Proceedings of the 7th JFPS International
Symposium on Fluid Power, TOYAMA 2008
September 15-18, 2008

OS5-1

ENERGY-SAVING HYBRID HYDRAULIC SYSTEM COMPRISING HIGHLY EFFICIENT IPM MOTOR AND INVERTER, FOR INJECTION MOLDING AND MANUFACTURING MACHINE

Takayuki IMAMURA, Yuzo SAWADA, Masashi ICHIKAWA and Hirokazu NAKAMURA

Oil Hydraulics Division, Daikin Industries, Ltd.
1-1 Nishihitotsuya, Settsu-shi, Osaka, 566-8585 Japan
(E-mail: takayuki.imamura@daikin.co.jp)

ABSTRACT

We have developed a novel energy-saving hydraulic pump system—Super Unit—that comprises a high-efficiency motor, low-inertia pump and an inverter controller (We call this type of system 'hybrid'). Compared with conventional hydraulic pumps each driven by a constant speed induction motor, our novel hydraulic pump system driven by a high-efficiency variable-speed IPMSM (Interior Permanent Magnet Synchronous Motor) features energy-saving of 40% or more when used for an injection molding machine which is a typical application of this new pump system.
By means of a pressure feedback control function and run speed control software on the controller, the pressure and flow rate of the hydraulic fluid are accurately controlled according to a command from the controller of the molding machine. This control software allows a high-torque high-precision motor to drive a low-inertia pump: as a result, high-speed high-response control of hydraulic actuators is realized, thereby the quality of molding products obtainable from injection machines controlled by our system is higher compared with quality resulting from conventional systems.
A series of our variable-speed pump system products adopting hybrid hydraulic pressure technology are available for NC lathes, machining centers and other industrial machines such as a press machine.

KEY WORDS

Inverter, Energy-saving, Hydraulic Pump, Molding, IPMSM

INTRODUCTION

In the technical field of industrial machinery, combinations of constant-speed induction motors and variable-displacement pumps have been often used on hydraulic power units. In the year 2000, we developed an energy-saving hydraulic unit product series, each hydraulic unit comprising a compact fixed-displacement pump and a variable speed inverter motor whose maximum speed is at least twice as high as that of conventional inverter motors.
Since then, this product line has been positively contributing to reducing energy consumption on machine tools. Furthermore, we have successfully developed a variable-speed energy-efficient hydraulic unit incorporating a highly efficient motor whose rotor has embedded rare earth magnets (IPMSM).
Currently, we are offering an unique line of products, each product type optimized for industrial machine application.
Figure 1 summarizes some examples of units we have so far developed and their typical features.
After development of the first product line intended for machine tools, we developed the next product line for general industrial machines such as a press machine, wherein the new hydraulic products incorporate the IPMSM in order to improve energy efficiency, feature increased pressure and flow rate so that they are more suitable for general industrial machines, and at the same time, they have enhanced functions for example in communication capability. We are further developing new line of products for molding machines: for this purpose, these new products feature not only improved response by way of an increased instantaneous motor torque but also an increased rated motor output capacity.
Functionality of our hybrid hydraulic pump system contributing to energy-saving is described below. Also, its advantages, when it is compared with conventional hydraulic system and electric servo motor mechanisms with ball-screws for molding machines are presented.

