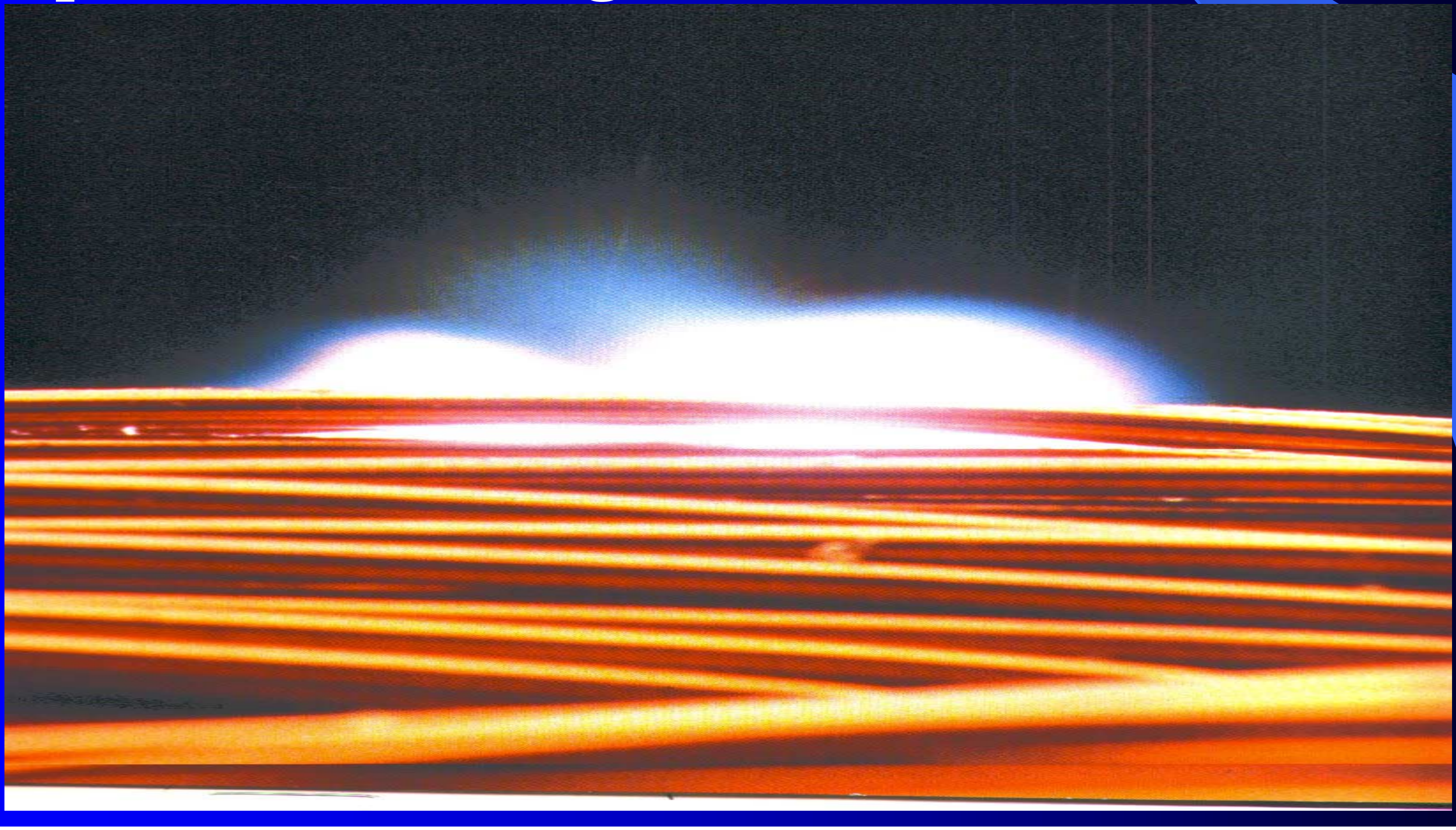
Damage to Electric Motors from Electronic Drives

Introduction

- Speed Controlling Electronic Drives Save



We’ll learn briefly

– what damage Drives do to motors and why
– How to Prevent the Damage:
  - When retrofitting drives to existing motors in the field
  - What your motor rebuilder can do to limit the negative effects of Drives
– Economic Common-Sense Considerations when Retrofitting a Drive to Existing Motors

