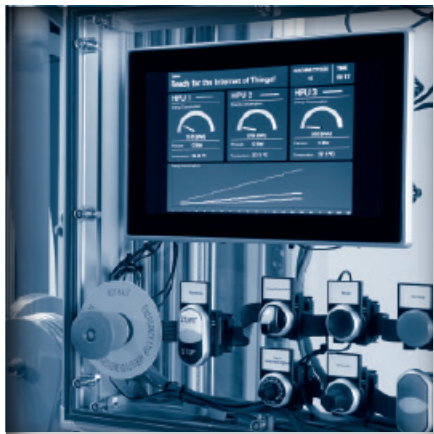


Planning and operating hydraulic power units to provide greater energy efficiency

Build it in.



Potential solution for reducing energy consumption and digitalization of data for smart power management

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EATON

Powering Business Worldwide



Introduction

Reducing energy consumption is a stated objective of the European Union. In 2007, EU Member States agreed to cut primary energy consumption by 20 per cent by 2020. Increasing energy efficiency is an important aspect in supporting this effort. This measure not only reduces energy costs, but also helps achieve a higher level of supply security and protects the climate. Every consumer sector offers considerable potential for energy savings across Europe. Industry plays a key role in this. For instance, in Germany almost 30 per cent of total final energy consumption is accounted for by the manufacturing sector¹. The initiatives launched by the EU in this area also include the Ecodesign Directive 2009/125/EC, which stipulates the ecodesign requirements for energy-related products.

However, the motivation for companies to improve the energy efficiency of their production processes should not only be driven by the need to fulfill political objectives. This is because increasing energy efficiency also produces tangible cost reductions, while also boosting competitiveness and making an important contribution to protecting the environment.

Using a hydraulically powered machine as an example, this white-paper will highlight how, by combining the right components, its energy efficiency can be significantly increased. Depending on the application, energy savings of up to 70 per cent can be achieved, which creates value and rapid return on investment (ROI) for the end user. In addition, the use of 'smart components' facilitates the collection of all relevant data, thereby providing the basis for comprehensive energy management.

¹ German Environment Agency (UBA), information about final energy consumption according to energy sources and sectors as of June 2015, <http://www.umweltbundesamt.de/daten/energiebereitstellung-verbrauch/energieverbrauch-nachenergietraegern-sektoren>

Background and basic framework

ISO 50001 – Continuously improving energy efficiency

Using energy in an efficient manner not only saves companies money, but also saves resources and combats climate change. The introduction of the international ISO 50001 standard in 2011 marked the first globally applicable standard for certifying energy management systems. It is based on the management model of continuous improvement (Plan, Do, Check, Act), which is also applied in other well-known standards such as ISO 9001 and ISO 14001. An energy management system operated according to ISO 50001 enables companies to implement equipment and processes that continuously improve their energy consumption – delivering the same or even increased performance – thereby allowing them to achieve maximum energy efficiency and consumption and reduce costs.

One key element in this type of energy management system is keeping a detailed record of energy consumption throughout the company. Detailed analysis of this data indicates where potential energy savings can be made, as well as provides the facts used to decide which investments in energy efficiency will give the quickest return. The consistent implementation of these measures for improving efficiency, cuts operating costs and boosts competitiveness in the long term. As a result, energy management will have a direct impact not only on organizational and technical procedures within the company, but also on employee behaviour. The aim is to reduce, from a commercial perspective, the company's total energy consumption, both with regard to the general building infrastructure in terms of heating and lighting, and to production.

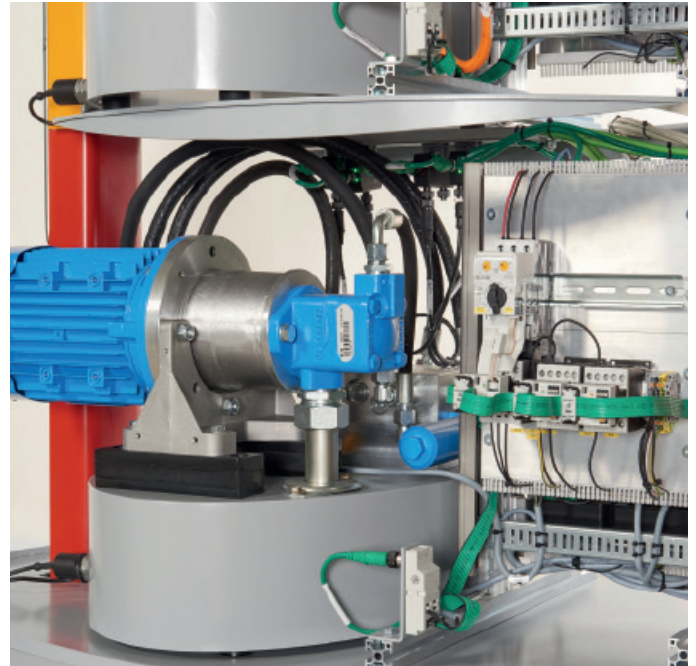
Legal frameworks and recommendations

In conjunction with the introduction of ISO 50001, which is a voluntary standard, binding requirements apply. These include the Ecodesign Directive 2009/125/EC (for energy-related products, ErP), which establishes a framework for setting ecodesign requirements in the EU. It applies to all energy-related products defined in the regulation, and stipulates the criteria that the affected consumers must meet in order to be introduced and used in Europe. Eaton produced a whitepaper on this topic in 2014. It discussed in detail the legal requirements, as well as opportunities for utilizing the potential savings in the right way in electrical drive technology (this can be downloaded from: www.eaton.eu/moem-ee).

