SMART PUMPING SYSTEMS: THE TIME IS NOW

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ABSTRACT

Several types of smart products are already available today in both the commercial and industrial marketplace. The pump industry has been behind the times in incorporating computer technology to operate, control and protect pumps and their systems. Smart pumping systems can match pump output exactly to system conditions and can detect and protect the pump and system against unusual operating conditions. Through the use of a smart variable speed controller these systems can significantly reduce pump-operating costs by eliminating the use of energy consuming control valves. The value of smart pumping systems to the user is in reduced life cycle costs. All of the major components of life cycle cost such as operating cost, maintenance cost, initial cost and installation cost should be evaluated when comparing smart systems to conventional systems.

INTRODUCTION

All types of products, which exercise some type of control over their function, are rapidly making their way into the marketplace. On the commercial side there is smart automobiles and more recently, smart appliances have also begun to appear. On the industrial side there is smart instrumentation, smart control valves and smart motors. The pump industry is behind the times in incorporating the use of computer technology to operate, control and protect pumps and their systems. Certainly over the past few decades-significant progress has been made in the areas of pump hydraulics, mechanical design and applications through the use of computerized tools such as computational fluid dynamics (CFD) and finite element analysis (FEA). However, only recently have manufacturers begun to develop “smart” pumps which incorporate microprocessors as part of their normal function.

A smart pumping system by definition must be capable of knowing when to adjust itself to system changes without manual intervention. The system must also be fault tolerant. Fault tolerance enables the system to recognize and safeguard itself from operating under conditions that may reduce its life. Adverse conditions such as dry running, operation against a closed suction or discharge valve and cavitation must all be recognized and reacted to before damage occurs. The system must also be capable of understanding when the system transient or unusual operating condition has cleared; thereby allowing normal pump operation to resume.

A “smart” pumping system consists of a pump, variable speed drive, instrumentation, microprocessor and special software. The pump can be any standard centrifugal pump fitted with instrumentation to measure suction pressure, suction temperature, discharge pressure and pump flow. All of the hydraulic characteristics of the pump, fluid characteristics, user control parameters, alarm settings and pump control software reside on the microprocessor of the smart controller. The pump control software enables the controller to sense pump and process conditions and react accordingly. These systems can be designed to maintain constant values of speed, capacity, pressure, level or pH and can be controlled either locally or through a distributive control system (DCS).

The value to the customer in using Smart-Pumping Systems is reduced life cycle costs. The major components of life cycle cost are:

- Operating Cost
- Maintenance Cost
- Initial Cost
- Installation Cost

LOWER OPERATING COST

System Curve

A system curve is comprised of a static component and a dynamic component. The static component of the system curve does not change with flow rate. The dynamic component is essentially proportional to the square of the rate of flow. It is also a function of other variables such as pipe configuration/size, surface roughness, quantity and type of fittings/valves and fluid viscosity. These can be represented by a single system constant and the dynamic or frictional head can be expressed as:

$$H_f = K\,Q^2$$

The dynamic head constant K is a constant for a given system. However, if a control valve position changes in the system the constant K will also change.

Conventional System

Figure 1 shows a typical control scheme for a conventional pumping system. Note the system curve includes a static component of 6.1 meters. This is the change in elevation between the suction and discharge source. In this type of system the pump operates at a fixed speed and the pump performance curve is based on an impeller diameter pre-selected to match the system requirements as closely as possible. It should be noted that it is common practice to add a safety margin to the design point where it is difficult to accurately define system losses. This can result

