MOTOR SAMPLE PROBLEM #1

Low-Slip Drive Belts

Low-slip drive belts have been recommended to the owner of **Grapes dù Räth** as a way to reduce the energy consumption of his wine cellar ventilation system. If cogged belts could save 2% of the 25 HP full load of the fan system, how much money could the owner afford to spend in order to recover his investment in 2 years? Assume that the average cost of electricity is 15¢ per kWh.

SOLUTION**:**

We are actually working this problem backwards; we are finding the investment cost from a stipulated simple payback period. First, let's determine the energy and cost savings for this measure:

kWh savings	= 2 % X 25 Hp X 0.746 kW / HP X 8,760 hrs. / yr.
	= 3,300 kWh / yr.
$ savings	= 3,300 kWh / yr. X $0.15 / kWh
	= $500 / yr.

Simple payback period is found from:

S.P.	= cost / savings

and re-arranging this to find the investment cost:

Cost	= S.P. X savings
	= 2.0 yrs. X $500 / yr. savings
	= $1,000

MOTOR SAMPLE PROBLEM #2

Reduce Fan Speed

The **1st Southern Regional National Bank** corporate office building had been drafty and noisy for several years. The management finally asked a test and balance service contractor to come in and adjust the air handler fan. They found that the 25 HP motor was fully loaded, but the air handling unit was delivering 15% more air than was needed. The test and balance contractor adjusted the fan pulleys and decreased the air flow by 15%, reducing the fan noise and eliminating most of the draft problems. The owner would now like to know if the energy savings justified the cost of the service. Approximately how much money will be saved by this adjustment, if the fan runs continuously for 8,760 hours each year, and the cost of electricity is 15¢ per kWh? (Ignore any difference in motor efficiency at the new load.)

SOLUTION:

We can begin by recalling the fan affinity relationship (fan law) that relates the fan power to the output:

$$HP_2 / HP_1 = (CFM_2 / CFM_1)^3$$

Re-arranging this to solve for the new motor horsepower, HP_2:

$$HP_2 = HP_1 \times (CFM_2 / CFM_1)^3$$

We don't have the actual measurements for airflow here, but we do know that the test and balance company reduced the air flow by 15%. That gives us a relationship of initial and final air flows as:

$$CFM_2 = 0.85\ CFM_1$$

Substituting this into the equation for horsepower gives:

$$\begin{aligned} HP_2 &= (0.85 / 1.0)^3 \times 25\ HP \\ &= 0.61 \times 25\ HP \\ &= 15\ HP \end{aligned}$$

The power reduction, kW is:

$$\begin{aligned} \Delta\ kW &= (25 - 15)\ HP \times 0.746\ kW / HP \\ &= 7.5\ kW \text{ (assuming 100\% motor efficiency)} \end{aligned}$$

The annual energy savings for this motor, operated 8,760 hours per year, is:

$$\begin{aligned} \text{kWh savings} &= 7.5\ kw \times 8{,}760\ hrs. / yr. \\ &= 66{,}000\ kWh / yr. \end{aligned}$$

The annual cost savings for this motor is:

$$\begin{aligned} \$\ \text{savings} &= 66{,}000\ kWh \times \$\ 0.15\ kWh \\ &= \$\ 9{,}900 / yr. \end{aligned}$$

MOTOR SAMPLE PROBLEM #3

Replace Existing Fan Motor

What are the estimated savings if we replace an existing 5 HP, three phase evaporator fan motor in a refrigerated warehouse with a premium efficiency motor, increasing the electrical efficiency from 85% to 89.5%? Assume 8,760 hrs. / yr. operation, cost of electricity 15¢ per kWh.

SOLUTION:

[Notice that in this problem, energy savings arise from two sources. The motor will use less energy, because it will be more efficient. But the refrigeration system will also save energy, because the waste heat from the motor (resulting from inefficiencies) will be reduced. This will decrease the refrigeration system load, but we will consider the fan energy savings only.]

A simple expression for evaluating the electrical savings for motor efficiency improvement is:

$$\Delta kW = HP \times 0.746 \{kW / HP\} \times [(1/\text{old efficiency}) - (1/\text{new efficiency})]$$

Substituting the values for this example:

$$\Delta kW = 5 \times 0.746 \times [(1/0.85) - (1/0.895)]$$
$$= 0.2 \text{ kW}$$

and energy savings:

$$\Delta kWh = 0.2 \text{ kW} \times 8{,}760 \text{ hrs. / yr.}$$
$$= 1{,}800 \text{ kWh / yr.}$$

$ savings = 1,800 kWh / yr. X $0.15 / kWh
= $270 / yr.