In addition to the ErP Directive, the German Engineering Federation (VDMA) also published a specifications document (VDMA 24580, Fluid power – Application notes for the optimization of the energy efficiency of hydraulic systems), which guides manufacturers of hydraulic systems for use on stationary machines to design them such that, when operating at their full functional capacity, are more energy-efficient and, therefore, more economic.

In addition, a binding directive for the mechanical engineering industry might also be relevant in the future. The reason for this is that in 2009, machine tools were also identified by the EU Commission, within the scope of the Ecodesign Directive, as an area subject to regulation. The relevant 'Lot 5' focusses specifically on energy efficiency. At time of writing this whitepaper, there are two proposed options for regulating this sector:

- a) voluntary self-regulation or
- b) binding measures based on a points system, which is yet to be devised.



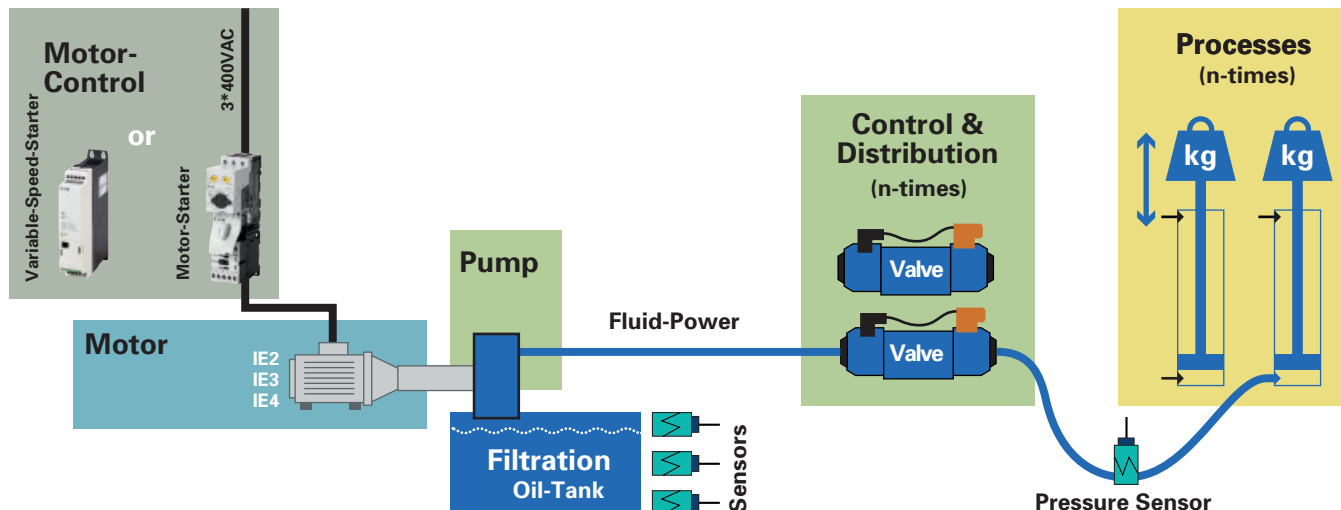
The 'binding measures' option allows manufacturers to develop solutions that are suited to their machine by choosing from a set of energy-saving measures. Each measure is assigned a particular number of points – a minimum number of points would have to be implemented to meet the requirements. This system appears flexible as it takes into account the sector's diverse nature.

There are no ongoing discussions, yet the EU Commission seems keen to address the machine tools sector. Whether or not this will be as part of the Ecodesign Directive or under other directives has not yet been revealed. However, there is every indication that, in the not too distant future, machine tools will be bound to comply with some form of energy efficiency regulations. During this undecided period, therefore, it may be prudent for manufacturers to focus their attentions on energy efficiency, in particular, when developing new machines and systems.

Pumps – number one target for energy efficiency

Pumps are responsible for most of the power consumption in industry. In relation to a pump's service life, energy costs amount on average to roughly 45 per cent of the total costs involved. There will also be costs for repairs and maintenance. Based on the experience of the German Energy Agency (dena), measures aimed at improving energy efficiency with pumps pay off quickly, in most cases². A study carried out in the industrial and business sectors indicates that the potential for reducing costs is, on average, between 20 and 30 per cent. In the case of a major steel producer, the measures applied just to two pump systems achieved a reduction in the annual power consumption of 2.7 million kWh, which is around EUR 220,000 in financial terms. In another case involving a medium-sized brewery, measures aimed at optimising the operation of selected pump systems resulted in a 73 per cent reduction in power consumption, thereby saving EUR 10,000 a year. This analysis included a diverse range of industrial pumps, but the potential energy savings may also be realized in hydraulic systems by applying the same principles.