Why Inverters are So Valuable in the Water Industry

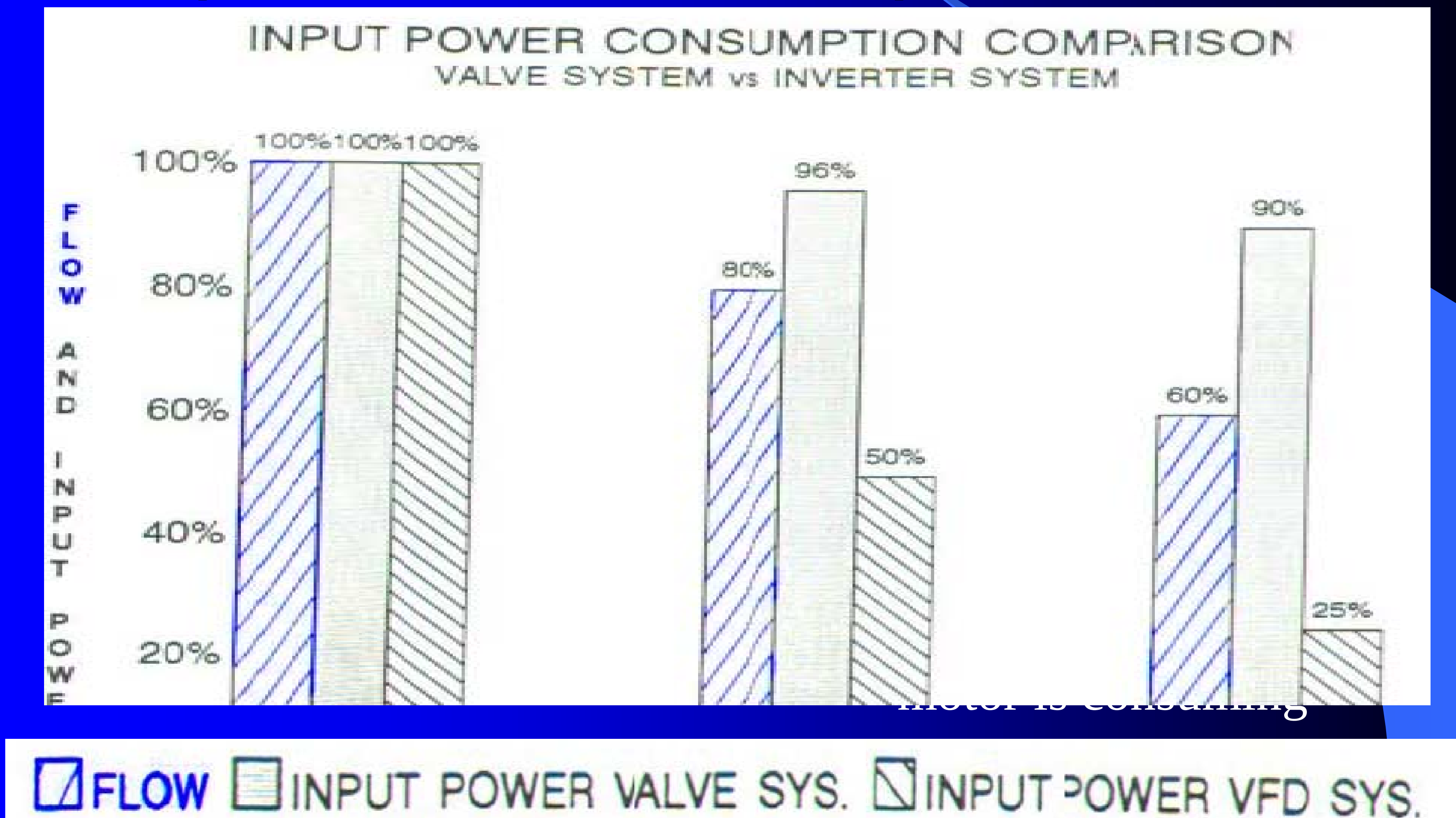
– Drives save Big

Electricity $ Costs

– and Mechanical Wear

Costs

Inverters Match Electricity Input to Water Output Needed



Inverters Match Mechanical Wear Costs to Water Output Needed

- On/Off Cycling for water volume control is hard on the whole system
- Inverters allow controlled start and stops to reduce water hammer problems
- Bearings and other mechanical rotating components subject to life-cycles based on number of rotations are needlessly consumed with valve control

Centrifugal Pumping Applications

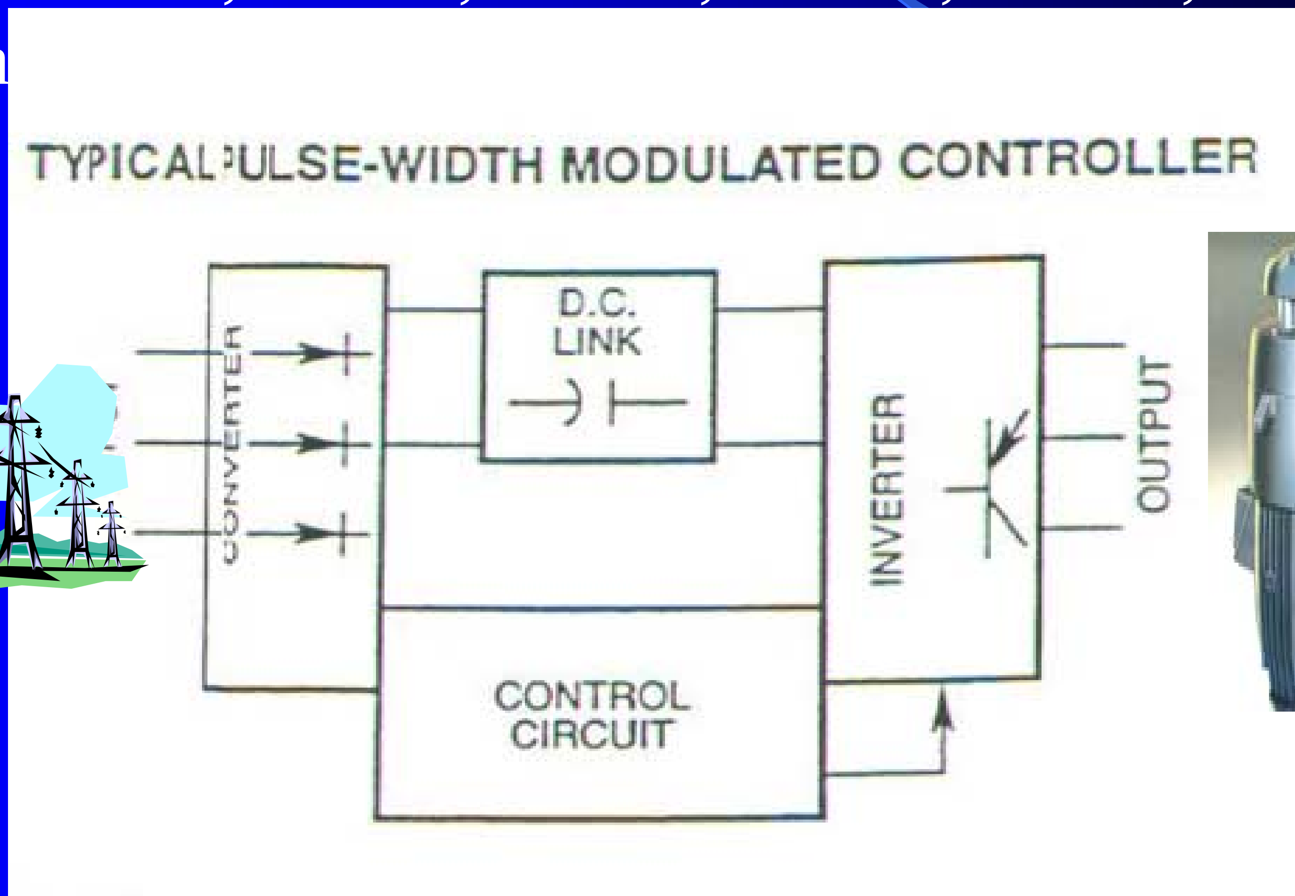
- involve torque and horsepower requirements which decrease greatly with speed reductions,
- Power Consumption varies with the ***Cube*** of the pump speed
- Inverter Retrofitting to existing motors is the least problematic - pump apps. reap the greatest savings from inverters with low risk
- Simply Turning Down the Motor Speed Provides very quick Paybacks on Retrofit Investment

But What About Those Pesky UNKNOWN Cost Factors?

- Unexplained motors failures
- Unplanned sudden downtimes & outages:
  - Costs of buying-out water or water quality fines
  - Costs to Remove & Re-Install
  - Repeat Failures After Repair
  - Even the New Replacement Motor Failed Early
  - Premium Price for an "Inverter Duty" New Motor
  - Costs of Repeated Trial & Errors to reach the "So That's What Our Problem Was…" Stage

