Energy Saving Efforts in Hydraulic Systems for Machine Tools

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In modern society, there is a need to take steps to reduce environmental impacts as measures against climate change to achieve carbon neutrality, in which greenhouse gas emissions are effectively reduced to zero. Methods to reduce energy use by hydraulic systems in production facilities were studied and examples of how they can contribute to energy saving are listed in this article.

Key Words: *energy-saving, machining tools, hydraulic system, pump, hydraulic unit, solenoid valve*

1. Introduction

In modern society, there is a need to take steps toward achieving carbon neutrality, in which greenhouse gas emissions are effectively reduced to zero as environmental action to address energy and climate change. As a result, energy savings which were previously conducted in order to reduce costs are increasingly recognized in recent years as a corporate social responsibility.

Of total electric power consumption in Japan, the manufacturing industry accounts for approximately 40%. Furthermore because approximately 80% of the electric power consumed in a plant is consumed by production facilities, saving energy in production facilities is important.

Based on the energy saving concept for each application (**Fig. 1**), JTEKT is working to expand its series of products that meet a wide range of needs for the hydraulic systems that are installed in production facilities.

This report introduces energy saving efforts for hydraulic systems (hydraulic units, hydraulic control valves) primarily for machine tools.

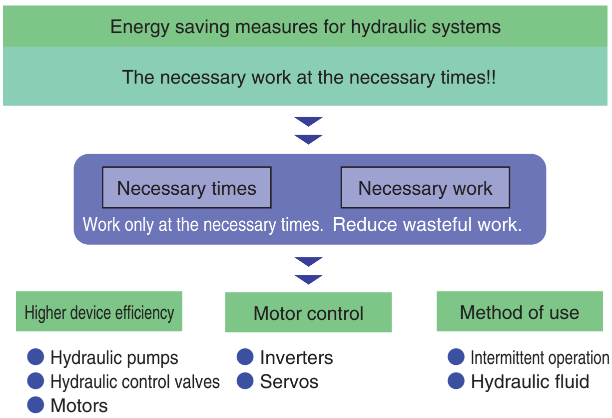


Fig. 1 Energy saving concept

2. Saving Energy in Hydraulic Systems

Generally, as energy saving measures for hydraulic systems, it is known that large improvements in electric power consumption can be produced by reducing energy loss in stand-by states when hydraulic flow is not necessary (**Fig. 2**), excepting times when actuators operate such as when clamping a workpiece or holding a tool. JTEKT has worked for efforts that combine motor rotation speed control and motor intermittent operation, as well as energy savings in hydraulic control valves. The results of these efforts and a comparison of energy saving by hydraulic units are shown in **Fig. 3**. Following is a description of energy savings achieved by (1) high efficiency variable-displacement vane pumps and (2) motor control using inverters, (3) intermittent operation by stopping motors, and (4) hydraulic control valves (solenoid valves).

