SESIÓN

BRÚJULA

CONGRESO DE MANTENIMIENTO & CONFIABILIDAD CHILE

4ª EDICIÓN

Presentación de una experiencia exitosa, caso de estudio o proyecto.

En la Sesión Brújula aprenderás de la experiencia compartida de una implementación exitosa que servirá de guía para iniciar o mejorar tus propios planes.

Soluciona problemas y mejora tu confiabilidad mediante la implementación de nuevas metodologías y tecnologías, conociendo el origen, análisis, plan de acción, paso a paso, logros, tropiezos y lecciones aprendidas que culminan con el caso de negocio.

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Asset Management Strategies to Reduce Your Energy Consumption by 20% or More

Drew D. Troyer, CRE, CEM

Principal Advisor, Bootleg Advisors, Inc

As an engineer, its your job to manage the efficient conversion of energy and its uninhibited transfer along the attended pathways.

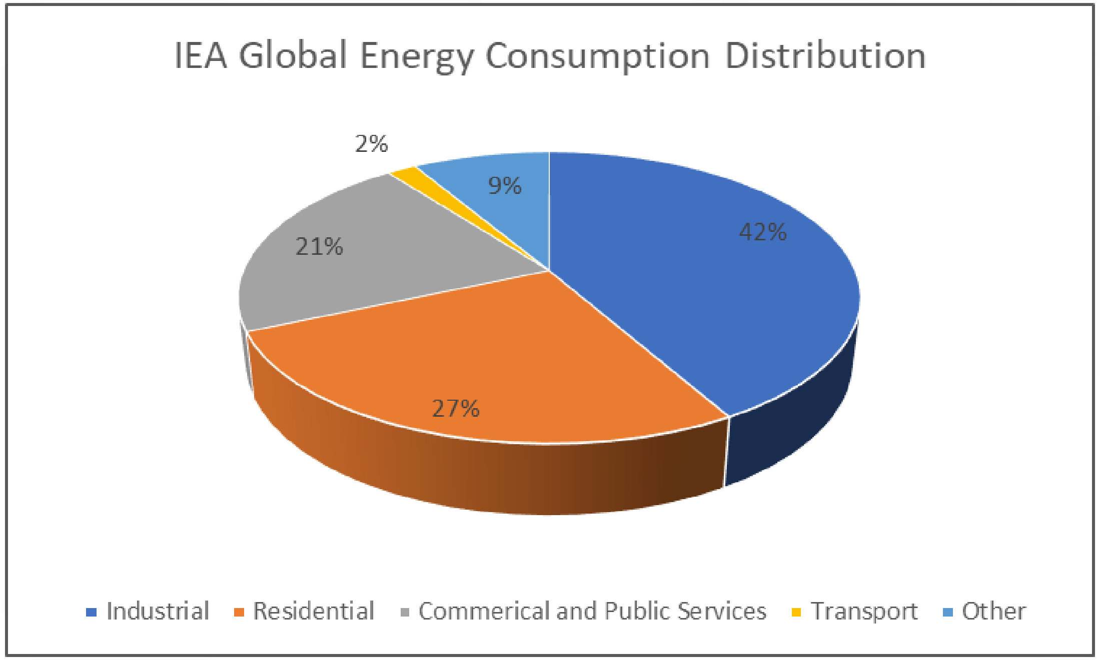
As a reliability engineer or asset manager, you're improving energy efficiency. Are you actively claiming those benefits?

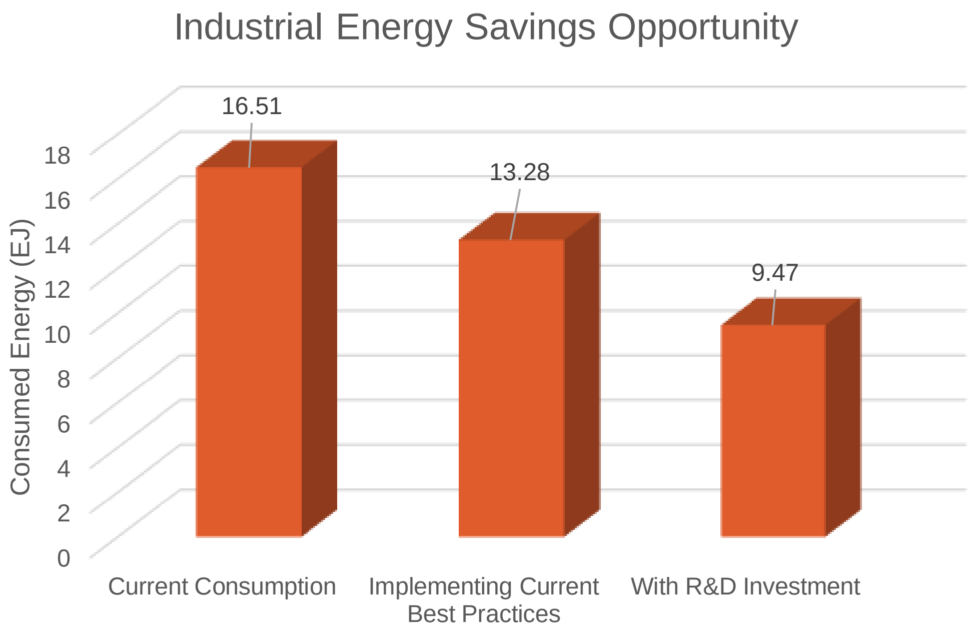
Meeting Overview

- What the US department of energy says about industrial energy savings opportunities
- Managing parasitic mechanical frictional losses
- Reducing fluid frictional losses
- Stop leaking energy with compressed and pressurized fluids
- Manage combustion efficiency
- Manage electrical harmonics
- Reduce electrical unbalance
- Making energy management work for you

• Opportunity to Reduce 8-18% of Global Energy Consumption – 636 Million MT of CO_2-eq

The International Energy Agency (IEA) estimates that industry consumes 42% of all global energy.

