Pump & Motor Efficiency

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Motors

13 per unit current instantaneous starting

17 per unit current instantaneous at starting

Some have experienced nuisance trips when starting

New standard
Industrial Processes

• The average energy cost as a proportion of manufacturing production costs is about 3%.
  – If energy represents 3% of production costs, and profits amount to 20% of production costs, then reducing net energy costs by one-third can result in a five percent gain in profits

• Available today, are a host of energy-efficient technologies, techniques, and approaches has emerged and energy management is being increasingly recognized for its potential to improve the “bottom line”
Industrial Processes

- Industrial applications, electric motors account for roughly 60% of electricity consumption
  - Most critical industrial sector to improve efficiency

- Motor-driven equipment—such as pumps, air compressors, and fans
  - consumes about 17% of all the energy used in U.S. industrial applications.

- Plants can begin reducing this energy usage and cost by using an integrated systems approach to improving performance, selecting motor-driven equipment with the highest possible energy efficiency, and implementing effective system management practices.
Industrial Processes

• High energy costs can be the result of inefficient system design
  – Not selecting or designing a proper motor and drive system for the application
    can also lead to power quality problems, such as voltage sags, harmonics, and
    low power factor.

• The primary causes of increased maintenance requirements
  – added stresses on the system
  – increased heat that accompanies inefficient operation.

• Poor system performance is a major cause of
  – increases in maintenance
  – decreases in reliability
  – Common indications include abrupt or frequent system starts and stops, high noise
    levels, and hot work environments.

• High noise levels are common in inefficient fluid systems
  – energy losses in fluid flow often dissipate as noise, systems with large flow losses
    tend to be loud. In addition
Motor Ownership

- Operating Costs
  - 97% to 98% of the life cycle costs

- Initial purchase price
  - 2% to 3% of the life cycle costs
    - Premium efficiency motors cost 15% to 25% more
    - 25% more copper

- Motor Repair
  - 65% of existing motors are repaired
  - One third of repairs
    - Motor efficiency is not affected
  - Two thirds of repairs
    - Efficiency drops by 1% (<40Hp)
    - Efficiency drops by 0.5% (>=40Hp)
Focus on efficiency of the complete System

- Indications of poor system design
  - High Energy Costs
  - Frequent Maintenance
  - High noise levels
  - Poor System Performance
  - Unbalance Voltage

- Industrial Motor Systems Potential Savings
  - Efficient Motors 13%
  - Adjustable Speed Drives 25%
  - Application Improvements (system) 60%

- Adjustable Speed Drives
  - Effective at improving motor system efficiency
  - Best effectiveness for systems with low % of static head to total system head
  - High static head to total system head systems require careful consideration
  - Typical System Savings Yields
    - Refrigeration 10%
    - Air compressors 15%
    - Pumps and fans 20%
Focusing on the Motor Driven System – Voltage Balance

- Motor efficiency decrease is proportional to the voltage imbalance, pronounced at reduced loads
- Unbalanced voltage to be 1% or less
  - Unbalance voltages produce a negative-sequence voltage having a rotation opposite to that occurring with balanced voltages
  - Produces an air gap flux counter the motor rotation
  - Increase current
  - Increase motor heating
  - Torque is reduced, for a given value of slip torque is proportional to impressed
  - Full load speed is reduced slightly
Focusing on the Motor Driven System

- Electric motors provide efficient, reliable, long-lasting operation

- Motor dictates running speed
  - Synchronous absolutely exact
  - Induction varies (slips) a few % with torque loading
  - Higher motor efficiency less % slip

- Load is oblivious to the potential power of a motor

- Load only requires a certain torque commensurate with load driven speed.
Focusing on the Motor Driven System

• Load dictates the torque required
  
  – **Constant Horsepower**
  • loads where the torque requirement is reduced as the speed is increased, and vice-versa.
  • The constant horsepower load is usually associated with metal removal applications, such as drill presses, lathes, milling machines, and similar applications.

