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Technical Article

Variable speed pump drives for industrial machinery—system considerations

The newest generation of hydraulics technology, such as Rexroth's Sytronix variable speed pump drive system, integrate powerful, energy efficient hydraulic pumps with advanced, intelligent electronics and controls.

The changing landscape of hydraulic drives is leading many fluid power specialists to quickly adapt to using variable speed pump drives. Optimum utilization of these drives requires, in many cases, additional system design considerations.

Despite ominous predictions in the '80s and '90s, the complete replacement of hydraulics with electrical drives did not occur, and fluid power still plays an important role in modern drive technology.

Moreover, it is impossible to imagine many fields of industry working without hydraulic drives.

The enormous power density makes hydraulic drives irreplaceable when

Technology trends

- Intelligent electrohydraulics enable much greater control and flexibility
- Significant improvements in system energy efficiency thanks to use of variable speed pump drive technology
- Reduction of throttling losses lowers oil reservoir cooling requirements
- Using Variable Frequency Drives with hydraulic power units can lower average noise emissions by 10-20 dB(A)

Key considerations

- Dynamic performance and power requirements determine the choice of the motor
- Select motor and drive size based on pressure-flow-time cycle (p/Q profile) for the application
- When selecting pumps, consider suitability of pump construction for variable speed operation
- Also consider mechanical and volumetric efficiency of the pump at the design operating points

large forces and high torques are required. Over the last 30 years "traditional" hydraulics has evolved into electrohydraulics, where the integration of electronics and closed loop controls has become an industrial standard.

For years it was common to depict hydraulics as "strong but stupid." Today this reputation no longer exists—hydraulics are not only strong, but also intelligent. Modern fluid power drives are perfect examples of highly integrated mechatronic devices.

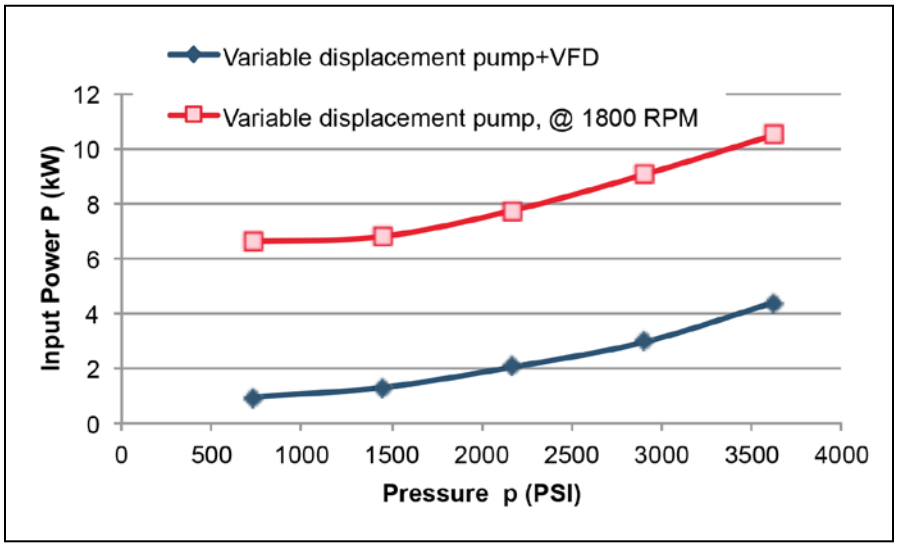
Drive for more advanced solutions

Ongoing competition with electrical drives and ever increasing requirements of performance and energy efficiency have led the hydraulic drive industry to new and more advanced system solutions.

The power control of electrohydraulic drives typically uses resistive or volumetric control. In resistive control, the system is controlled by a valve, usually a proportional device, to throttle oil flow delivered from a power-supply source. In volumetric control, flow is controlled by adjusting the displacement of a pump or by directly changing the drive speed of a fixed or variable displacement pump. Resistive control possesses excellent dynamic characteristics; however it exhibits poor energy efficiency. Significant power losses occur due to dissipation in the control valve. This is, in effect, hydraulic resistance.

There are a number of broad manufacturing trends that are influencing the increased interest in and potential value of variable speed pump drives:

- Rising costs of energy and increased awareness of environment issues have resulted in new trends in drive systems. Over the last two decades, improvements in electro-hydraulic efficiency were a main goal of many companies and research institutes. Given advances in drive technology and closed loop control, the resistive throttling method is being replaced more often by more efficient volumetric control using speed variable pump systems.
- Reducing throttling losses lowers the amount of heat transferred to the oil and oil reservoir. Lower heat generation allows for a smaller capacity cooling system and lower parasitic power needed to maintain optimum oil temperature.
- Using Variable Frequency Drives (VFDs) with hydraulic power units can also lower average noise emissions, as the pump speed is reduced during partial load operations, such as pressure holding or idling. The average sound level can be lowered by as much as 10-20 dB(A), improving environmental working conditions.