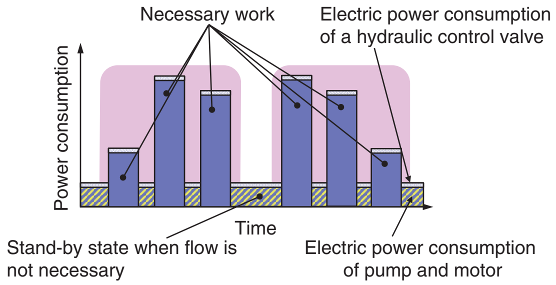


Fig. 2 Energy saving measures

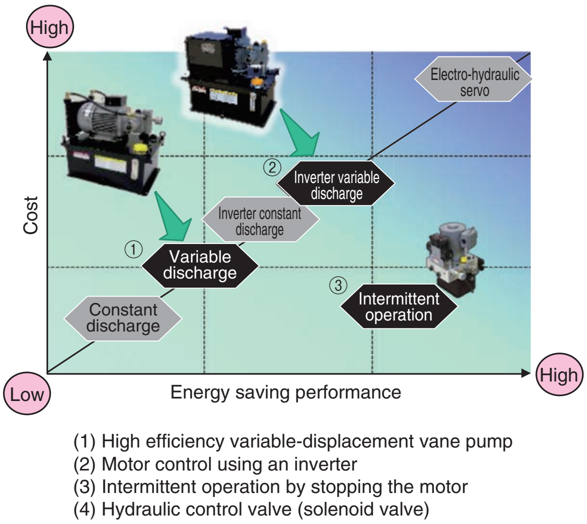


Fig. 3 Comparison of energy saving by hydraulic unit

3. Efforts for Development of Energy Saving Hydraulic Systems

3. 1 Improvements to High Efficiency Variable-Displacement Vane Pumps

Hydraulic pumps are one component element of energy saving hydraulic units (**Fig. 4**). A reduction in electric power consumption is achieved by reducing the amount of internal oil leakage, reducing the sizes of component parts, and installing motors of the premium efficiency class (IE3: high-level efficiency grade in International Energy Efficiency Regulations). Following is a description of efforts for development of this high efficiency variable-displacement vane pump.

Fig. 4 Hydraulic unit with high efficiency variable-displacement vane pump

3. 1. 1 Structure of a Variable-Displacement Vane Pump

A variable-displacement vane pump is shown in **Fig. 5**. This pump is a displacement pump that utilizes the changes in volume of a space composed of the rotor, ring, and vanes. The discharge rate can be adjusted by changing the eccentricity of the ring relative to the rotor. For example, when hydraulic pressure is generated at the OUT side, and the component of hydraulic pressure force acting on the ring exceeds the spring pressing force, the ring moves in the rotor center direction, reducing the eccentricity and reducing the discharge rate.

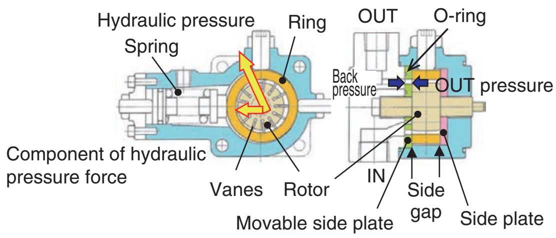


Fig. 5 Structure of variable-displacement vane pump

A side gap is provided between the rotor and side plate, and when the OUT pressure rises, deformation of the side plate increases the side gap, and this increases leakage. For this reason, the OUT pressure is directed to a back pressure receiving area surrounded by an O-ring on the back of the side plate. This acts opposite to the rotor-side OUT pressure, forming a movable side plate that can produce an appropriate gap.

3. 1. 2 Features and Energy Saving Performance of a High Efficiency Variable-Displacement Vane Pump

In order to save energy with a vane pump, the back pressure was optimized to control the deformation of the movable side plate and reduce leakage. The sizes of component parts were reduced by 20%, reducing friction loss. This increase in efficiency achieved a 16% reduction in electric power consumption. A cross section of a vane pump is shown in **Fig. 6**.

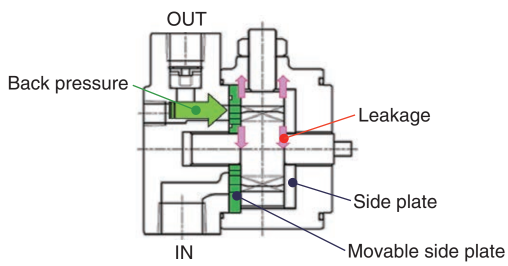


Fig. 6 Cross section of pump

1) Reducing the amount of movable side plate deformation

With the movable side plate in a conventional product, the back pressure receiving area which is opposite the rotor-side OUT pressure area is large, and there is large localized deformation toward the rotor side. It was necessary to increase the size of the side gap and prevent interference with the rotor. In order to reduce the amount of deformation, deformation of the movable side plate back pressure receiving area was optimized by means of FEM analysis. This reduced the maximum amount of deformation by 40% compared to a conventional product (**Fig. 7**, **Fig. 8**).

This reduced the amount of localized movable side plate deformation and made it uniform, allowing a small side gap to be set and enabling a reduction in leakage.