  – **Constant Torque**
  • load where the amount of torque required to drive the machine is constant, regardless of the speed at which it is driven.
  • torque requirement of most conveyors is constant, certain positive displacement pumps and blowers (piston, screw, gear, progressive cavity) have a constant torque profile

  – **Variable Torque**
  • Load requiring low torque at low speeds, with torque varying as the square of the speed change and HP varying as the cube of the speed change
  • variable torque loads are centrifugal fans, compressors and centrifugal pumps
Horsepower Torque RPM Nomogram

- \( T = \frac{\text{HP} \times 5252}{\text{rpm}} \)

- [Nomogram Image]
Focusing on the Motor Driven System

• Power is proportional to speed times torque

• Motor sizing
  – Optimum motor loading 60% to 80% of name plate
    • Under loaded motor < 75% load; less efficient with lower power factor.
    • Purchase smaller replacement
  – Operating Range 50% to 100% of name plate
  – Limited Time operation 20% to 50%, and 100% to 120% of name plate

• Motors that typically run within the range of 50% to 100% of full load
  – usually operate more efficiently than at less than 50% of full load
  – or into their service factor (greater than 100% of full load)
Focusing on the Motor Driven System

- Two parameters of importance in a motor are efficiency and power factor. The efficiencies of induction motors remain almost constant between 50% to 100% loading
  - Most peak near 75% load

- Opportunity for savings with motors rests primarily in their selection and use.

- Replacement of under loaded motors with smaller motors will allow a fully loaded smaller motor to operate at a higher efficiency.
  - Requires system analysis

- While input power measurements are fairly simple, measurement of output or losses need a laborious analysis
Focusing on the Motor Driven System

• When load is variable determine the average load carried
  – Power monitoring of input power
  – Determine the appropriate period of time the weighed average for each motor load
  – Remember that the system efficiency is the product of the ASD efficiency, the motor efficiency at its load point, and the driven equipment efficiency at load point
  –

• Examples of variable load
  – Motor driven equipment against defined heads: different but continuous
  – Motor driven equipment with inlet valve control: Random load
  – Motor on/off control: two levels of different but constant load
Focusing on the Motor Driven System

• Oversizing motors is a common practice.
  
  – If the criteria used to select the size of replacement motors is based on the size of the motor being replaced the oversize is perpetuate
  
  – At least 40 percent of motors in use are operating at less than 40 percent full load
Focusing on the Motor Driven System

- Replacement of Oversized Underloaded Motors Saves Energy
  - Possibility of a Myth
    - oversized underloaded motors <50% rated load are inefficient
      - The specific instant case must be evaluated
  - Motors operating < 50% of rated load require careful evaluation before replacement with a smaller motor.
  - Estimate the motor load
    - Kw measured directly
    - Amperage ratio technique
    - Slip method
  - Motor Efficiency
    - Large motors (100hp & larger) higher full load and part load efficiency
    - Below 50% load efficiency declines more rapidly for small motors
    - A large motor operating at less than 50% of rated load, may operate as efficient as a small motor operating at rated load.
Focusing on the Motor Driven System

- Replacement of Oversized Underloaded Motors

- Speed Load Relationship
  - Oversized and lightly loaded motors operate at a speed approaching synchronous
  - An appropriately sized motor operate approaching full slip from synchronous

- Motor speed correction
  - Use manufactures data for speed vs. load
  - Existing and replacement speeds should not be ignored
  - Savings may be over/under estimated
  - Process may be over/under supplied

- MotorMaster compare section is specifically designed for analysis of oversized underloaded motors
% Motor Load: kilowatt ratio

- Kilowatt ratio method should be used when input Kw measurement is available
  
  
  - Else
  
  - $\sqrt{\quad}$
Motor Efficiency field determination

- $E$ = efficiency as operated
- $Pr$ = Nameplate rated horsepower
- $Pi$ = three phase power in kw
- $L$ = Load % of rated power

- $E = 0.746 \times Pr \times L / Pi$

- It is a three step process
  - Use power, amperage or slip measurements to identify the operating load
  - Obtain motor part-load efficiency values consistent with the approximate load
  - Derive a revised load estimate using both the power measurements at the motor terminals and the part-load efficiency obtained
% Motor Load: Line Current Method voltage compensated

• The amperage draw for a motor varies approximately linearly as referenced to load to approximately 50% of full load.