Shown is power consumption, in a dead-head condition, for a 125cc axial piston pump driven by a 100HP premium efficiency motor. The energy used is considerably lower when using a VFD as compared to a constant speed drive.

Growth of variable speed pump drives

The combination of advanced electric drive technology and hydraulics opens a new chapter in electro-hydraulic drive systems. Machine builders can now benefit from the traditional hydraulic characteristics of robustness and power density and additionally benefit from the well-known advantages of electric drives: inherent drive "intelligence" and ease of integration with factory automation systems.

This changing landscape of hydraulic drives pushes fluid power specialists to quickly adapt to using variable speed pump drives. For many engineers, this may not be an easy step. Optimum utilization of variable speed pump drives requires, in many cases, additional system design considerations and modifications to a hydraulic system design.

Fluid power engineers need to understand the distinctive features of VFDs and the requirements of the

production process being driven. This will define the critical points for the electric and hydraulic elements.

The goal of the system is to meet the requirements of dynamics and accuracy, but also keep the focus on overall energy efficiency. When applying a VFD driven pump, using a conventional induction motor or a permanent magnet servo motor (PMM), the dynamic behavior will differ from a traditional system using a constant speed pump drive and throttling control valve.

System design options

Systems using variable speed pump drives can use a number of different design solutions. The selection of the design solution depends on a number of factors. The type of hydraulic circuit, the required response times and accuracy, the power required and other factors all come into play when deciding the best drive and circuit design.

Dynamic performance and power requirements determine the choice of the motor. For applications requiring the fastest response times and highest accuracies, a PMM may be the best selection. Today this technology is used extensively in plastic injection molding machines. These drive systems offer extremely high performance and have high productivity rates.

Due to their high power density and low drive inertia, PMMs have the highest acceleration capabilities. These high dynamics allow complex machine control tasks, such as direct force, speed and cylinder position control to be realized without proportional valves. The

The Sytronix DFEn variable speed pump combines high dynamics and high power output, for pressure, flow and power control applications.

main limitation when using PMMs is maximum continuous output power, typically less than 60kW. Power units with higher output power, greater than 60kW, may require multiple PMM-Pump groups.

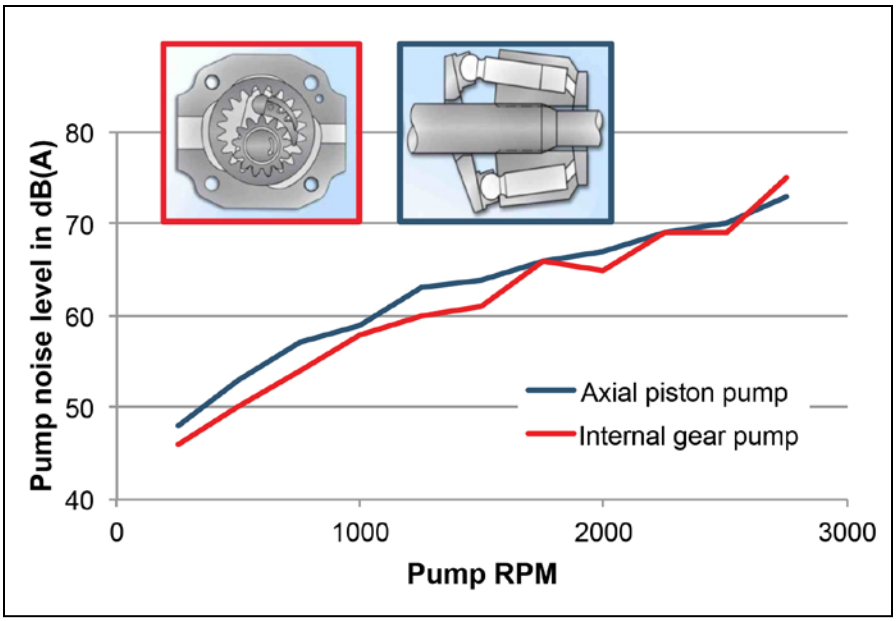
Standard asynchronous induction motors driven with VFDs can be used in higher power applications, or where direct control of high dynamic axes is not required. Using standard induction motors with VFDs, operating in a sensorless vector control mode (no separate motor feedback device required) results in a cost-effective system. However, the system designer should be aware of the limitations of direct control using these drives.

The system response times can be long as a result of the high inertia of the induction motor. Variable speed pump drives using standard induction motors with VFDs are used today in the woodworking industry, on press applications, in plastics machinery, heavy industry applications and machining tool applications where the control task is typically regulating system pressure or flow.

Selecting motor size

The motor size and drive should be selected based on the pressure-flow-time cycle (p/Q profile) for the application machine. In practice, motors on standard HPUs are often sized on “corner power”, calculated from the maximum pump pressure and flow, and duty cycle is commonly not taken into account. This results in the installation of excess motor HP. If partial load comprises a significant portion of the machine cycle, the excess motor power can be significant.