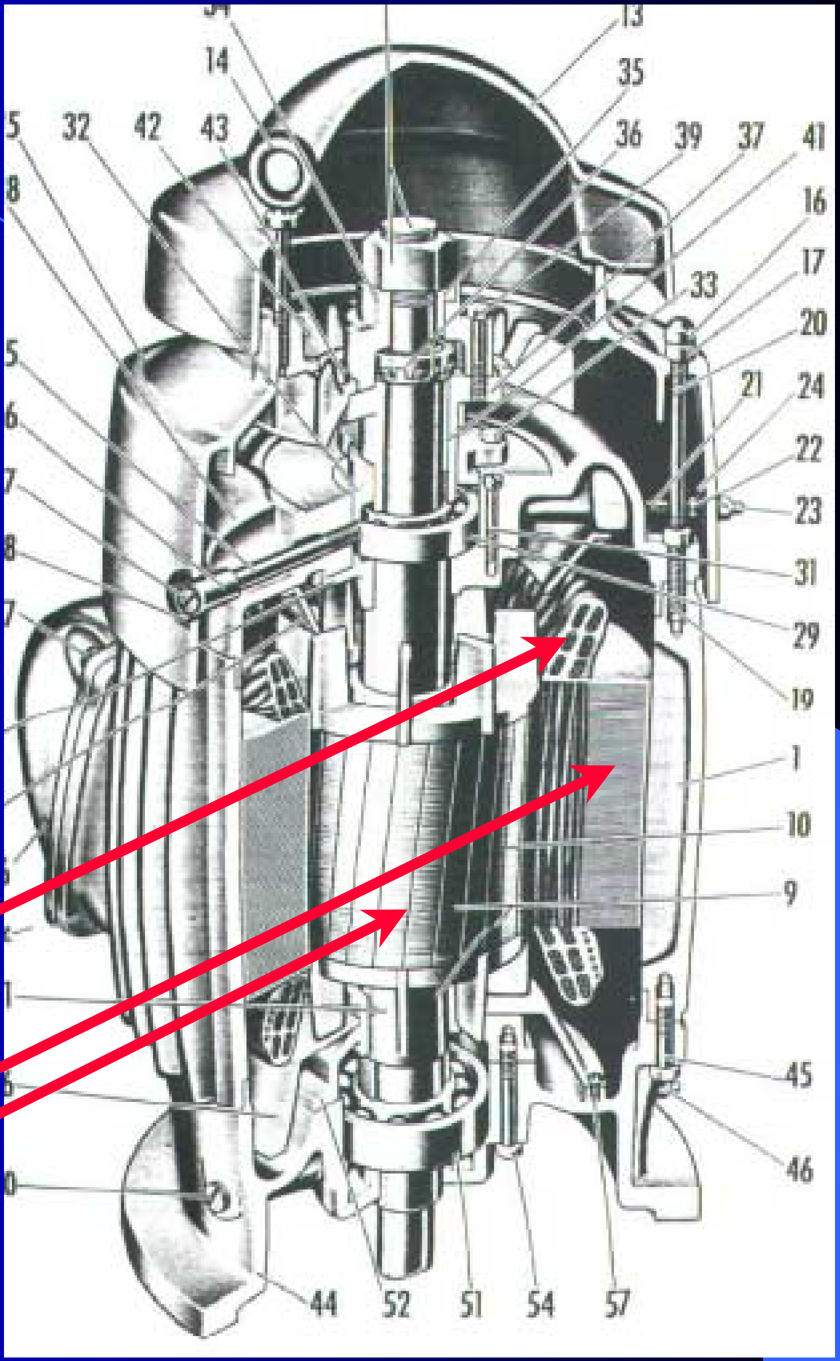
Vocabulary

- “Inverters, Drives, VFD’s, AFD’s, ASD’s, Va
  - – g AC

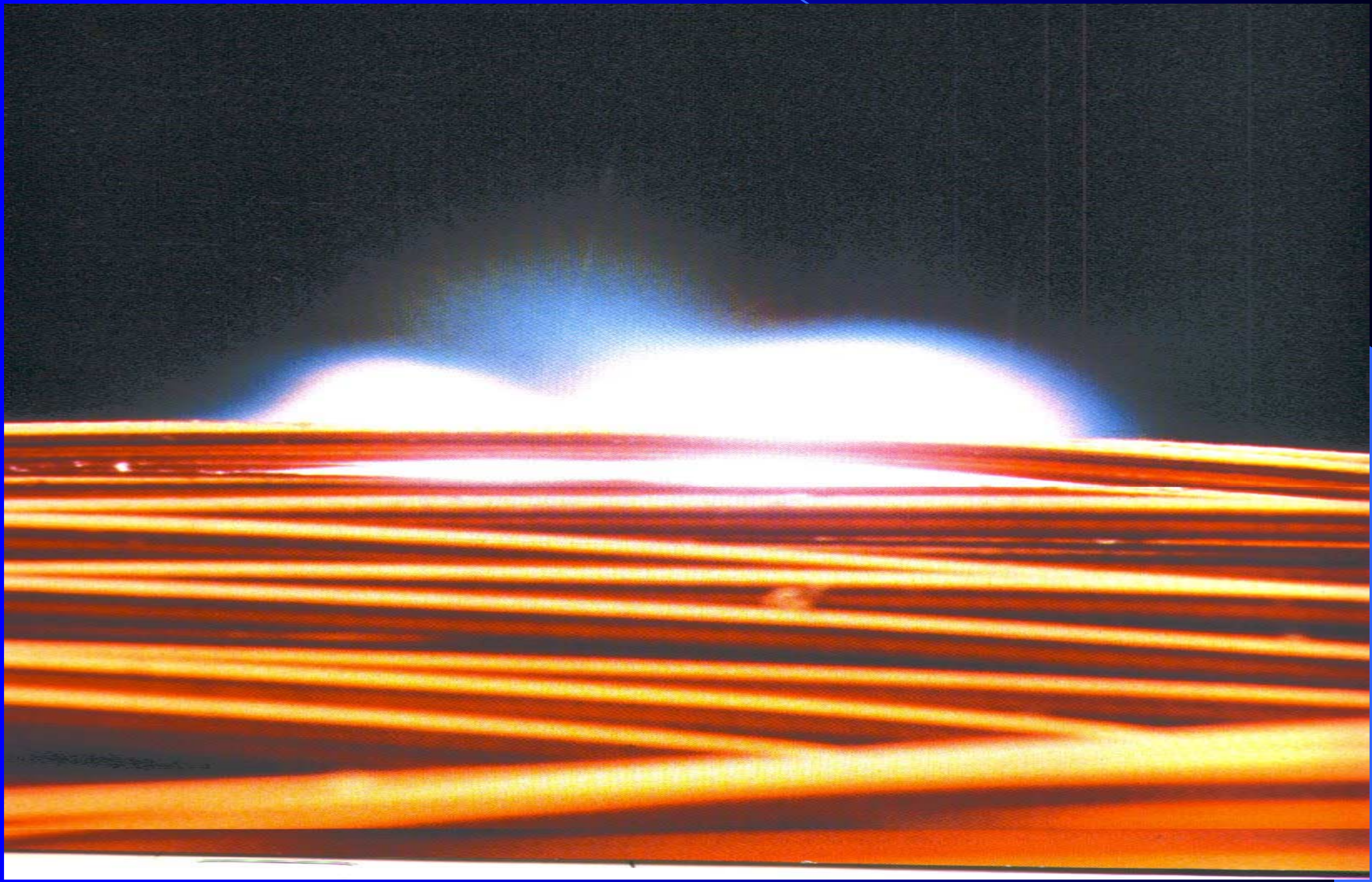


Vocabulary...