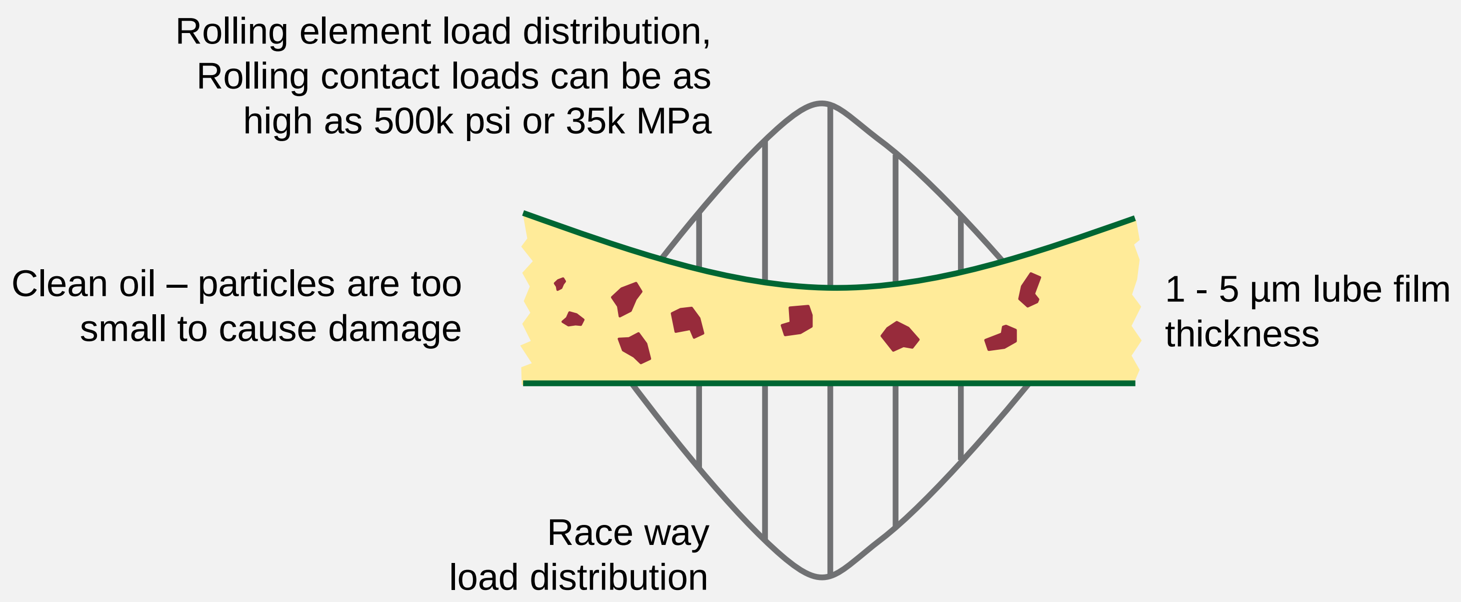




The US Department of Energy (DOE) suggests that this can be reduced by 20% by implementing current best practices and 42% with investment in R&D.

Managing Parasitic Frictional Losses

Cutting the FLAB is your best weapon to reduce wear and failure!

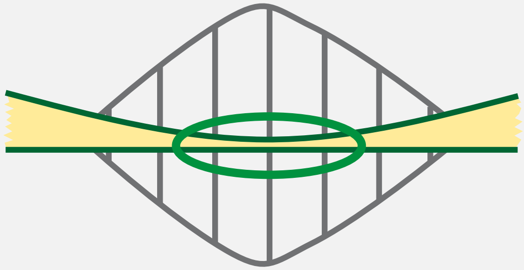
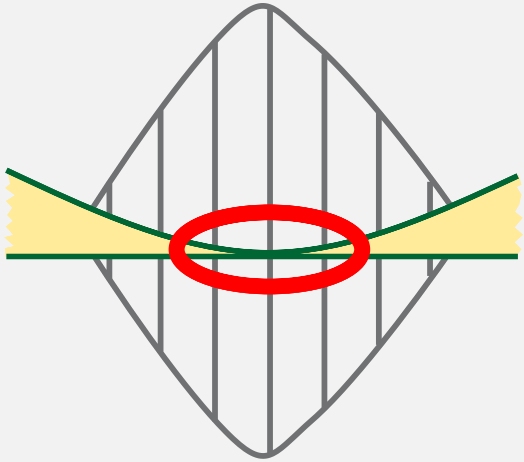


Presumes

- **F**astener Integrity
- **L**ubrication Effectiveness
- **A**lignment
- **B**alance
- Proper Operation

Under these conditions, a bearing can have an infinite life!

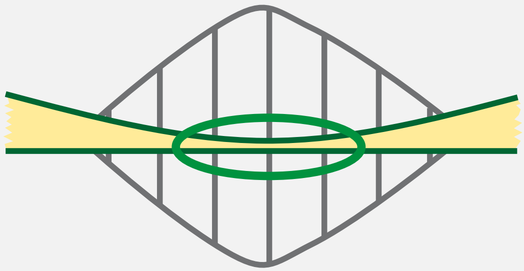
How Loose Fasteners Cause Frictional Energy Losses

Normal Operation:	Loose fasteners leads to…	Mechanical looseness induced vibration force leads to:
 Under normal loads, the lubricant provides adequate film separation	 … increased vibration and increased load.	 … lube film strength is overwhelmed, which causes friction, wear and failure.

Focus on the FLAB! Loose fasteners reduce film strength, producing surface to surface contact, friction, fatigue and wear.

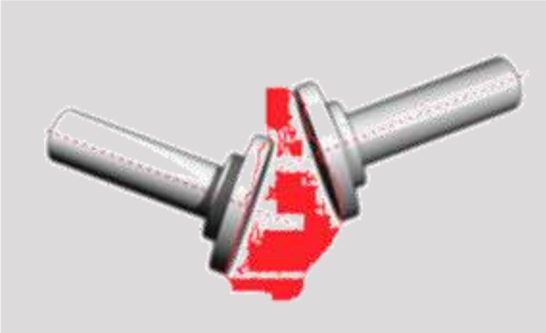
How Misalignment Causes Frictional Energy Losses

Normal Operation:



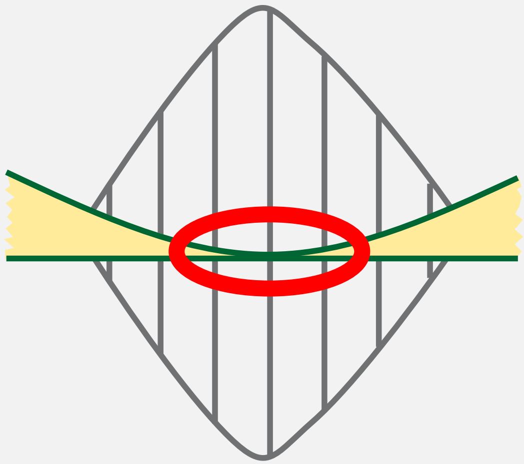
Under normal loads, the lubricant provides adequate film separation

A Misalignment force leads to:



… increased vibration and increased load.

Misalignment induced vibration force leads to:



… lube film strength is overwhelmed, which causes friction, wear and failure.

Cut the FLAB! Misaligned equipment reduces film strength, producing surface to surface contact, friction, fatigue and wear.

Energy Savings Example - Alignment

Alignment Method	Parasitic Energy Losses
Straight Edge	14%
Dial Indicator	4%
Laser	1.5%

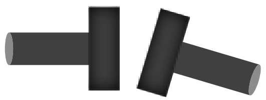
Ref: Howard Penrose, PhD – www.theramreview.com

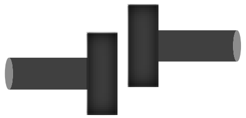
Example Savings: 500 kW Motor – 8,000 Hours Per Year:

- **Energy* = 500,000 kWh**
- **Money* @ $0.10/kWh = $50,000**
- **GHG Emissions** = 354 metric tons**
- **Social Cost of Carbon*** = $17,675**

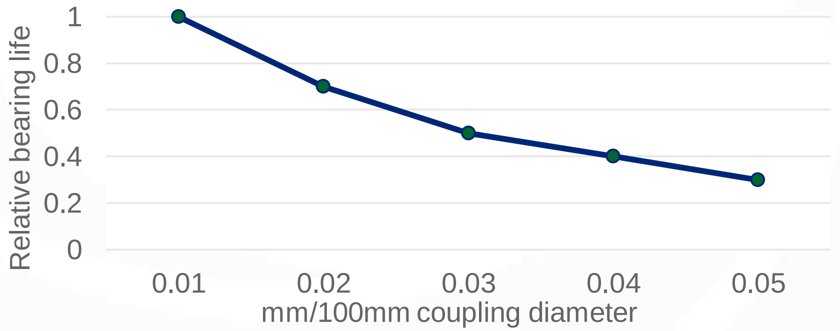
* H. Penrose
** DOE
*** W. Nordhaus - Yale

