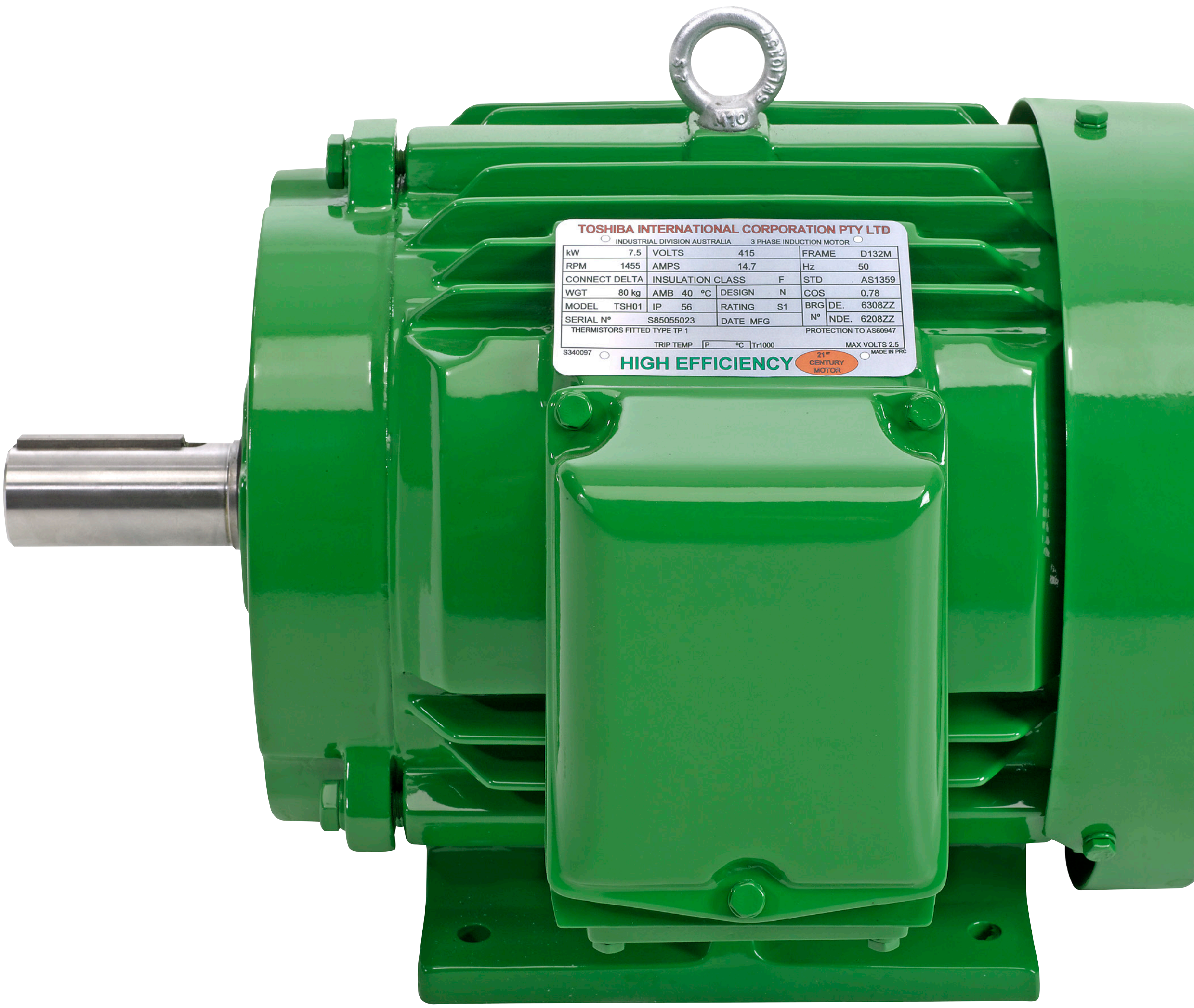
WHITE PAPER

Energy efficient control of pumps

Cyclic control vs VFD



BENSHAW
Applied Motor Controls

Efficiency in focus

Improving the efficiency of pumping systems is an important focus for energy efficiency efforts. Almost half (45%) of the electricity produced globally is used by motors [1], and a large proportion of these motors drive centrifugal pumps. Efficiency gains result in significant reductions in total energy use over time, dramatically lowering operating costs and environmental impact.

A recent trend has seen a significant push towards using variable frequency drives (VFDs) for improved pump efficiency, particularly where throttling valves have been used to control flow. However, there is increasing evidence that for many pumping applications where real-time flow control is not necessary, VFDs are not the most energy efficient solution [2].