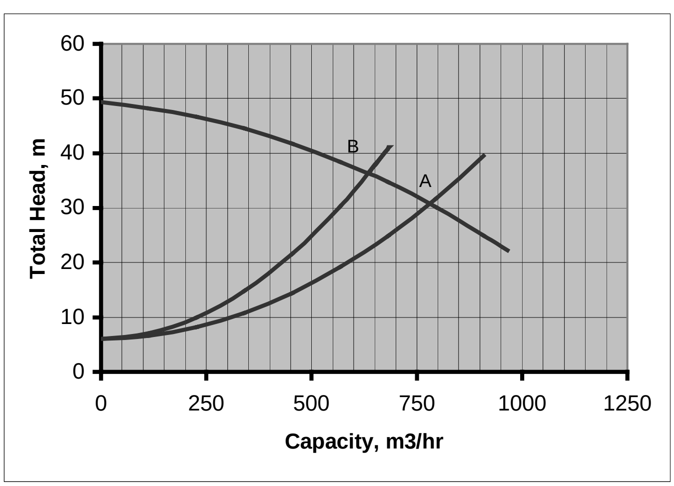

Figure 1. Conventional Pumping System Control

in an oversized pump which runs out too far on the curve and absorbs too much power. The total system head curve intersects the pump head-capacity curve at point “A” with the control valve wide open. The design flow for this system is 638 m^3/hr so the friction head (point “B”) must be increased to 37 meters in order to operate at this point. The most common method of varying the capacity in a conventional system is to introduce a variable resistance device that will alter the system friction curve; this is the main function of a control valve. Control valves are throttling devices, which use some of the available pumping energy to control the process. The amount of consumed energy will vary depending on the method of control, valve sizing and the operating point. In the U.S., a common control valve standard (PIP PCECV001) specifies that the control valve shall be 50-80% open at design flow, at least 10% open at minimum flow and no more than 90% open at maximum flow. Other methods base the amount of pressure drop on past plant practice or rules of thumb.

Variable Speed System

In a variable speed system the controller will match the pump output to system head requirements without the need for a control valve. Safety factors and pressure margins typically built into dynamic head systems can be eliminated and in some cases result in a lower cost pump selection. Since the smart controller can adjust the pump speed to suit the required system conditions only one impeller diameter need be stocked. This offers the benefit of lower inventory cost. In variable speed systems the design point no longer needs to be based on a fixed speed. This yields a larger number of selections over a given pump range with a better chance of operating at or near the best efficiency flow. Variable speed control is most effective and efficient in all friction head systems. The effectiveness diminishes somewhat for applications having high static head and low dynamic head, since the intersection of the pump and system curve moves further to the left of the best efficiency flow[1]. Careful selection is required for these applications.

Figure 2 shows a variable speed system with system curve “A” identical to that shown in Figure 1. Head-Capacity curves are shown at various speeds. If the desired operating flow is 638 m^3/hr it is shown that the pump can operate at a substantially lower speed and head. In this example, the savings of the variable speed system over a conventional system is represented by the difference in head between points “B” (Figure 1) and “C” (Figure 2).

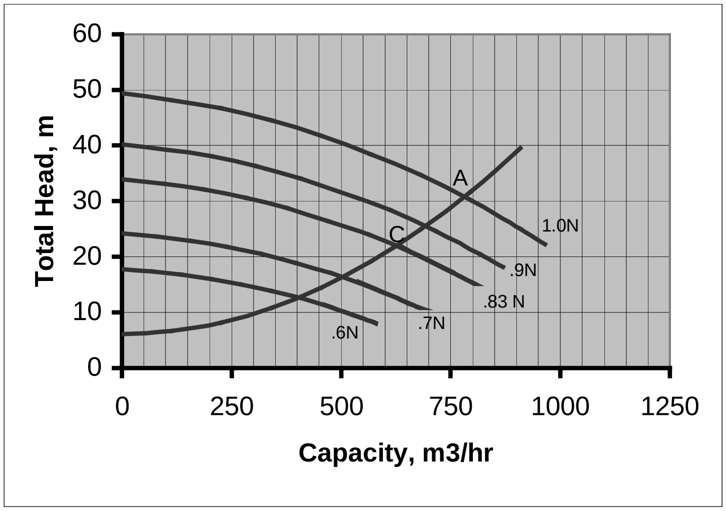

Figure 2. Variable Speed Pumping System Control

Life Cycle Operating Cost

This difference in system head requirements can often translate to thousands of dollars in energy savings over the life of a pump. Table I exemplifies these savings and is based on a cooling tower installation[2] represented by Figures 1 and 2. Note that the total pump head has been reduced from 37 meters to 23 meters. As a result, the pump power has dropped nearly 30 kW and operating speed has been lowered by over 300 rpm.