Typical tolerances for misalignment



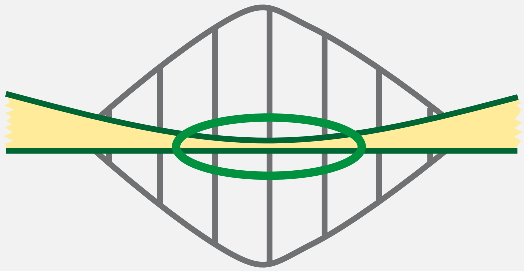


RPM	Angular Misalignment (mm/100mm coupling diam.)		Offset Misalignment (mm)	
	Excellent	Acceptable	Excellent	Acceptable
750	0.09	0.13	0.09	0.19
1500	0.05	0.07	0.06	0.09
3000	0.03	0.04	0.03	0.06
6000	0.02	0.03	0.02	0.03



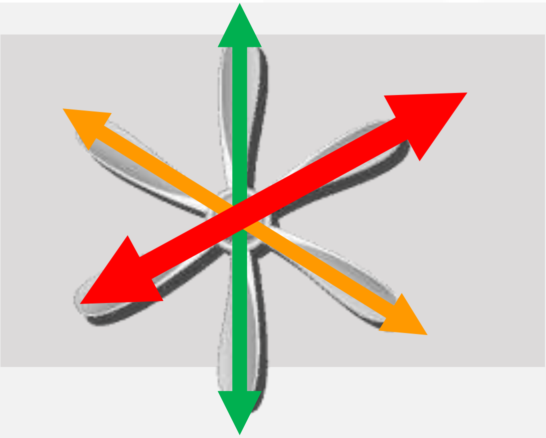
How Unbalance Causes Frictional Energy Losses

Normal Operation:



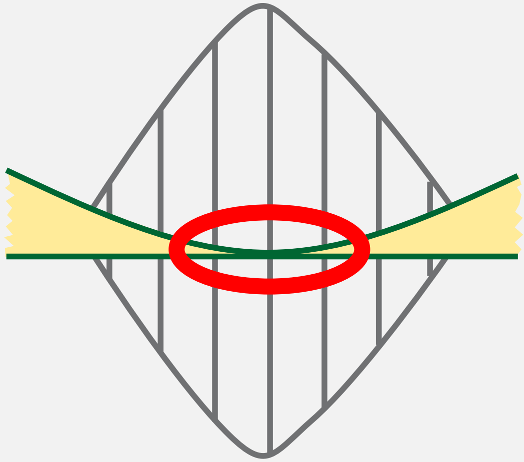
Under normal loads, the lubricant provides adequate film separation

An unbalance force leads to:



… increased vibration and increased load.

Unbalanced induced vibration force leads to:

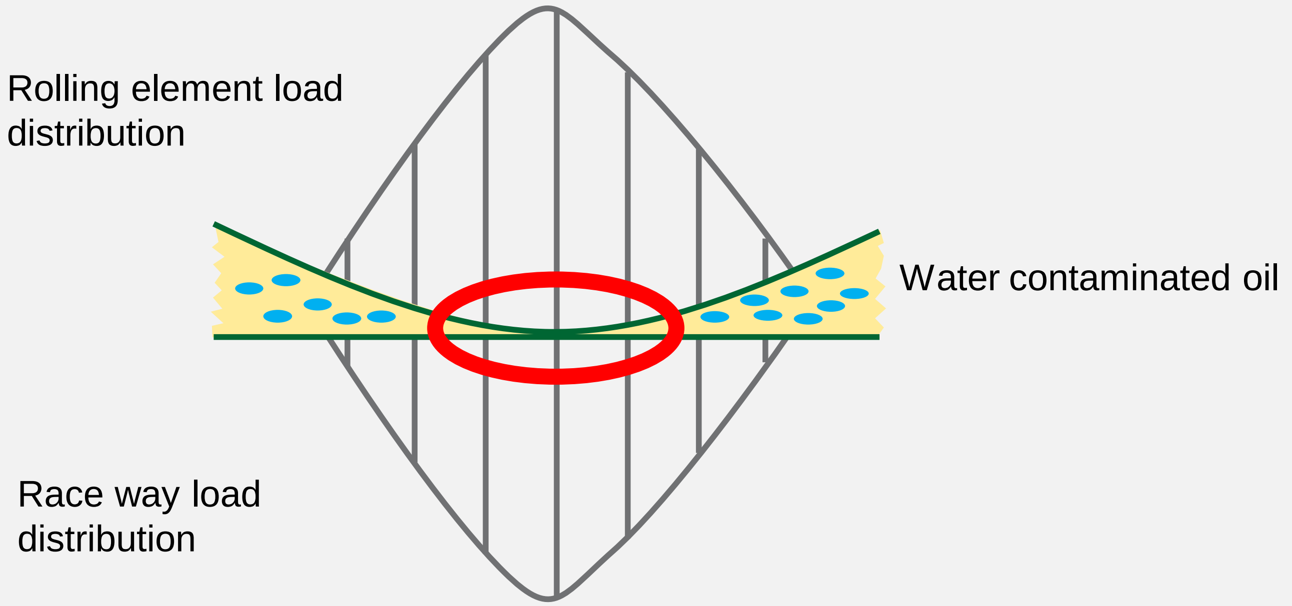


… lube film strength is overwhelmed, which causes friction, wear and failure.

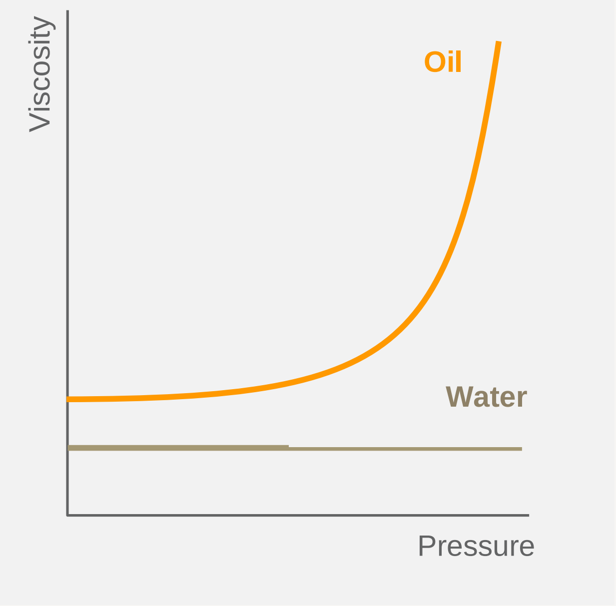
Cut the FLAB! Increased load reduces film strength, producing surface to surface contact, friction, fatigue and wear.