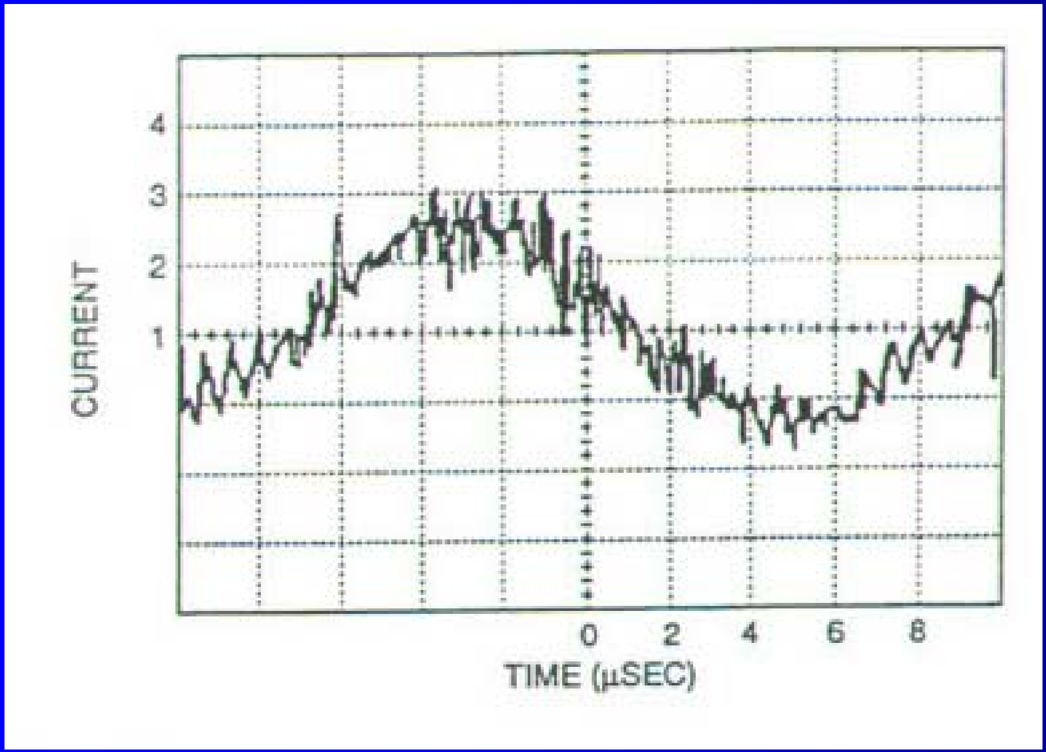
- Inverter (in our discussion) is limited to the now prevalent PWM types
- Retrofitting - Installing an Inverter to control the speed of an existing pump motor
- Winding, Stator & Core, Rotor



Effects of Inverters on Motors



Electrical Potential Problems



- Increasing Area of Concern due to Higher & Higher "Switching Frequency"
  - "Switching Frequency" or "Carrier Frequency" is the Inverter's final stage at which power is sent to the motor at a frequency level which will produce the motor speed you've selected. This is the speed control stage.

Electrical Problems Created by Inverter Changes

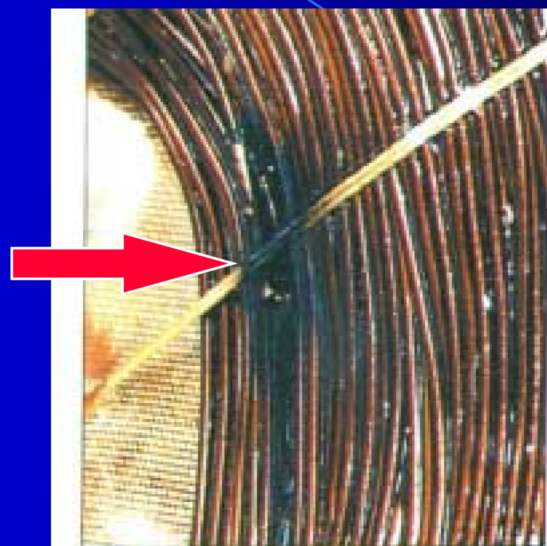
- Inverters started with the 1rst old “SCR” type which performed switching at only 300 times per sec (300Hz)
- Progressed over the decades through GTO’s types to the now widespread IGBT types which switch at up to 20,000Hz!!!
- Advantages of the High-Switching “IGBT” types:
  - Lower energy loss within the drive allowing smaller and lower cost inverters
  - Higher carrier frequencies reduce audible motor noise (**big + on wells in residential areas**) and reduced current harmonics
  - Reduced losses in the motor, meaning higher efficiency, cooler running motor, more torque-producing current over the speed range

Motor Damage from Inverters

- Long wire runs between motor and inverter can now cause problems
  - Voltage Overshoot or "Ringing" and Voltage "Reflected Wave" or "Standing Wave"
    - Conditions are created when long wiring runs between motor & inverter create a capacitor system-Hi Voltage potentials & spikes

Motor Damage from Inverters

- Severe Electrical Stresses to the Motor Insulation System
  - Rate of Voltage Rise, repetitive voltage transients, pulses, high voltage potentials within localized portions of the motor winding creating an ozone buildup which attacks parts of the motor insulation creating destructive "corona".



Close-up of a burned out field winding end turn of a three-phase induction motor. Failure occurred within two months after the application of a VFD. The insulation breakdown was caused by the very high rate of voltage rise with respect to time of the carrier frequency and because of the constant high rate of repetition of this pulsing frequency (in kHz).

Motor Damage ….

- heat buildup in the motor components which shortens normal insulation life
- Electrical “Shaft Currents” thru the Bearings causing pits in brg parts and eventual failure

Mechanical Potential Problems

- Turning down the motor speed, decreases the motor's self-cooling ability
  - Usually not a problem on Centrifugal Pumps. As speed is decreased, motor losses to heat decrease with lowering speeds more than the motor ventilation decreases.

Mechanical Problems….

– Resonance & 1rst Shaft Critical Speed Problems
  - All machinery has a natural frequency point which, when excited, will cause them to vibrate or resonate (bell, tuning forks, rubbing the rim of a glass to excite it's resonant frequency)
  - Std. Motors are designed with this resonant frequency (shaft critical point) above the running speed
  - Inverters can overspeed motors to run above normal speed and can hit these resonant frequency points

Mechanical Problems

– RPM levels in excess of rotor structural strength relating to centrifugal force
– Consistent Operation at Speeds beyond original bearing design and bearing lubrication

Prevention Onsite

- Keep Wiring Runs between Inverter and Motor AS SHORT AS POSSIBLE !!!
  - Lead Wire Runs under 50 ft are safe without filtering and usually are safe up to 150 ft
  - When wiring runs over 150ft can't be prevented or problems are experienced:

    - 3 Phase Output Reactor located at the Inverter output solves majority of premature motor failures due to long lead runs. These devices have a great effect at a relatively low cost.
    - Motor-Protection Output Filters can ensure dependable operation at lead runs of up to 2,000 ft by conditioning the Inverter signal. (Tuned Filter Traps for Harmonics, Active Filters)
  - Always use Shielded Wire on new lead wiring Runs to prevent affecting adjacent wiring

Prevention Onsite….

Suggested maximum cable length for motors on IGBT inverter
(Data for motors manufactured by Marathon Electric.)

Inverter input,Vac	Carrier frequency, kHz			
	3	6	9	12
General purpose motors:				
460	125 ft	80 ft	65 ft	55 ft
575	40 ft	25 ft	20 ft	15 ft
Inverter duty motors:				
460	875 ft	550 ft	400 ft	325 ft
575	275 ft	175 ft	125 ft	100 ft

Cable Run Limits

Prevention Onsite...

- Shaft Currents destroying Bearings?
  - Try a shaft grounding brush which provides a path for shaft currents to leak off of instead of arcing between the balls and races of the bearings
- Lower the Inverter's "Carrier Frequency" or Switching Frequency to the lowest frequency possible without creating audible noise problems
  - – Reduces the voltage rise / time spikes that the motor sees

Common Sense Retro-fitting Strategy

- Choices (in order of safety)
  - Replace Motor with matching “Inverter-Duty” Motor recommended by Drive Manufacturer (Highest Cost, must be depreciated over a 7 yrs.)
  - Replace Motor with low-bid “Inverter-Duty” Motor - (low risk of un-matched system) #2 Cost

Common Sense Strategy...