Sizing PMMs for variable speed pump drives should follow methods



Using VFDs with hydraulic power units can lower average noise emissions. Since the pump speed is reduced during partial load operations, average sound levels can be reduced by as much as 10-20 db(A).

commonly used in electro-mechanical actuator drives: calculating the root mean square (RMS) value based on the load torque and average drive speed. Once a pump size is determined, the motor torque and speed are calculated from the required pump pressure and flow. Additionally, the dynamic torque requirements for accelerating and decelerating the motor's rotor and pump inertia needs to be added.

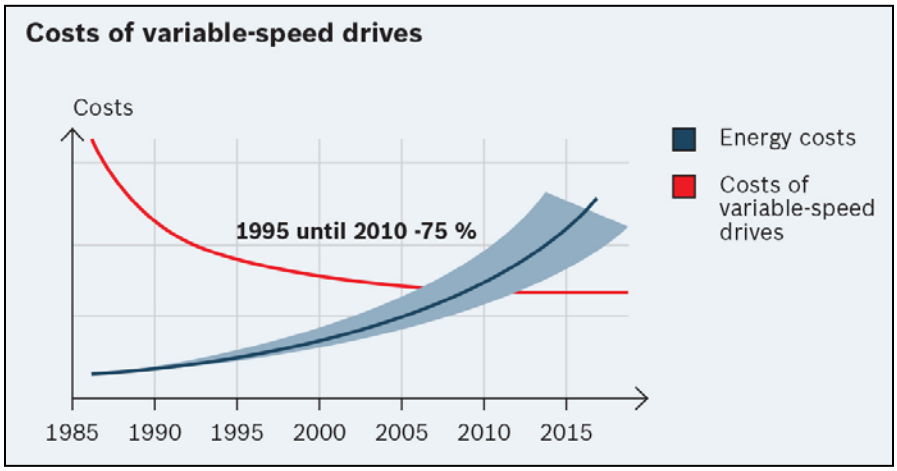
These calculated values are used to select the proper size drive and motor. Drive sizing and system optimization can be done using specialized tools, such as Bosch Rexroth's SytronixSize, which allows analyzing p/Q profiles and motor load factors. For a more complex analysis, a numerical simulation can be used to model the system.

Dynamic simulations help by providing more insight to the system dynamics, such as pressurization dynamics, and to investigate interactions between the drive and the hydraulic system. Analysis of the performance of closed loop controls can be done as well. These dynamic simulations can be carried out using software that includes drive and hydraulics model libraries. Simulation tools, such as Bosch Rexroth's Simster 3, ITI SimulationX or MATLAB/Simulink Simscape can be used for these requirements.

Pump selection criteria

When selecting the pump for variable speed operation, several important factors must be considered:

- Is the pump construction suitable for variable speed operation?
- What are the minimum and maximum allowed RPM for the pump?
- Can the pump be used bi-directionally, and if so are there any pressure and speed limitations?
- Is the pump suitable for start and stop operation?
- What is the maximum operating pressure allowed for the pump, and does pressure affect the maximum allowable pump speed?
- What fluid will be used in the system and does it limit the pump's pressure and speed, based on viscosity and pump lubrication?
- What is the mechanical and volumetric efficiency of the pump at the design operating points?



In recent years, the cost of using variable-speed drive technology has become more economical, making it effective to combine variable-speed electric drives with hydraulics to provide an energy saving, high-performance alternative for use in many applications.

- Consider pump acoustic noise level, based on expected speed, pressure, and displacement.
- What will the pressure and flow pulsations be over the range of operating speeds?
- Is the hydraulic circuit of open or closed type?

Improper pump selection or operation outside allowed conditions can result in premature pump failure or suboptimal control performance. Pumps used with speed variable drives are typically internal gear or piston pumps. In some cases properly selected vane pumps may also be used.

Internal gear pumps are characterized by high efficiency, low flow ripple, low mechanical inertia and high pressure capability. Due to these characteristics, they are widely used with PMMs on injection molding machines. The limitations are fixed displacement and limits on the minimum drive speed during pressure holding operation.

Axial piston pumps, either fixed or variable displacement design, have the desired property of high efficiency at low speed, making them ideal for pressure holding operation. Using a variable displacement pump allows the possibility to lower the motor torque during pressure holding in the machine cycle. This can result in higher system efficiency, since the motor and pump can operate under more desirable operating conditions. High response variable displacement pumps, such as Rexroth's DFEn 5000 can have reaction times an order of magnitude faster than a VFD driven induction motor. Combining this pump with a VFD controlled induction motor results in greater efficiency and much higher system response than does variable speed alone. This is of greater value when used with higher HP drive motors.

It is expected that speed variable pump drives will replace an increasing number of standard motors in hydraulic power units in the future. This change is already utilized by many plastic machinery OEMs and is quickly expanding in press applications. Understanding the principles of variable speed drives and the interaction between hydraulics and electric drives will be key to future fluid power engineering.

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