• Below 50% of full load amperage quickly becomes non-representative of load
  – reactive magnetizing currents requirements
  – power factor deterioration
  – Non-linear amperage

• Calculation
  
  _ _ _
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  _
  _
% Motor Load: Amperage ratio technique

- This version of the amperage ratio load estimation uses a linear interpolation between the motors full and half load current values.

- Useful in the 50% to full load range
  - While the amperage of a motor is approximately linear down to 50% load the relationship is not directly proportional.
Measuring a motor's speed provides a way to determine a motor's load. Motor speed and slip are proportional to its load. At zero load, the motor operates at (or very near) the synchronous speed. At full load, the motor operates at its rated speed with design % of slip. Motor speed varies nearly linearly between full load and no-load.
% Motor Load: Slip Method

- Voltage compensated slip

- Slip method
  - Favored for safety
  - Largest uncertainty tolerance in reporting nameplate full load speed.
    - 20% slip is allowed, can represent rpm
    - Greater rpm deviation a possibility if motor was rewound
MotorMaster 4.1

- Select the best available new or replacement motor 1hp to 2000hp

- Ability to inventory motors and operating data
  - Optimize inventory and sizing
    - Scan for motors operating sub-optimum
  - Target energy intensive systems
  - Maintenance logs
  - Spare tracking

- Energy accounting and reporting

- Life Cycle costing analysis

- Replacement motor comparison
Motor Efficiency Economics

• 

\[
\frac{\left( \frac{1}{(\quad)} \right)}{\left( \frac{1}{(\quad)} \right)} - \frac{\left( \frac{1}{(\quad)} \right)}{\left( \frac{1}{(\quad)} \right)}
\]

• Present Worth of Savings

\[
\frac{\left( \frac{1}{(\quad)} \right)}{\left( \frac{1}{(\quad)} \right)} - \frac{\left( \frac{1}{(\quad)} \right)}{\left( \frac{1}{(\quad)} \right)}
\]
Motor Load and Speed Relationships

• Energy efficient motors tend to operate with less full load slip
  – Slightly higher speed than a motor of reduced efficiency
  – For centrifugal fans and pumps a minor change in the motors operating speed may translate into a significant power consumption.

• Affinity laws define this power relationship
Efficient Motors key performance area

- In an AC motor, there are five components to the power that is lost:
  - Friction loss
  - Windage loss
  - Sound loss
  - Copper loss
  - Iron loss

- The first three, are mechanical losses, Friction, Windage, and Sound:
  - fairly constant
  - represent a very small fraction of the total wasted or lost power.

- Copper loss:
  - energy lost to heat in the windings and is a function of the load.
  - $I^2R$ losses
  - Stator windings and rotor conductor bars and end rings:
    - Increasing stator minding mass decreases the electrical resistance
    - Rotor slip losses difference in rpm between the rotational speed of the magnetic field and the actual rpm of the rotor and shaft
    - Rotor losses are reduced by decreasing the degree of slip,, accomplished by increasing the mass of the rotor conductor bars and end-plates
Efficient Motors key performance area

- **Iron loss**
  - energy lost due to eddy currents and hysteresis effects and magnetic saturation in the magnetic iron cores of the stator and rotor
  - a function of the voltage at the motor terminals
  - is independent of the load
  - Steel containing up to 4% silicon for the laminations reduce hysteresis and saturation losses, reduce lamination thickness, lengthen the lamination stack, eddy current losses reduced by ensuring adequate insulation between the laminations
Efficient Motors key performance area

- A motor is operating most efficiently when the iron loss and the copper loss are equal, which occurs when the motor is driving ~75% to 90% of the full rated load.

- As the load increases, the copper loss dominates.

