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***Beam Me Up, Scottie*!**

Transport Energy: Motors, Fans, and Pumps

Created & Presented By:
Hank Jackson, PE
ETech Solutions
HZJackson@juno.com
www.ETechSolutions.biz

Date of Creation: March 2010 **Version #3-2012**

Copyright Materials

Objectives

- Understand basic applications of electric motor systems in commercial settings: fans and pumps, variable speed drives
- Learn how to estimate motor loads for fan and pump applications, and use the affinity laws for fans and pumps. Understand how variable speed drives are used to reduce energy consumption
- Learn how to calculate savings in pump and fan applications

Introductions

- Your Speaker
- You!
  - Who are you?
  - Where do you work?
  - Why are you here?

Review of Basic Concepts

- AC motor fundamentals
- Fan, pump power formulas
- Affinity laws (fan / pump "laws")

AC Motor Synchronous Speed

- "No load" RPM_s = 120 X frequency / number of stator poles (depends only upon construction and power supply frequency)
- Commercial / industrial motors are generally 1200, 1800, or 3600 RPM_s
- Dual speed motors (900 / 1800 RPM_s) have a switching means to combine poles electrically

AC Motor Nameplate

INDUCTION MOTOR			
MODEL: 5K254AK205		SERIAL NO.: 1105842	
HP 15	SERVICE FACTOR 1.15	TIME RATING CONT	
FL RPM 1775	ENCLOSURE ODP		
VOLTS 230/460	CYCLES 60	PHASE 3	
FL AMPS 38.6/19.3	FULL-LOAD POWER FACTOR 87.2%		
TYPE K	FRAME 254T	NEMA CLASS DESIGN B	CODE G
INSULATION CLASS B		MAXIMUM AMBIENT 40° C	
DRIVE END AFBMA BRG 45B003		OPP DIVE END AFBMA BRG 35BC02	
Full-load Efficiency 91.7%			

Courtesy Office of Industrial Technologies, US DOE

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Motor Slip

- Slip results from motor loading
- Usually a linear relationship with load; can be used to estimate motor load
- Full load slip = 1 – (FL RPM / RPM_s)
- Actual slip = 1 – (Actual RPM / RPM_s)
- % load = (Actual slip / FL slip) x 100

Governing Equations

- Pump HP = $\frac{\text{(GPM X head [feet] X s.g.)}}{\text{(3,960 X pump eff.)}}$

- Fan HP = $\frac{\text{(5.2 X CFM x pressure)}}{\text{(33,000 x fan eff.)}}$

- Torque (ft-lb) = HP X 5,250 / RPM

(1 HP = 746 watts; 0.746 kW)

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Affinity Relationships

(for centrifugal pumps and fans)

$$\frac{CFM_1}{CFM_2} = \frac{RPM_1}{RPM_2}$$

$$\frac{SP_1}{SP_2} = \left(\frac{RPM_1}{RPM_2}\right)^2$$

$$\frac{HP_1}{HP_2} = \left(\frac{RPM_1}{RPM_2}\right)^3$$

Affinity relationships **CANNOT** be used to compare one fan or pump against another!!

Power required is proportional to the cube (x^3) of the volume for centrifugal fans and pumps; reducing volume flow by 5% reduces power by almost 15%!

Small Group Exercise #1

- Get into groups of 2 – 3 people
- For a 10 HP motor with a synchronous speed of 1,800 RPM, calculate the slip if a tachometer shows the shaft to be turning at 1775 RPM (your answer will be a decimal number; convert to %)

Motor Efficiency Standards

- NEMA standard MG1 (newest revision 2011), tables 12-12 and 12-11 define nominal electrical efficiencies for alternating current motors manufactured for sale in U.S.
- Previous NEMA Premium™ efficiency motor standard now merely defines nominal performance
- Always check the nameplate or catalog data for actual efficiency

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INSULATION CLASS B		MAXIMUM AMBIENT 40° C	
DRIVE END AFBMA BRG 45B003		OPP DIVE END AFBMA BRG 35BC02	
Full-load Efficiency: 91.7%			

Courtesy Office of Industrial Technologies, US DOE

ASHRAE 90.1

- Sets fan power limitation on HVAC systems designed by Prescriptive Path, section 6.5.
- For constant volume systems < 20,000 CFM, limit is 1.2 HP / 1000 CFM and 1.1 HP / CFM > 20,000 CFM; works out to approximately 6.1- 5.6 in. w.g. with 80% efficient fan
- For VAV systems < 20,000 CFM, limit is 1.7 HP / 1000 CFM and 1.5 HP / CFM > 20,000 CFM; approximately 8.6 - 7.6" w.g. with 80% efficient fan
- Corrections allowed for filter drop and / or low temperature supply air