- Rebuild Existing Motor for "Inverter-Duty" - (***be sure written specifications are agreed on***) (4rth Lowest Cost, can deduct entire cost of rebuild in 1rst year to reduce taxes)
- Replace Motor with a "Premium Efficiency" Motor - (minimal risk-may or may not have inverter duty wire, does have upgraded insulation system for higher temp) #3 Highest Cost
- Recondition existing motor and reuse
- Use Existing Motor "As-Is" (Lowest Cost, Highest Risk)

"Replacing Motors" Retrofit Strategy

- New "Inverter Duty" Motor is Safest and MOST Expensive Retrofit Method
- Must be depreciated over 7 years - tax advantage lesser than Rebuild Method
- Delivery Leadtimes for "Inverter-Duty" usually longer than all other choices (improving)
- Freight Costs may be a factor
- Installation Problems-different mounting, drive accessories, conduit location, space
- Best Choice if:
  - Downtime risk is absolutely unacceptable; highly critical application
  - Budget/Money is no concern
  - Removal / Reinstall Costs are equal or greater than the cost of the motor

"**Rebuilding Motors**" Retrofit Strategy

- Low-Risk as most key "Inverter-Duty" New Motor Specs. are incorporated
- Total Rebuild Costs can be used to reduce taxes in the very 1rst Yr
- Delivery Time usually a few days
- Freight usually not an issue

“Rebuilding Motors” Strategy...

- Installation Problems Avoided since it’s the same original motor
- Warranty period is usually the same as new
- Middle of the road choice - Balance between safety and economics

"**Recondition**" or Use "**As-Is**" Retrofit Strategy

- Higher Risk but very low Up-Front Cost
- If Inverter is located right next to motor your risk is greatly reduced
- "Reconditioning" (dismantle, testing, steamclean, dip & bake, new bearings) is about 20% of Rebuild (rewinding) and gives a good idea of the health of the motor

Use "**As-Is**" Retrofit Strategy...

- "As-Is" Retrofit most likely avoids all motor related costs:
  - Removal & Reinstallation
  - Rebuilding, Reconditioning, Replacing
- What have you got to lose?
  - (If not on a critical application)
  - If already in service for 5 years, a large portion of the useful winding and bearing life is already used up (depending on amount of routine servicing / reconditioning)

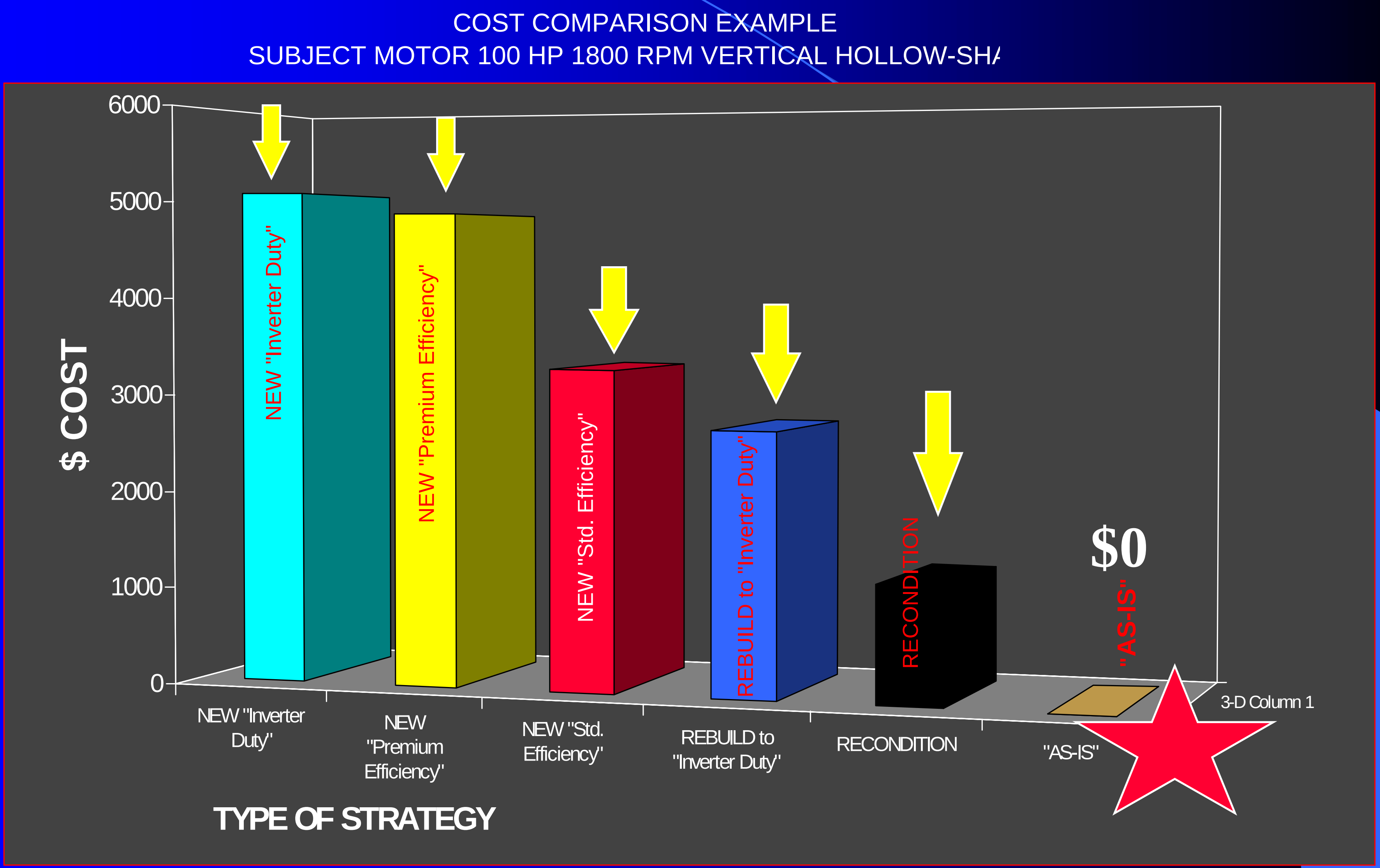
"As-Is" Motor Strategy...