Estimated cost for fan, installed: $750 ($500 plus $250 installation)

Simple payback = $750 / $270 / yr.
= 2.8 years

MOTOR SAMPLE PROBLEM #4

Pump Motor Variable Speed Drive

A local mining company transports minerals from the mine to the refinery in a water slurry. The pump used for this job must deliver a maximum of 1,000 GPM (gallons per minute) of slurry with a specific gravity of 1.25. The piping runs uphill from the mine a total of 22 feet in elevation, while the piping system friction resistance is 25 PSIG at full flow. (The elevation difference is called “static head” and the pressure drop that occurs because of friction losses is called “dynamic head”.)

In order to regulate the flow of slurry during slow production periods, a throttling valve is installed at the pump outlet. If the cost of electricity is 15¢ per kWh, what would be the economic benefits of using a VSD instead of the throttling valve?

SOLUTION:

First, calculate the total pumping head required at design conditions; note that the static head is simply added to the dynamic head to get total pumping head. (A conversion factor we need here is 1 PSIG = 2.31 ft. head).

Total head = 22 ft. + (2.31 ft. / PSIG x 25 PSIG)

= 80 ft. (approx.)

Next, construct a system curve for the pumping system using Equation 1. It is used to calculate the system pressure for various load points along the curve. For liquid flowing through a piping system, the system pressure varies with the square of flow rate (affinity law for pumps):

$$P_2 / P_1 = (GPM_2 / GPM_1)^2 \qquad \text{(Equation 1)}$$

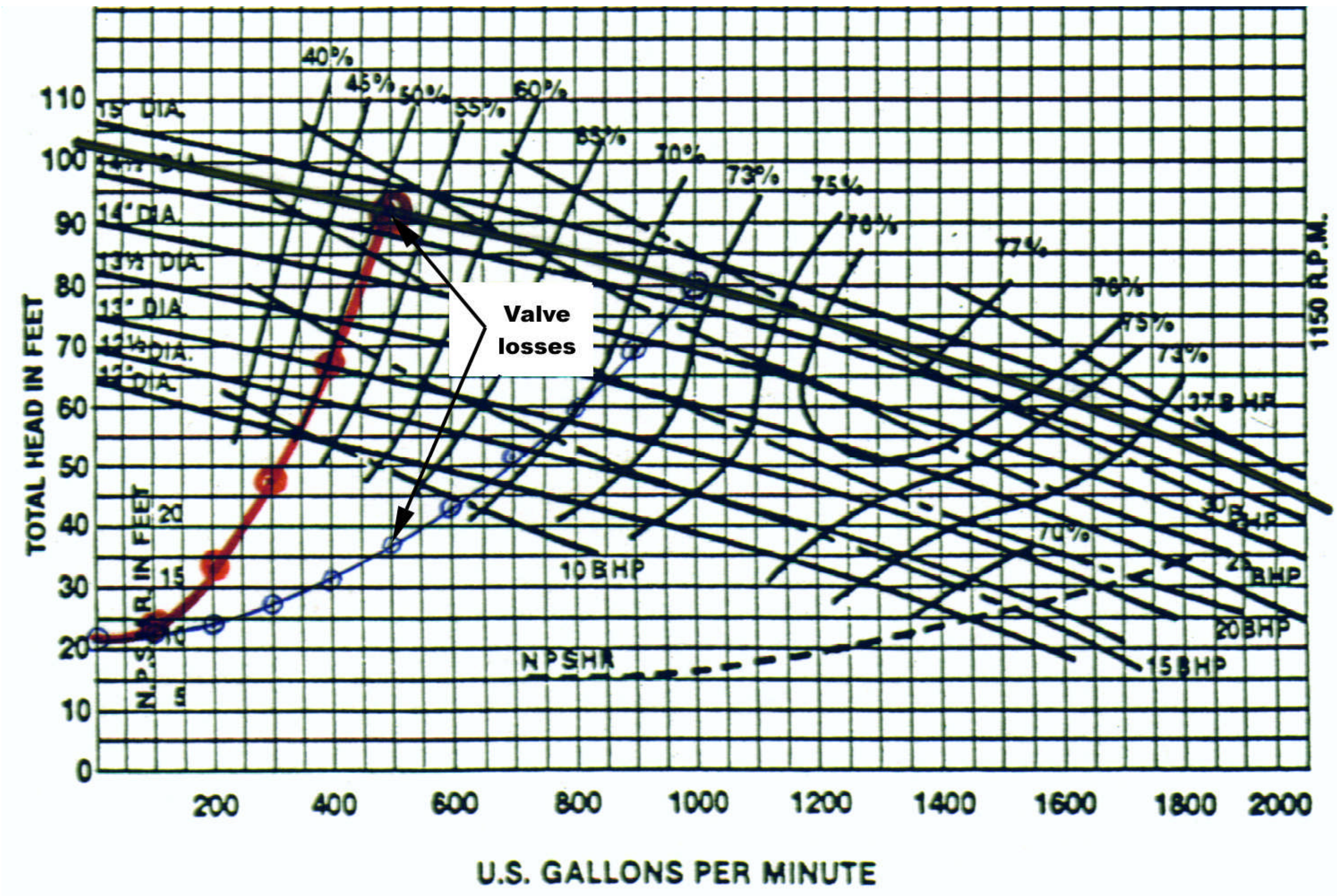
where P = system dynamic pressure or head and GPM = gallons per minute flow rate, and the subscripts denote initial and final conditions.