Table I. Life Cycle Operating Cost Savings

	Conventional System	**Smart Pumping System**
Pump Size	8x10-13 (ANSI B73)	8x10-13 (ANSI B73)
Rating at design, m^3/hr	639	639
Rating at design,Total Head, meters	37	23
Speed, r/min	1780	1476
Yearly Operation, hrs	8760	8760
Rating at Design, kW	77.3	47.7
Equipment Life, Years	15	15
Yearly Energy Use, kW-hr	707,700*	456,400**
Total Energy Use, kW -hr	10,615,000*	6,845,000**
Electricity Cost, $(US)	0.06	0.06
Total Life Cycle Operating Cost, $(US)	636,900*	410,700**

Life Cycle Operating Cost Savings: $(US) 226,200

* Includes motor losses

** Includes motor and VFD losses

The above difference in energy costs between a conventional system and a variable speed system represents a 35.5% decrease in operating costs over the life of the pump.

LOWER MAINTENANCE COST

The primary components in pump failures are bearings and mechanical seals. Excessive vibration, excessive loads and/or poor lubrication are the primary causes of failure for these parts. Designing a pump with a larger shaft and bearings does not guarantee longer life. Many failures can be attributed to operator error and application factors. Operating range, impeller diameter and operating speed all have an effect on the overall reliability of a pump.

Operating Range

A centrifugal pump is designed to operate most reliably at one capacity for a given speed and impeller diameter. This capacity is usually at or near the best efficiency flow. As pump operation moves away from this optimum capacity, turbulence in the casing and impeller increases. As a result hydraulic loads, which are transmitted to the shaft and bearings, increase and become unsteady. These loads are related to the impeller diameter in a cubic manner. The severity of these loads can have a negative effect on reliability.

Impeller Diameter

Impeller diameter affects reliability by the loads that are imposed to the shaft and bearings as the impeller vanes interact with the volute cutwater. These loads are also related to the impeller diameter in a cubic manner. Maximum or near maximum impeller diameters result in a less than optimum gap between the cutwater and impeller. As each vane passes the cutwater a large pulse is produced which results in an accompanying unsteady deflection of the pump shaft. These unsteady deflections can be very damaging to mechanical seals. There is an optimum cutwater gap that will limit these unsteady deflections[3]. With larger than optimum gaps the damaging cutwater effect is minimized but the effects of suction and discharge recirculation become of more concern, especially if vane overlap is lost due to large impeller trims.

Operating Speed

Operating speed affects pump reliability through rubbing contact and wear in seal faces, reduced bearing life due to increased loads, lubricant breakdown due to excessive heat and wetted component wear due to abrasives in the pumpage.

In addition, an increased operating speed can easily push a low suction energy pump into a high suction energy region with accompanying noise, vibration and possible cavitation damage. The onset of high suction energy levels in pumps is directly related to operating speed, suction specific speed, specific gravity and the thermodynamic properties of the liquid being pumped, as well as impeller geometry and operating point[4].

How Smart Pumping Systems Help

As mentioned earlier in this paper, the smart pump controller will match pump output exactly to system head requirements. If upstream system conditions change due to a transient the pump will either increase or decrease its speed in order to maintain a constant output. This eliminates the need to add safety margins that will oversize the pump. With variable speed systems there is a better chance of finding a selection which will operate at or near the best efficiency flow; this usually occurs at a speed less than the pump maximum design speed. In many cases a smaller pump can be selected in a variable speed system when compared to a conventional system.