How Water Contaminated Lubes Cause Frictional Energy Losses

Water contaminated lubricant causes wear and failure



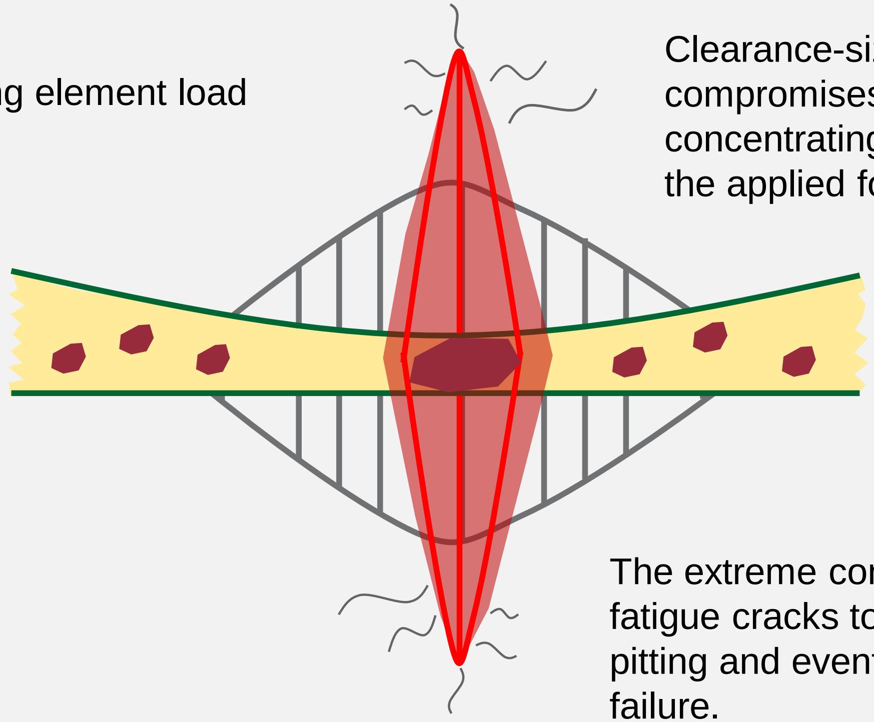
Pressure vs. Viscosity



Even under normal load, water in the oil reduces the lubricant‘s film strength, thus reducing film thickness and increasing the risk of friction and wearing contact.

How Dirty Lubes Cause Frictional Energy Losses

Dirty lubricant causes wear and failure



Hard Particles Cause Wear

Particles concentrate load between component surfaces.

If the normal loads are 35K MPa (500k psi) and the particle concentrates the force to one tenth of the area, the new load can be as high as 350k MPa (5,000k psi).

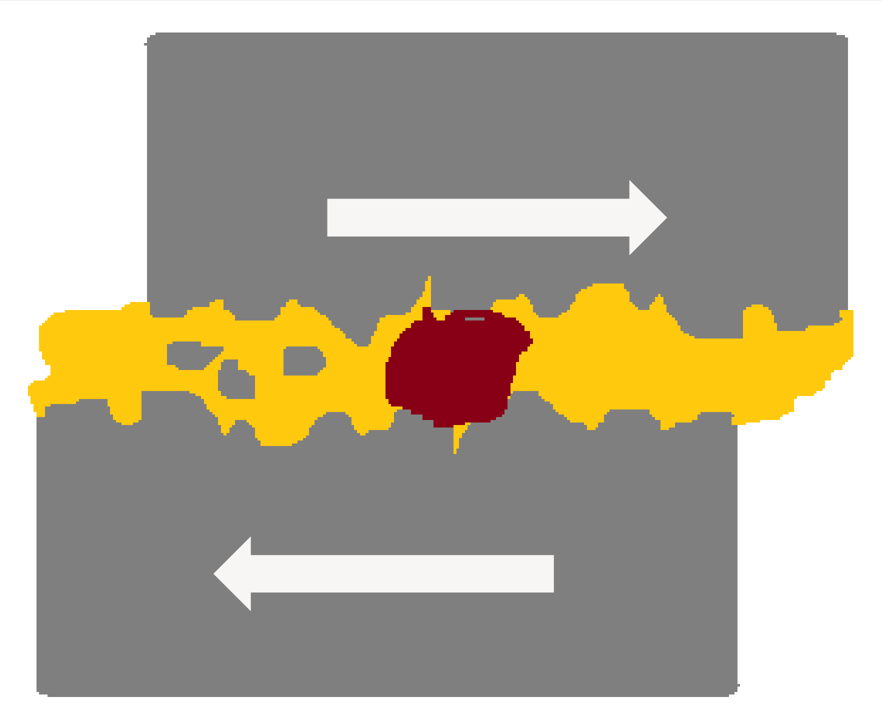
Particles that are clearance sized or slightly larger (5-15 µm) cause the most damage and they don’t settle out easily.

The Problem is Even Greater on Sliding Contacts

We've used rolling element bearings and rolling contacts in our example, but the same forcing functions cause wear and failure in sliding contacts to produce abrasive (cutting) and adhesive wear.

Cutting Wear

Adhesive Wear



Minimize Leaks and Churning Losses

Excessive ΔP and Leaks Waste a Great Deal of Energy

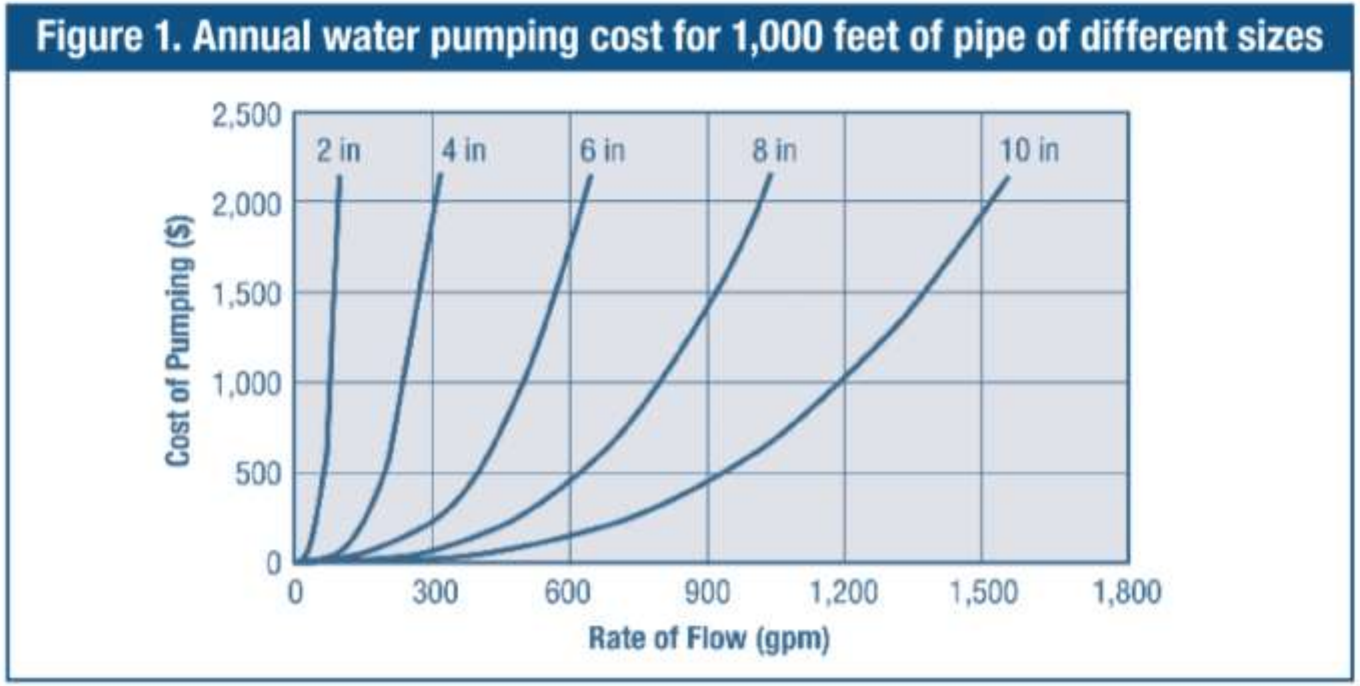
$$P_w = \frac{0.4344 \times f \times \Delta P}{P_e}$$