Constant Horsepower Loads

- Torque varies inversely with speed
- HP = RPM X Torque / 5,250
- Considered constant work
- Deadlifting applications such as cranes, hoists, winders, tooling such as lathes, drills
- Typical load presented by fans and pumps running at constant speed

Image courtesy DOE / NREL

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Constant Torque Loads

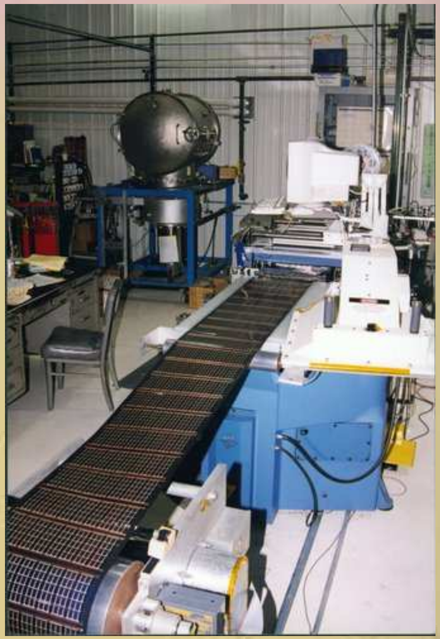

Image courtesy DOE / NREL

- Horsepower varies almost linearly with speed
- Torque = force X distance
- Constitute a large percentage of industrial loads, other than fans and pumps
- Conveyors, positive displacement pumps, hoists

Variable Torque Loads

- Pumps and fans constitute variable torque loads; most common HVAC load types
- Low torque at low speeds, high torque at high speeds
- May vary almost linearly (positive displacement pumps) or quadratically (centrifugal pumps and fans)

Image courtesy DOE / NREL

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Measuring motor loads

- Direct measurements
  - *Voltage, amperage; assumed power factor*
  - *Utility-grade power meter instrumentation*
  - *Tachometer measurements of slip*
- Indirect measurements
  - *T&B reports, submittals, log data*

Small Group Exercise #2

- You know the drill!
- For the same 10 HP motor with an actual measured RPM of 1775 RPM and a FL RPM of 1,750 RPM, what is the motor load in horsepower? In kW?
- How might you go about verifying this?

Variable Speed Drives

- Energy benefits are found in fan and pump affinity laws – changing the speed changes the volume, which changes the power requirement

- Basic principles of operation

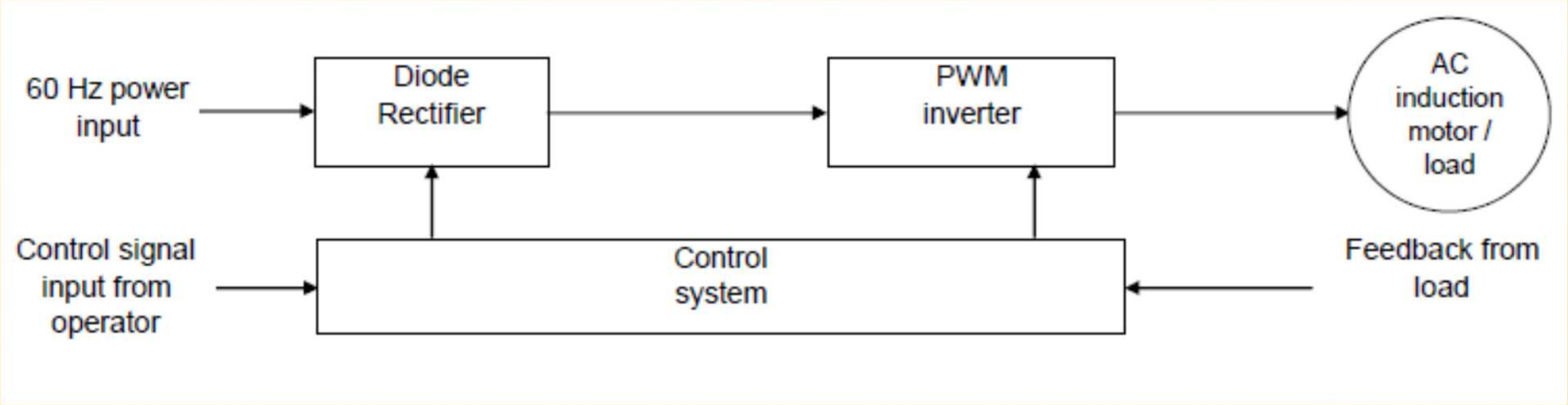
  - *DC rectification, voltage stabilization*
  - *A/C inverter with frequency synthesis*
  - *Motor link with filtering*