² dena, article about major potential savings for companies using pumps, November 2010
<http://www.dena.de/presse-medien/pressearchiv/grosse-einsparpotenziale-fuer-unternehmen-bei-pumpen.html>



Components in a hydraulic system

With regard to the hydraulic power units that are in general use today, they largely comprise the following components:

- Motor control
- Motor
- Pump
- Valves
- Cylinder or actuator
- Accessories: sensors, filtration, hoses

Each one of these components has an impact on the system's energy efficiency.

Motor control

Various equipment is deployed in automation technology to control electric motors. Motor starters are often the most convenient and efficient solution for controlling motors, especially for fixed speed applications. Depending on the requirements of the application, the engineer may choose to use a direct starter, star-delta starter or soft starter. One common feature to all of these starter types is their ease of use, but they cannot regulate the speed.

The variable speed starter (VSS) establishes a link between motor starters and variable frequency drives. It combines the benefits of both these commonly used methods of controlling electric motors. For instance, the variable speed starter is as easy to handle as a motor starter, but it also offers the option of variable speed control. Therefore, it offers a useful alternative for making applications currently operating at a fixed speed more energy efficient and for complying with the increasing legal requirements in this area.

On the other hand, variable frequency drives allow a guided, continuous motor start with nominal torque and also offer continuous speed control. Depending on the characteristics of the model chosen, they can also allow accurate speed control on the otherwise slip-dependent asynchronous motor.

Lastly, the servo drive combines with the servo motor to form the servo system. This controls the motor's movement via adjustable setting values, such as angular position or speed. This enables the motor to perform highly accurate and dynamic movements.

Motor

The motor in a hydraulic power unit converts electrical energy into mechanical energy, which ultimately sets the pump in motion.

The three-phase asynchronous motor is the most widely used electric motor in the industry. It can be operated directly from the three-phase or AC mains without any control device, and is very

robust in terms of handling electrical and mechanical overloads. It is also relatively easy to manufacture, making it affordable.

PM-Motors are fitted with permanent magnets in the rotor. This negates the need for an external electrical power source to generate the magnetic field. As a result, the motor's efficiency level is 1-10% better, compared to that of an asynchronous motor.

Servo motors (PM-Motor with feedback system) offer extremely high power density and dynamic force as a result of their small inertia and permanent magnetic field. This high dynamic performance means that their movements can be precisely controlled and they are well-suited for demanding motion control applications. This set up enables them to achieve a high level of energy efficiency as there are no energy losses in the rotor. However, they are expensive to purchase and can only ever be operated along with a servo controller.

The efficiency level according to standard IEC 60034-30 offers an overview of the motor's energy efficiency. It defines efficiency classes (IE = International Efficiency), with the efficiency level increasing as the number increases. The following classes are defined in IEC 60034-30-1 for asynchronous motors:

- IE1 (Standard Efficiency)
- IE2 (High Efficiency)
- IE3 (Premium Efficiency)
- IE4 (Super Premium Efficiency)

Pump

The hydraulic pump converts the mechanical energy supplied by the electric motor into fluid power (volume flow, pressure). A distinction is made between fixed displacement and variable displacement pumps. The latter category includes pump types such as axial piston pumps, internal gear pumps or fixed displacement vane pumps.

Fixed displacement pumps generate a steady delivery rate at a constant drive speed. This type of pump is generally designed so that it can permanently supply the energy required for the machine to move at maximum load and speed. However, this also entails a high dissipation rate, especially when operating in part load and standby mode.

On the other hand, variable displacement pumps can modify their geometric displacement volume. Therefore, they only supply as much energy as required in each case.

There are also pumps available on the market that have been optimised for use at different speeds. Pumps designed for four-quadrant operation are a special case. They can switch both rotation and torque direction and are ideally designed for tasks involving

variable speeds. However, they are subject to increased wear and tear due to the constantly switching load and variable speeds.

Valves

To be able to control the volume flow to the actuators, hydraulic systems require valves. Directional control valves can be used to start, stop and change the direction of the volume flow.

Proportional or servo valves control the volume flow to the actuators in hydraulic systems using fixed or variable displacement pumps. This allows users to regulate the speed of movement. Proportional valves are valves where the outlet size – pressure or volume flow – is modified in direct proportion to the inlet size. A servo valve accommodates any intermediate position for the valve opening and, therefore, for the liquid flow rate as well.

When considering the energy efficiency of a hydraulic power unit, a valve’s efficiency level is a particularly relevant factor. Every valve causes a loss in pressure, as well as losses through leakage, to a lesser extent.

Actuators

Single- and double-acting cylinders are used to produce linear movements in hydraulic systems. Rotational movements are produced using hydraulic motors. There are now hydraulic actuators available in the sector that are already significantly more energy efficient thanks to design enhancements.

