



# Motor Systems Virtual INPLT Training & Assessment

Session 2



# Motors Virtual INPLT Facilitator



Ron Wroblewski, PE,  
Productive Energy Solutions, LLC  
Madison, Wisconsin

[ron@productiveenergy.com](mailto:ron@productiveenergy.com)  
(608) 232-1861

# Acknowledgments

- Johnny Douglas, P.E.
- Gil McCoy, P.E.
- Dr. Hugh Falkner, England
- Dr. Anibal De Almeida, University of Coimbra, Portugal
  
- Many industrial clients – both in the US and internationally

# Safety and Housekeeping

- Safety Moment
  - Motors can be dangerous, and caution should be used around them
  - Ensure that belt guards and equipment covers are fully in place
- You are welcome to ask questions at any time during the webinar
- When you are not asking a question, please MUTE your mic and this will provide the best sound quality for all participants
- We will be recording all these webinars and by staying on-line and attending the meeting you are giving your consent to be recorded
  - A link to the recorded webinars will be provided, afterwards



# Learning Objectives

- Discuss impact of poor power factor and its causes
- Review external factors affecting motor efficiency
- List 4 primary categories of causes of motor failure
- List 3 preventive maintenance strategies for improving motor reliability
- List 5 factors that to considered before repairing a burnt-out motor

# Power factor and power factor correction

Power factor is a measure of how much work is being done by the delivered amps

$$Power(kW) = \frac{Amps \times Volts \times Power\ Factor \times \sqrt{3}}{1000}$$

*Where Volts is phase-to-phase voltage*

- A low power factor “fills” the feeders and transformers with non-productive amps
- Some utility companies charge extra for low power factor

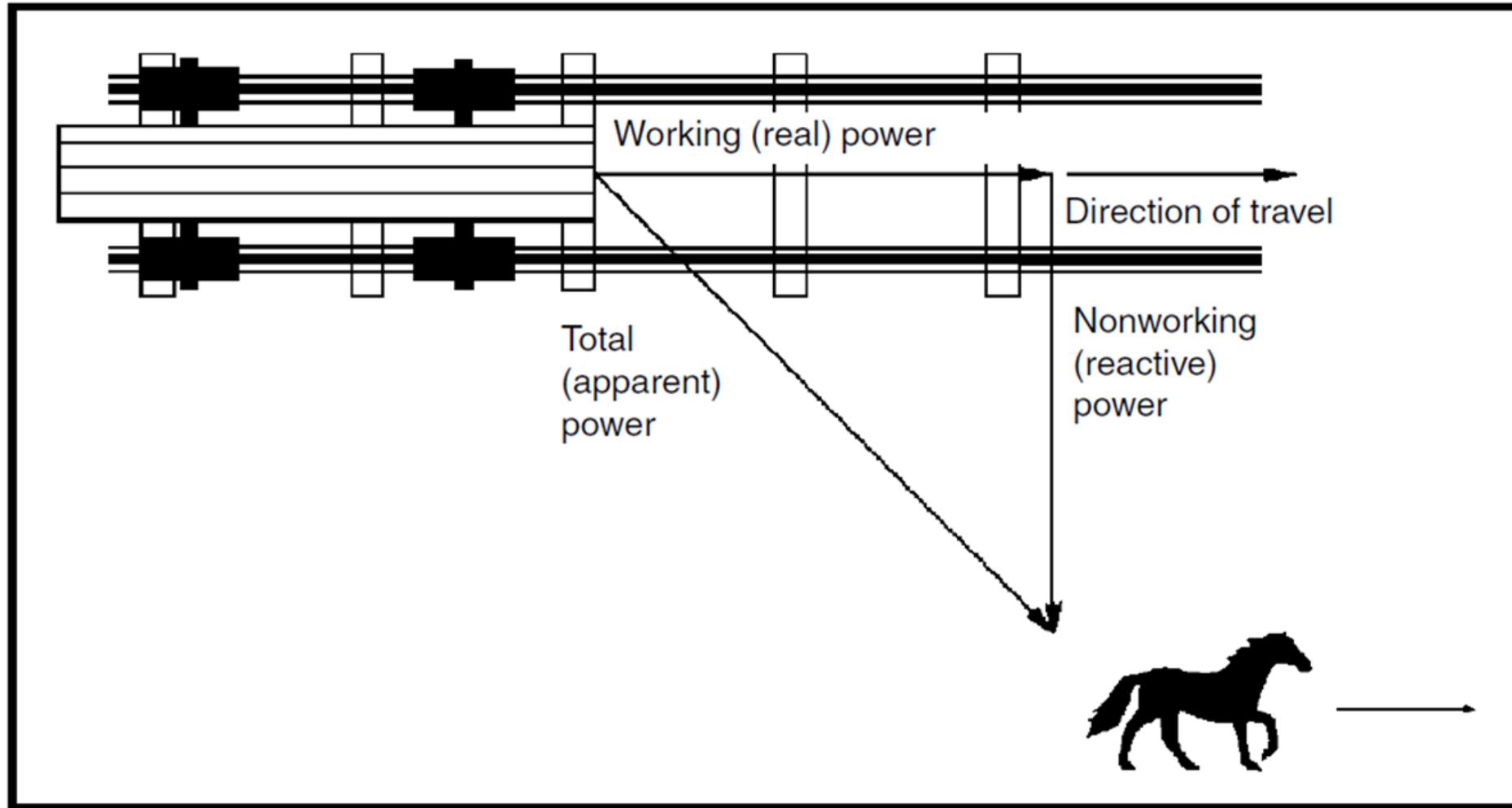


Low PF



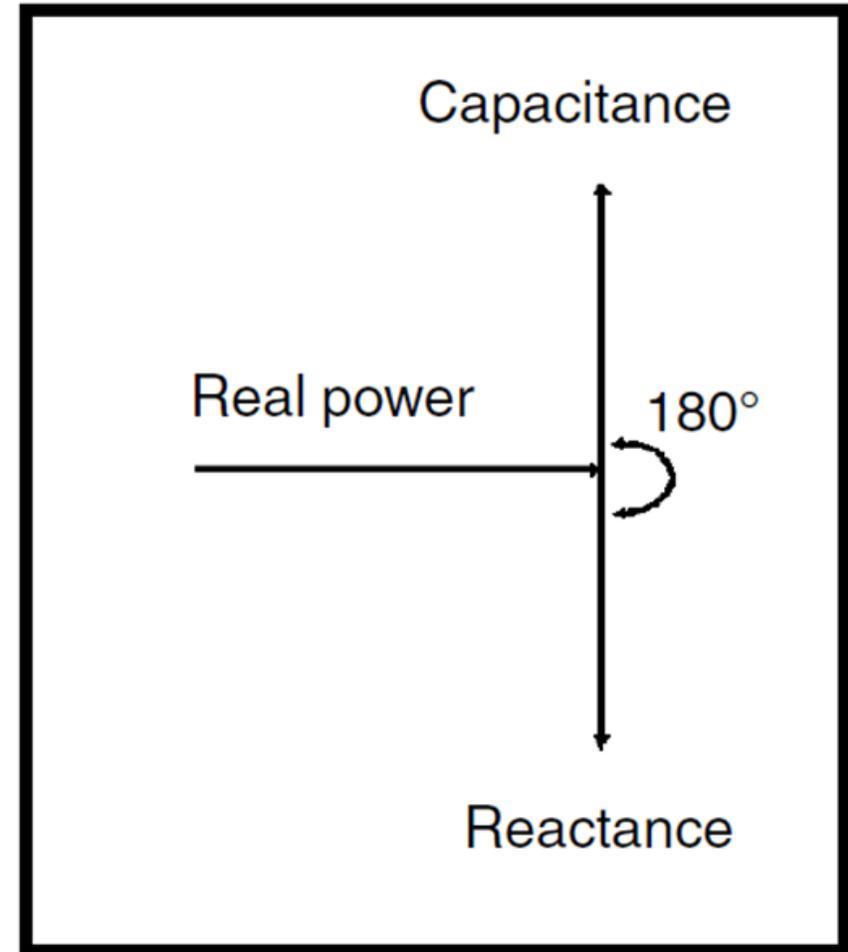
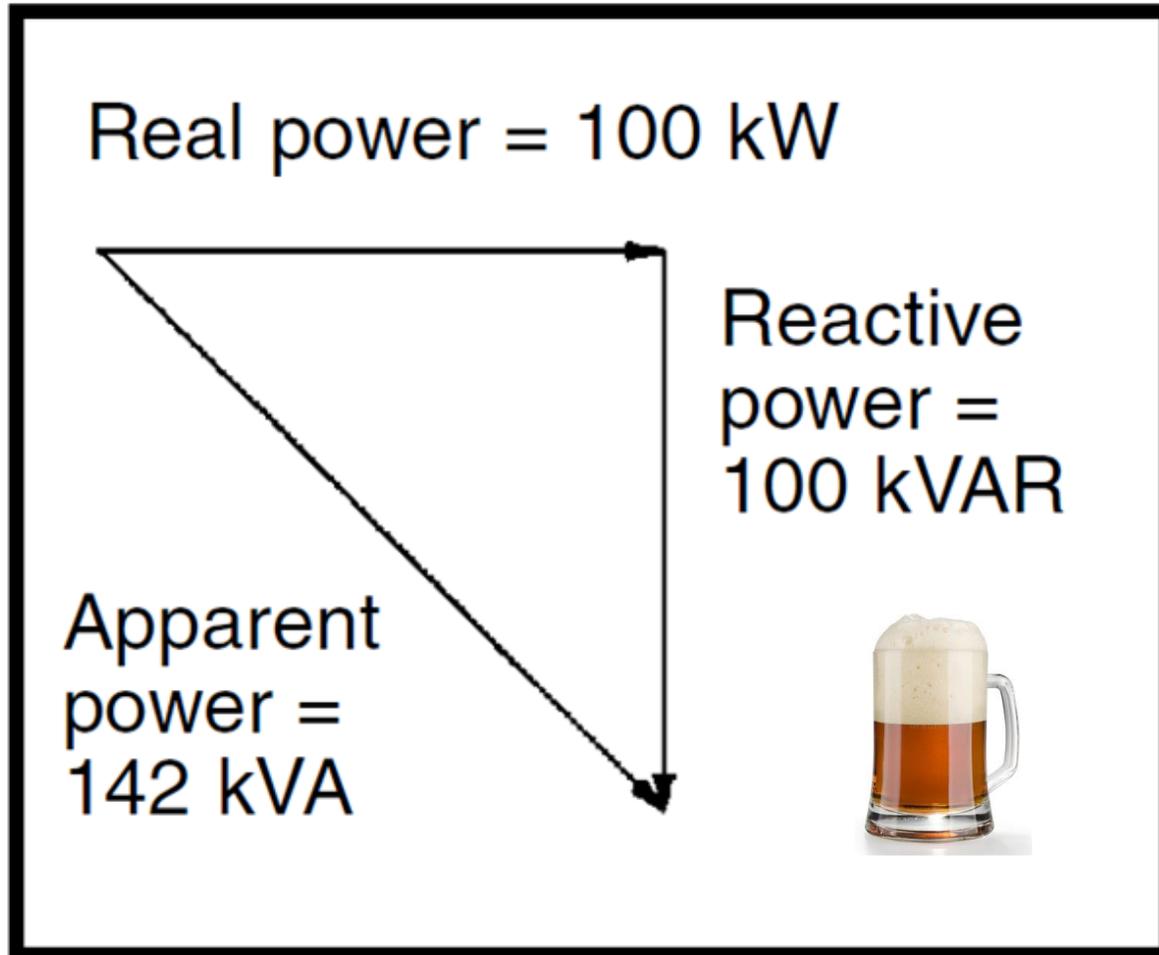
High PF