- When the load is very low, the iron loss dominates, representing most of the energy loss.
Efficient Motors key performance area

- **Motor Room Ventilation**
  - Cooling air discharged at 40°C above ambient at full load
  - Temperature of room could continue to rise above ambient
  - Local pockets of hot room air may exist

- **A Clean Motor**  Runs cooler
  - Heat Transfer maintained
    - Avoid thick coat of paint or dirt
  - Dirt
    - Abrasion on insulation
    - Absorption into insulation
    - Raise motor operating temperature
    - Contaminate lubrication
Motor

• The US Department of Energy (DOE) publishes MotorMaster+4.1
  – a free software tool that can be used to estimate savings associated with motor replacement and repair
  – MotorMaster+ is a comprehensive savings calculation and motor inventory tool that also includes product information for motors 1 to 5000 hp
  – It includes resources to record and maintain a customized motor inventory. Available at


• Pumping System Assessment Tool, PSAT DOE
• FAST, Fan System Assessment Tool, DOE
Motors

- Greater than 90% of motor purchases are made at the plant level verses the corporate level.

- MotorMaster+4.1 Software provides inventory and selection guidelines
Motors

- Adopting standard policies and specifications for purchasing efficient motors will help in replacement situations.

  - Typical Motor Specifications in general order of importance
    - Temperature rise/Insulation class
    - Maximum starting current
    - Minimum stall time
    - Power factor range
    - Efficiency and test standard
    - Load inertia
    - Expected number of starts
    - Suitability to facility operating environment
    - Ease of reparability
Motor

• Rewinding Opportunities
  – encourage replacement of failed motors with Premium Efficiency or Ultra Efficiency
  – If rewind, ensure that best practices are used so that degradation of efficiency is minimized
  – Electrical Apparatus service Association EASA provide formal standards and quality control procedures

• Typical Rewind decision factors in order of importance
  – Capital cost of rewound motor vs. cost of new motor
  – Installation cost of rewound motor vs. installation cost of new motor
  – Cost of electricity used by rewound motor vs. electric cost of new motor
  – Reliability of rewound motor vs. reliability of new motor
Motor Repair - Maintaining Efficiency During Repairs

• How can a repair cause your efficiency to diminish?
  – Heat damage to stator core
  – Wrong wire size or turn count
  – Higher friction bearings/seals
  – Bad re-design of winding pattern
  – **Premium Efficiency Motors unique techniques not duplicated**
    • As example: Intentionally unequal coil turns in the stator winding
Maintaining Efficiency During Motor Repairs

- Motor Rewind Repair
  - Repair phase is significant manual work requiring a high degree of skill and accuracy
  - Restore to original name plate efficiency
    - Little evidence improve efficiency beyond name plate value
  - Possibility of degraded name plate efficiency
    - Generally 0.5% to 3% below name plate value
Maintaining Efficiency During Motor Repairs

- Critical Considerations During Rewind Repair
  - Addressing one element can have negative effect on other elements critical to efficiency.
    - Example: in an effort to reduce resistance by reducing the number of turns will result in a current increase producing an increased core and copper losses from the increased current.

- When quality controls are lacking reductions in full load efficiency of 1% to 3% are common.

- With strict attention to design parameters and quality controls the full load efficiency reduction is limited to 0.5% or less and in some cases improved efficiency is obtained.
Maintaining Efficiency During Motor Repairs

- Motor losses directly effected by repair method
  - Rewind
    - Stator copper (I^2R) losses
    - Iron core losses
  - Repair not requiring rewind
    - Bearing friction

- Motor losses normally not affected by repair
  - Rotor cage losses
    - A winding of bars and end rings, rarely altered during rebuilding
  - Stray load losses
    - Losses not normally identified
Maintaining Efficiency During Motor Repairs

• Stator Winding Losses
  – Root cause: increased copper losses, increase in winding resistance
    • Smaller cross-sectional area of wire
    • Increased number of turns in the coils
    • Increasing the distance coils extend from the stator