Smart Pumps Monitor System Conditions

Some of the more common causes of failures are attributed to the following upset conditions:

- Dry running caused primarily by closed suction valves
- Continuous operation below minimum flow
- Cavitation due to insufficient NPSH available
- Heat build-up and subsequent liquid vaporization due to a closed discharge valve

Smart pumping systems are capable of detecting all of these conditions. This is accomplished by mapping the entire performance characteristics of the pump including NPSHR over a range of speeds. Fluid characteristics such as specific gravity and vapor pressure are also mapped over the operating temperature range. Smart pump instrumentation consists of a suction pressure transducer, discharge pressure transducer, flow meter and suction temperature transmitter. These instruments transmit 4-20 mA analog signals back to the smart controller where they are processed and converted to the appropriate measurement. These measurements are constantly compared to the actual pump hydraulics, which reside on the microprocessor.

Protection Against Transients

An NPSH margin tailored to the particular application is specified as one of the protective parameters in the software. If the measured suction head drops below this margin the smart pumping system can either alarm, alarm and control or alarm and trip depending on user requirements. The alarm and control mode reduces the pump speed just enough to maintain the specified NPSH margin requirements. However, once the transient has cleared the pump will resume normal pumping operation.

A low flow monitor will detect a dry running condition, operation below minimum flow or a closed discharge valve condition. If flow cannot be maintained user settings can be selected to alarm, alarm and control or alarm and fault. Magnetic drive pumps can especially benefit from dry run protection[5].

Other safeguards warn and protect against overpressure, overtemperature, overcurrent and overspeed. Setpoints can be selected to restrict operation to user specified ranges.

Smart pumping systems can also incorporate self-diagnostic features to compare current pump performance to the as new factory performance. An alarm setting will advise the user when the actual performance degrades past a certain preset value. This will give ample warning to the user to schedule planned maintenance on the unit during the next outage. If a fault history and time stamp is provided it will enable the user to accurately determine system behavior at the time of the fault. This will facilitate troubleshooting and remedying of system transients.

The protection that smart pumping systems offer will no doubt translate to extended meantime between failure and improved life cycle maintenance cost. One method of quantitatively predicting these life cycle cost savings is outlined by Bloch and Geitner[3]. In this method, reliability factors for operating speed, operating point and impeller diameter are assigned values between 0 –1, where higher values indicate more reliable selections. A reliability index, which is the product of the three reliability factors, can then be compared to pumps of similar design to give an indication of overall reliability. Table II shows the effect on life cycle maintenance savings for the cooling tower application using this method. It assumes an average MTBF for a conventional sealed pump of 18 months at an average cost per repair of $(US) 2,500.

Table II Life Cycle Pump Maintenance Cost Savings

	Conventional System	**Smart Pumping System**
Reliability Index	0.2	0.3
Average MTBF, Months	18	27.1
Equipment Life, Years	15	15
Total No. of Repairs	10	6.6
Total Pump Maintenance Cost (US)	25,000	16,600

Life Cycle Pump Maintenance Cost Savings: $(US) 8,400

The difference in pump life cycle maintenance savings for this smart pumping system represents a 33.5% decrease when compared to a conventional system and MTBF is extended from 18 to 27 months.

INITIAL COST

Many users become pre-dispositioned at the sound of the words "smart variable speed controller" when they think of cost. However, if the total initial cost of a smart pumping system is compared to that of a conventional system it can be shown that smart systems can be very competitive in price. When compared to total life cycle cost these systems can have an overwhelming advantage.

As mentioned earlier in this paper the smart controller continuously monitors both pump and system conditions and matches pump output to system requirements exactly. Since the smart controller is a variable speed device there is no need for an automatic control valve in the system. One manufacturer has a patented method of measuring process flow internal to the pump discharge nozzle. The casing nozzle is used as a differential pressure device with an accuracy between 2–5% and a rangeability of 3:1. In many applications this could eliminate the need for an external flowmeter in the system, such as a magmeter. Additionally, smart controllers have integral starters and there is no need for a separate starter. One of the many safeguards built-in to smart controllers is to protect against operation below minimum flow. Operation can also be restricted to user specified ranges. Depending on system design, recirculation lines and valves can also be eliminated. Since added safety margins are not required when controlling with a variable speed system, in some cases a smaller pump can be used. *Figure 3* shows a conventional system with pump/motor, control valve, flowmeter, isolation valves, recirculation line, DCS and starter. Smart pumping systems integrate the functionality of several of these pieces of equipment as shown in *Figure 4.*