The aim of this paper is to examine variable frequency control versus cyclic control, within systems that do not require real-time flow control, to establish which applications are more suitable for each particular method of control.

Energy efficient control of pumps

FLOW CONTROL

Pumping applications can be roughly separated according to their requirements for real-time flow control or time-averaged flow control.

Real-time flow control

Typically, real-time variable flow control applications require flow or pressure to be adjusted directly in accordance with the requirements of the system as they change.

For applications genuinely requiring real-time variable flow control, there are typically two control methods:
1) the traditional flow control valve (throttling), which is generally accepted to be inefficient;
2) a VFD, which is considered to be a superior method.

For real-time variable flow systems at low static heads, the VFD typically provides a significantly more efficient method than throttling. But at high static heads the savings a VFD can make diminish [3].

Time-averaged flow control

A large proportion of applications require average control of the flow over a relatively long period of time, ie time-averaged flow control. Typical examples of this are pumping from a holding tank, or to a reservoir (Figure 1).

Consider wastewater pumping: a pump is controlled to empty a tank as the tank nears capacity, then switch off when the tank is empty, repeating the cycle when the tank fills again.

For applications requiring time-averaged flow control, cyclic control is a method that is commonly used to provide energy savings and reduce installation costs. Cyclic control switches the motor and pump on (at full speed) and off, according to the average demands of the system.

This is achieved with a fixed speed controller such as a soft starter or direct on line (DOL) starter. When the pump is running it will operate near to its best efficiency point (BEP) and when it is not operating, the system neither consumes nor wastes any energy.

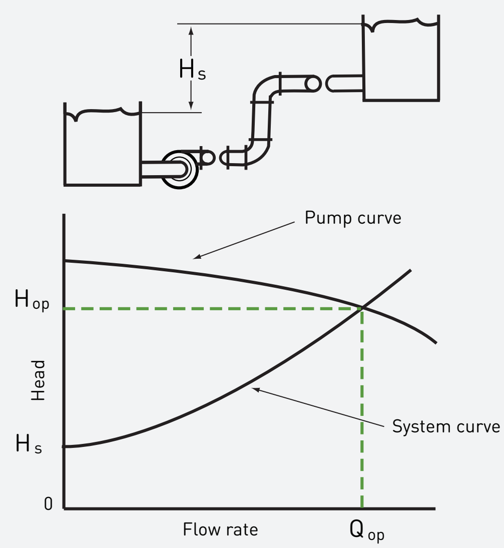


Figure 1: Pumping from a holding tank or to a reservoir

PUMPING SYSTEMS AND ENERGY LOSSES

Static head (H_S) is the height the liquid is to be pumped and friction head is the frictional losses of the system measured as an equivalent height.

Frictional losses will vary in relation to the flow, whilst the static head typically remains constant. The operating head (H_{OP}) is the static head plus the friction head at the operating flow (Q_{OP}).

THE EFFICIENCY OF A PUMPING SYSTEM DEPENDS ON:

- The hydraulic design - most energy is lost within the pump and pipework.
- How it is controlled to meet the flow demands of the application. The method of control can play a significant role in the performance of the system.

SYSTEM DESIGN

The design and characteristics of each type of pumping system can vary widely and so can the way the energy usage and losses are distributed within the system.

- In a high static head system most of the energy is used elevating the liquid to the desired head or height (Figure 2). This type of system is also referred to as static head dominant.
- In a low static head system most of the energy is lost as friction (Figure 3). This type of system is also referred to as friction loss dominant.

Pump systems are typically designed to ensure a guaranteed target maximum operational flow (Q_{op}). An ideal pump will be chosen to operate at its BEP at the operational flow.

However, a suitable 'real' pump will usually have a greater flow since it is unlikely that the ideal pump exists for the exact operational flow at the BEP. Therefore, the pump will be operating slightly off its BEP (the impeller can be machined to correct for this).