Using this equation, we construct a table of values for the pumping system. Notice that the system dynamic head at each load point is calculated separately, and the static head is then added to find the total head, just as for the initial operating conditions. These points are plotted on the pump curve included in this example, beginning at the initial conditions of 80 ft. head and 1,000 GPM at full load. (Pump curves can be obtained by the manufacturer if the model number is known.)

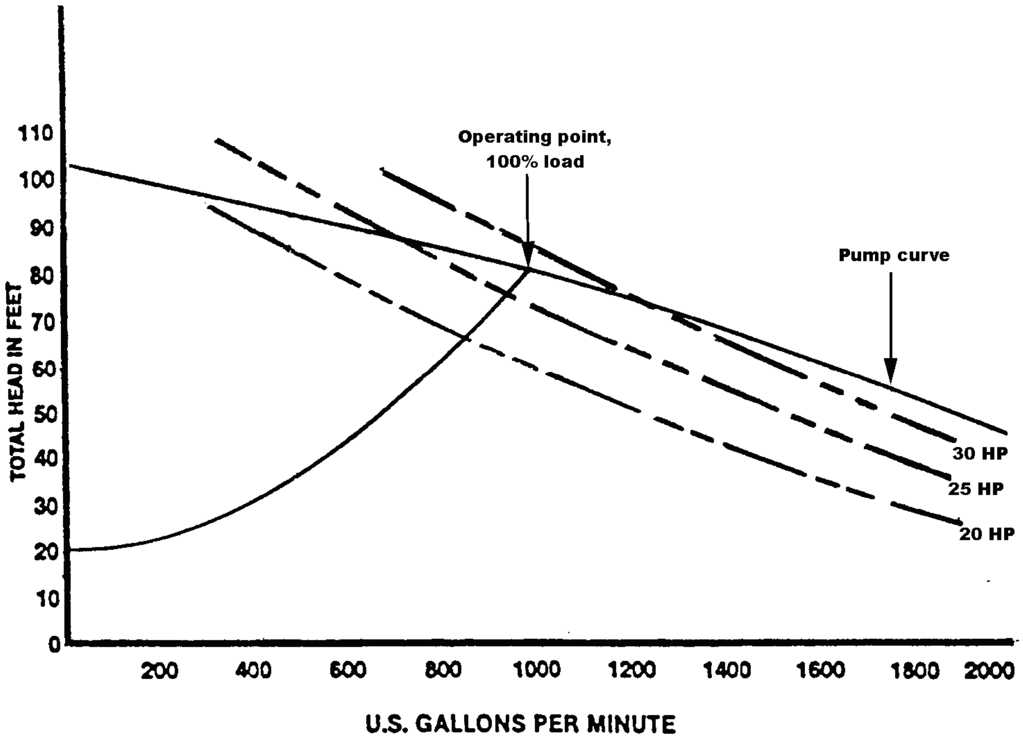
Notice that the pumping power shown on the curve is about 28 HP. Since pump curves are usually drawn for water, we have to adjust the values for horsepower by multiplying by the specific gravity of our fluid. In this example, specific gravity is 1.25; multiplying by 1.25 gives 35 horsepower.

Table 1: System curve data, 100% load

GPM	Total Head
1,000	80
750	55
500	37
250	26



In order to make the pump curve information clearer, from this point we will use a simplified pump / system curve diagram:



Simplified pump / system curve

To determine the possible benefits of VSD for this application, we need an estimate of the load profile for the pumping system. For this example, we will arbitrarily assume the following profile:

Example Load Profile

% Load	% Time	Hrs/Yr	GPM
100	15	1,314	1,000
90	20	1,752	900
80	25	2,190	800
70	10	876	700
60	10	876	600
50	10	876	500
40	10	876	400
Totals	100	8,760	

Take the case of 50% of design flow. We want to determine the effect of using a VSD rather than a throttling valve to control flow. Start by finding the new pump head corresponding to the reduced GPM, at the intersection of the system curve with the pump curve.