# Power Factor



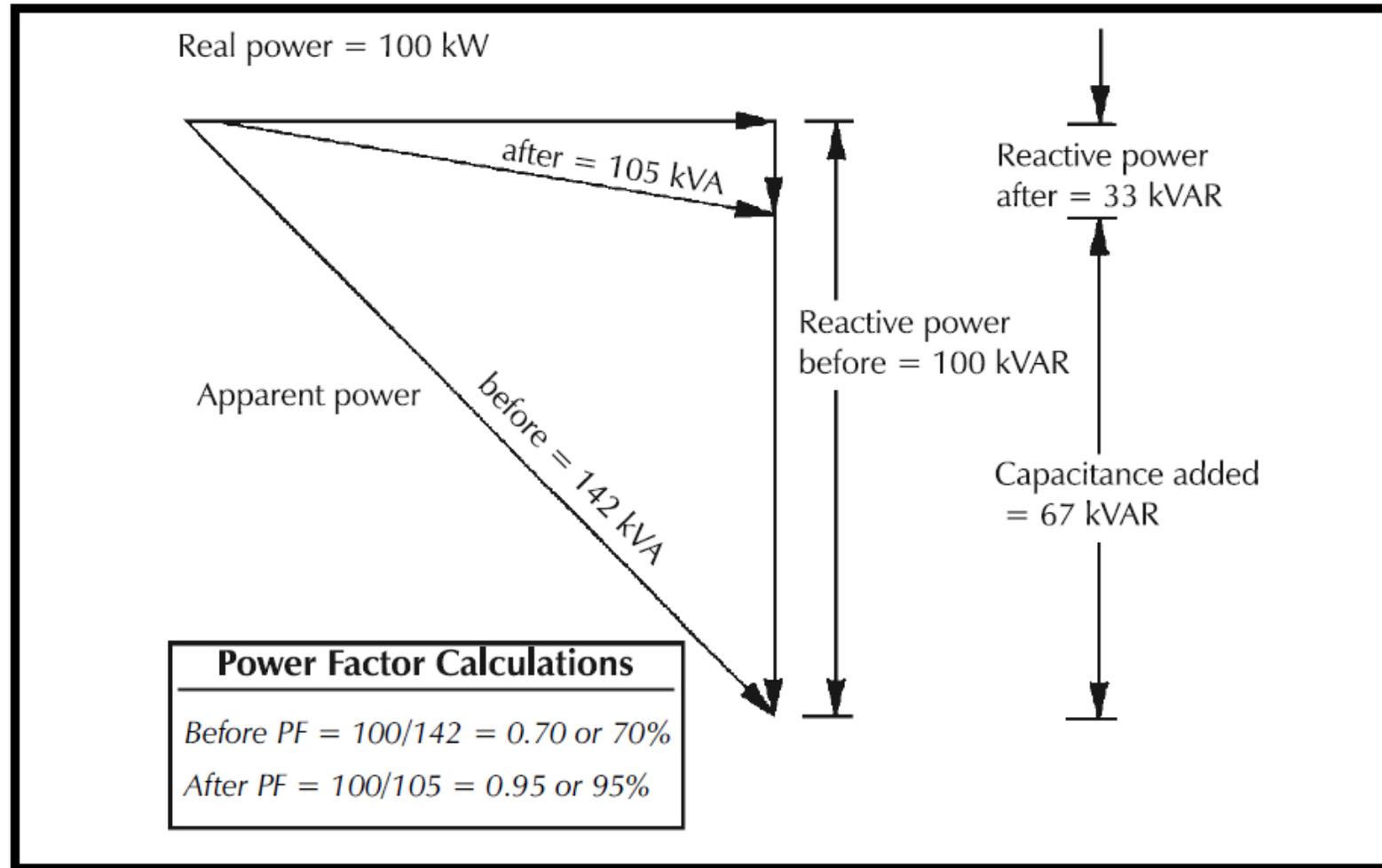
Courtesy of DOE ITP

# Power Factor



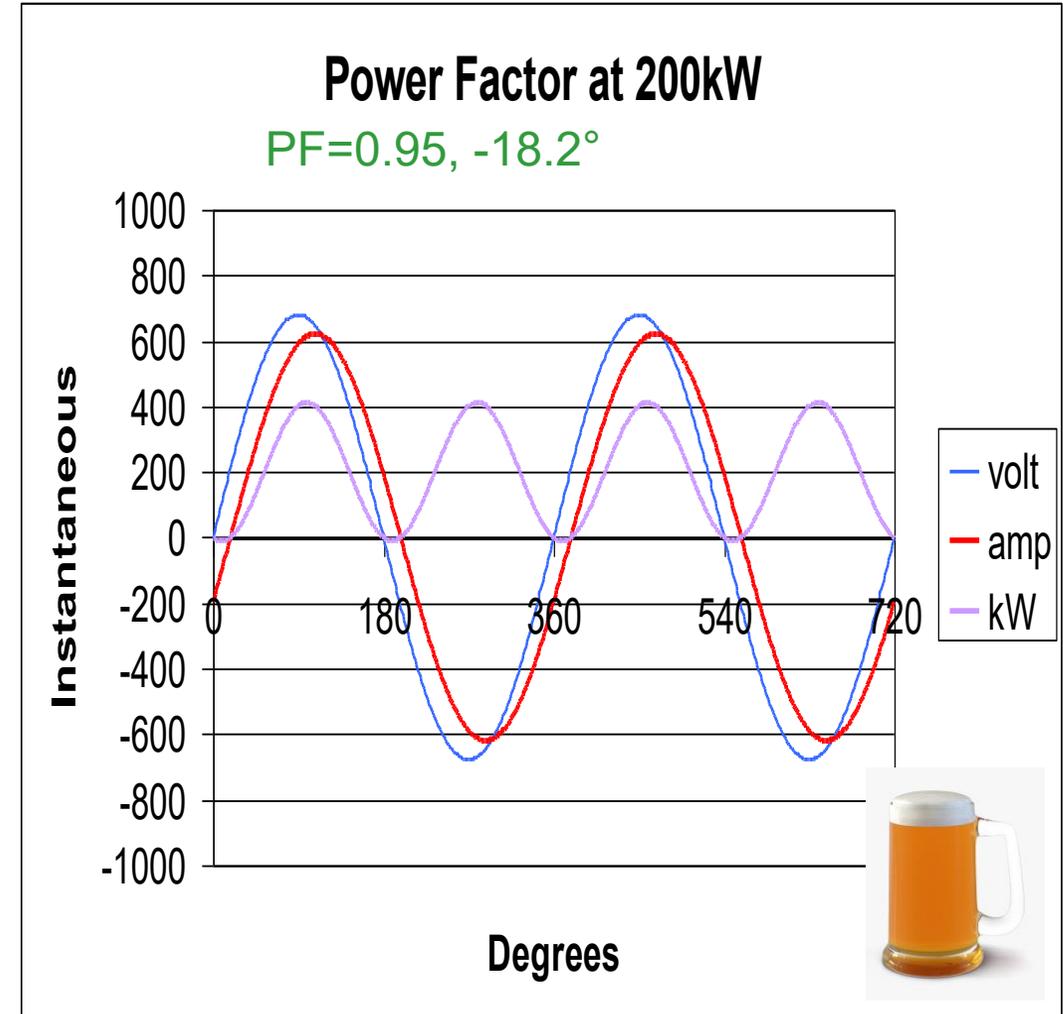
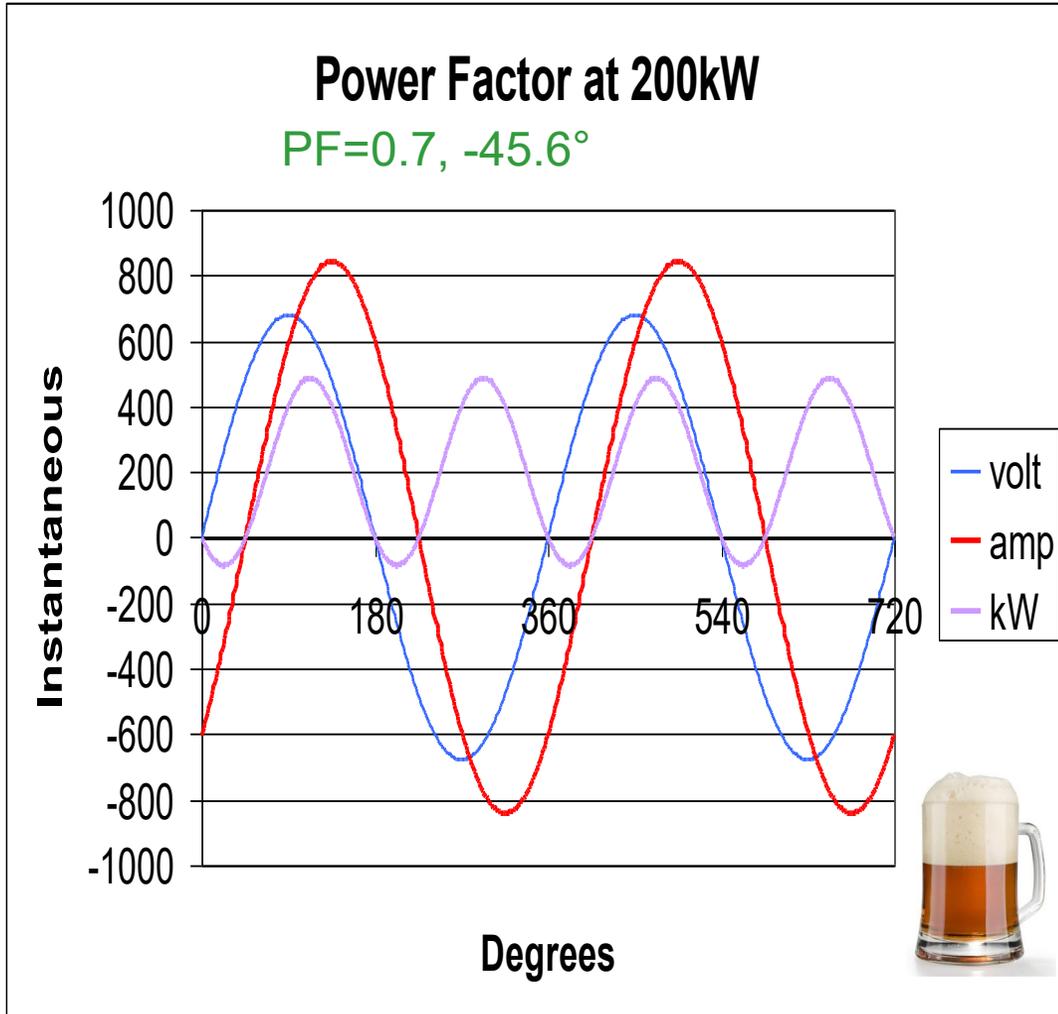
Courtesy of DOE ITP

# Power Factor Calculations



Courtesy of DOE ITP

# Poor Power Factor



# External Factors Affecting Motor Efficiency

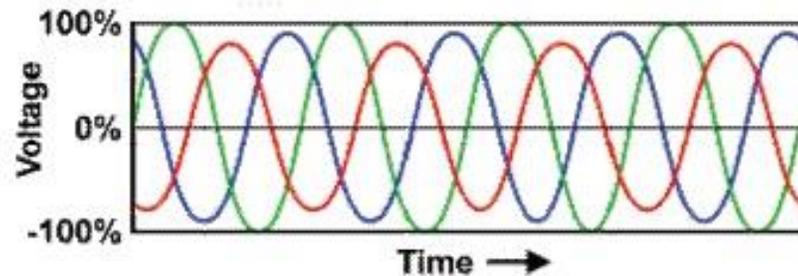
- Efficiency is never constant. External factors can reduce efficiency and require derating. Beginning with the worst, these include:
  - Voltage unbalance
  - Voltage deviation
  - Voltage harmonics

# Voltage Unbalance

## Definition

Voltage unbalance is given by:

$$\%VU = \frac{\text{max. voltage deviation from the avg. voltage}}{\text{avg.voltage}} \times 100$$



Courtesy Anibal T. De Almeida and Hugh Falkner and UNIDO