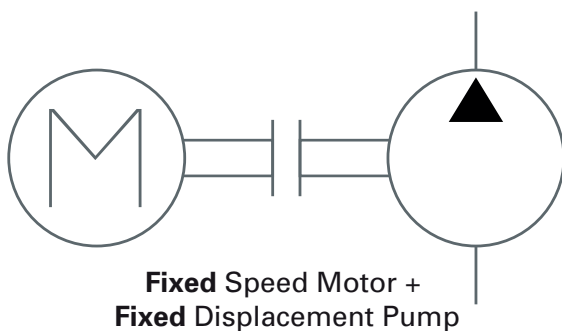
Accessories: Sensors, filtration, hose

Sensors also have an important role to play in power units when considering energy requirements. The reason is that sensors provide valuable information about temperature, level, volume flow and pressure. Constant monitoring of these values contributes considerably to the system’s efficient operation.

When selecting filtration products, it prudent to look for ones that have been developed with efficiency in mind. Effective cleaning of the fluid, increases the operating lifetime and overall performance of the hydraulic system, especially those operating in harsh and dirty environments. Hydraulic hose and hose fittings convey the fluid around the system. There is a wide range of hose types available on the market to suit almost every area of application, pressure strength and fluid type.

Typical combinations in hydraulic power units

1) Basic-Solution

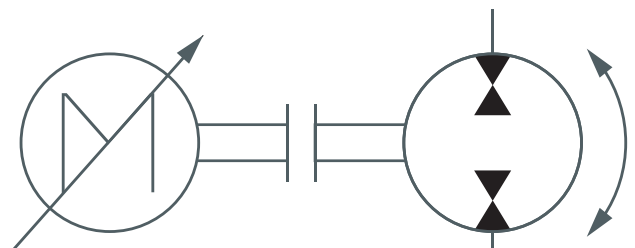


Efficiency	Dynamic	Cost
very low	medium	very low

„70 per cent market penetration – with descending trend“
 „many parallel processes / actuators possible“

The overwhelming majority of hydraulic power units currently in use operate with their motor and pump running at a continuous constant speed. Pressure and volume flow are regulated as part of this via hydraulic valves. This basic solution offers a variety of benefits. Firstly, low-cost asynchronous motors can be used, which are controlled via a similarly low-cost motor starter. They power a fixed displacement pump, which also requires relatively little investment because of its simple design. If designed properly, the whole system can supply almost any number of actuators in parallel. The relevant valves are used to control the individual processes. Overall, in terms of the investment that needs to be made, this solution should be assigned to the low-cost category, which is another reason for its market success. On the other hand, there is the relatively high energy consumption to consider. The overall hydraulic power unit is designed to support the maximum pressure and volume flow required and can deliver this output even if this is not required. In addition, there are high levels of heat inflow into the hydraulic fluid through the constantly operating pump. This heat must be dissipated, which requires additional cooling capacity. Further losses occur at the valves. This means that, overall, the energy efficiency of constant pressure systems of this kind is low.

2) Servo-Solution



PM-Servo Motor-Drive + Fixed Displacement 4Q-Pump

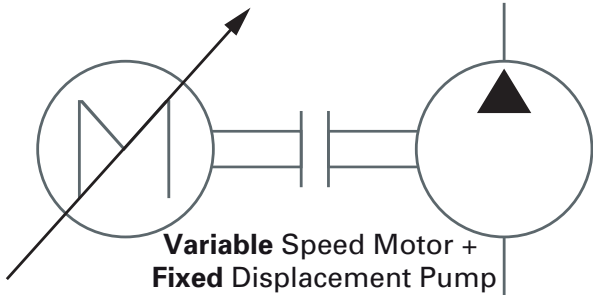
Efficiency	Dynamic	Cost
good	very high	very high

„10% per cent market penetration – with stable trend“
 „for one process / actuator only“

In contrast to the simple structure of constant pressure systems, the four-quadrant direct drive (servo solution) is available as a high-end solution. In this case, the hydraulic unit operates as a pump and hydraulic motor. The speed is specified by a servo drive – at slow speeds the volume flow rate is low, this rises as the speed increases. Sensors provide the servo controller with feedback on the position of a cylinder and/or on the pressure in the system. The servo drive controls the speed so precisely, and with it the pressure and volume flow rate, that a position can be reliably held and forces controlled with a high level of accuracy. Therefore, valves and flow restrictors are no longer required to control the actuators. The drive only runs with the power that is actually required by the system. Depending on the application being used (vertical or horizontal axis), the system also needs a small energy supply when operating in an idle state, which is discharged in the form of heat into the hydraulic oil. In this case, the oil only needs to be cooled slightly. Overall, this type of hydraulic power unit is many times more energy efficient than a system with a constant pressure. However, a direct drive can only ever supply one process at a time. If hydraulic power is available for several different processes, an equivalent number of hydraulic power units is required. In general, the four-quadrant direct drive with servo motors is a solution that should be placed at the upper end of the scale in terms of investment requirement. Therefore, the use of appropriately structured hydraulic power units is limited to applications that require a very high-end, motion control solution.

Electric drive technology plays a key role in terms of increasing a hydraulic power unit's energy efficiency, as it offers the chance to reinforce synergy between electrical and hydraulic drive technology. The basic approach involves not operating the hydraulic power unit's main pump constantly, but based on the relevant process and the actual power required. Energy is only ever consumed if the system also actually generates power (Power on Demand). Using a variable speed drive enables the output flow to be easily adapted to the current demand, so that dissipation rates can be reduced efficiently and significantly.