Image courtesy DOE / NREL

PWM Inverters

- Pulse Width Modulation - method of synthesizing the A/C waveform
- DC pulses are combined to form AC output
- Most common type of present-day VSD

VSD Block Diagram



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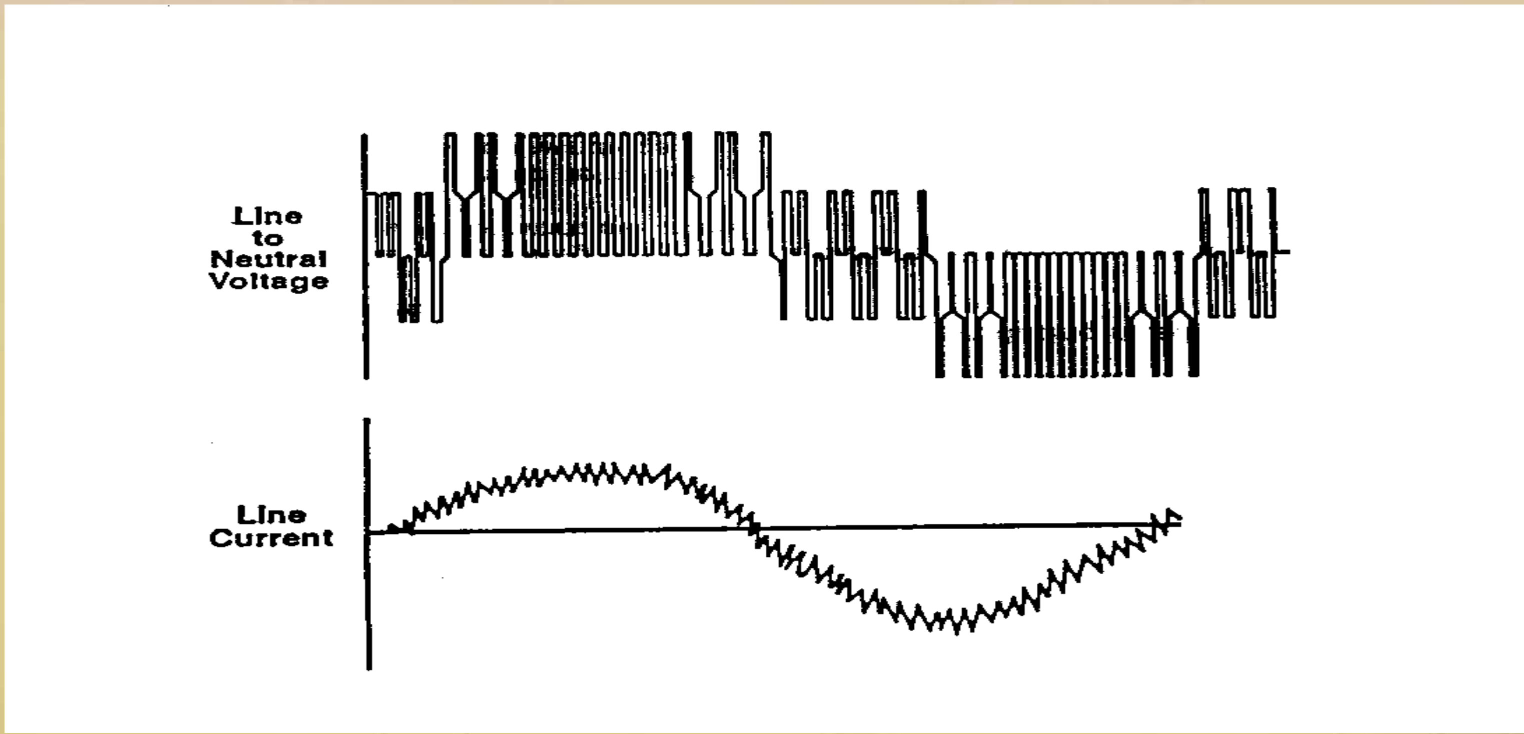
PWM A/C Output



