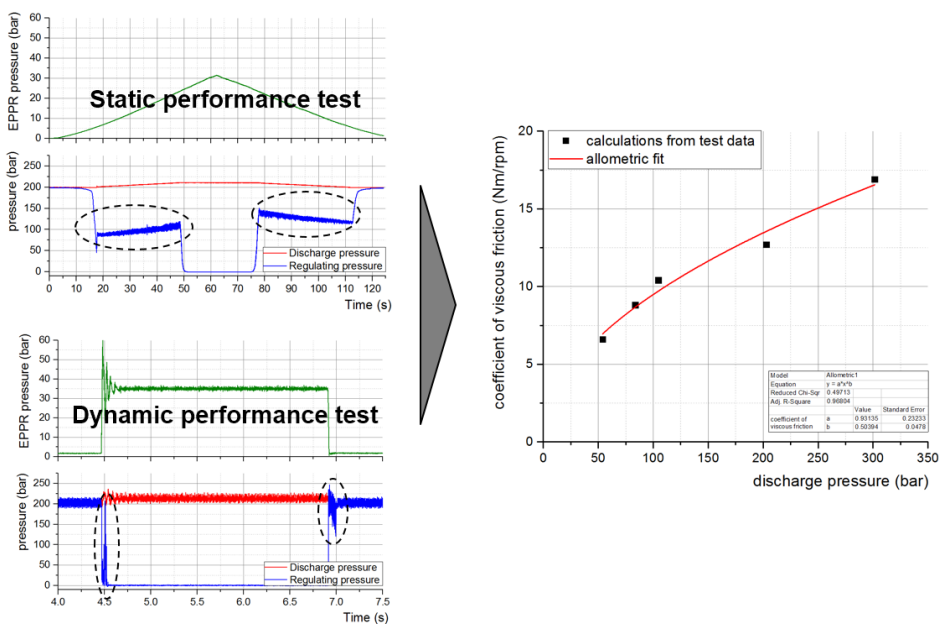


FIGURE 11. Calculated viscous friction

The viscous friction is calculated with the assumptions as follows.

1. Viscous friction coefficient is constant whether swash angle increases or decreases.
2. Angular velocity of swash plate is constant while swash angle changes.
3. The influence of swash angle on viscous and the coulomb friction could be ignored.

But the viscous friction could not have the same value when swash angle increases and decreases because of the difference of damping inside of cylinders. The pressure inside of cylinders changes with the change of swash angle and it causes damping on the swash plate. The difference of viscous friction due to damping inside of cylinders could affect just one of the rising and falling response times such as the swash moment.

Fig. 12 shows that the viscous friction in the case of the decrease of swash angle is about 3 times larger than in the case of the increase. The viscous friction between the swash plate and supporting housing could be theoretically estimated with an assumption of gap height between them. So, it could be guessable with the difference of damping inside of cylinders and theoretically estimated viscous friction between the swash plate and supporting housing that the viscous friction of the swash plate in the case of the decrease of swash angle is about 30% larger than in the case of the increase.