• Stator Core Losses
  – Losses may change due to winding removal process
  – Pyrolyzing temperature controlled
    • Organic lamination insulation max temp not to exceed 680°F
    • Inorganic lamination insulation max temp not to exceed 750°F
    • Newer cores may accept higher temperatures refer to manufacturer
  – Oven loading is critical to temperature uniformity
  – As practicable the part temperature should be monitored and recorded
  – Do not use a open flame
  – Sandblast core iron with glass beads, walnut shells, corncobs other similar materials
  – When removing varnish from stator bore take care not to increase the aim bore diameter or short the laminations.
  – Increasing the bore diameter of the stator or reducing the rotor diameter by taking a cut off, will increase the air gap increasing the magnetizing no-load current increasing the losses
Maintaining Efficiency During Motor Repairs

• Bearing friction losses
  – Prime concern non-rewinds
  – Maintain the same bearing or recommended duplicate
    • Contact seals to replace a bearing without seals, losses increase
  – Lubrication
    • Too much lubricant used
    • Excess grease causes churning, increase heat, mechanical deterioration of ball retaining cage
Adjustable Speed Drive (ASD)

- Overall ASD Efficiency
  - On average the variable frequency drive VFD relative full load power is 8% higher than the power for a properly designed full load across the line system
    - No change in motor efficiency, efficiency at point of load
    - Approximate 3% loss in efficiency through the VFD
    - Approximate air conditioner parasitic load of 5%
    - Estimate of Air Conditioning Power Required approximate
      - \((100\% - \text{VFD\% eff}) \times 2 \times \text{VFD Input HP Rating}\)
  - On average magnetically coupled and hydro-kinetic type fluid drive ASD relative full load power is 4 to 10% higher than the power for a properly designed full load across the line system.
Adjustable Speed Drive (ASD)

- A Variable Frequency Drive (VFD), however, provides the best of both worlds, ultra low inrush and high breakaway torque

- VFD’s vary both Voltage and Frequency across the speed range
  - motor’s impedance is reduced with frequency

- Not as much voltage is required to create the rated torque levels, at speeds lower than 60 hertz
VFD drive speed torque curve

**VFD max torque with overload**

Speed torque curve dependent upon motor, drive current capability of the VFD, and the VFD technology used (flux vector, pulse width modulation)

For illustration only
VFD as a starter

<table>
<thead>
<tr>
<th>Starter Type</th>
<th>Starting Current % of FLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>VFD</td>
<td>100</td>
</tr>
<tr>
<td>Wye-Delta</td>
<td>200 to 275</td>
</tr>
<tr>
<td>Solid State soft starter</td>
<td>200</td>
</tr>
<tr>
<td>Autotransformer starter</td>
<td>400 to 500</td>
</tr>
<tr>
<td>Across the line start</td>
<td>600 to 800</td>
</tr>
</tbody>
</table>
VFD drive efficiency

![100 HP VFD Efficiency % Graph]
Typical Loading Control Configurations

Graph Intended for illustration

ByPass control
Throttle control
Magnetic Coupling VSD
VFD

VFD does not include a/c loss
ASD Savings Estimates and Overestimates

- **Adjustable Speed Drives**
  - save energy by reducing the system flow and pressure required.

- **System relationship between flow and pressure drop**
  - Velocity losses, Friction losses, Entrance, Exit and other minor losses in a constant or equivalent diameter flow system.

- **Affinity Laws for pumps and Fans**
ASD Savings Estimates and Overestimates

- The Affinity Laws do not apply to losses that do not follow
  - Systems with a potential energy component
    - elevation change or constant head pressure
    - Hydraulic water systems, booster water systems, air compressor systems, boiler feed pump
    - Systems with elevation head, Open cooling towers, or other open transfer systems
      - Closed systems do not apply
      - Systems with siphon gain only that portion unrecovered
  - Losses not proportional to
    - Coils, filters, disk type water meters etc.