Where:

P_w = Pumping energy (Watts)
F = Flow rate (gpm)
ΔP = Pressure differential
P_e = Pump efficiency (%)

Typical Pumping Efficiency

- **Centrifugal Pumps = 50 – 70%**
- **Positive Displacement Pumps = 80 - 90%**



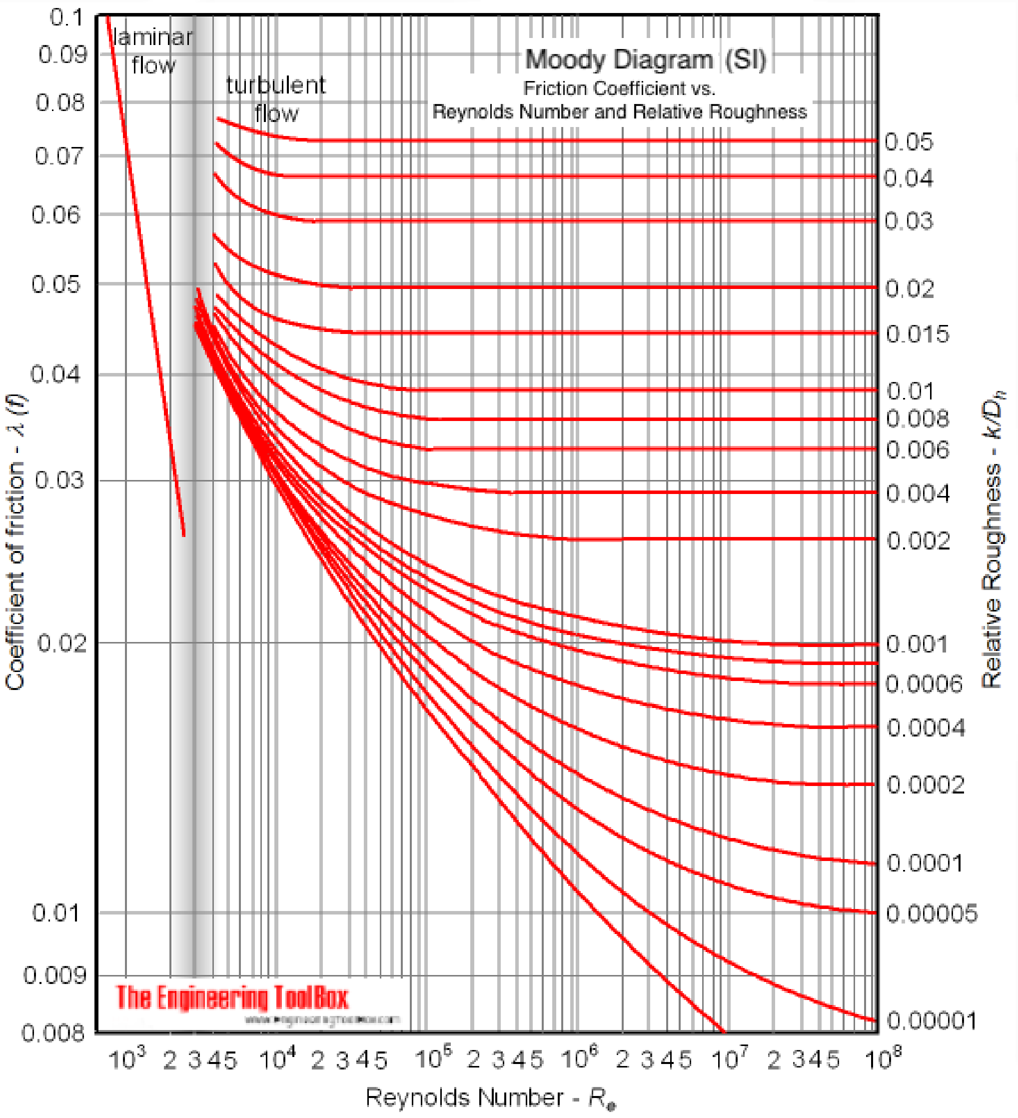
Based on 1,000 ft. for clean iron and steel pipes (schedule 40) for pumping 70°F water. Electricity rate—0.05 $/kWh and 8,760 operating hours annually. Combined pump and motor efficiency—70%.

Ref: US DOE

Ref: J. Siegenthaler, PM Magazine

Factors Affecting ΔP In Pressurized Liquid Systems

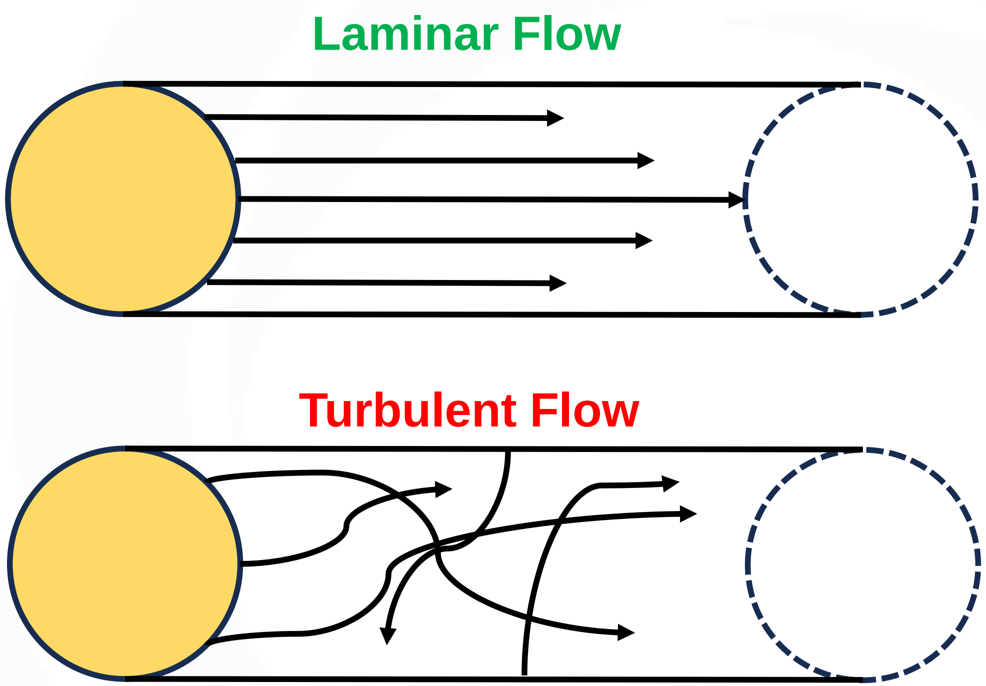
- Fluid density
- Fluid viscosity
- Internal pipe roughness
- Reynold’s number (laminar vs. turbulent flow)
- Friction factors (Moody and Colebrook-White charts)
- Friction loss in piping (Darcy-Weisbach estimation method)



Ref: The Engineering Toolbox

Reduce Parasitic Friction in Pumping Systems

- Employ piping with adequate diameter and surface smoothness
- Minimize turns > 30°
- Properly size pumps
- Optimize when shared load parallel pumps are employed
- Employ variable speed drives
- Select valves properly
- Maintain all systems with a high degree of precision



Rule of Thumb: At 70% efficiency, you pay for about for 37 Watt-hours per psi of ΔP per gallon pumped.