# Voltage unbalance example

$$L1 = 600 \text{ V}$$

$$L2 = 585 \text{ V}$$

$$L3 = 609 \text{ V}$$

$$\textit{Average Voltage} = \frac{600 + 585 + 609}{3} = 598 \text{ V}$$

$$\textit{Max. deviation from avg.} = 598 - 585 = 13 \text{ V}$$

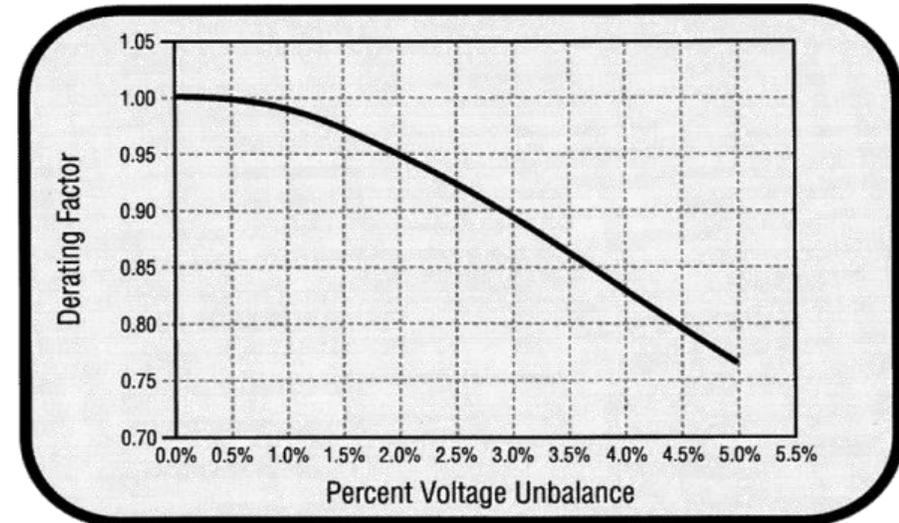
$$\textit{unbalance} = \frac{13}{598}$$

$$\textit{unbalance} = 0.02 \text{ or } 2\%$$

Courtesy Anibal T. De Almeida and Hugh Falkner and UNIDO

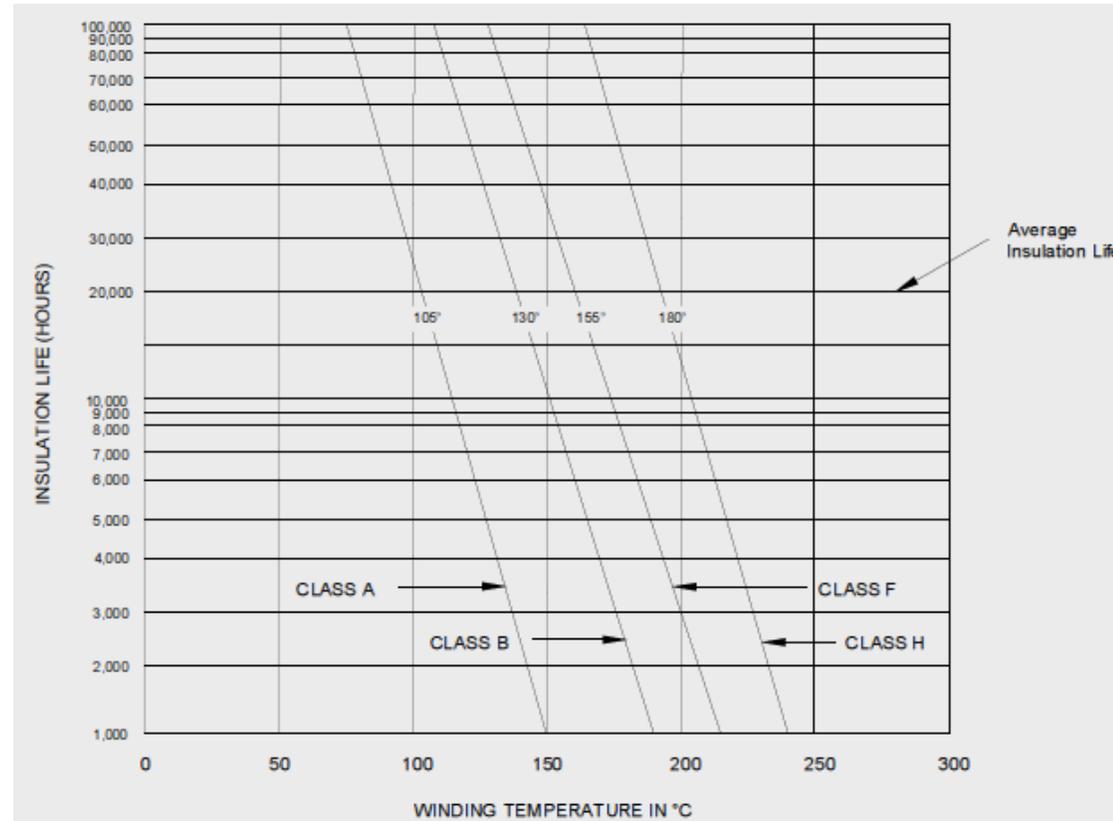
# Voltage Unbalance

- Unbalances greater than 5% should be immediately corrected.
- Significant increase in motor losses.
- Possible causes:
  - Improper transformer setup
  - Single phase loads
  - Faulty regulating equipment
  - Utility unbalance
  - Open connections
  - Unequal conductor or component impedance.