3.) Power-On-Demand Solution



Efficiency	Dynamic	Cost
very high	high	low

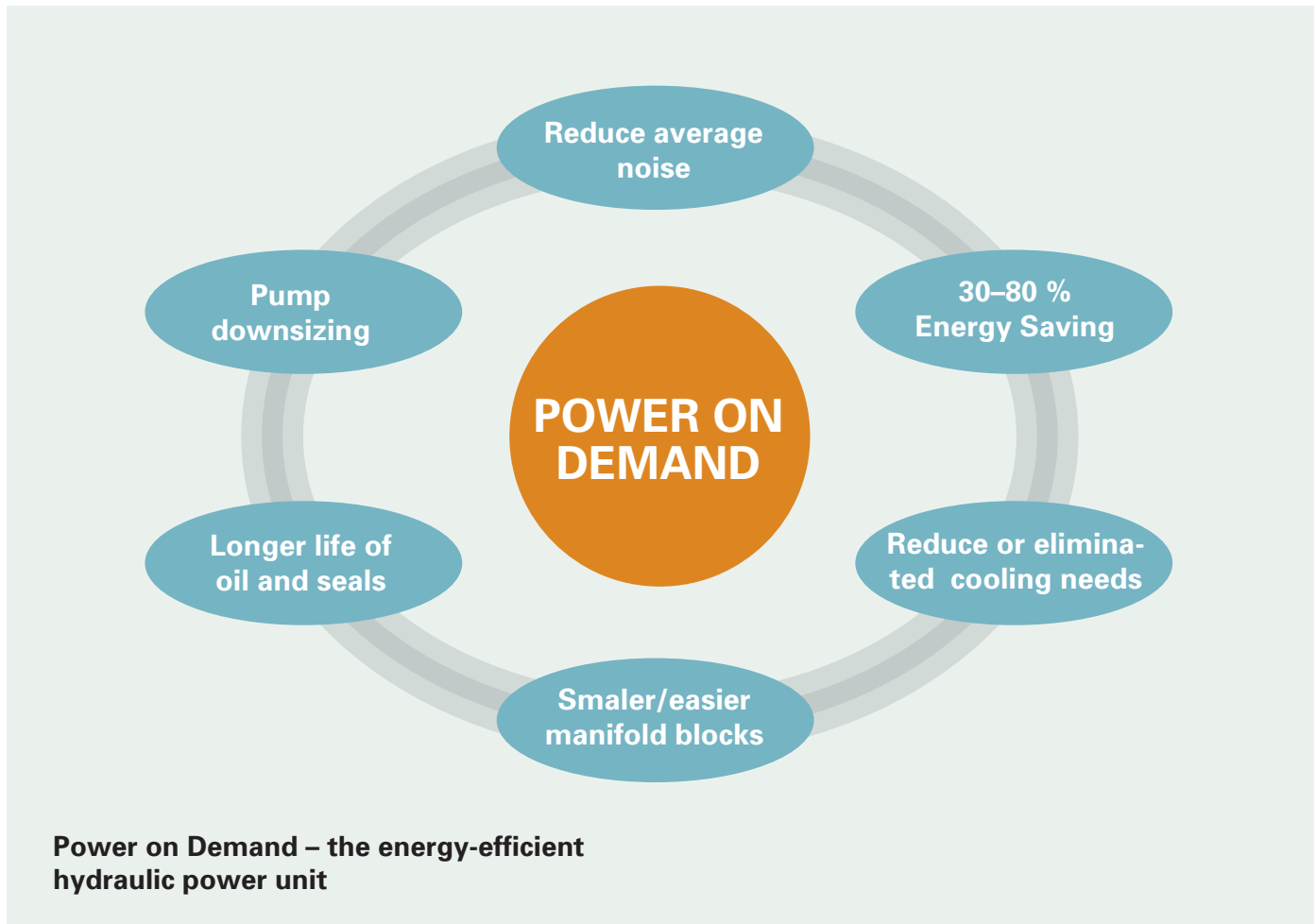
„10% per cent market penetration – with increasing trend“
 „several multiple processes / actuators possible“