– What have you lost in the following example:
  - "As-Is" Retrofit 5 Existing Motors with 5 yrs average in-service time
  - Usual worst case is 1 or 2 of the 5 would fail within a year
  - You've only lost what little life was left in those 1 or 2 motors
  - If you replaced all the motors with "Inverter Duty" compare the cost and tremendous savings
  - If you had replaced all 5 motors, the old motors were of little value to you then anyway
  - You now only have the Inverter-Duty Rebuild Cost of these 1 or 2 Weak Motors which was the next cheapest avenue anyway

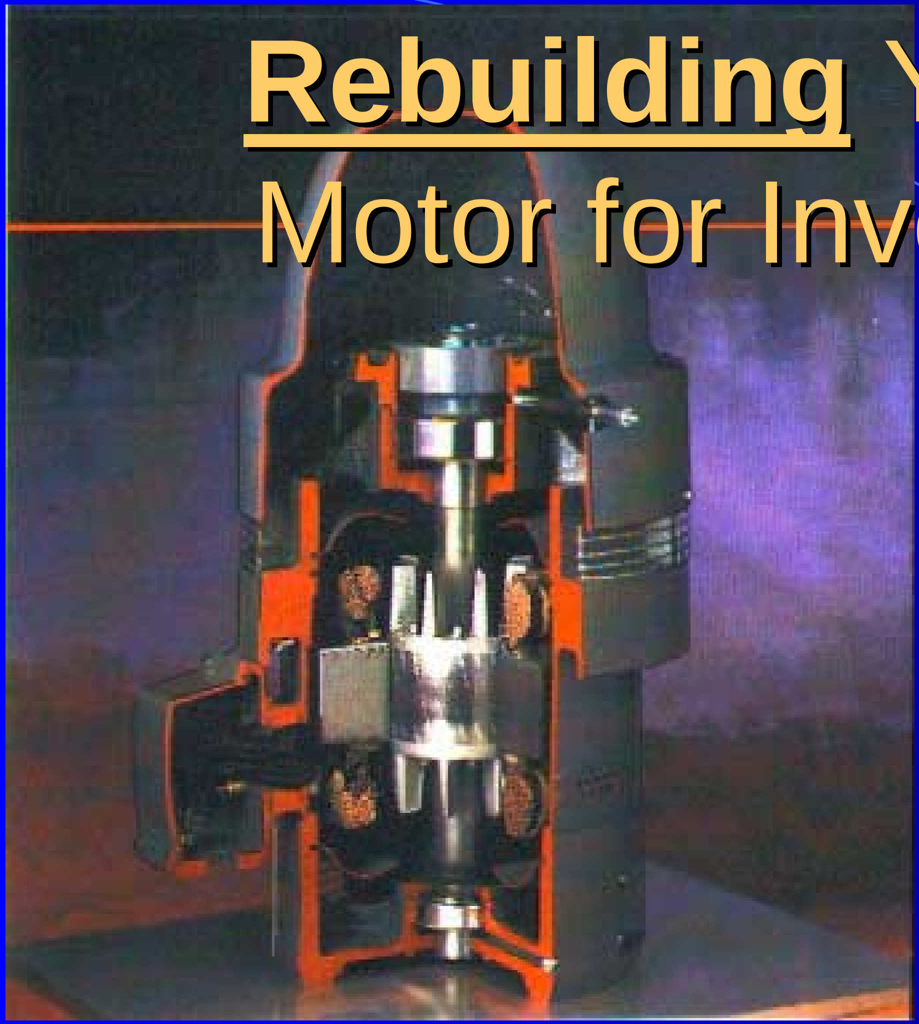
Cost Comparison Example

- **Example Subject Motor: 100 Hp 1800 RPM Vertical Hollow-Shaft ODP**
- NEW "Std. Efficiency" $2,981 - $3,292
- NEW "Premium Efficiency" $3,975 - $4,871
- NEW "Inverter Duty" $4,334 - $5,093
- REBUILD to "Inverter Duty" (Rewind, new brgs) $2,056 - $2,700
- RECONDITION (Steamcln,tst,dip & bake,brgs) $ 650 - $1,200
- "AS-IS" big fat 0

Strategy $ Comparison



Rebuilding Your Existing Motor for Inverter Retrofit



THERMALEZE® Q^{S} (TZ QS)

Stator Core Specification

- Computerized Core Testing (Lexseco or Phenix)
  - No “Marginal” or “Bad” rated cores
  - Core Test “Before” & “After” stripping of the old winding

Stator Core Specs….

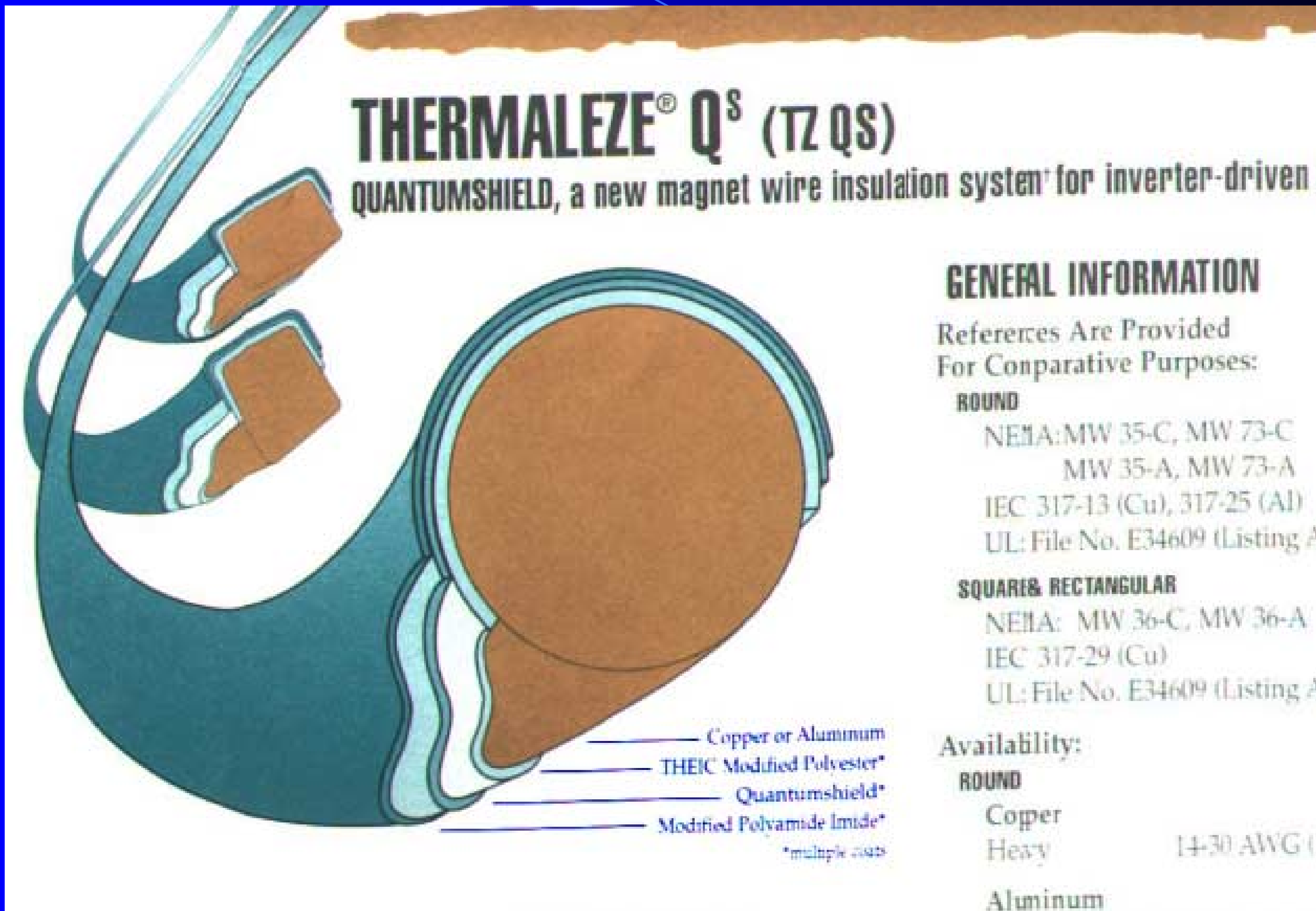
– Part of the old winding Stripping Process involves placing the stator which holds the winding in a “Burn-out” or “Charring Oven”