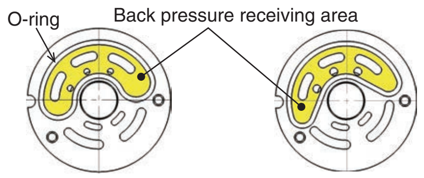


Fig. 7 Comparison of movable side plate

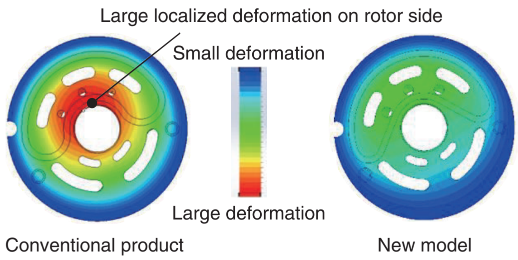


Fig. 8 Result of FEM analysis (Axial deformation)

2) Lower surge pressure

The port angle was changed to the spring side (**Fig. 9**), and the hydraulic pressure acting on the ring was moved closer to the spring direction. This increased the movement speed of the ring by approximately two times, and reduced the surge pressure occurring when the actuator stops (oil hammer occurring when the pump OUT side is shut off) (**Fig. 10**, **Fig. 11** and **Fig. 12**). This improves the reliability of hydraulic piping and devices, and helps improve machining accuracy when a clamp circuit is used.

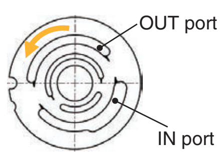


Fig. 9 Change of port angle

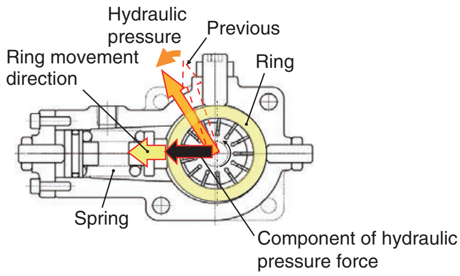


Fig. 10 Hydraulic direction of ring

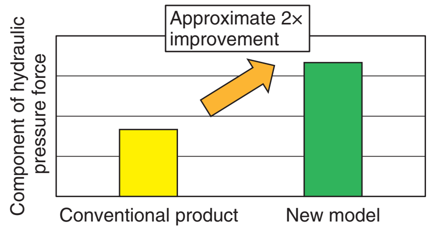


Fig. 11 Hydraulic pressure in spring direction

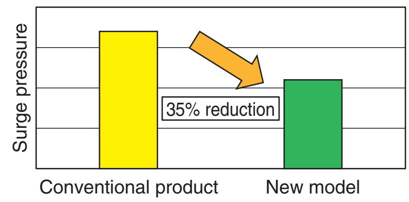


Fig. 12 Surge pressure

3) Size and weight reductions

The lower surge pressure made it possible to reduce the sizes (diameters) of the ring, rotor, and other component parts, achieving reduced frictional torque and reduced weight (**Fig. 13**, **Fig. 14**).

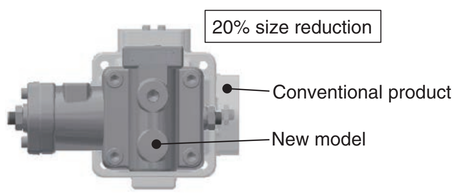


Fig. 13 Downsizing of pump components

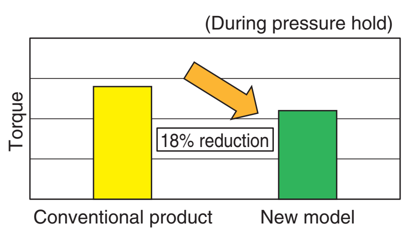
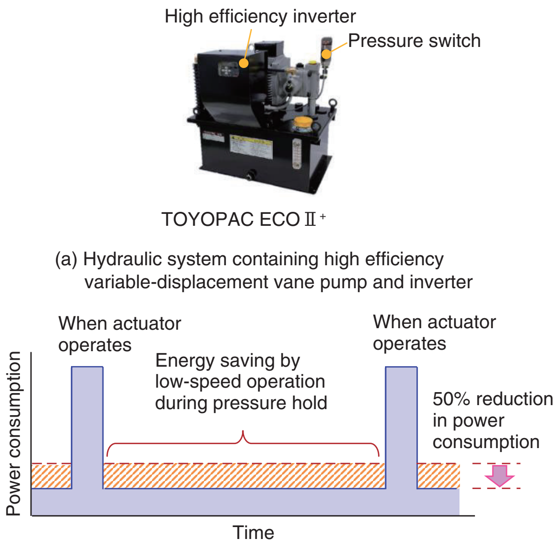