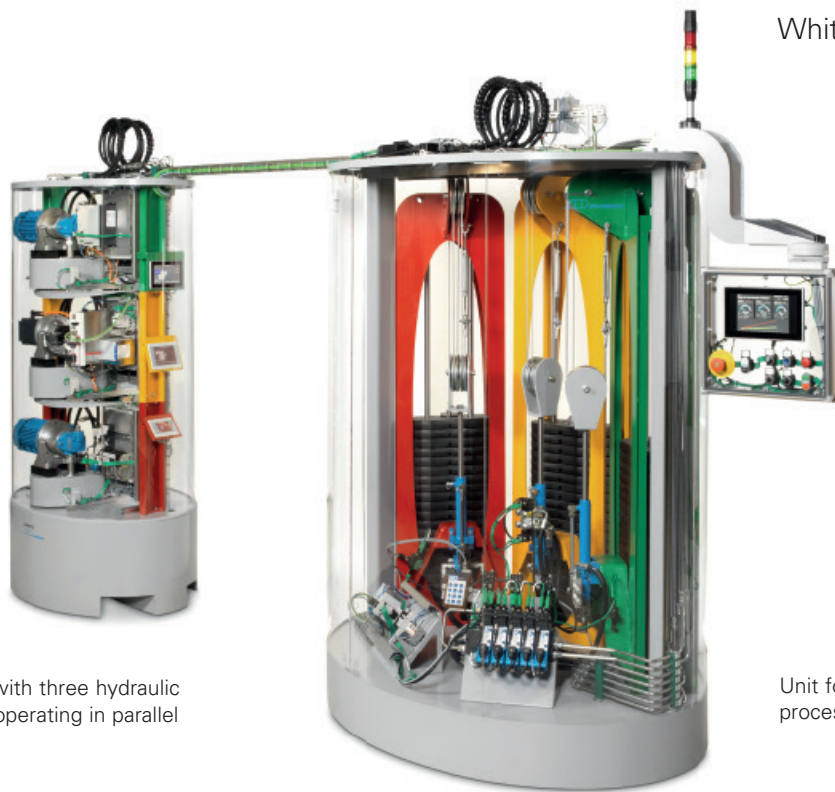
This kind of technology can be implemented using a conventional asynchronous motor where, depending on the operating cycles and runtimes, motors in the IE2 to IE4 efficiency classes need to be used. A further increase in energy efficiency can be achieved by using permanent magnet motors, but they also incur higher investment costs. The speed control function is taken over by either a variable speed starter or variable frequency drive. Using the variable frequency drive allows more complex functions to be carried out. Variable speed starters cost less and are easier to put into operation.

The motor control unit receives data from a pressure sensor about the pressure in the hydraulic system and, based on this, adjusts the motor's speed to the volume flow requirement of the hydraulic devices consuming the energy. This setup also allows several parallel processes with a similar volume flow and pressure requirement to be supplied, enabling the various actuators to be controlled via direction control, proportional or servo valves.

Potential applications for variable speed pump drives

Variable speed pump drives are ideal for numerous applications, ranging from injection moulding machines and machine tools to presses, casting techniques and steel processing. With all these applications, users benefit from a longer machine service life thanks to the generation of less heat, as well as from greater operator safety and improved comfort as a result of reducing the pump's noise level. Consequently, major potential savings can be achieved by using variable speed drives in the relevant applications, whether in terms of energy consumption or through being able to deploy a more compact, smarter hydraulic solution. Users can also derive a positive benefit in terms of Total Cost of Ownership (TCO).





Control unit with three hydraulic power units operating in parallel

Unit for running hydraulic processes

Practical example: Machine model for a hoisting application

To be able to show all the hydraulic power units described above operating in a single application, Eaton developed, in cooperation with its solution partner ATP Hydraulik AG, a model machine that was presented during the SPS IPC Drives 2015 exhibition, held in Nuremberg. The machine consists of three electro-hydraulic systems operating in parallel. Several control and drive variants carry out defined vertical stroke movements of about 200mm, with a maximum load of 600 kg, through cylinders with a 22 mm diameter. Therefore, this model machine allows a direct comparison to be made of the units in terms of dynamics, energy consumption and TCO. This model also allows process steps to be simulated, such as longer downtime periods, pressure holding times or part-load operation, which are typically seen in plastic and pressure die casting machines or machine tools, as well as in presses.

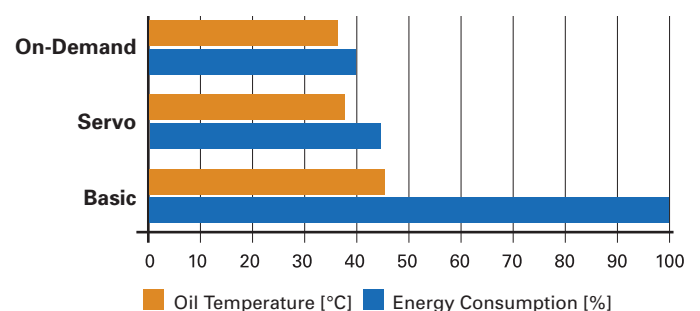
These three power units all operating independently, can communicate with each other and are controlled via a central system control unit. The digitized data for each unit (like pressure, temperature, oil level and oil filtering status) is available anytime and anywhere as it can be transferred via networks or cloud services to desktop or mobile communications devices.

Apart from demonstrating the innovative mechanical and hydraulic engineering aspect, the system also features new machine interface concepts, intelligent wiring and communication technology, scalable power generation and management.

In terms of controlling the electric motor, the first hydraulic power unit is the basic solution operated with a motor starter. The second power unit uses the servo solution with a servodrive, while, in the case of the third unit, the variable speed starter allows the main pump to be controlled according to the actual power required, based on the Power-on-Demand principle.

After a few hours of operation, during which the three power units were put through comparable movement sequences, the distribution of the energy consumption values was presented as a percentage in the graph, along with the corresponding oil temperatures.

When a direct comparison is made of the three options, the benefits of the energy-efficient Power-on-Demand hydraulic power unit are evident. Compared with the basic solution, this configuration can achieve energy savings of around 60 per cent.