- Burn-out Temp. should be limited to 650deg F
- Should be temperature controlled with a fire box that prevents direct flame onto stator
- Should have an “Over-Temp Protection System” to prevent runaways (caused by mat’ls such as epoxies)

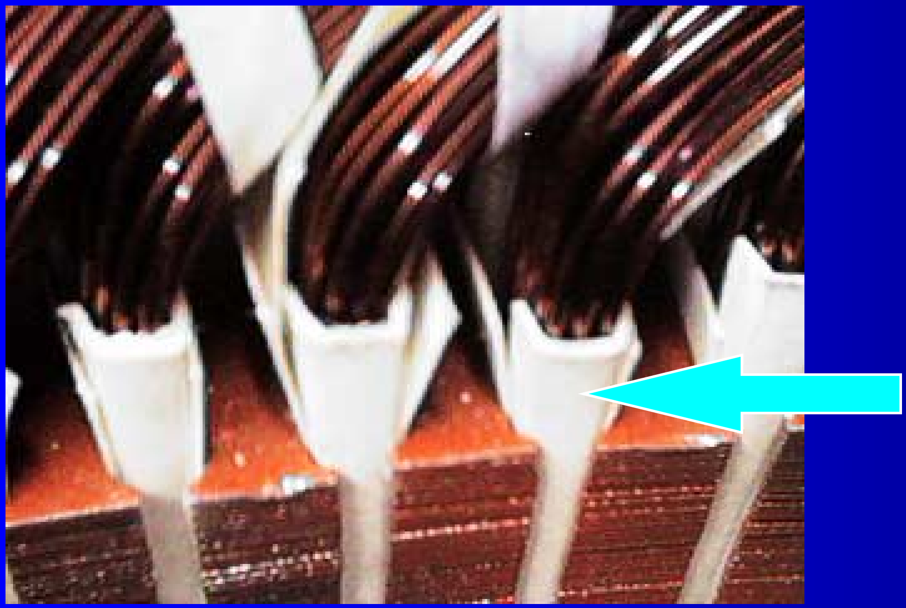
Winding Specifications

- Rewind using the new Magnet Wire developed for Inverter Duty
  - Phelps Dodge “Thermaleze QS (Quantamshield)”
  - Essex “Ultra Shield”
  - Rea “Pulse Shield”
  - They have an insulation enamel chemistry designed to withstand the voltage pulses or spikes from inverters without increasing the enamel thickness (efficiency not reduced due to less copper) without compromising other insulation functions (i.e. thermal life, chemical resistance)

the New "***Inverter Wire***"

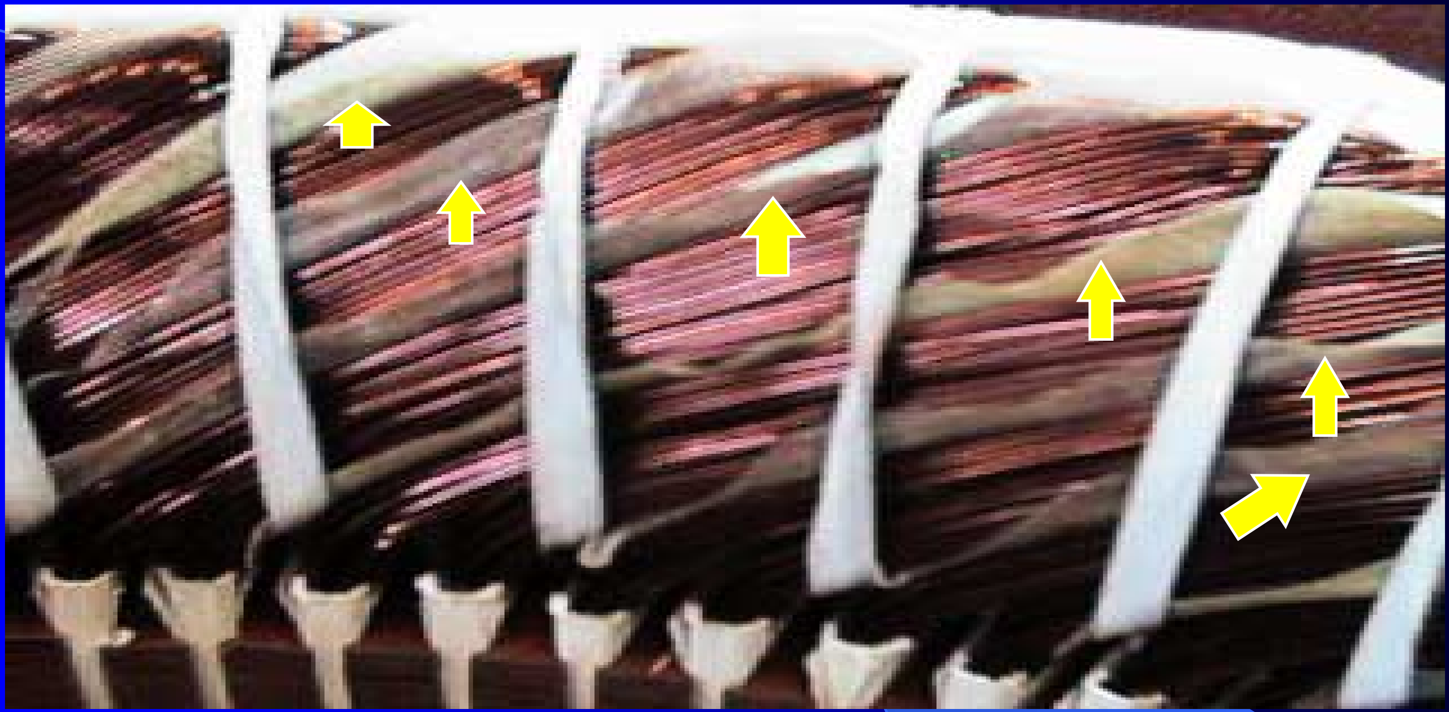


Winding Specs….



- Avoid loose windings- Tie end turns on both ends, & use slot fillers if needed due to winding configuration, use top sticks

Winding Specs….