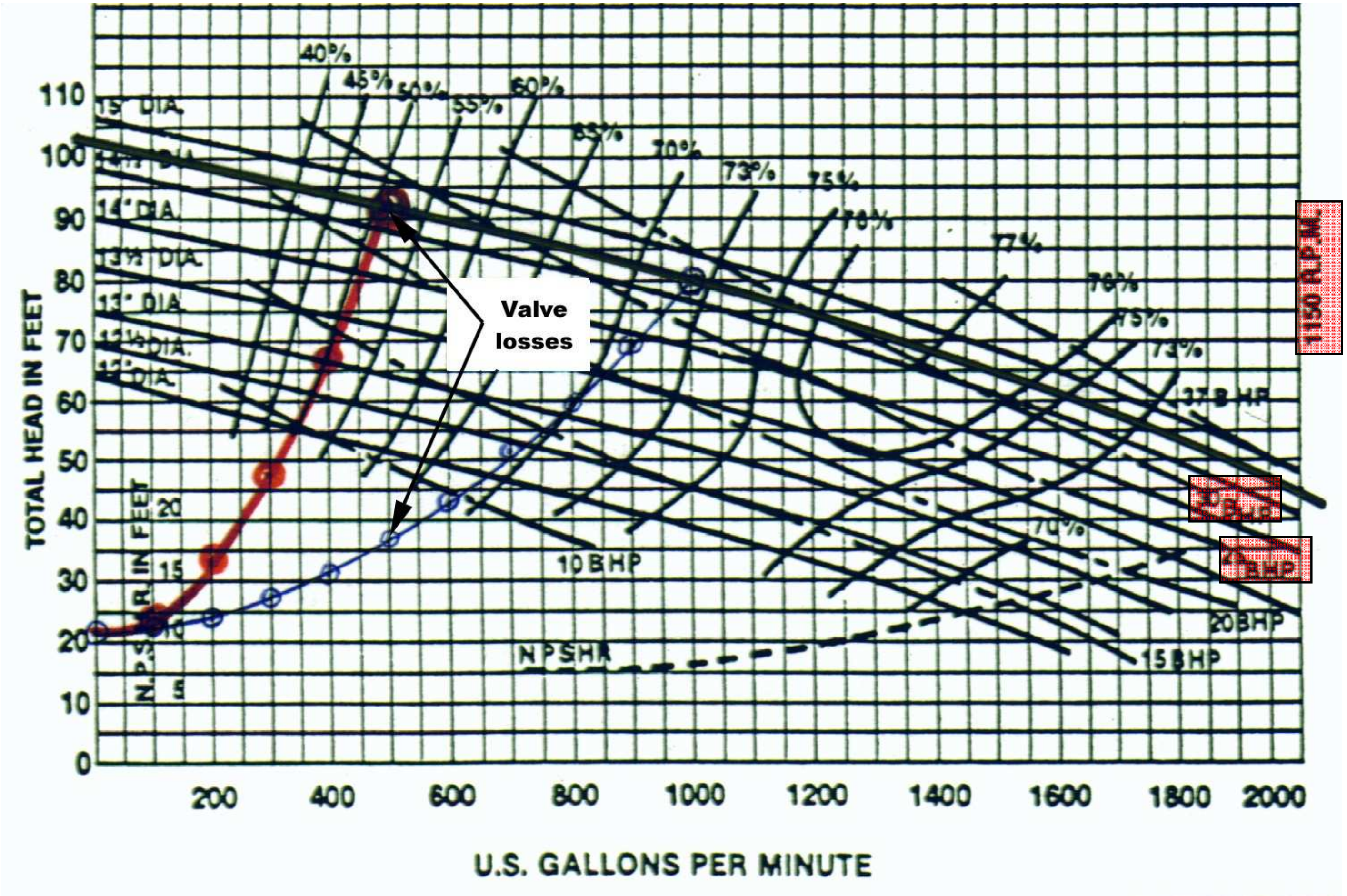
Basic Calculations for Fan and Pump Savings

- Establish a load profile
  - *Measure or estimate magnitude of load points*
  - *Measure or estimate annual operating hours at load*
- Calculate power requirements at each load point (kW)
- Calculate energy used at each load point using operating hours (kWh)