- Power required for non flow resistance will not contribute to potential energy savings.
Typical Pump Curves

- "1" Positive Displacement
- "3" single point
- "4" system resistance head
- "5" srh + static head
- Linear ("2" constant head)
Pump Curves

- **Curve 1**
  - Positive displacement pump
    - Capacity will remain almost constant at constant operating speed
    - Maximum head is determined by driver capacity and or casing / piping limits
    - Increase speed increase capacity

- **Curve 2**
  - Constant head
    - Head remains constant as capacity varies
    - Boiler feed pump, hydraulic system is an example
    - Filling a process tank, from the top or against a process static pressure

- **Curve 3**
  - Single point of operation
    - Constant capacity
    - Circulating pump for a steaming bof hood, boiler circulation pump, tank circulating pump
    - A boiler feed pump for a power boiler operating at rating
Pump Curves

- **Curve 4**
  - System Resistance Head
    - All resistance is from the system
    - Typical of systems where is from flow resistance: circulating water systems etc.
    - Pumping to a tank with little elevation change

- **Curve 5**
  - Static Head + System Resistance Head
    - Pumping with elevation and static head changes
Some Typical Pump Energy Efficiency Practices

• Improve System operating efficiency
  – Check coupling alignment, belt: condition, tightness and alignment
  – Lubricate bearings and replace worn ones, as needed
  – Clean system components regularly
  – Match motors to required system load demands
  – Match motors and drives properly
  – Select energy-efficient or premium-efficiency replacement motors
  – Replace V-belts with cogged or synchronous belt drives
  – Use adjustable-speed drives
  – Reduce fluid flow noise level
Some Typical Pump Energy Efficiency Practices

- Shut down unnecessary pumps
- Restore internal pump clearances
- Seals selection
  - Mechanical
  - Packing
- Optimize pump Size to match system demand
  - Properly sized
  - Trim or replace impellers
- Retrofit of systems with ASDs
  - Remove throttling valves
- Reconfigured piping and filters to reduce pressure drops in system
- Optimum pipe sizing
- Reduce flow rate, system operating pressure, length of operation
Operation of Centrifugal Pumps at reduced Flow

- The thermodynamic problem that arises from the operation of a centrifugal pump at extremely reduced flows is caused by heating of the liquid handled
  - At or near shut off

- °F Temp rise/min = 42.4 * Po / ( Ww * Cp )
  - 42.4 conversion fr. Bhp to btu/min
  - Po brake horsepower at shutoff
  - Ww weight of fluid in pump lb
  - Cp specific heat of fluid
Operation of Centrifugal Pumps at reduced Flow

• The difference between the brake horsepower consumed and the water horsepower developed represents the power losses within the pump itself, excluding the small losses in the pump bearings.

  − When flow is moving through the pump, conditions stabilize, the temp rise through the pump is given by

  − Temp rise \( F = (bhp - whp) \times 2545 / (\text{flowing capacity \#/hr}) \)
  − Or
  − \( T = H/778 \times (1/\text{eff} - 1) \)
    • 2545 conversion btu equivalent of 1hp-hr
    • \( H \) total head feet
    • Eff pump efficiency at capacity evaluated
Operation of Centrifugal Pumps at reduced Flow

• General rules for water

• Minimum capacity gpm = 0.3*Po
  – Po is shutoff horsepower

• Or

• Minimum capacity gpm = 6*Po/delta T*F
NPSH Pumps

• The required head at the suction condition centerline to insure proper pump operation.

• Plunger Pump
  – NPSHA = the static head + atmospheric pressure reservoir elevation – friction loss – vapor pressure – velocity head – acceleration head all in feet available at the suction connection centerline.
    • Acceleration is not a loss since the energy is restored on deceleration
    • Acceleration loss may be the highest (commonly 10 times the sum of all others)

• Centrifugal pump
  – NPSH α
  – Available NPSH = absolute pressure on free surface + velocity head – vapor pressure of liquid reservoir elevation – liquid flow losses
Piping friction pumping costs

• Increase piping diameter to reduce friction losses
• Select pipe material with reduced friction requirements

• Friction

  \[ f = \text{friction factor} \]
  \[ L = \text{length of pipe feet} \]
  \[ Ho = \text{hours of operation} \]
  \[ \text{gpm} = \text{gal per min} \]
  \[ d = \text{pipe dia inches} \]
  \[ \text{Effp} = \text{efficiency pump as decimal} \]
  \[ \text{Effm} = \text{efficiency motor as decimal} \]
  \[ Sg = 1 \text{ water} \]

• Pipe friction consumes approx 16 % of a systems pumping power
Pump Imbalance Determination