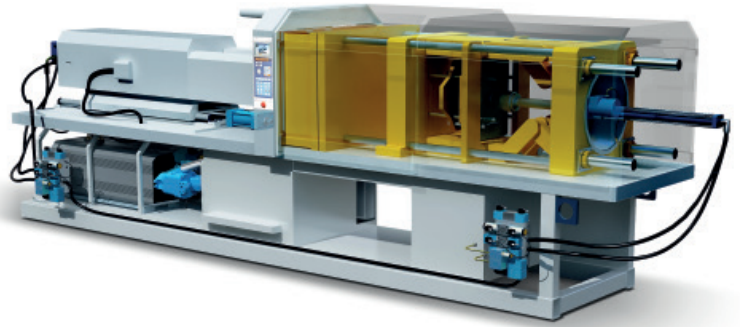


Practical example: Retrofitting of an injection moulding machine

As part of an ongoing project aimed at increasing the energy efficiency of a machining operation, a component part manufacturer made an analysis of its injection moulding machines. In this case, the average potential for reducing energy consumption depended on various factors – cycle time, tonnage and the complexity of the hydraulic system. Here, cycle time was the key factor; long cycle times present many opportunities for saving energy.

The example presented here is based on a 20-year-old, 50-ton injection moulding machine that is driven by a traditional 15 kW asynchronous motor, operating a hydraulic unit at a constant speed of 1500 rpm. In this case, the cycle time is 13 s, which is short, but typical for production of small components. A traditional set-up is used with a load-sensing pump. This means that the pump's volume flow is mechanically controlled and, even when the volume flow is small, energy must still be consumed by the motor running at a constant speed. The amount of energy consumed is measured as 20 Wh for a cycle time of 13 s.

The drive was upgraded using a variable frequency drive (Eaton PowerXL DA1), a permanent magnet motor and an axial piston pump (Eaton 425 piston pump). At the same time, the pressure and volume flow are also regulated by the micro-controller that controls the motor. A PID controller is used for the pressure, while the volume flow is represented using the flow rate/speed characteristic. Since the motor is regulated according to the load and power is only required for it if the process needs it (Power on Demand), energy can be saved. In this example, the following hourly values are outputted:



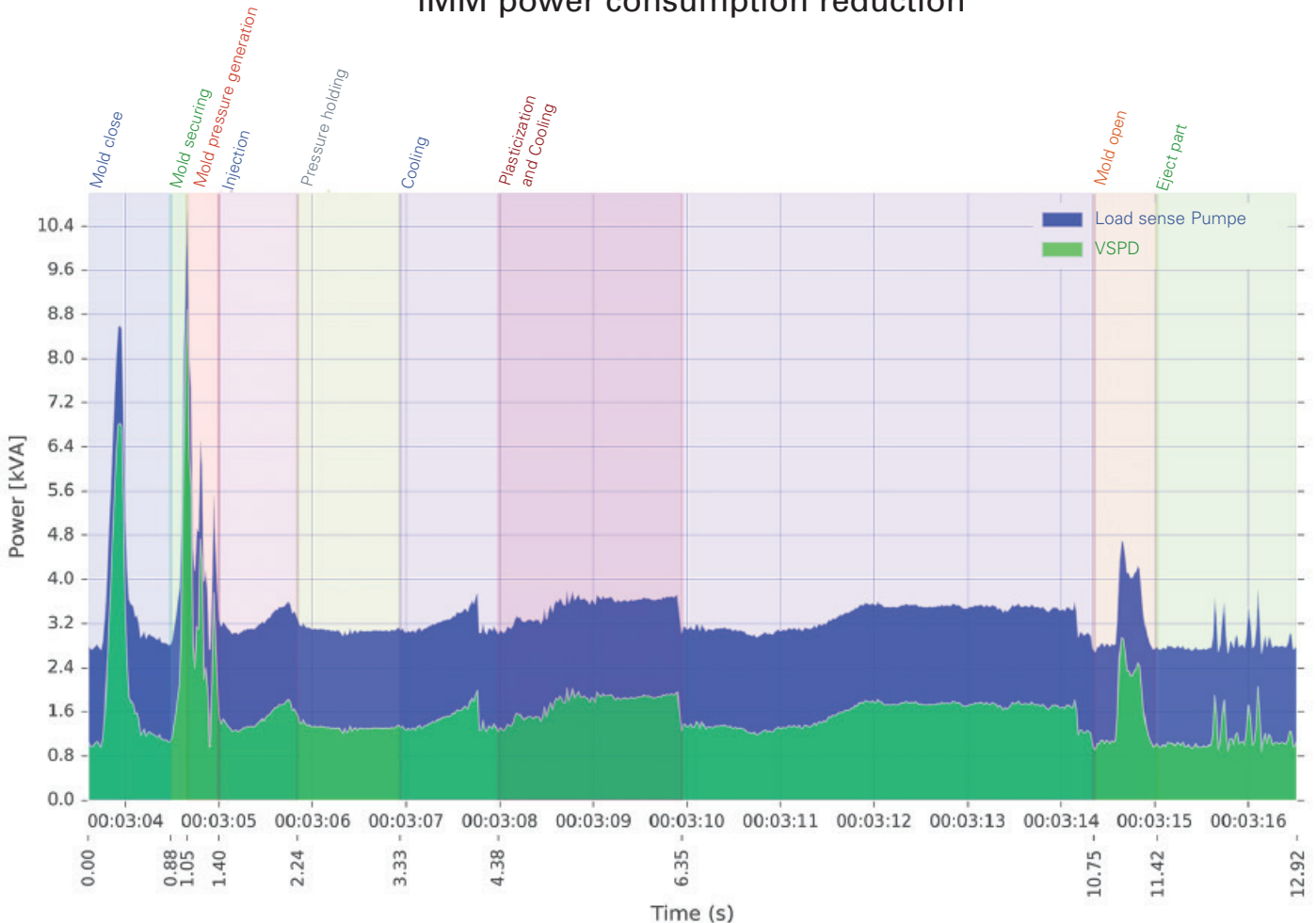
Basic solution with variable displacement pump: 5.6 kWh