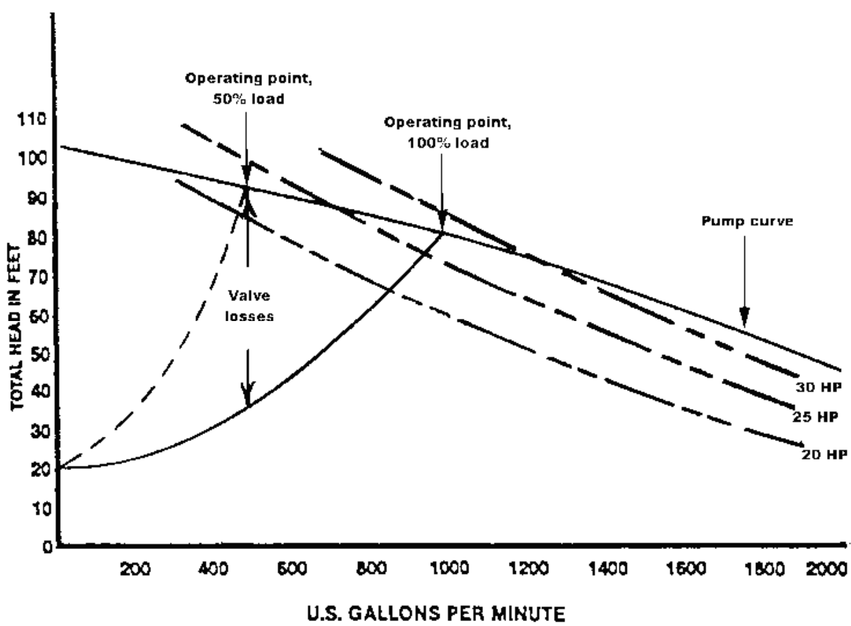
The pump will produce 92 ft. of head at this point, and the throttling valve will reduce the pressure to that actually required by the piping system as shown on Figure 1. After subtracting the static head of 22 ft., we are left with 70 ft. of dynamic head.

We can use this value and Equation 1 to calculate values at any number of arbitrarily selected points and generate a new table of total head pressure values and new system curve, for the case of 50% load. Remember that we add the static head back to the dynamic head to get the total.

Table 2: Pump system curve data, 50% load

GPM	Total Head
500	92
400	67
300	47
200	33
100	25

These data are superimposed on the pump curve. The pump curves include most of the information needed to complete the calculation. Reading the curve values at 500 GPM at the intersection of the pump curve, we find that the horsepower required is approximately 23 HP. Multiplying by specific gravity of 1.25 gives 29 HP.



Simplified pump curve and system curves, 50% load

To compare the power requirement for the system with a throttling valve to a VSD control application, use the affinity law for pumps to calculate the horsepower needed if the flow is controlled by reducing the pump RPM. Recall that the initial power requirement is 35 HP.

SOLUTION:

$HP_2 = HP_1 \times (GPM_2 / GPM_1)^3$ Equation 2

$HP_2 = 35\ HP \times (500\ GPM / 1000\ GPM)^3$

$= 4\ HP$

HP savings over throttling valve:

$\Delta HP = 29\ HP - 4\ HP$

$= 25\ HP$

kW demand savings over throttling valve:

$\Delta kW = 25\ HP \times 0.746\ kW / HP$

$= 19\ kW$

kWh savings over throttling valve at 50% load:

$\Delta kWh = 19\ kW \times 876\ hrs. / yr.$

$= 17{,}000\ kWh / yr.$

Cost savings over throttling valve at 50% load:

Savings = 17,000 kWh / yr. X $0.15 / kWh

= $2,500 / yr.

MOTOR SAMPLE PROBLEM #5

Winder Motor Variable Speed Drive

A plastic film manufacturer has asked you to evaluate the installation of a VSD to control a take-up winder used to pull plastic film sheet from a production machine and roll it onto an 8' wide core. The core is initially 6 inches in diameter but as the film accumulates the finished roll increases to a diameter of 40 inches. The plastic film must be wound under a constant tension of 5 lb. per linear inch, and the velocity of the film coming off the machine is 2,000 FPM. Determine the power requirements for the winder motor and any benefits that might be realized by using a variable speed drive.

SOLUTION:

We can determine from some straightforward geometric relations that the torque varies linearly with the diameter of the winder, which in turn varies over time as more paper is wound.