# Insulation Life vs. Temperature

Higher temperatures lead to reduced insulation life



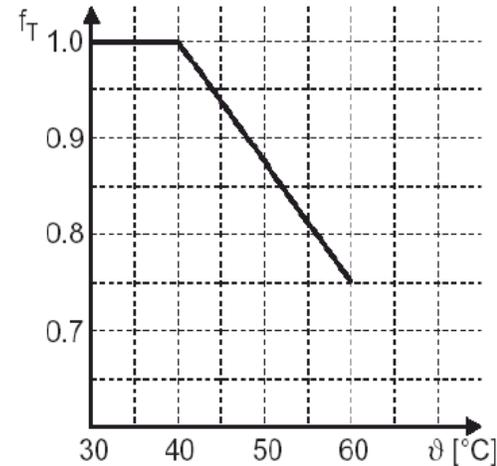
Courtesy Anibal T. De Almeida and Hugh Falkner and UNIDO

# Motor Derating

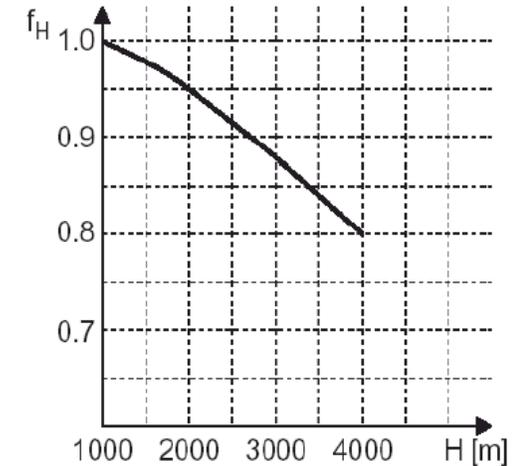
Available motor power should be derated for:

- High Temperature applications
- High altitude applications

For temperatures between 40°C and 60 °C



For altitudes above 1000m



$$P_{Nred} = P_N \cdot f_T \cdot f_H$$

Courtesy Anibal T. De Almeida and Hugh Falkner and UNIDO

# Motor Starts / Stops

Allowable starts per hour and minimum off-time between starts

- 10 hp / 1800 RPM 12.5 (46 sec)
- 50 hp / 1800 RPM 6.8 (72 sec)
- 200 hp / 1800 RPM 4.0 (300 sec)
  - Source: NEMA Standard MG 10

Motors need “recovery time” from the inrush current at startup.  
Larger motors need much more recovery time

# The Starter

Four elements: (generally in a box on the wall)

- Means of isolation (positive shutoff)
- Circuit protection (protect upstream wiring from shorts)
- Motor controller (stops, starts, ramps up; may even regulate voltage)
- Motor protection (protects motor from overload current and certain other fault conditions).

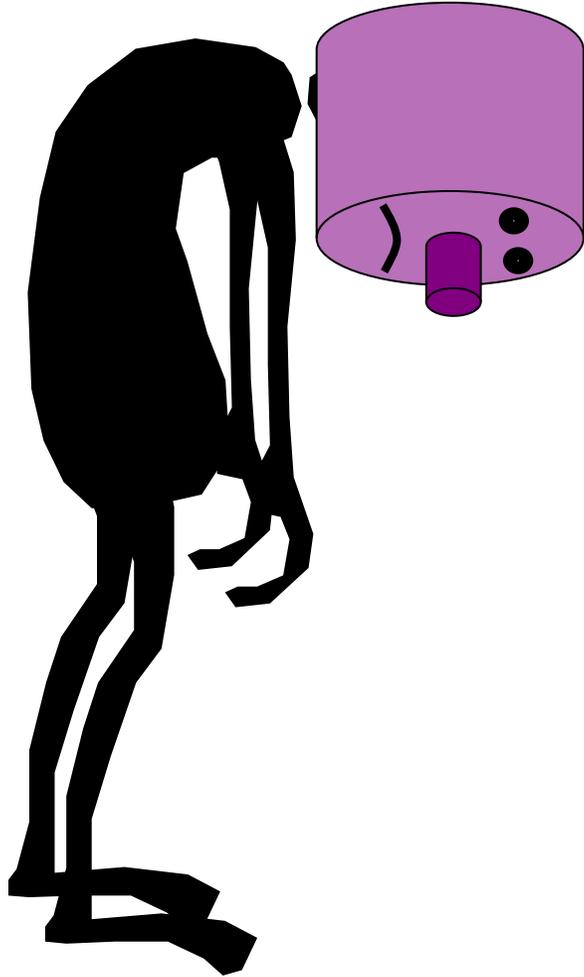
# The Load

- **Constant Torque**
  - This means the load's torque demand does not vary with motor speed.
- **Variable Torque**
  - The load varies with torque. Most common is the cube law variation. Torque varies as the square of speed (plus a constant) and horsepower varies as the cube. Pumps and fans (i.e. centrifugal loads) are the most common examples.

# Load Characteristics - Inertia

- High inertia loads present a challenge for motors to accelerate.
- Motors capability to start high inertia loads is covered in NEMA MG1 Part 20.
- If load inertia is too high, it may be necessary to upsize to a larger motor
- Variable Frequency Drives can be programmed for a slow ramp up without overheating. Other reduced voltage drives may overheat.

# Why/how do motors fail?



- Neglect / abuse
- Misapplication
- Severe Environment
- Normal Wear and Tear

# Failures of Neglect and Abuse

- Dirt
- Bad Lubrication
- Poor Power Quality
- Harmonics
- Unbalance in voltage
- Over/under voltage
- Poor belt drive maintenance



# Failures of Misapplication

- Under-sizing
- Over-sizing
- Wrong enclosure
- Coupling, Belts & Shimming



# Failures of Severe Environment

- Hot Ambient
  - Requires derating
- High Altitude
  - Causes overheating – requires derating
- Humidity
  - Motors in storage (zaps insulation or bearings)
  - Motors with significant off time (zaps insulation)
  - Requires internal or ambient heating
- Airborne Contaminants
  - Damages insulation or bearings
  - Kills by abrasion or chemical deterioration

# Failures of Normal Wear and Tear

Without unusual stresses, motors sometimes last for many tens of thousands of operating hours but will eventually succumb to...

- Bearing wear
- Insulation failure due to time and temperature.

# How much maintenance?

<i>Size</i> <i>Importance level</i>	<i>Maintenance Level</i>
<b>Small non-critical</b>	<b>Break down o.k. Preventive recommended</b>
<b>Medium non-critical</b>	<b>Preventive</b>
<b>Medium, &amp; Large Critical</b>	<b>Preventive &amp; Predictive</b>

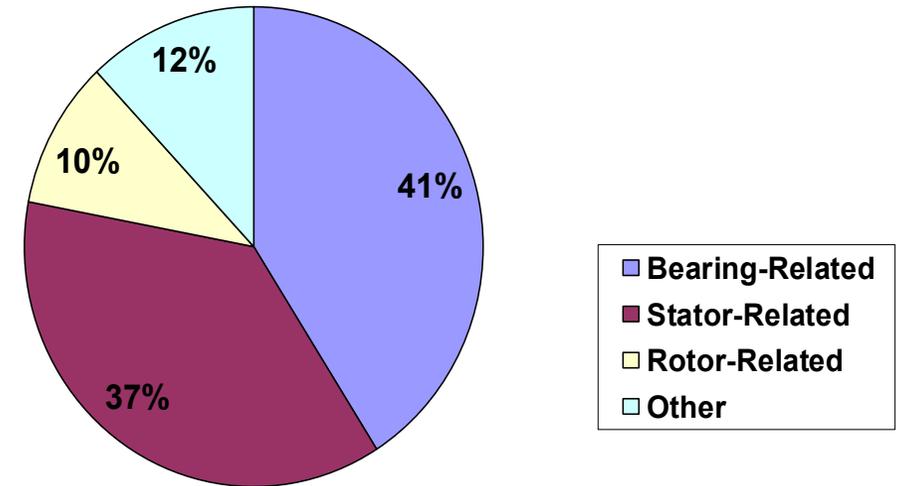
Image courtesy DOE

# Computerized Maintenance Management System - CMMS

- Many software providers offer CMMS products to track maintenance, prioritize work, maintain spares, inventory, trend condition changes, and generate reports to organize and optimize whole plant maintenance.