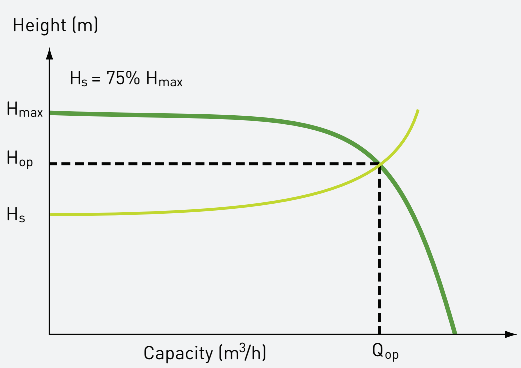


Figure 2: Hydraulic system with high static head

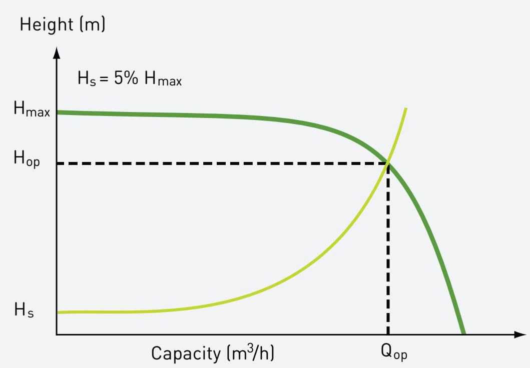


Figure 3: Hydraulic system with low static head

EXPERIMENT SETUP

To investigate the efficiency of variable flow versus cyclic control, four time-averaged pumping scenarios were analysed. These scenarios considered four different hydraulic systems, to cover various ratios of static to operating head: 5% (friction loss dominant), 25%, 50% and 75% (static head dominant).

Each system was analysed with both real-time variable flow control (ie using a VFD) and time-averaged cyclic control (ie using a soft starter). The overall system efficiencies were then compared.

The pump system was designed by choosing a typical pump from KSB and using the published pump data. When calculating the efficiency the losses within the motor, controller and pump were included. The pump losses vary according to the speed of the pump.

A detailed analysis of each pumping system and control method was done using Simulink and the Simulink Hydraulic Toolbox.

System design

- Operating head = 70 m (made up of static and frictional components).
- Maximum flow = 1200 m^3/hr
  = 20,000 L/min (229 kW).
- Static head 5% (3.5 m), 25% (17.5 m), 50% (35 m) and 75% (52.5 m). The remainder in each case is frictional head.

Pump

- KSB ETAnorm-R300-500 [4] (BEP @ P=318 kW, Q=1240 m^3/hr, H=82 m).
- Impeller machined to 492.4 mm (from 520 mm) to achieve operating point just above the BEP at 20,000 L/min.
- Efficiency = 86.4% @ 20,000 L/min.
  Pump efficiency curve implemented in the simulation model.
- Power Input = 268.8 kW @ 20,000 L/min.
  Pump power input curve implemented in the simulation model.
- Assume no cavitation.

Motor

- Losses include copper losses, windage, friction and stray, and are modelled as a function of speed.
- $P_{loss} = (k_1 \omega 2) + (k_2 \omega) + k_3 + k_4 (P/\omega)2$
- Where k_1 = 10%, k_2 = 14%, k_3 = 4%, k_4 = 72% [5, 6]
- ω = speed

VFD losses

- Known efficiency for rated load frequency.
- Efficiency decreases as the load decreases (curve fit).
- Efficiency decreases as the frequency decreases (divide by frequency).
- Reactive power not considered.
- $P_{loss} = (k_1 \times I2) + (k_2 \times I) + k3$
- Where k_1 = 0.16, k_2 = 45, k_3 = 3100 [7]
- Increased motor losses due to harmonics add 0.7% to the losses [7].

Cyclic controller

Internal losses are insignificant, assuming low resistance electromechanical contacts, ie bypassed soft starter.

RESULTS AND CONCLUSIONS

The results of this research are shown in Figure 4. It shows all the power losses in the system for each pumping scenario. The power that is used to elevate the liquid to the height of the static head is not a loss as it does useful work. Note that, for cyclic control, the line on the graph is the same for all four different static head scenarios.

The results of this investigation are compelling: Cyclic control is the most efficient method of control for applications with medium to high static head. Even at the relatively low static head of 25%, there is little overall difference in efficiency between real-time flow control and cyclic control. Real-time flow control becomes increasingly inefficient for higher static heads. These results agree with the conclusion presented by ABB [2].

Using real-time flow control in place of cyclic control for low static head applications

For low static head applications, real-time flow control could be used in place of cyclic control for a small improvement in efficiency (5% static head, Figure 4).

To achieve any efficiency gains, the flow rate would need to be continually adjusted to the real-time requirements of the application. However, at high and low flow rates, this method of control would be less efficient than cyclic control.

Low flow rates achieved through variable frequency control should be avoided to minimise problems with clogging and cavitation.