Pressurized Fluid Leaks are Very Costly

- High pressure (125 psig) steam leaks = $300 to $1,000 per leak per shift.
- Low pressure (15 psig) steam leaks = $60 to $220 per leak per shift.
- Compressed air leaks (100 psig) = $60 to $180 per leak per shift.
- For pressurized liquid leaks, calculate using the Siegenthaler to determine cost per gallon

Ref: US EPA

Ultrasonic Leak Detection and repair (LDAR)

For compressed air and gas lines

1. Inspect compressed air and gas lines with airborne ultrasonic device set to 40 kHz.
2. If possible, fix leaks as found.
3. If not fixed as found, tag each leak with a unique identifier.
4. Log each leak to record:
   A. Tag number
   B. Location
   C. Volume of leak
   D. Cause
   E. Required action
5. Prioritize and execute corrective actions.
6. Eliminate root causes.
7. Verify effectiveness of corrective actions.
8. **STOP LEAKING ENERGY!**

LDAR – Liquid Leaks

For tough leaks

1. Introduce fluorescent dye into host fluid.
2. Allow the fluid to circulate.
3. Inspect machine with black light – leaks will glow fluorescent.
4. If possible, fix leaks as found.
5. If not possible, tag each leak with a unique identifier.
6. Log each leak to record:
   A. Tag number
   B. Location
   C. Volume of leak
   D. Cause
   E. Required action
7. Prioritize and execute corrective actions.
8. Eliminate root causes – vibration, wrong fittings, etc.
9. Verify effectiveness of corrective actions.
10. **STOP LEAKING ENERGY**

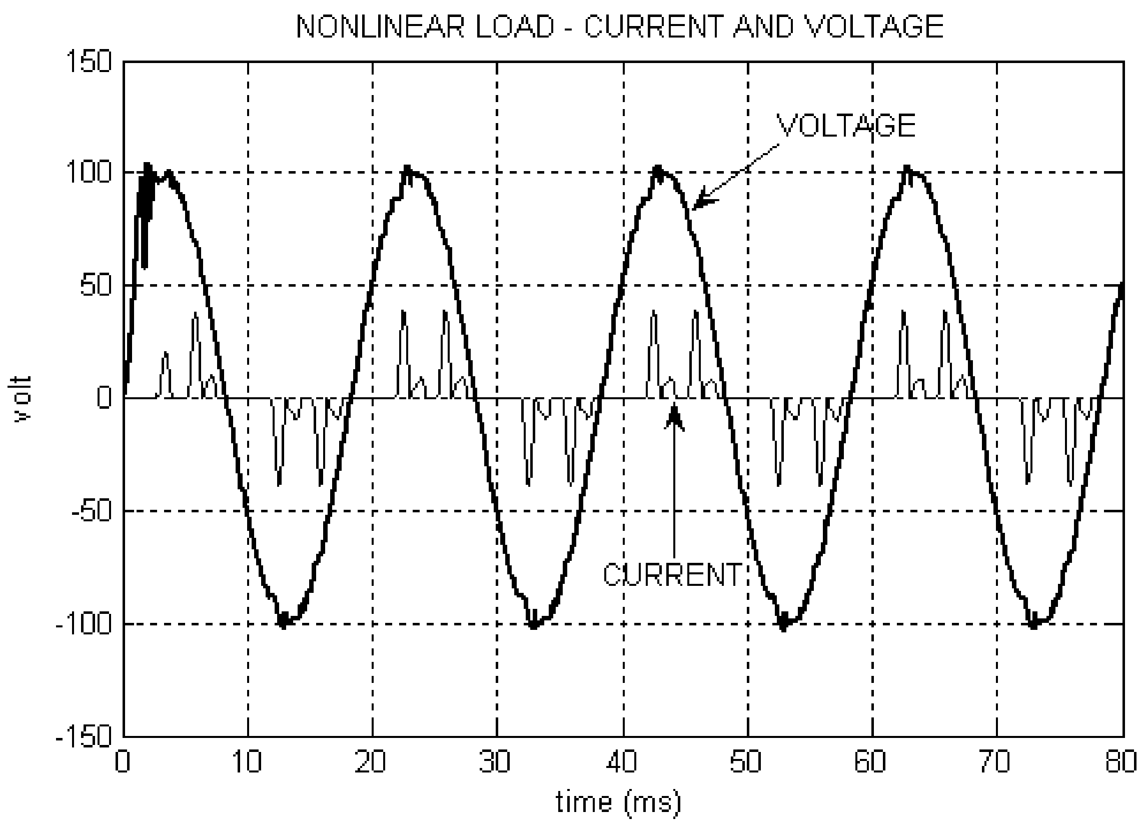
Achieving High Combustion Efficiency

- Utilize high quality fuels (e.g., high cetane number fuel oil).
- Keep fuel clean and free of contamination
- Ensure proper fuel to air ratio
- Maintain fuel injection systems to optimize nebulization
- Routinely tune burners
- Employ heat recovery processes where feasible and employ insulation
- Analyze flue gas and tailpipe emission to detection combustion problems

Hydrocarbon	Formula	Structure	Cetane Number
n -decane	$C_{10}H_{22}$	paraffin	76
n -dodecane	$C_{12}H_{26}$	paraffin	80
n -hexadecane	$C_{16}H_{34}$	paraffin	100
2,2,4,6,6-pentamethylheptane	$C_{12}H_{26}$	isoparaffin	9
4,5-diethyloctane	$C_{12}H_{26}$	isoparaffin	20
2,5-dimethylundecane	$C_{13}H_{28}$	isoparaffin	58
1,3,5-trimethylcyclohexane	C_9H_{18}	naphthene	31
trans -decalinb	$C_{10}H_{18}$	naphthene	32
cis -decalinb	$C_{10}H_{18}$	naphthene	42
n -butylcyclohexane	$C_{12}H_{24}$	naphthene	36
1,3-diethylbenzene	$C_{10}H_{14}$	aromatic	9
biphenyl	$C_{12}H_{10}$	aromatic	21
n -hexylbenzene	$C_{12}H_{18}$	aromatic	26