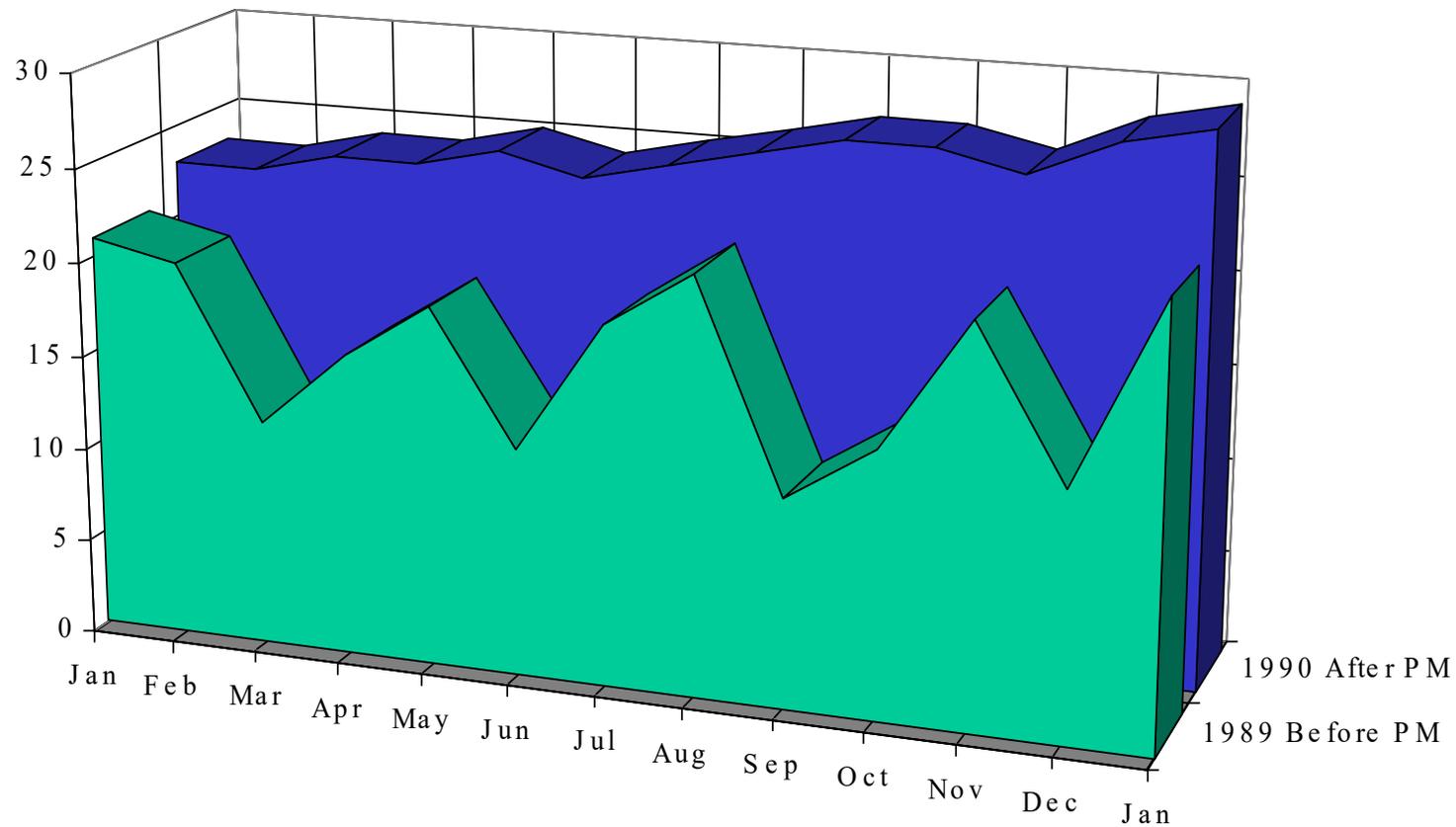
# Importance of Motor Maintenance

- According to the 2021 Motor Systems Market Assessment Report:
- Collectively, all US industry suffers from 6 million hours of downtime annually due to motor-related failures
- On average, an industrial facility will experience 47 hours per year of downtime due to motor-related failures



# Foundry Case Study – Implemented PM program

## Foundry Production in Tons



# Mechanical Transmissions - Gears

- Used for low speed, high torque loads
- Several types: helicoidal, spur, conic, and screw
- Losses are related to the friction of gears and bearings, windage and lubricating viscosity.



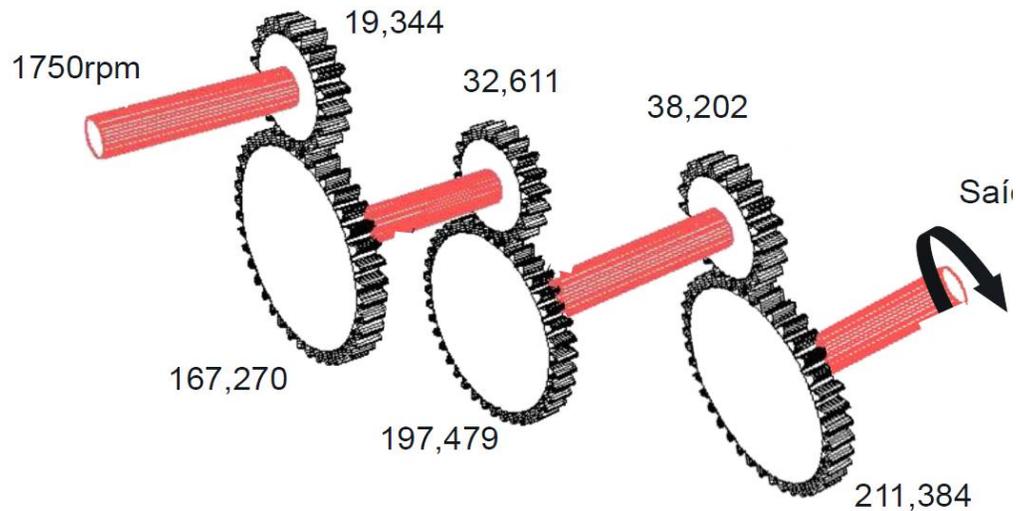
# Mechanical Transmissions – Gears

- Worm gear efficiency between 50 & 85%, depending on:
  - The transmission ratio
  - Speed
  - Lubricant
  - Temperature



Courtesy Anibal T. De Almeida and Hugh Falkner and UNIDO

# Mechanical Transmissions Helical Gears

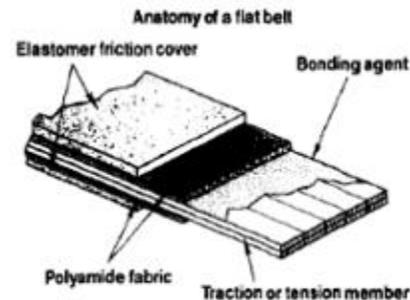
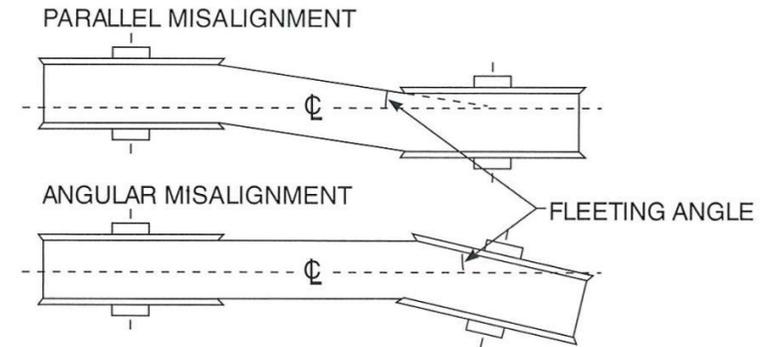


Helical and conic gears have an efficiency of 98-98.5% per stage (1.5-2% loss per stage)

Courtesy Anibal T. De Almeida and Hugh Falkner and UNIDO

# Mechanical Transmissions - Belts

- 1/3 of motors use belts.
- High flexibility of speed adjustment.
- Several types:
  - Vee belts
  - Vee belts without cogs
  - Flat belts
  - Synchronous belts
- The Vee type is the widely used, with an efficiency of 90-96% for larger motor sizes (depending on the motor size, elasticity, tension slip, and alignment).
- If the tension is excessive: accelerated wear of the belts and bearings.
- If the tension is too low: the slip and losses increase.
- The most efficient belt types are the flat and the synchronous. The synchronous has an efficiency of about 98-99%.