Fig. 14 Frictional torque reduction effect

3. 2 Reducing Motor Rotation Speed with the Use of an Inverter

By using an inverter and reducing the motor rotation speed, and operating the motor at low speed when waiting to hold pressure, we reduced stand-by power consumption by 50% compared to the standard JTEKT continuous operation systems (**Fig. 15**).



(a) Hydraulic system containing high efficiency variable-displacement vane pump and inverter

(b) Reduction of machining cycle power consumption

Fig. 15 Speed control of motor

The inverter adjustment setting is completed at the time the product is shipped. The pressure holding state is automatically detected by a pressure switch, allowing inverter control of the motor rotation speed. As a result, in the same manner as a hydraulic system where the motor rotation speed is constant, operation is possible using only the pressure settings of the hydraulic pump and pressure switch, and handling is simple.

The inverter control system is specialized for the flow characteristics of a high efficiency variable-displacement type pump, and stable operation is possible even when pressure variations occur. Furthermore, lowering the rotation speed of the pump and motor also improves the noise environment—an environmental issue on the same level as saving energy.

In order to meet preventive maintenance needs, the IoT is supported using the inverter monitor functions. For example, this can help improve productivity with functions that monitor motor electric current and torque, and that perform hydraulic system fault diagnosis using anomaly detection of the load conditions.

An example of introduction in a machining center is shown in **Fig. 16**. In the case of annual operating time of 4 000 hours, motor capacity of 2.2 kW, and CO_2 emissions coefficient of 0.55 kg-CO_2/kWh, this can reduce annual electric power consumption by 660 kWh per machine, and CO_2 emissions by 365 kg per machine. Supposing that a plant contains 200 machines, it is possible to reduce CO_2 by 73 tons and electric power by 132 000 kWh.

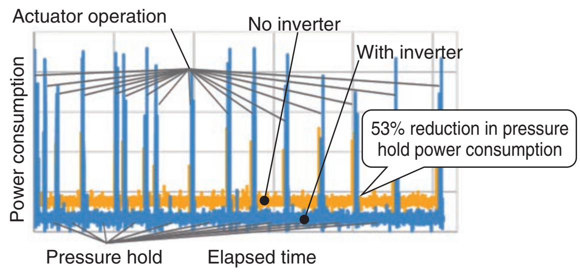


Fig. 16 Energy saving effect

In order to reduce energy use, motor efficiency regulations are being strengthened in each country. In order to further save energy and comply with these stronger efficiency regulations in each country, we have installed an interior permanent magnet (IPM) motor which is more efficient than an induction motor and is not subject to the regulations. This has also enabled us to prepare a model that does not need to be produced separately for each individual destination (**Fig. 17**).

Fig. 17 Hydraulic unit with IPM motor

3. 3 Intermittent Operation by Stopping the Motor

Intermittent operation stops operation of the motor when waiting to hold hydraulic pressure. It ensures circuit pressure and flow rate during cycle operation, and provides leak compensation when holding pressure, reducing electric power consumption when holding pressure to zero (**Fig. 18**).

This system is ideal for the jig clamps used in compact machining centers.

An example of installing a hydraulic unit with an intermittent motor in a machining center is shown in **Fig. 19**.

In the case of annual operating time of 4 000 hours, motor capacity of 0.75 kW, and CO_2 emissions coefficient of 0.55 kg-CO_2/kWh, this can reduce annual electric power consumption by 1 300 kWh per machine, and CO_2 emissions by 720 kg per machine.