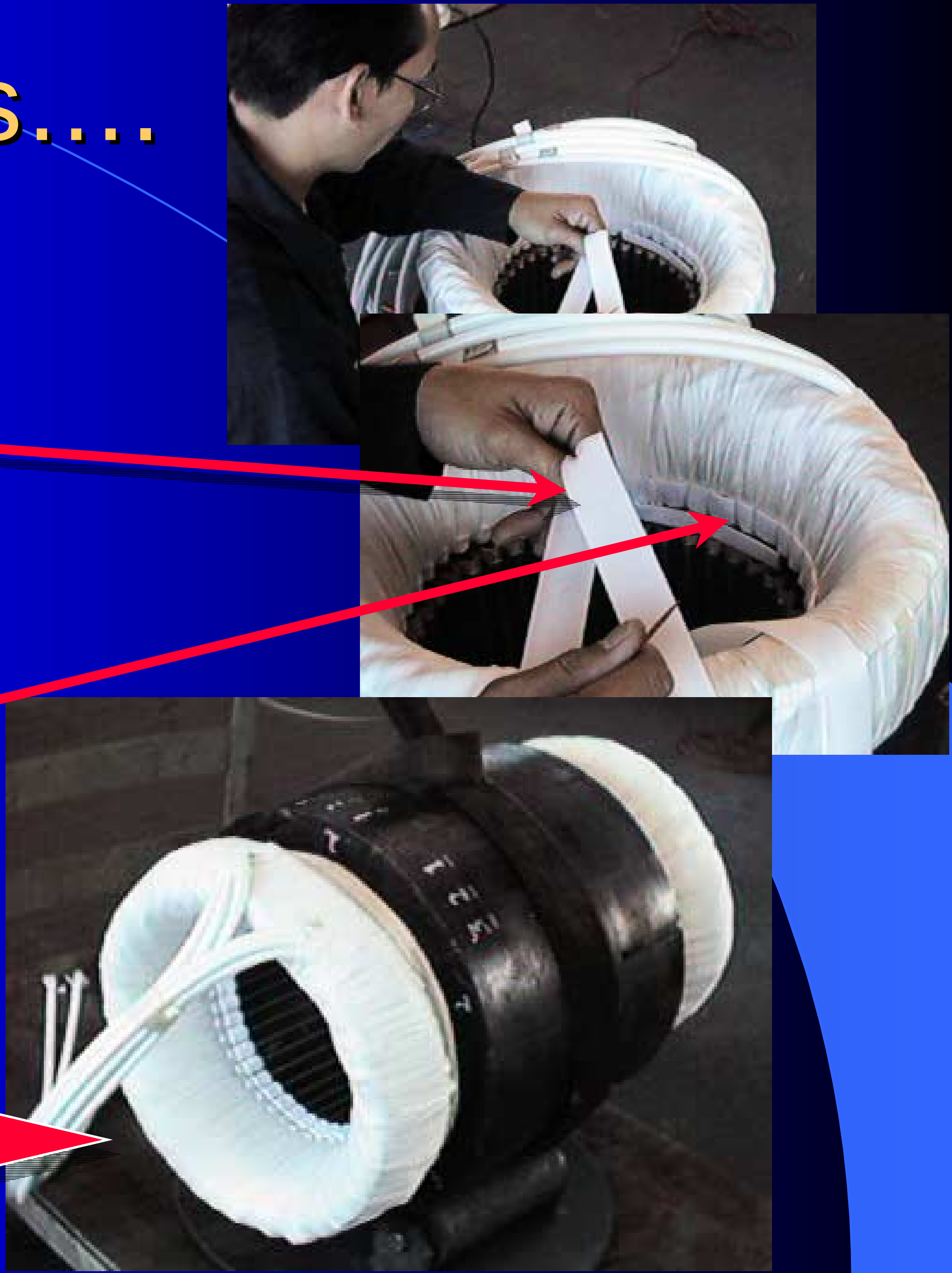
Use **Phase-Insulation** between each coil on the end turns (not just between phases)

Winding Specs….

- Round Wire Rewinds using only Lap or Diamond Winding (not continuous phase)

Winding Specs….

- Full Tape the End Turns
- Glass-Felt Wrap Coils at Slots
- Not Available on New Inverter Duty Motors



Winding Specs...

- **Use either 2 VPI cycles or**

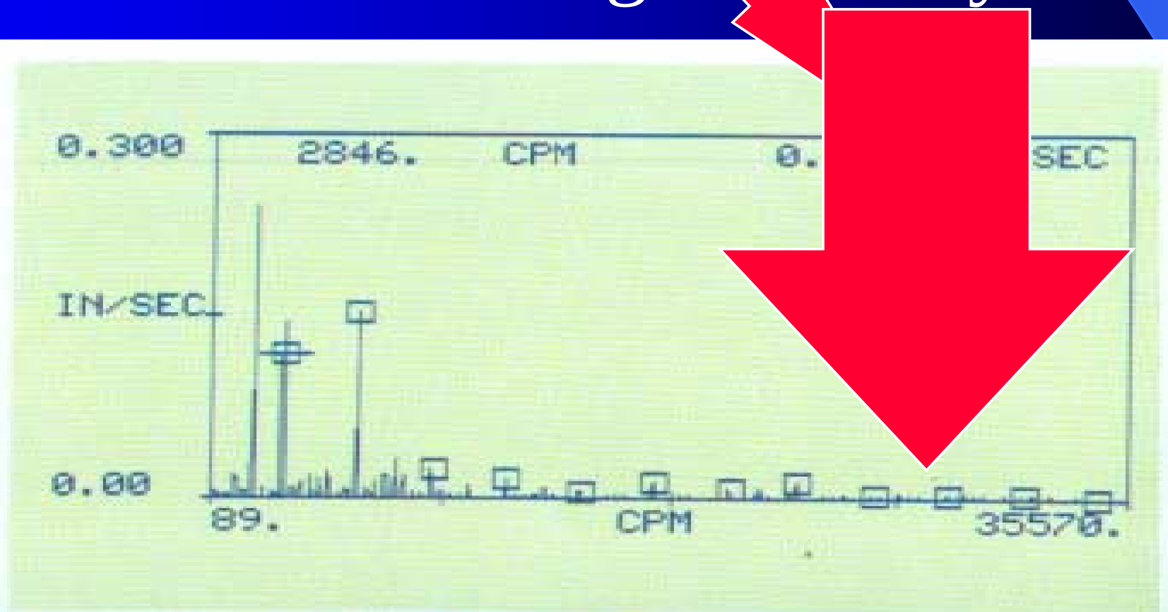
3 Dip & Bake Cycles

Winding Specs….

- Use only UL Class H (180deg C) Insulation (Class F Lead Wire OK)
- Allow no internal splicing of Mag Wire!
- On Medium or Hi-Voltage Motors (2,300 V & up), additional turn insulation on the first and last turns of each phase. (possible due to rectangular wound)

Mechanical Specs

- Vibration Limits of .08 to .1 ins/sec (pk to pk) “Overall” reading.
- No spikes in the bearing frequency bands



Harmonic cursors allow quick identification of :requencies.

Mechanical Specs...

- Large motors or super-critical small motors: Insulate the outboard bearing against bearing currents and / or shaft bleed off brush or slip ring system
  - Shaft Currents or Bearing Currents are a Big problem area that is still under heavy research
  - Inverters can cause “Common Mode Voltages”. Capacitive coupling between stator winding and the rotor surface results in allowing the Inverter to force current through this “coupling”, thru the rotor, the shaft, through the bearing to the grounded motor frame.

Mechanical Specs….

- Shaft Currents...
  - Result: Minute arcing between the balls and bearing race ruins the bearing
  - Always investigate any premature bearing failure on an inverter fed motor for this electrical pitting damage.
    - If electric-arc pitting is found in the bearing, insulate the bearing housing as the best resolution, shaft bleed-off brush is a secondary choice.

Summary Tips

- All New Project - Always buy “Inverter-Duty” Motor
- Retrofit Project - Study your options, Rebuilding or using Existing Motors “As-Is” is often a wise Economical Choice, especially when the Inverter is located next to Motor.
- Filters, Chokes, Isolation Transformers, “Inverter-Duty Rebuilding” can solve after the fact problems
- Early failure after Inverter Retrofit: Study the Motor to ID specific cause for fixes
- **Keep *Sh* [illegible] from Motor to Inverter; his is the most effective problem prevention**

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