Non-linear Loads and Harmonics

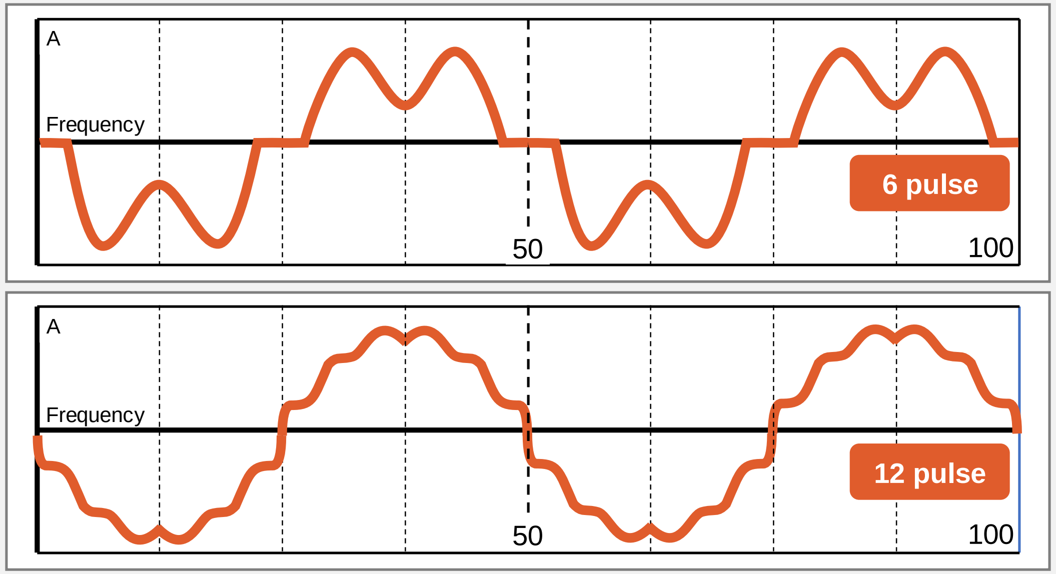
- A non-linear load is an electric load that with current consuming characteristics that don’t exhibit the same shape as the applied voltage waveform, which in turn produces voltage harmonics.
- Sources Include:
  - Rectifiers
  - Variable frequency drive control units
  - Any AC to DC / DC to AC conversion/ inversion



Electrical Harmonic Distortion

THD defined

- Total harmonic distortion is a misalignment with the core power sinusoid.
- THD is caused by non-linear loads which produce spikes at harmonics of the base frequency. For a 50 Hz system, harmonics can occur at 100 Hz, 150 Hz, 200 Hz, etc.
- IEEE standard 519 calls for the following limits:
  - A. < 5% THD, less is better
  - B. < 3% for any single harmonic, less is better
- Minimal distortion is preferred.
- Wastes energy – as much as 20% or more.
- Generates a great deal of heat.
- Reduce equipment life and reliability.



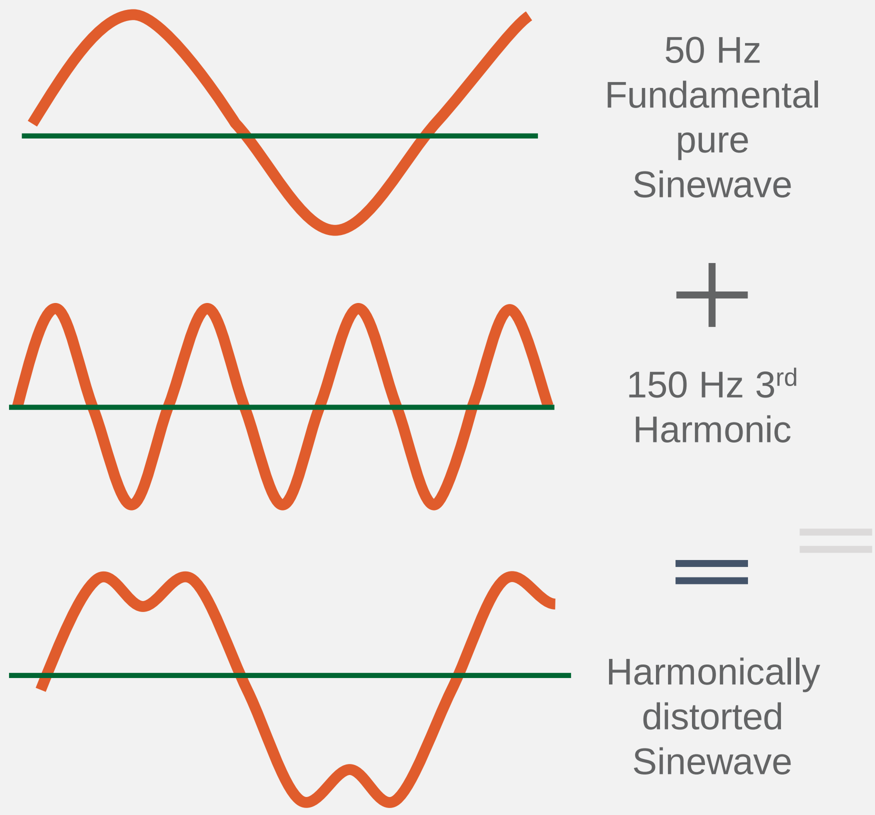
$$THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + V_5^2 + \ \dots}}{V_1}$$

Correcting Harmonic Distortion

Machine condition monitoring

- Employ active harmonic filters
- Employ passive harmonic filters
- Employ passive harmonic filters on ground and neutral loops, which feedback to transformer and introduce resonance.

Note: We've seen 10-15% (and more) energy reduction using passive ground and neutral filters



Motor Electrical Imbalance

Phase to phase motor imbalance

1. Primary types:
   A. Voltage imbalance
   B. Current imbalance
   C. Resistive imbalance
   D. Inductive imbalance
2. Voltage imbalance creates current imbalance, which causes heat.
3. Current imbalance can be caused by voltage imbalance and/or circuit problems.
4. Resistive imbalance can be a proactive precursor to current imbalance.
5. Test with Motor Current Analysis. General limits:
   A. < 2% voltage imbalance – less is better
   B. Current imbalance generally equals 7 x the voltage imbalance, but this can vary.
6. Reject form-wound motors with > 7% inductive imbalance – 12% for loose-wound motors - Less is best.

$$\%\ \textit{Electrical Imbalance}: = \frac{\textit{Maximum Single Phase Deviation from Average}}{\textit{Average of All Three Phases}} \times 100$$

Applicable for

- Voltage imbalance
- Current imbalance
- Resistive imbalance
- Inductive imbalance