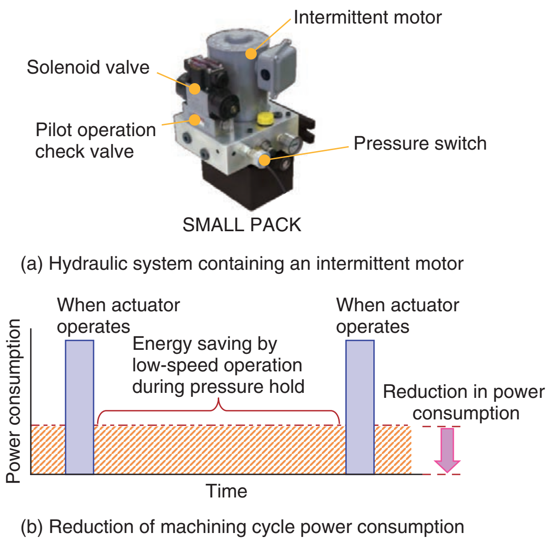


Fig. 18 Intermittent operation

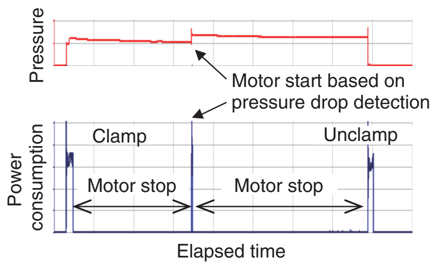


Fig. 19 Energy saving effect

3. 4 Efforts for Lower Power Solenoid Valves

The structure of a solenoid valve is shown in **Fig. 20**. A solenoid valve controls the direction of oil flow when excitation of the solenoid switches the spool. By improving the magnetic efficiency of the solenoid and optimizing the pull force characteristics, we reduced electric power consumption by 30%. This section presents efforts for creating a low power solenoid valve.

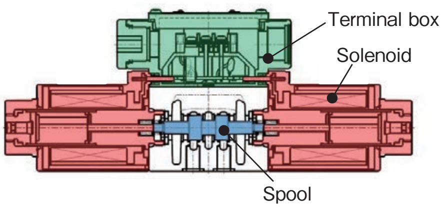


Fig. 20 Structure of solenoid valve

3. 4. 1 Structure of a Conventional Product

The structure of a conventional solenoid is shown in **Fig. 21**, and the results of magnetic field analysis are shown in **Fig. 22**. The number of components in a magnetic circuit is large (six components), and magnetic saturation occurs between the components, reducing magnetic efficiency. For this reason, to reduce the required electric power, it was essential to review the structure of the solenoid magnetic circuit and improve magnetic efficiency.

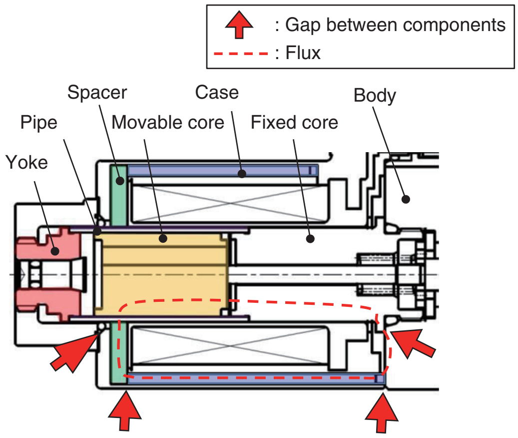


Fig. 21 Structure of conventional product

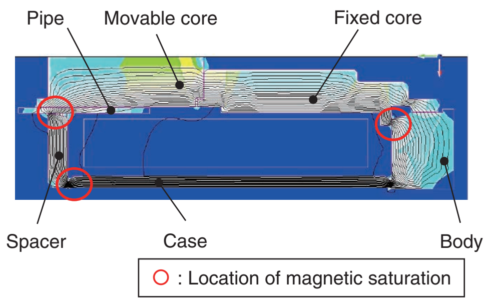


Fig. 22 Result of magnetic field analysis (Conventional product)

3. 4. 2 Structure of the New Model Solenoid

1) Improving the efficiency of the solenoid magnetic circuit

The results from magnetic field analysis of the new model solenoid are shown in **Fig. 23**. The following structures were changed in order to resolve the issues facing the conventional product.