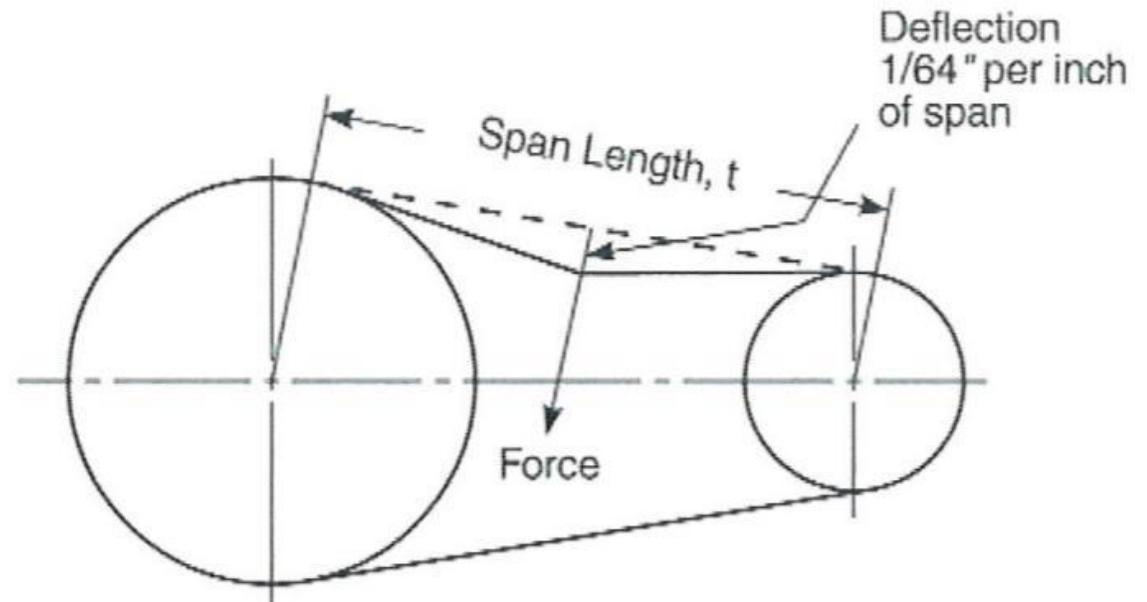


# Critical V-Belt Installation Parameters

- Replace all belts at the same time.
- Never use a crowbar to put on the new belts.
- Align the shafts and pulleys.
- Tension the belt properly using a:
  - Sonic tensioning meter or
  - Straight-edge & belt tensioning testing tool
- Run the machine for 24 hours.
- Re-tension the belts.

# Belt Tensioning Tools & Techniques

- Use Manufacturer's recommended deflection force.



Images courtesy Gates Rubber

# Critical Elements for Proper Motor Greasing

## RTFM

- Schedule
- Type of Grease
- Amount of Grease
- Purge old Grease



Image courtesy Peterson Predictive Maintenance

# Lubrication Interval Guide

Recommendations by  
Electrical Apparatus Service  
Association



<b>Lubrication Guide: Frequency in Months</b>			
<b>RPM</b>	<b>Frame Range</b>	<b>Type of Service</b>	
		<b>8 Hours/Day</b>	<b>24 Hours/Day</b>
3600	143T-256T	*	*
	284TS-286TX	6	2
	324TS-587US	4	2
1800	143T-256T	*	*
	284T-326T	48	18
	364T-365T	12	4
	404T-449T	9	3
	505U-587U	6	2
1200 and below	143T-256T	*	*
	284T-326T	48	18
	354T-449T	12	4
	505U-587U	9	3

\* These motors often do not have bearings that can be relubricated.  
Replace after 14,000 to 17,000 service hours.

# Corporate culture & lubrication

- Leverage QC processes to document correct procedure
  - Six Sigma
  - ISO
- Delegate to a responsible team
- Consider outsourcing?
- Consider using more motors with sealed bearings?

# Infra-Red Photography

## Hot Bearing Headed for Failure

- The motor is supposed to be warmer than the bearing

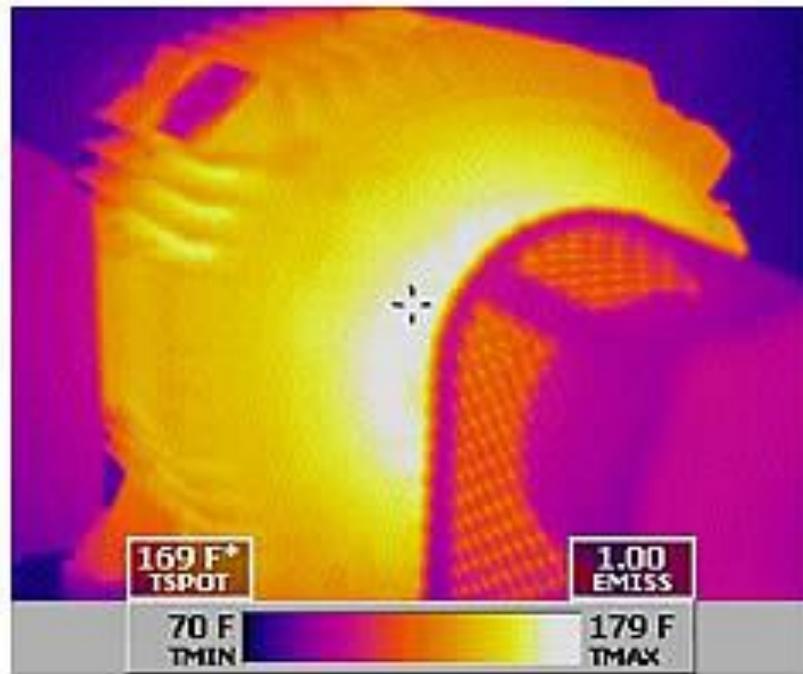


Image courtesy Peterson Predictive Maintenance

# Ultrasonic Bearing Maintenance



Bearing Check



Acoustic Grease gun  
adapter

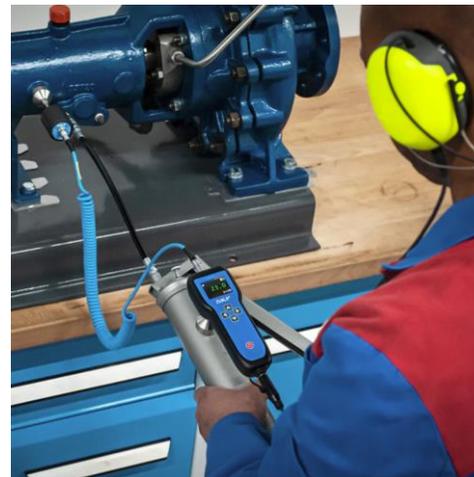
Image courtesy UE systems and SDT North America

# Ultrasonic bearing maintenance

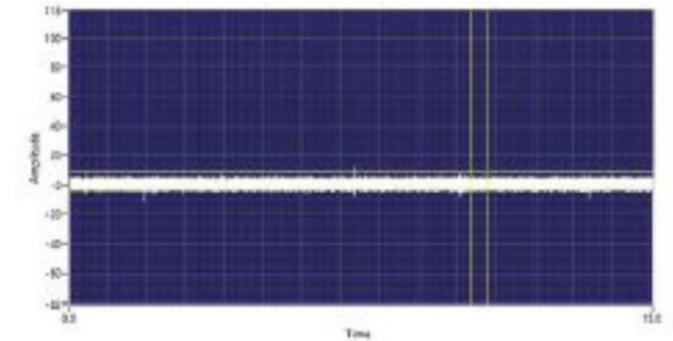
The operator can hear the bearing noise and see the wave form to discern what's happening internally.

The same ultrasonic listening device can probably also:

- Find air leaks in compressed air systems
- Find refrigerant leaks in air conditioning equipment
- Pinpoint electrical arcing faults
- Test closed valves for leakage



Good motor bearing



Damaged motor bearing

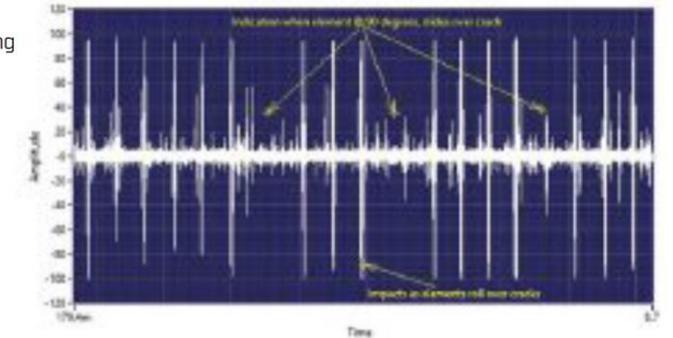


Image courtesy UE systems

# Equipment Set-Up: Mechanical

- Provide a flat, rigid mounting for motors and driven equipment.
- Ensure that motor and load are properly aligned.
- Proper Alignment:
  - Reduces motor frame distortions
  - Reduced motor frame stress
  - Reduced vibration
  - Increases motor life
  - Increases efficiency