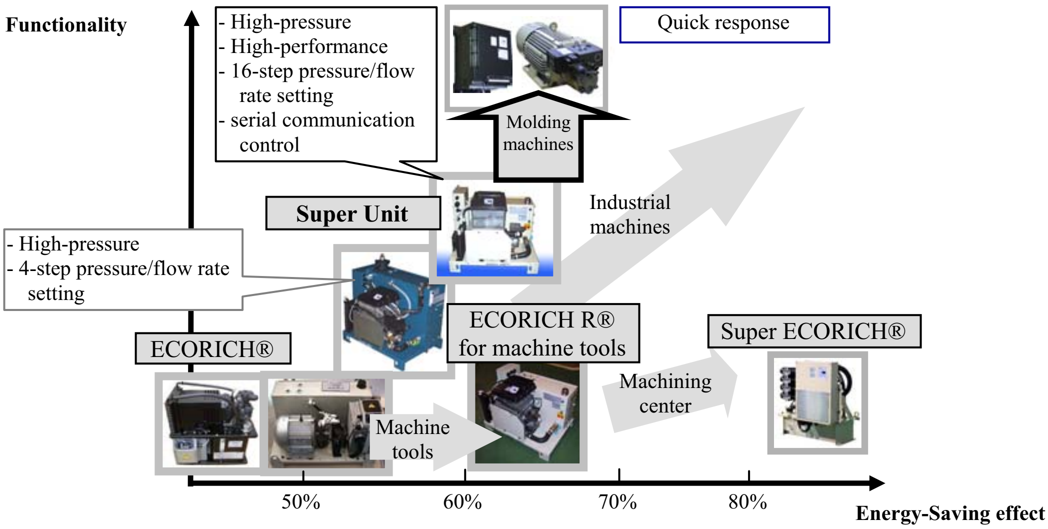

Figure 1 History of Daikin's development works for energy-saving hydraulic pump units

ENERGY-SAVING WITH HYDRAULIC PUMP SYSTEM FEATURING VARIABLE SPEED CONTROL

As shown in Figure2, in a pressure maintaining mode on a conventional hydraulic pump system, where the hydraulic actuator is not executing an effective work such as when the hydraulic cylinder is at its stroke end and is maintaining the hydraulic pressure, the motor remains running at a speed (usually, 1800 min^{-1}) same as in the situation where the cylinder is being actuated. Consequently, energy is wasted in this mode owing to mechanical frictional resistance and viscous friction resistance that results from stirring of the hydraulic fluid.

Since the cylinder velocity, which is proportional to the flow rate, on a conventional hydraulic system is usually controlled by varying the resistance of the valve flow passage, pressure loss, which is consumed as waste heat, will inevitably occur. In contrast, our "Super Unit" is a unique energy-saving hydraulic pump system, whose running speed is regulated by an inverter controller so that the hydraulic fluid is fed at a necessary flow rate only during an appropriate period according to the loading condition. (Arrows and a solid line in Figure 2)

Figure 3 schematically illustrates a control block for our hydraulic pump system. With this system, the pressure and flow rate of hydraulic fluid are regulated appropriately according to the following pressure feedback scheme:

[1] When the hydraulic actuator is operating, necessary amount of flow is supplied by high rotation.

[2] By monitoring the pressure, necessary amount of flow is supplied in accordance with load condition.

[3] While the pressure is maintained, the minimum amount of flow is supplied to compensate for the leakage from the circuit by low speed rotation.

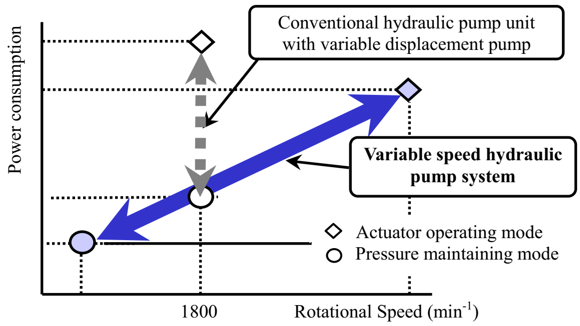

Figure 2 Difference between conventional hydraulic unit and variable speed hydraulic pump system

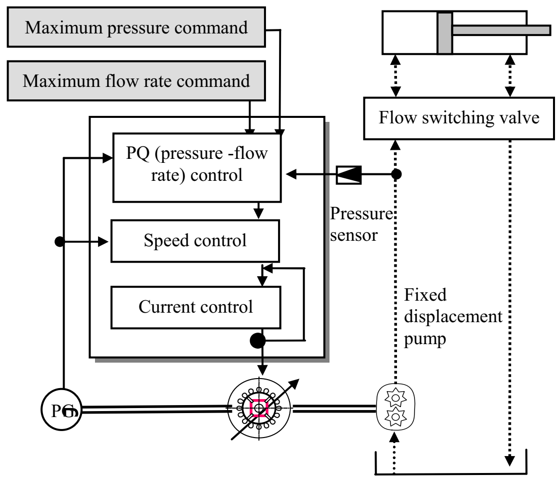

Figure 3 Control block for variable speed hydraulic unit

HIGH-EFFICIENCY HIGH-RESPONSE IPMSM

The IPMSM (Interior Permanent Magnet Synchronous Motor) was originally developed for energy-saving arrangement on Daikin's air-conditioning equipment, and its response and velocity control performance has been improved in order to adopt for our hydraulic pump system.
As shown in Figure 4, the rare earth magnets are embedded in the rotor. Through synchronous control that helps efficiently develop both a magnet torque and a reluctance torque, the synchronous motor attains a very high degree of efficiency as high as about 95%.