(1) The case and spacer were integrated, creating a structure with no gap between the components.

(2) A structure was adopted with close contact between the case and yoke end, creating a contact surface area where magnetic saturation does not occur.

(3) In the conventional product, the contact surface area that forms the magnetic circuit was small between the fixed core and body. Therefore a body-side spacer was added to create a contact surface area where magnetic saturation does not occur.

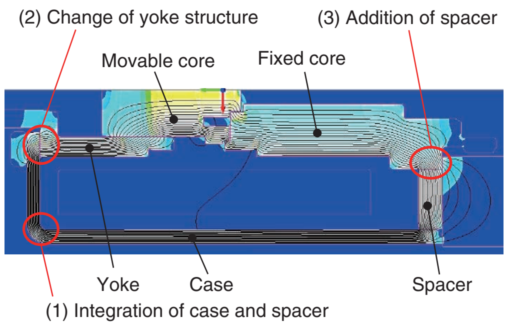


Fig. 23 Result of magnetic field analysis (New model)

2) Optimization of the pull force curve

The load applied to the spool in opposition to the pull force consists of the spool sliding resistance, spring reaction force, and flow force. The spool is switched when solenoid pull force that is larger than the applied load presses on the spool (**Fig. 24**).

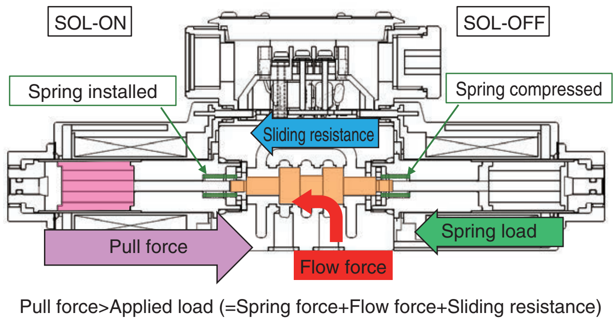


Fig. 24 Pull force and applied load

In a conventional solenoid when the current is reduced by 30%, because the pull force at the maximum load position where the flow force is the largest is equal to or less than the applied load, it cannot press the spool all the way and is unable to switch it.

The relationship between the movable core stroke and pull force is shown in **Fig. 25**. In a conventional product, while there is a margin in the pull force relative to the applied load throughout the stroke, the pull force is particularly high close to the adsorption position, and is excessive relative to the applied load (hatching part of **Fig. 25**).

Because the characteristics of the pull force curve change depending on the shape of the plunger adsorption surface, we reviewed the plunger adsorption surface shape to reduce the excessive pull force close to the adsorption position and increase the pull force at the maximum load position and positions where the margin is small.

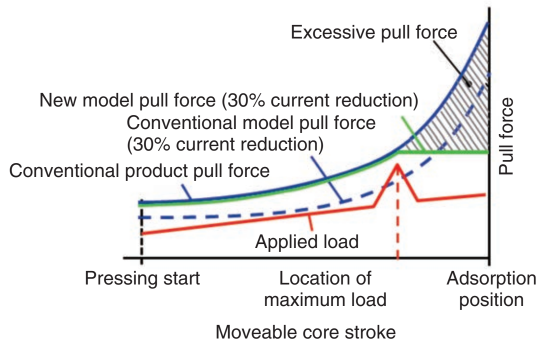


Fig. 25 Pull force of conventional product and new models

The combination of optimized pull force characteristics and improved magnetic efficiency ensured the necessary pull force relative to the applied load, and reduced electric power consumption by 30%.

4. Conclusion

This report has described energy savings that were achieved in hydraulic systems for machine tools based on the JTEKT concept of energy savings in hydraulic systems. In the future, we will continue to implement development of energy saving hydraulic systems to meet a wide range of needs, with “supplying the necessary oil flow at the necessary time” as the basic concept.

References

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