• Imbalance between requirements and supply

• % Imbalance

• \[ \left( \frac{\text{Supply}}{\text{Requirements}} \right) \]

• When % imbalance is approximately 20% a system review is warranted.
Pump Imbalance Penalty

• The cost of Imbalance between requirements and supply

• Imbalance Kwh

  ( )
Affinity Laws Pump

- **AFFINITY LAWS**
- The performance of a given pump at various speeds and the performance of geometrically similar pumps is governed by a set of formulas known as the *affinity laws*.
  - $Q \alpha N$
  - $H \alpha N^2$
  - $NPSH \alpha N^2$
  - $HP \alpha N^3$

- where:
  - $Q =$ pump capacity in gallons, per minute at best efficiency point (b.e.p.)
  - $H =$ pump head in feet at b.e.p.
  - $NPSH =$ required NPSH in feet at b.e.p.
  - $HP =$ required horsepower at b.e.p.
Affinity Laws Pump and Fan

• Affinity Laws Model Pump to Prototype Pump (the same for fan)
  • Volume
    \[ \frac{q_1}{q_2} = \left( \frac{n_1}{n_2} \right) \left( \frac{d_1}{d_2} \right)^3 \]
  • Head
    \[ \frac{H_1}{H_2} = \left( \frac{n_1}{n_2} \right)^2 \left( \frac{d_1}{d_2} \right)^2 \]
  • Power
    \[ \frac{P_1}{P_2} = \left( \frac{n_1}{n_2} \right)^3 \left( \frac{d_1}{d_2} \right)^3 \]

  \( q \) = volume flow capacity
  \( n \) = wheel velocity – rpm
  \( d \) = wheel diameter
  \( H \) = Head
  \( P \) = power

• Fan Affinity Laws Model to Prototype Pump (note same for model to prototype pump)
  • Volume
    \[ \frac{q_1}{q_2} = \left( \frac{n_1}{n_2} \right) \left( \frac{d_1}{d_2} \right)^3 \]
  • Head
    \[ \frac{H_1}{H_2} = \left( \frac{n_1}{n_2} \right)^2 \left( \frac{d_1}{d_2} \right)^2 \]
  • Power
    \[ \frac{P_1}{P_2} = \left( \frac{n_1}{n_2} \right)^3 \left( \frac{d_1}{d_2} \right)^5 \]

  \( q \) = volume flow capacity
  \( n \) = wheel velocity - revolution per minute - (rpm)
  \( d \) = wheel diameter
  \( H \) = Head
  \( P \) = power

For a specific pump or fan
Affinity Laws Pump

• The affinity laws govern the performance of geometrically similar pumps – that is, pumps which are identical except for size.
• Performance of a given model pump is known
  – the performance of a prototype pump can be predicted
  – A prototype pump is made from a model by multiplying all dimensions of the model by the same factor
  – The size factor is denoted as – In this case, the prototype pump and the model are said to be homologous to each other.

• In the case of homologous pumps:
  – \( \text{subscripts } p \text{ and } m \text{ denote prototype and model respectively} \)
Only wheel Outside diameter changing (non- homologous)

- Existing Pump Affinity Laws (not the same for fan)
  - Limit 10% to 20% of \( d \)
- Volume
  - \( q \) = volume flow capacity
  - \( n \) = wheel velocity – rpm
  - \( d \) = wheel diameter
  - \( H \) = Head
  - \( P \) = power

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    - \( n \) = wheel velocity – rpm
    - \( d \) = wheel diameter
    - \( H \) = Head
    - \( P \) = power
  - Power
    - \( q \) = volume flow capacity
    - \( n \) = wheel velocity – rpm
    - \( d \) = wheel diameter
    - \( H \) = Head
    - \( P \) = power

For a specific pump or fan
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- Motor eff with vfd
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- CEE motor guide
- doe EEM purchase guide
- Effect V and Hz
- Motor repair tech doe
- Maintain eff during repair
- Pumps V Speed
- Pump vsd calc sheet
- Pump and fan
- Mag drive
- Vfd overest avoid
- ABB oversize eff
- PWM vfd eff doe
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