Calculation Steps for Fan and Pump Energy Savings

- Begin with design operating point on the fan or pump curve
- Calculate operating curve for off-design conditions (flow versus system resistance)
- Compare pump or fan curves to operating curve
- Use affinity laws to determine power reductions, energy savings possible using VSD compared to valves or dampers

Example Pump Curve



HVAC 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 EXAMPLE 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, HP2:

$HP2 = HP\ 1 \times (CFM2 / CFM1)^3$

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:

$HP_2 \quad = (0.85 / 1.0\ )3 \times 25\ HP$
$\qquad = 0.61 \times 25\ HP$
$\qquad = 15\ HP$

Example Problem #2, cont'd

The power reduction, kW is:

Δ kW = (25 - 15) HP X 0.746 kW / HP
= 7.5 kW (assuming 100% motor efficiency)

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

kWh savings = 7.5 kw X 8,760 hrs. / yr.
= 66,000 kWh / yr.

The annual cost savings for this motor is:

$ savings = 66,000 kWh X $ 0.15 kWh
= $ 9,900 / yr.

HVAC SAMPLE PROBLEM #5

Winder Motor Variable Speed Drive

A plastic film manufacturer has asked for your opinion about installing 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 core 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.

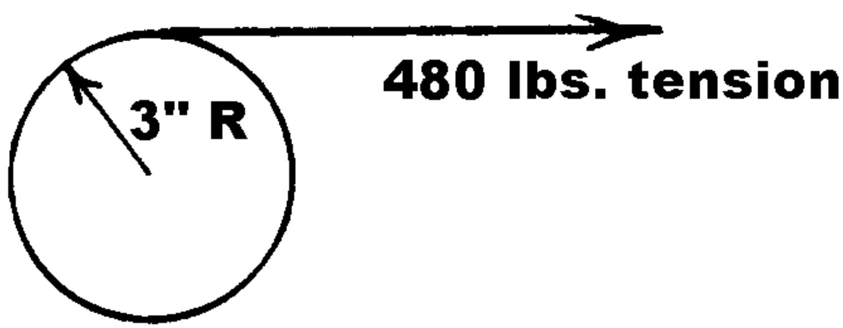
= 480 lbs.

Example Problem #5, cont'd

Torque is usually expressed in ft. - lbs., which means that we need divide the core 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.

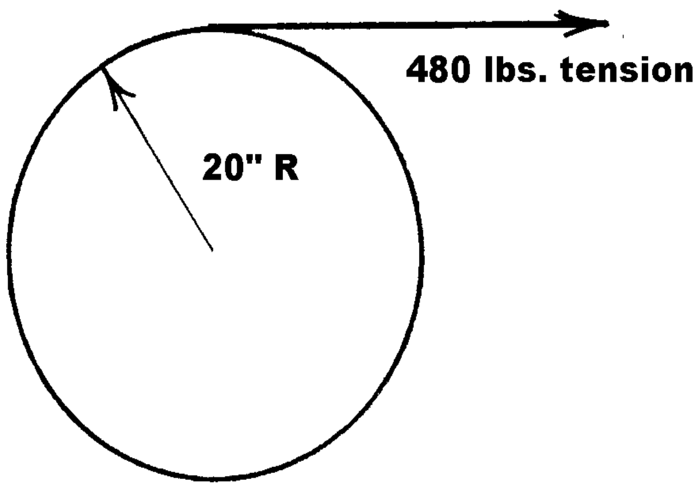
= 120 ft. - lbs.



Example Problem #5, cont'd

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

= 800 ft. - lbs.



Example Problem #5, cont'd

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 $\div$ C

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

= 1,300 RPM

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

= 190 RPM

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

HP = (Torque X RPM) / 5,250

Example Problem #5, cont'd

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

Saving Energy Through O&M Practice

- Lubrication
- Check drive train
  - *Loose belts*
  - *Broken belts*
  - *Use low-slip or cogged belts*
  - *Check shaft and pulley alignment*

O&M Recommendations (cont'd)

- Check loading; use properly sized motors
- Don't rewind small motors
- ALWAYS buy premium efficiency motors; lifetime operating cost >>> first cost; establish a motor purchasing specification (must exceed NEMA table 12-12) and make it stick!
- Replacing working motors is not cost-effective; replacing instead of rewinding IS

Questions?

Contact for More Information

Further questions and information may be obtained by contacting the speaker:

Hank Jackson, PE

HZJackson@juno.com

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THANKS!