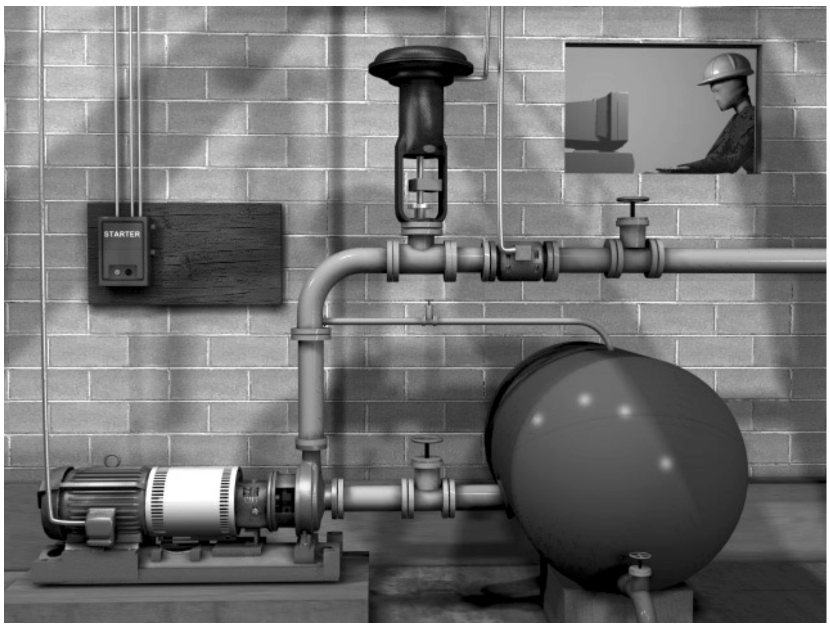

Figure 3. Conventional Pumping System

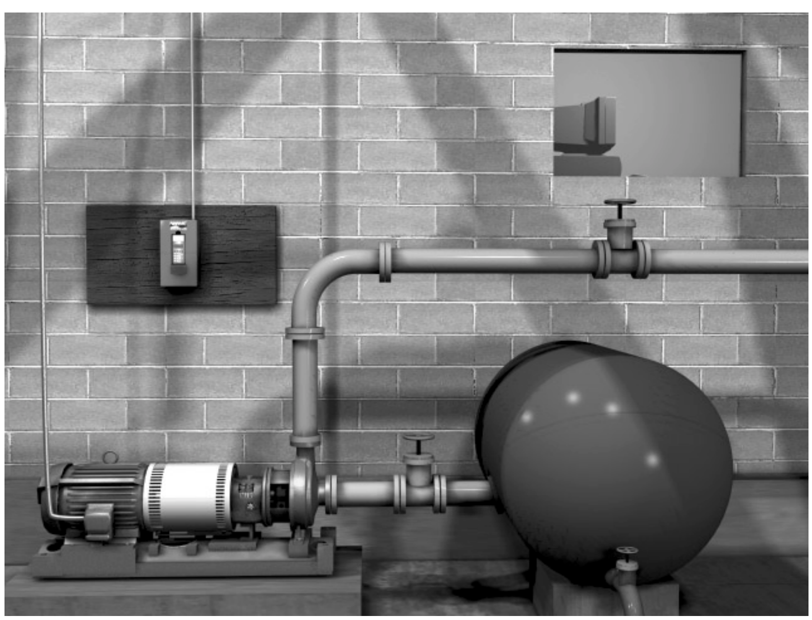

Figure 4. Smart Pumping System

Table III Life Cycle Initial Cost Savings

	Conventional System, (US)	**Smart Pumping System, $(US)**
Pump, baseplate, coupling and motor	10,600	10,000
Smart Controller and Instrumentation	0	9,800
Control Valve	4,700	0
Flowmeter	4,300	0
Recirculation Line	0	0
Motor Starter	1,000	0
Total Life Cycle Initial Cost, $(US)	20,600	19,800

Life Cycle Initial Cost Savings: $(US) 800

Table III shows that the life cycle initial cost savings for a smart pumping system compares favorably with a conventional system.