Laser Alignment

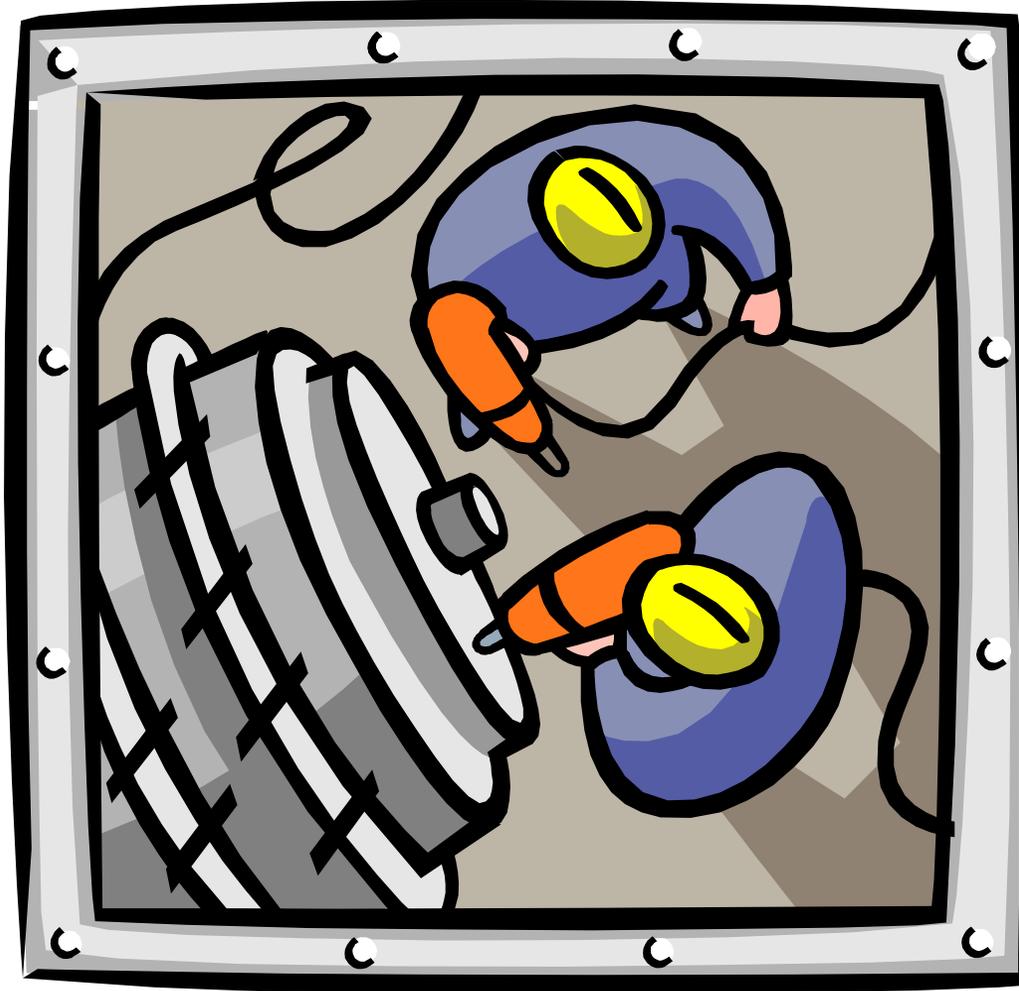
*If not properly aligned, the coupling will quickly fail*

# Equipment Set-up: Electrical

- Electrical codes generally based on 2% loss
- Suggested practice –  
*upsized wire gauge one size larger than required by code*
- Specify adequate conductor size:
  - Reduces line losses
  - Mitigates harmonics
  - Reduces sags
  - Reduces undervoltage
  - Accommodates load growth
  - Accommodates low power factor
  - Accommodates Design A motors



# Repairing, Rewinding, and Rebuilding



# Repair vs. Replace policy:

## According to the 2021 Motor Systems Market Assessment Report...

- Only 54% of industrial facilities have a repair replace policy, and sometimes these are very informal.
- In 36% of industrial facilities, the guiding policy is lowest first cost among the repair vs replace options.
- 4% of industrial motors were rewound in the last 2 years
- Less than 1% of commercial motors were rewound over the past 2 years

# Repair vs. Replace:

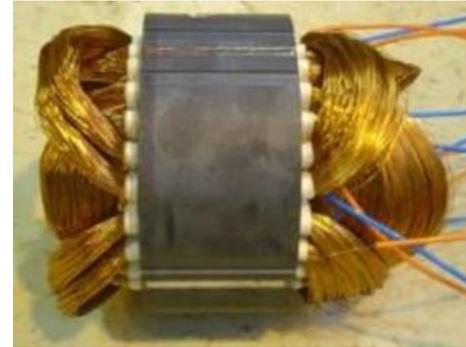
## Things to Consider...

- Rewinding a motor \*can\* reduce efficiency 0.5 to 1% (if not done according to EASA best practices)
- First cost of repair and new purchase.
- Efficiency of existing and proposed new motor.
- Urgency and availability of each alternative.
- Possible modifications to the mounting.
- Annual hours of operation.
- Cost of down time and repairs from a possible early failure in either scenario.

# How does a poor rewind degrade efficiency?

## Stator Winding

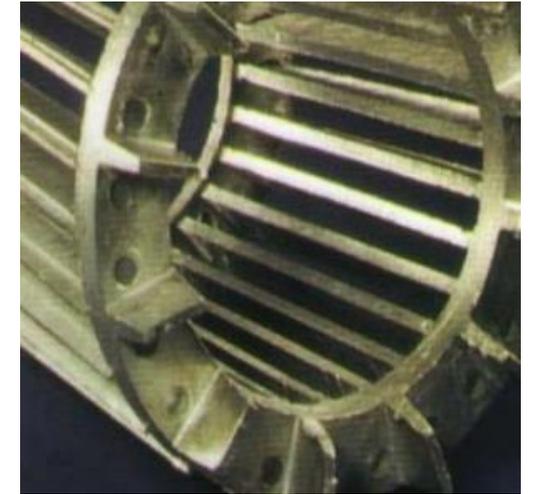
- Undersize wire may be used.
- Errors can occur in the turn count.
- Winding pattern may be revised



# How does a poor rewind degrade efficiency?

## Rotor

- Damaged rotor bars may be missed and not repaired.
- Machine work on the rotor may increase the air gap or smear the laminations together on the rotor surface.
- Failure to repair bent shaft can interfere with magnetic flux uniformity in the air gap.



# How does a poor rewind degrade efficiency?

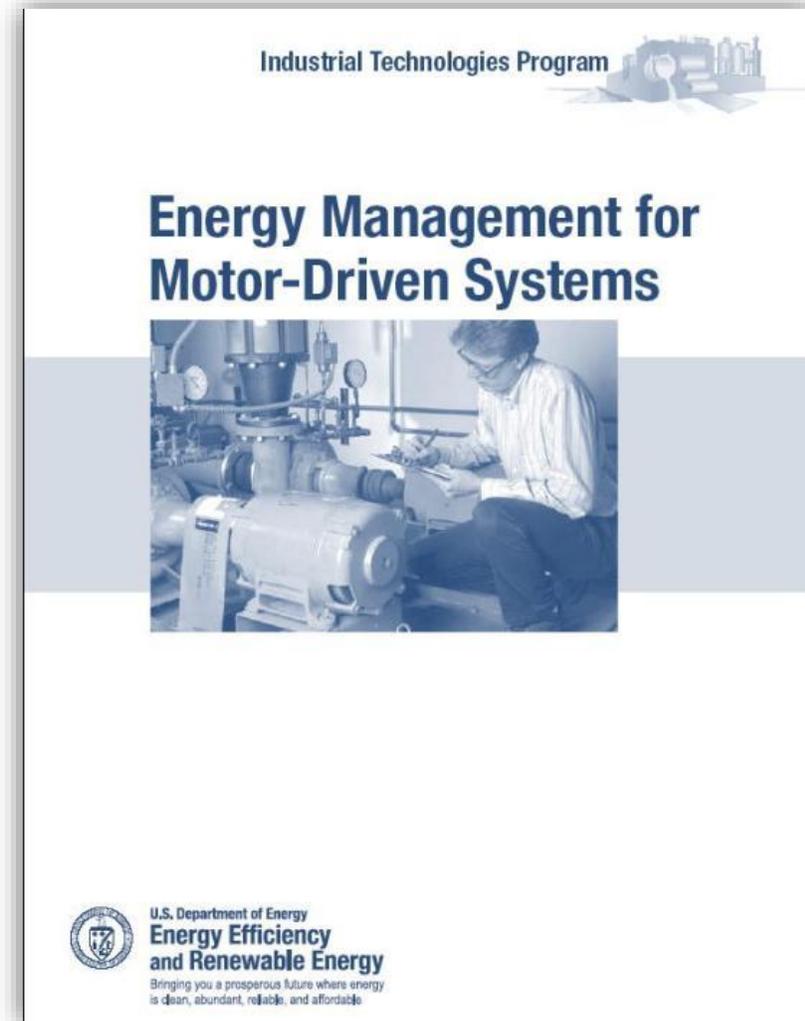
## Stator Core Iron

- Overheating to roast out the old windings can damage interlaminar insulation.
- Machining can increase the air gap or smear the laminations together on the stator surface.
- Failure to repair damage from the actual fault condition can leave a hole in the stator or welded laminations.



# Energy Management for Motor Driven Systems

This book is a very comprehensive guide to managing your electric motor systems for an improved bottom line.