Voltage Imbalance – Worked Example

Phase To Phase Voltages

- Phase 1 = 235
- Phase 2 = 225
- Phase 3 = 238

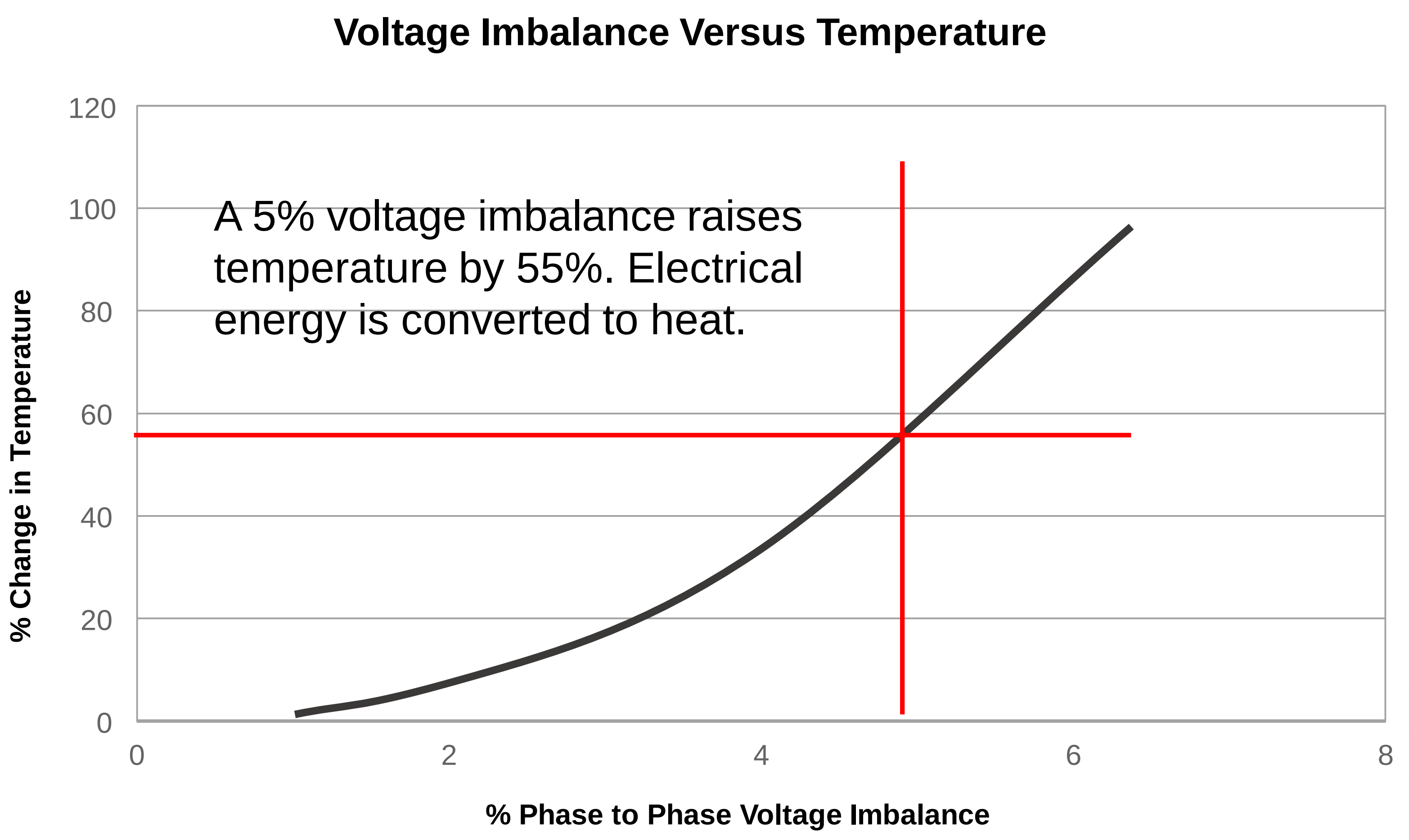
$$Average\ Voltage = \frac{235 + 225 + 238}{3} = 232.66$$

Phase to Phase Deltas:

- Phase 1 – 1%
- Phase 2 – 3.29%
- Phase 3 – 2.3%

$$Voltage\ Imbalance[\%] = \left(\frac{7.66}{232.66}\right) \times 100 = \mathbf{3.29\%}$$

Motor imbalance Heats up the Motor



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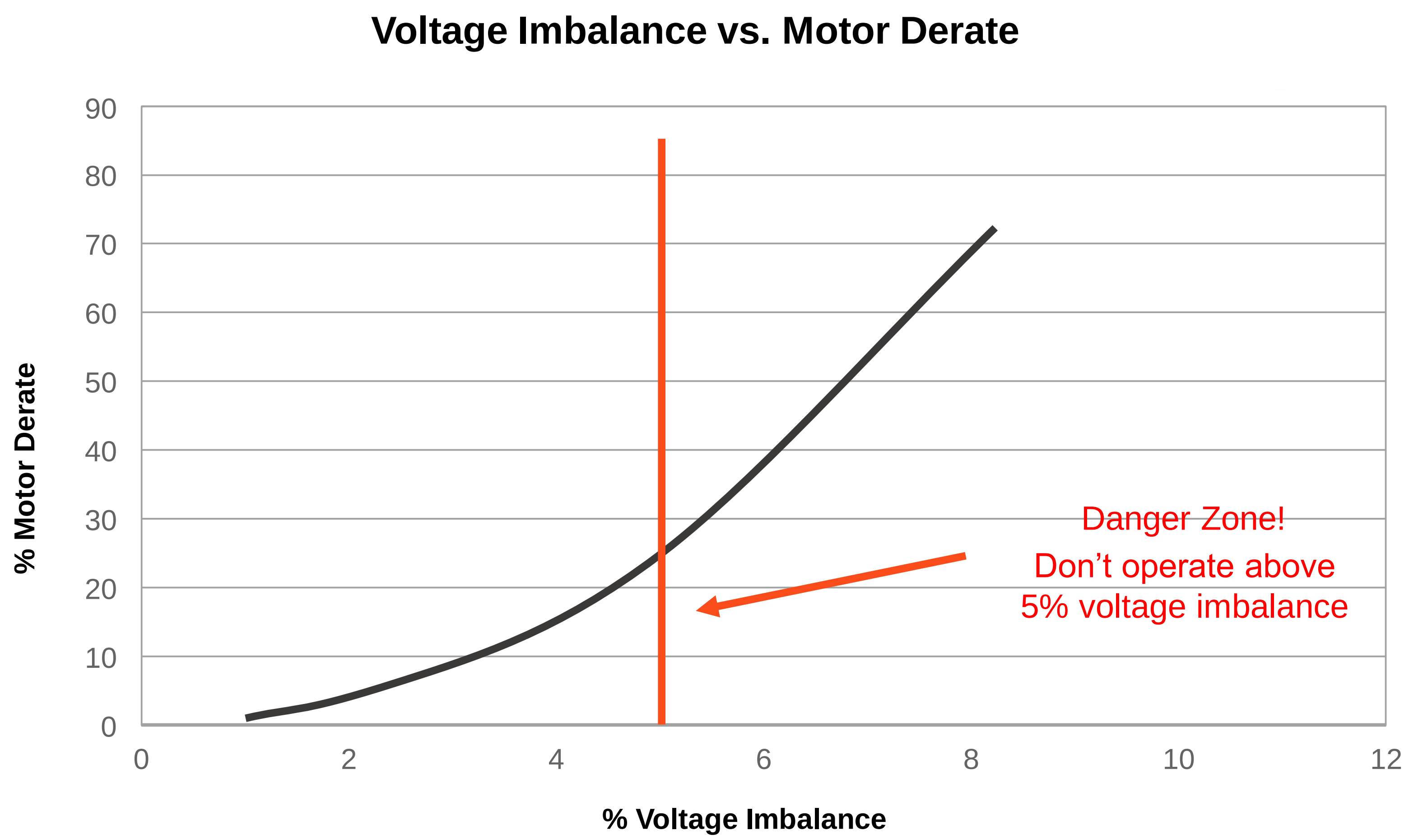
Voltage Imbalance vs. Motor Performance



Every dollar saved in energy consumption goes straight to the profit line, reduces your carbon footprint, and minimizes wear and tear on the equipment.

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THANK YOU!

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