INSTALLATION COST

By reducing the amount of equipment in a system both installation and maintenance costs are decreased. The installation costs associated with piping, air lines, wiring and communication lines can all be decreased by eliminating a control valve, flowmeter, separate starter and recirculation line valve and piping.

Table IV shows the effect on life cycle installation savings for the application shown in Table I. In this example pump installation costs are based on 5x initial cost. Installation costs for the control valve, flowmeter and starter are based on 3x initial cost of these components.

Table IV Life Cycle Installation Cost Savings

	Conventional System $(US)	**Smart Pumping System $(US)**
Pump, baseplate, coupling and motor	53,000	50,000
Smart Controller and Instrumentation	0	3,750
Control Valve	14,100	0
Flowmeter	12,900	0
Recirculation Line	0	0
Motor Starter	3,000	0
Total Life Cycle Installation Cost, $(US)	83,000	53,750

Life Cycle Installation Cost Savings: $(US) 29,250

The difference in pump installation savings for this smart pumping system represents a 35% decrease as compared to a conventional system.

Since the control valve and external flowmeter have been removed from the smart pumping system, maintenance for these items can also be eliminated as shown in Table V.

Table V Life Cycle Other Maintenance Cost Savings

	Conventional System $(US)	**Smart Pumping System $(US)**
Smart Controller and Instrumentation	0	2,000
Control Valve	3,200	0
Flowmeter	2,800	0
Total Life Cycle Installation Cost, $(US)	6,000	2,000

Life Cycle Other Maintenance Cost Savings: $(US) 4,000

TOTAL LIFE CYCLE COST SAVINGS

A summary for each of the major life cycle cost components is shown below for a conventional and smart pumping system.

Table VI Life Cycle Cost Summary

	Conventional System $(US)	**Smart Pumping System $(US)**
Life Cycle Operating Cost	636,900	410,700
Life Cycle Pump Maintenance Cost	25,000	16,600
Life Cycle Other Maintenance Cost	6,000	2,000
Life Cycle Initial Cost	20,600	19,800
Life Cycle Installation Cost	83,000	53,750
Total Life Cycle Cost	771,500	502,850

Total Life Cycle Cost Savings: $(US) 268,650

The total life cycle savings for the smart pumping system is $(US) 268,650 for this installation. This represents a 35% saving over a fifteen-year equipment life. The present value of these savings, assuming a 10% interest rate, is $148,300 and the difference in initial capital investment is negligible.

CONCLUSIONS

Smart pumping systems react and adjust themselves to system changes without manual intervention. These types of systems must have the ability to recognize and safeguard themselves from operating under conditions, which may reduce mean time between failure (MTBF). A smart pumping system should be capable of understanding when the system transient or unusual operating condition has cleared, thereby allowing normal pump operation to resume. The value of these systems to the user is in reduced life cycle costs. Smart systems utilize a variable frequency controller that can match pump output to system head requirements thereby reducing operating costs significantly over the life of the pump. Energy consuming control valves are no longer required. The smart-control software will not permit the pump to operate outside user specified ranges or under conditions that typically cause pumps to fail. As a result, maintenance costs will decrease and MTBF will increase for these systems. Smart pumping systems can integrate the functionality of several pieces of equipment from a conventional pumping system to reduce both initial and installation cost. If the total initial cost of a smart pumping system is compared to that of a conventional system it can be shown that the smart system can be very competitive in cost. When comparing to total life cycle cost smart pumping systems can have an overwhelming advantage.

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