Power-on-Demand solution with a variable speed drive: 2.8 kWh

Assuming that the machine operates for two eight-hour shifts, 300 days a year, the annual energy savings made for each machine is EUR 2,016. The period for achieving the return on investment (ROI) in this case is 2.2 years.

This example indicates that introducing a variable speed hydraulic drive can – depending on the cycle time – help achieve energy savings of around 50 per cent. Even higher values can be achieved with longer cycle times. These savings come with other benefits, such as a reduction in the noise level and increased productivity.

IMM power consumption reduction





Focus on energy consumption

Reducing the hydraulic power unit's energy consumption is the first step towards creating an energy-efficient system. The second is to create the right conditions for an energy management system. The key to this is data collection. Extensively recording and analysing energy and machine data is the only possible way of monitoring energy consumption, identifying opportunities for improvement and checking the impact of the measures implemented.

Connecting numerous components

Assuming the use of numerous sensors, for instance, for measuring pressure, position or temperature, as well as for getting information about the status of each individual component.

In the case of traditional system architectures, this means the additional use of wires and cables for connecting the components to the programmable logic controller (PLC). In a conventional set-up where individual cables are connected, this results not only in considerable effort during the installation process, but also increases the risk of errors.

Power unit with smart cabling

An intelligent, low-level device wiring system, such as Eaton's SmartWire-DT, offers clear advantages in comparison with conventional wiring. It allows components such as switching devices, circuit breakers, pushbuttons, sensors and actuators to be connected to each other using a single cable instead of using old-fashioned point-to-point wiring with the control system. At the same time, standard components are turned into smart, communication-enabled devices using an ASIC module. The cable supplies power to the connected devices, while also supporting data communication.

If this approach also includes the option of connecting not only components within the control cabinet but also, IP67 I/O modules to be used in the peripherals, this provides engineers with new scope for freedom in terms of system architecture. This enables sensors and actuators to be simply connected to the system, to monitor the vertical motion of cylinders and the pump system's temperature or pressure, for instance. With less cabling being required and less material being used, this can make the construction of new machines and the retrofitting of existing machines cost-effective. Apart from saving energy, it also reduces the ROI period of the energy efficiency measure implemented.

IoT-readiness integrated

Through gateway modules, a properly designed hydraulic power unit offers the option of connectivity to fieldbus systems, such as Profibus, Profinet, CANopen, Modbus-TCP, Ethernet/IP, Powerlink or Ethercat, as well as to the Internet. If control devices are used with an OPC UA interface, all data – down to device level – can, for instance, be supplied for cloud-based power management software. This makes the system 'IoT ready'. Mechanical engineers and end users can then, regardless of location, obtain an up-to-date, detailed overview of all the relevant data, such as temperature and pressure. This enables those with the necessary authorization to check the energy consumption at any time and quickly identify any malfunctions using appropriate mobile devices such as a smart phone or tablet. Another option offered is for predictive maintenance to be carried out, as well as machine troubleshooting and control functions.

Summary

Variable speed electro-hydraulic drives are smart systems that offer a perfect solution for complying with both national and international standards and requirements, such as the Ecodesign Directive, as well as for reducing energy consumption of the drives in numerous applications. They not only help protect the environment and save energy, but also reduce the TCO.

The higher investment costs incurred compared with traditional hydraulic solutions are offset by lower energy costs and shorter ROI periods. The Power-on-Demand feature offers the benefit that more compact systems can be produced, which come with a lower cooling requirement and reduced noise emissions.

Variable speed pump drives allow substantial energy savings to be made quickly with hydraulic power units, for a relatively small investment. In practice, a reduction in energy consumption of up to 70 per cent has already been achieved. In general, the ROI is achieved in around two years. In addition, the ROI period can be reduced further by using intelligent wiring and communication solutions at device level. Nowadays, it is already possible to connect hydraulic systems to the Internet and Cloud so that energy-related and operational data can be accessed at any time, from anywhere in the world. Another upshot of this is that it opens up new opportunities for machine and system builders to generate additional revenue streams in their business model.

At Eaton, we're energized by the challenge of powering a world that demands more. With over 100 years experience in electrical power management, we have the expertise to see beyond today. From groundbreaking products to turnkey design and engineering services, critical industries around the globe count on Eaton.

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