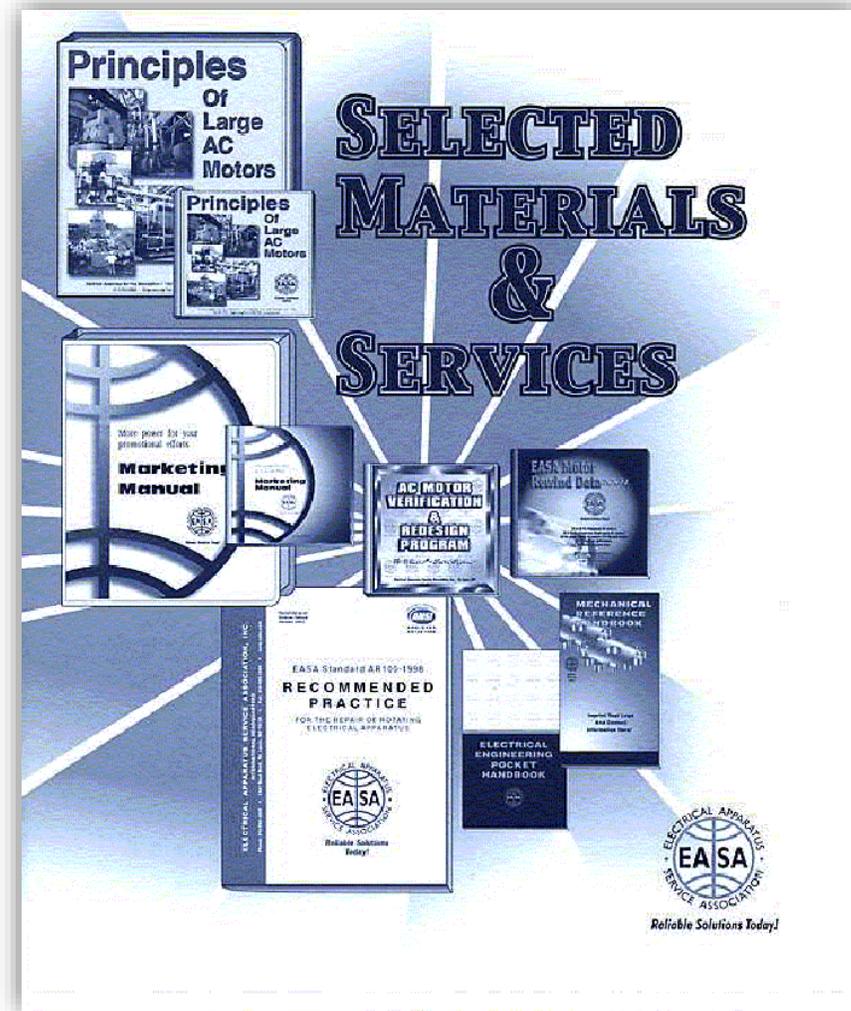


# Resources Pertaining to Motor Repair and Rewinding

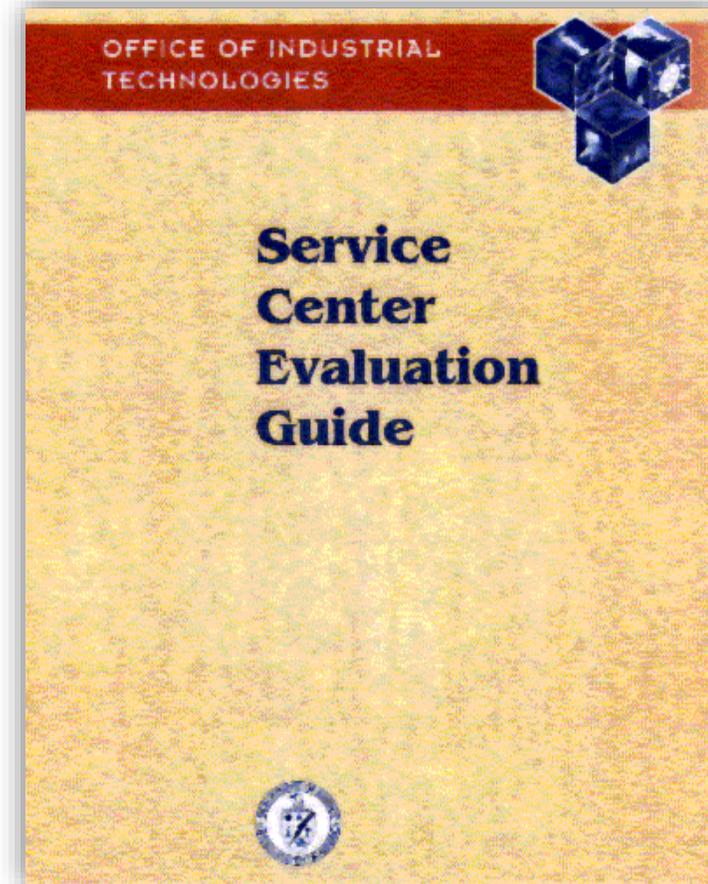
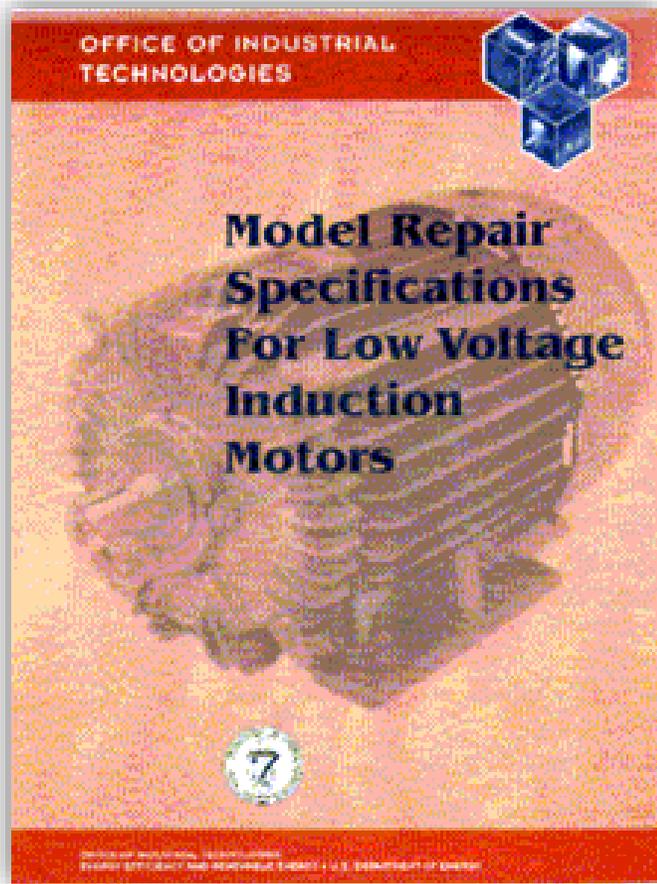
**Electrical  
Apparatus Service  
Association**

**EASA**

Catalog of Resources  
[www.easa.com](http://www.easa.com)



# Resources Pertaining to Motor Repair and Rewinding



# Switch to live demonstration of MEASUR motor calculators

The screenshot displays the MEASUR web application interface. At the top left is the U.S. Department of Energy logo. The main header features the MEASUR logo and a welcome message: "Welcome to the most efficient way to manage and optimize your facilities' systems and equipment." Below this, a navigation bar offers "Add New" and "Home" options. The "Home" section contains a list of assessments and examples, including "New Motor Inventory", "Class demo Combustion air fan", "Kiln Fan", "Combustion air blower", "Boiler ID fan 75% firing rate", "ACME", "ACME International", "ACME International 100% firing rate", "ACME International 75% firing rate", "ACME International 60% firing rate", "ACME", "Boiler ID fan - 100% firing rate", "Boiler ID fan - 60% firing rate", "Boiler ID fan - 75% firing rate", "Examples", "Toy Factory (copy)", "Treasure Hunt Example", "Steam Example", "Process Heating - Fuel Example", "Fan Example", "Pump Example", "Boiler ID fan 75% firing rate", and "Boiler ID fan 60% firing rate".

The main content area is divided into three sections:

- Create Assessment:** Model a system and explore multiple optimization scenarios. Options include:
  - Create Pump Assessment (formerly DOE Pumping System Assessment Tool (PSAT))
  - Create Compressed Air Assessment (formerly DOE AirMaster+)
  - Create Process Heating Assessment (formerly DOE Process Heating Assessment and Survey Tool (PHAST))
  - Create Fan Assessment (formerly DOE Fan System Assessment Tool (FSAT))
  - Create Steam Assessment (formerly DOE Steam System Modeler Tool (SSMT))
  - Create Treasure Hunt (Energy efficiency calculators for facilitating a Treasure Hunt)
  - Create Waste Water Assessment (Based on the Bio-Tiger Model for Wastewater Treatment Plants)
- Properties & Equipment Calculators:** Generate detailed properties and test a variety of adjustments. Options include:
  - General
  - Compressed Air
  - Fans
  - Lighting
  - Motors
  - Process Cooling
  - Process Heating
  - Pumps
  - Steam
  - Waste Water
- Inventory Management:** Create and manage equipment inventory. Options include:
  - Create Motor Inventory (based on DOE's MotorMaster+ tool)
  - Create Data Exploration (based on DOE's LogTool)

A blue arrow points from the "Motors" option in the "Properties & Equipment Calculators" section to a pop-up window titled "Motors Calculators". This window lists several motor-related calculators:

- NEMA Energy Efficiency:** Shows the predicted efficiency of an induction motor, based on size, rotating speed and efficiency class.
- Motor Performance:** Plots current, efficiency, power factor vs motor shaft load for a given motor description.
- Percent Load Estimation:** Calculate percent load via slip method or field measurements.
- Motor Drive:** Compares the annual energy cost of different motor drives.
- Replace vs Rewind:** Compares the cost and energy of rewinding a failed motor versus replacing it with a new energy-efficient model.
- Full-Load Amps:** Calculate the full-load amps of a motor.

# Thank you!

For Questions or Comments please reach out to the following:

Ron Wroblewski, PE  
Productive Energy Solutions, LLC  
[ron@productiveenergy.com](mailto:ron@productiveenergy.com)

Thomas Wenning  
Oak Ridge National Lab  
[wenningtj@ornl.gov](mailto:wenningtj@ornl.gov)