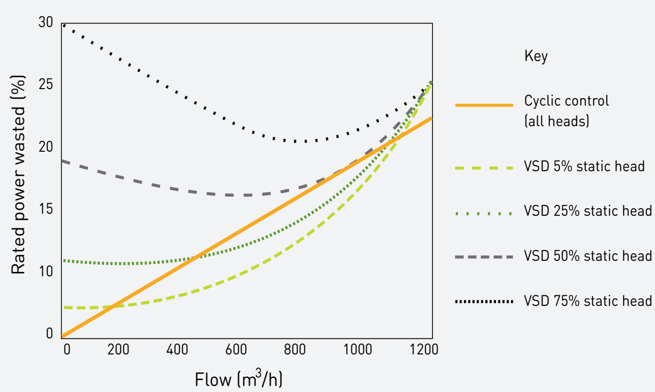


Figure 4: Pumping losses: cyclic control vs variable frequency control

Good practice - design pump systems for cyclic control

To minimise energy consumption, each pumping application must be carefully designed and the method of control selected appropriately. As a rule of thumb, except for very low static head applications, it is best to design pumping systems for cyclic control, taking advantage of the better energy efficiency of cyclic control using soft starters or DOL starters.

For example, design pumping systems to pump from a holding tank or to a reservoir and gain the following benefits:

- Improved energy efficiency by using cyclic control with a soft starter or DOL starter.
- Prevent potential problems with clogging of pumps which occur when pumps are run at low speeds.
- Minimise wear on the pump by eliminating cavitation that occurs when pumps are run at low speeds.
- Liquid storage in a holding tank or reservoir during power failures can allow the system to continue until the power is restored.
- Lower installation costs by minimising the maximum flow requirements on the motor and pump by having a holding tank or reservoir which is capable of high flow rates for a short period of time.
- Lower installation costs of electronic motor control because a soft starter is significantly less expensive than a VFD.
- Remove the effect of harmonics on the supply and motor, associated with VFDs.

Bad practice - cyclic control using a VFD

A VFD may be used for real-time flow control and can also be used for cyclic control by switching the motor to either full speed or off. However:

- VFDs have significantly higher losses than fixed speed controllers.
- The installation and running costs of VFDs are much higher than for fixed speed controllers.
- VFDs introduce harmonics to the system, further reducing the overall efficiency and can also affect the electrical network.

Only fixed speed controllers such as soft starters or DOL starters should be used for cyclic control.

References and additional resources:

1. Waide, P.; Brunner, C.; et al. Energy Efficiency Policy Opportunities for Electric Motor-Driven Systems; IEA Energy Efficiency Series Working Paper: Paris, 2011.
2. Engineered Software Inc.; http://kb.eng-software.com/questions/317/VFD+Pumps+Can+Cut+Energy+Costs+but+Static+Head+Reduces+Savings+(accessed October 2012).
3. Sagarduy, J.; Kristensson, J.; Kling, S.; Rees, J. Saving the best for last Softstarters or variable-speed drives, or both?; ABB Review: April 2010.
4. KSB Aktiengesellschaft; Etanorm Performance Curves Booklet 50 Hz: April 2003.
5. Bednarczyk, J.; Induction Motor Theory; PDHonline course E176 (3PDH): 2012.
6. ERIKS Industrial Services Ltd; Induction motor: Energy efficiency replacement charts and report: 2008.
7. Energy Efficiency and Renewable Energy; Adjustable Speed Drive Part-Load Efficiency; Motor Tip Sheet #11; US Department of Energy: June 2008.

24/7 Technical Support

Benshaw is dedicated to providing comprehensive 24-hour-a-day, 7-day-a-week phone support. Benshaw provides repair, spare parts, field engineering, retrofit and training services, when and where you need us. You can count on our experienced team, backed by the latest diagnostics and repair tools and an extensive part inventory to support your operations.

Call 1.800.203.2416

24/7 Hotline Support from our operations in Pittsburgh and Listowel (Canada):

- Technical phone support
- Overnight parts shipment
- 24-hour service dispatch
- Coordination of all service capabilities

Repairs

Repairs are made on Benshaw equipment by trained, experienced personnel, using the latest diagnostic and test equipment.

Field Services are performed on-site by skilled technicians, engineers or complete team if needed, including:

- Start-up commissioning
- Field repairs
- Field analysis/data collection
- Preventative maintenance
- Retrofits

The Benshaw Product Line

A wide range of motor controls and drives is available.

- Solid-state starters fractional up to 30,000HP at 15kV
- LV AC drives to 2,000HP, MV AC drives to 10,000HP
- Electromechanical controls to 800A

Benshaw express is a 24/7 online inventory and order entry system for authorized Benshaw distributors:

- 24/7 shipment
- Air or truck delivery

Visit us online at Benshaw.com and benshawexpress.com, or contact:

BENSHAW, Inc.
615 Alpha Drive
Pittsburgh, PA 15238
Phone: 412.968.0100

BENSHAW Canada
550 Bright Street East
Listowel, Ontario N4W 3W3
Phone: 519.291.5112
Fax: 519.291.2595

©2021 Benshaw, Inc.

BENSHAW
Applied Motor Controls