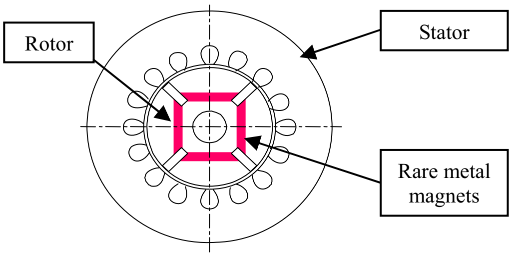

Figure 4 Cross-section of IPMSM rotor and stator

Response of conventional variable-displacement pumps falls in a range of about 0.1 second from the minimum flow rate to the maximum flow rate. In variable-speed pump system, the response time from the minimum running speed (100 min^{-1}) to the maximum running speed (3500 min^{-1}) must be not longer than approximately 0.1 second. In conjunction with an optimally designed inverter controller, our IPMSM satisfies this requirement.

ENERGY-SAVING PERFORMANCE OF SUPER UNIT FOR INDUSTRIAL MACHINES

Figure 5 graphically plots the energy-saving effect of 3.7 kW Super Unit for industrial machines, compared with conventional hydraulic system.

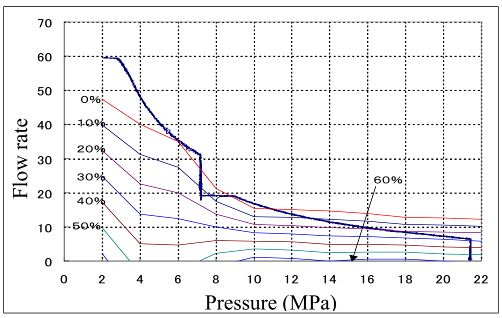

Figure 5 Energy-saving performance of 3.7 kW Super Unit

OTHER FEATURES OF OUR HYDRAULIC PUMP SYSTEM FOR INDUSTRIAL MACHINES

In addition to its energy-saving performance, our hydraulic pump system features lower loss on its hydraulic circuit, thereby increase in the hydraulic fluid temperature is inhibited and noise is kept at a low level.
Because the pressure and flow rate is regulated by the running speed of motor, our hydraulic pump system needs a smaller number of valves, thus its hydraulic circuit can be simplified.
Figure 6 illustrates a typical circuit for a conventional hydraulic circuit and that for our variable-speed hydraulic pump unit.

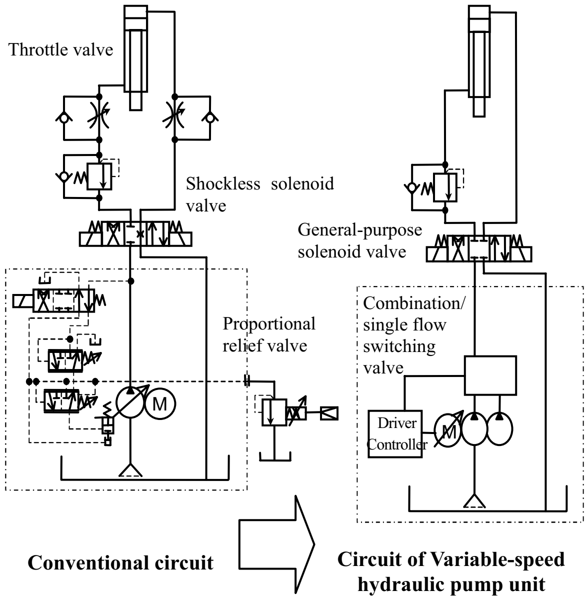

Figure 6 Simplification of hydraulic circuit with Super Unit

FEATURES OF SUPER UNIT FOR INJECTION MOLDING MACHINES

Figure 7 11 kW Super Unit for injection molding machines

Resent years, electric servomotors and ball-screws have been commonly used to drive the injection molding machines, particularly in Japan. Hybrid hydraulic drive molding machines, adopting hybrid hydraulic pump system has advantages over conventional hydraulic drive machines or electric servo drive machines.
Figure 7 shows a hydraulic pump system that incorporates an 11 kW IPMSM. By adopting a low-inertia geared pump and using an IPMSM whose

inertia moment is minimized for application to injection molding, our Super Unit achieves quick response—acceleration to maximum speed in 50 msec: previously, this level of response time was obtainable only with electric servo motor mechanisms with ball-screws.