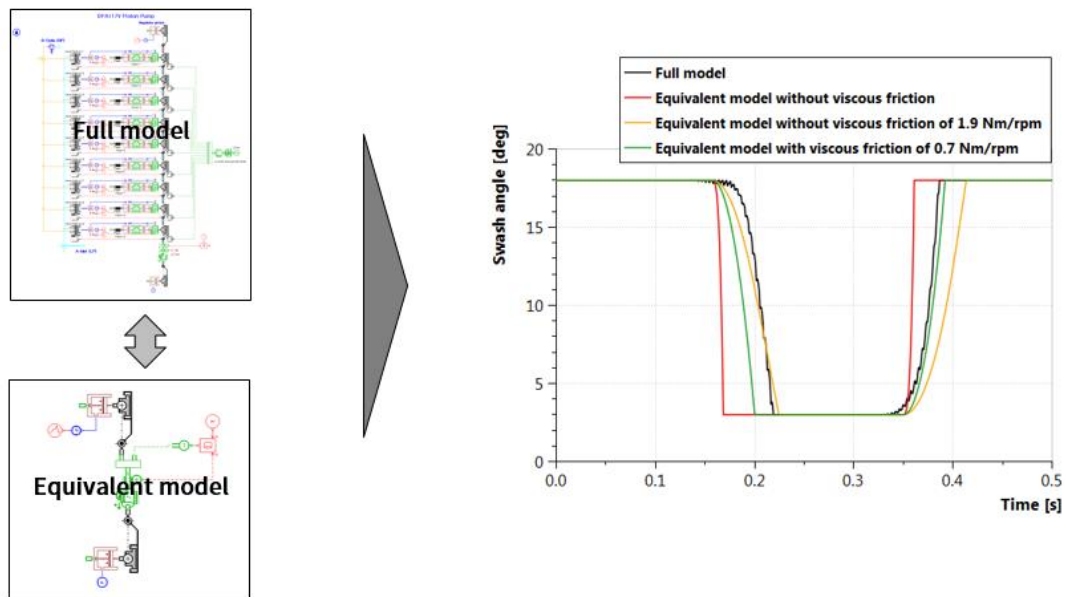


FIGURE 12. Viscous friction by damping inside cylinders at discharge pressure of 50bar

The dynamic performance of the pump is resimulated with the Coulomb friction, the viscous friction, and the swash moment calculated from static/dynamic performance test results. As shown in Fig. 13, the simulation model considered the eccentricity of the piston shoe rotation circle changes and the damping inside of cylinders could predict the dynamic performance well.

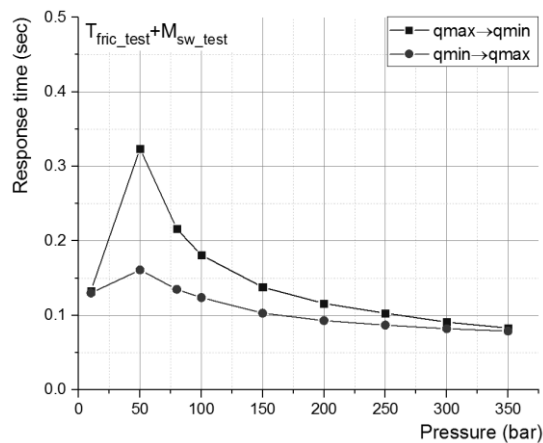


FIGURE 13. Simulation results of response time with tested swash plate moment

CONCLUSION

This paper shows a simulation model for the prediction of pump dynamic performance and that swash plate moment and swash plate friction are main influence factors on the dynamic performance of pump.

Especially, the flowing facts were found, based on the simulations and measurements:

1. Swash moment could change by the eccentricity of piston shoes rotation circle
: The eccentricity of piston shoes rotation circle due to tilting of piston shoes and deformation of components should be considered in simulation of swash moment
2. Eccentricity of piston shoes rotation circle changes depending on swash angle and discharge pressure, and the effect of swash angle is greater than discharge pressure.
3. Viscous friction of swash plate could not has the same value when swash angle increases and decreases because of the difference of the damping inside of cylinders.
: The viscous friction of swash plate in case of decrease of swash angle is about 30% larger than in case of increase for this test pump.
4. Swash moment and viscous friction causes the different dynamic performance of a pump between rising and falling of swash angle.

Several improvements to improve the dynamic performance of the prototype pump was founded using this simulation model, the low dynamic performance in low pressure operating condition could be solved with the improvements as shown in Fig. 14.

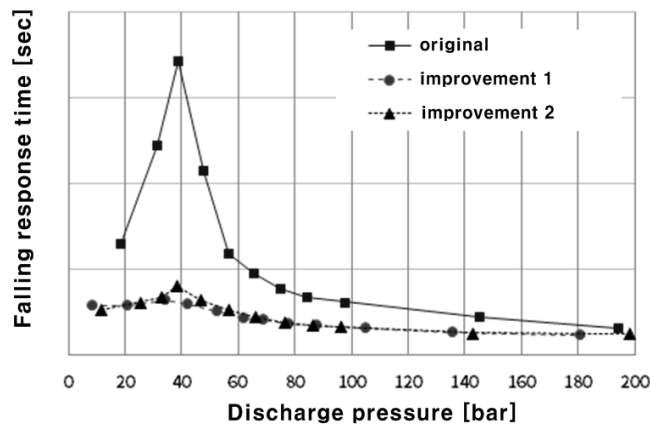


FIGURE 14. Test results of dynamic performance with improvements

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