The torque is calculated from the relationship:

Torque = R X F

where R is the radius of the roll and F is the force, or film tension. The film tension is given by:

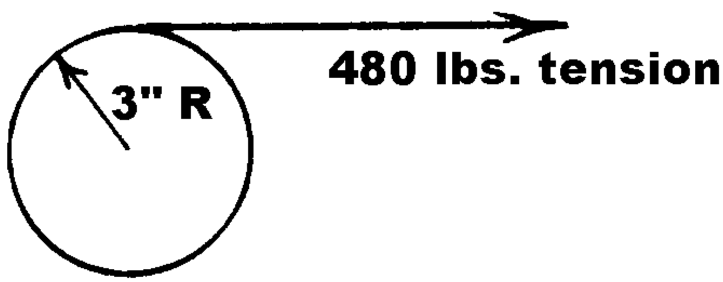
F = 5 lb. / inch X 12 inches / ft. X 8 ft.

= 480 lbs.

Torque is usually expressed in ft. - lbs., which means that we need to divide the roll radius by 12 inches / foot. Calculating the beginning and end conditions will yield the maximum and minimum values of torque. This will bracket the power requirements for the drive motor, and would allow us to develop a load profile for the motor if we desired to do so.

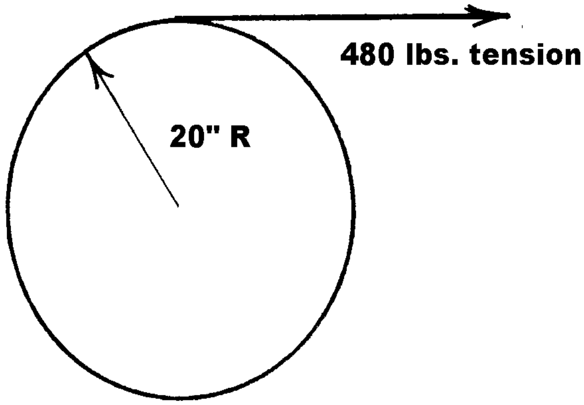
Empty torque= (3 inches X 480 lbs.) ÷ 12 in. / ft.

= 120 ft. - lbs.



Full torque = (20 inches X 480 lbs.) ÷ 12 in. / ft.

= 800 ft. - lbs.



The rotation of the winder will slow as it fills, in order to maintain a constant linear velocity of 2,000 FPM. As the roll grows larger, its circumference increases and the drive motor must slow down in order to maintain the same linear take-up rate. The roll circumference is given by:

C = Diameter X π

and the roll RPM is:

RPM = 2,000 FPM ÷ C

Initial RPM = (2,000 ft. / min. X 12 in. / ft.) ÷ (6 in. X π)

= 1,300 RPM

Final RPM = (2,000 ft. / min. X 12 in. / ft.) ÷ (40 in. X π)

= 190 RPM

The power requirement for the winder motor is found from the relationship:

HP = (Torque X RPM) / 5,250

We can determine the initial and final power requirements of the motor using this relationship and the initial and final RPM for the winder.

Initial HP = 120 ft. - lbs. X 1300 RPM / 5,250

= 30 HP

Final HP = 800 ft. lbs. X 190 RPM / 5,250

= 30 HP

Surprise!!! Notice that a winding application such as this is a constant motor horsepower application, and energy savings for VSD are unlikely. However, there are reasons to use VSD for such an industrial application:

Can use readily available AC motor, instead of DC motor and controls

Can use premium efficiency, inverter duty motors

AC motors are generally less expensive

GLOSSARY

Breakaway (breakdown) torque – the maximum torque a motor can produce, usually not developed at full rated speed. Also referred to as pull-out or maximum torque.

Foot-pound – the amount of energy required to raise a one-pound weight a distance of one foot

Full load speed – the actual speed of an AC motor at which the full rated horsepower is developed. See **slip**.

Full load torque – the torque provided by a motor that is producing full rated horsepower at full load speed

Horsepower – a unit for measuring the power of motors. One horsepower equals 33,000 foot-pounds of work per minute.

Poles – the number of magnetic fields set up inside the motor by the placement and connection of the stator windings.

Rotor – the rotating core (and sometimes the windings) of a motor

Slip – the percentage difference between synchronous speed and the full load speed; a measure of motor loading

Starting torque – the torque applied to a load at rest by a motor that is not rotating when power is first applied

Stator – the stationary core (and usually the windings) of a motor

Synchronous speed – the maximum speed for an AC motor, determined by the number of poles in the stator windings and the frequency of the power source

Torque – the rotating force produced by a motor; measured in pound-feet, ounce-inches, or ounce-feet