Furthermore, compared with conventional hydraulic power units each comprising a piston pump and an induction motor, our hydraulic pump system features smaller degree of pulsation, and therefore, an injection molding machine with our system run at a lower speed stably and delivers quality moldings.

Like a result from our hydraulic pump system for industrial machine such as a press machine, our Super Unit for molding machines features smaller heat generation compared with conventional hydraulic pump systems, and therefore an oil cooler can be eliminated or downsized. Another advantage not available on an electric servomotor mechanism is that our Super Unit is free from the grease maintenance and a problem associated with a limited life of ball-screws.

ENERGY-SAVING PERFORMANCE OF SUPER UNIT FOR INJECTION MOLDING MACHINES

Figure 8 shows graphical plotting of comparison in terms of power consumption with injection molding machine in pressure maintaining mode.

Compared with power consumption with a conventional hydraulic drive system that comprises an induction motor and a piston pump, Super Unit apparently exhibits significant reduction of power consumption.

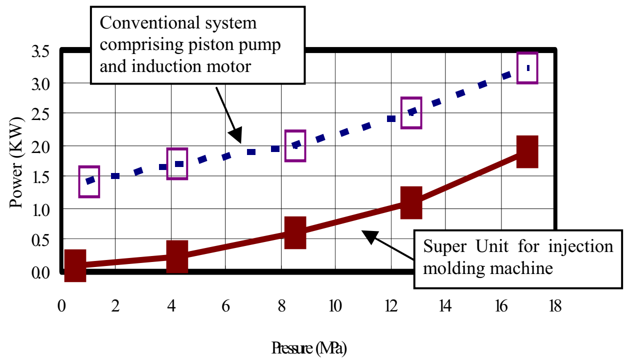

Figure 8 Energy-saving effect with Super Unit for injection molding machines (in pressure maintaining mode)

Figure 9-1 shows pressure-flow rate waveforms obtained from a run pattern (dry run) of an injection molding machine driven by the Super Unit, while Figure 9-2 provides those of the pressure-flow rate for the same run pattern of the machine driven by a conventional hydraulic pump unit. We can see that both pressure and flow rate can be reduced. Table 1 summarizes comparison in terms of average power consumption, resulting from these run patterns. Under this run pattern, our Super Unit exhibits 41.5% reduction in power consumption compared with conventional hydraulic system.

Table 1 Comparison in terms of average power consumption

		Super Unit	Conventional piston pump + induction motor
Power consumption	kW	**2.4**	**4.1**
Cycle	sec	14.4	14.4
Operating mode		Dry run	
Number of shots		248	248
Duration of measurement	hrs.	1.0	1.0

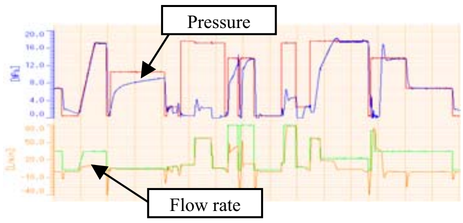

Figure 9-1 Pressure-flow rate waveforms with Super Unit (run cycle for injection molding machine)

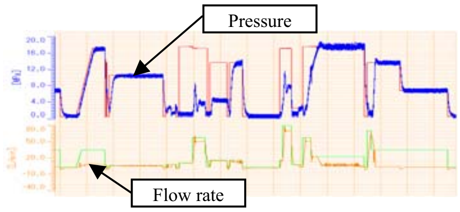

Figure 9-2 Pressure-flow rate waveforms with conventional hydraulic pump unit (run cycle for injection molding machine)

CONCLUSION

The features of the energy-saving hybrid hydraulic pump unit series—Super Unit—have been presented. As the needs for conservation of the global environment have been growing in the industrial fields including that for injection molding machines, we believe the role of Super Unit will be increasingly important. We will remain committed to further improved energy-saving effect and more diversification of its applications.

REFERENCES

1. Shigetoshi Simoo, Hitoshi Horiuchi, Tetsuo Nakata, Yoshiyuki Ochi, Energy saving High Pressure Duplex Pump System driven by IPMSM (Interior Permanent Magnet Synchronous Motor), 2003 Spring Lecture on Fluid Power System, theses, pp.86-88.
2. Shigetoshi Simoo, Hitoshi Horiuchi, Yoshiyuki Ochi, Energy saving and Time Sharing Proportional Pressure Control System for NC Lathe, 2004 Autumn Lecture on Fluid Power System, theses, pp.59-61.