

The image is a composite of three industrial scenes. The top-left shows blue electric motors in a factory. The top-right shows a large metal gear assembly. The bottom-left shows a worker in a red safety jacket and blue hard hat looking at a tablet. The background is a dark grey grid of white lines.

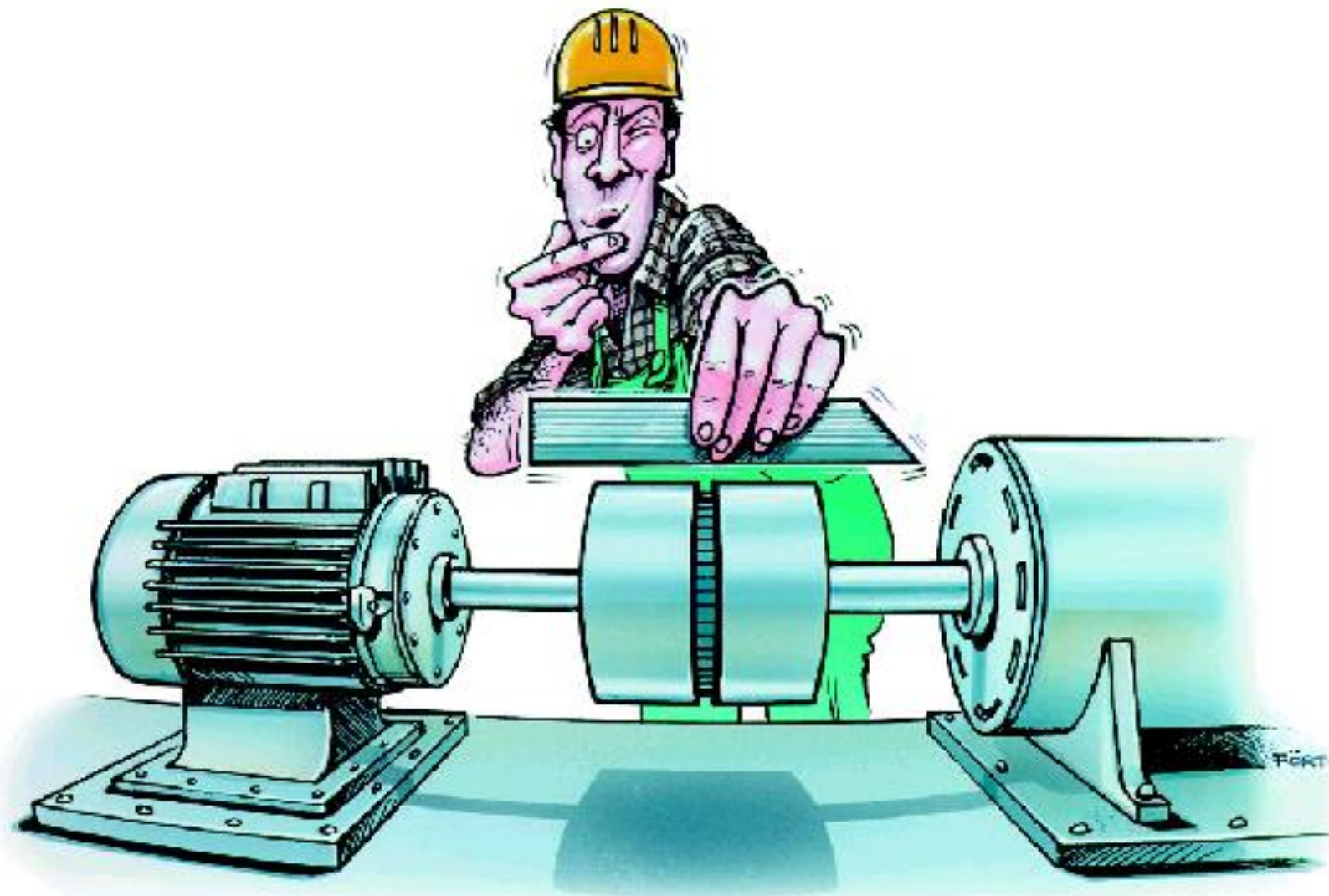
FLUKE®

Reliability

The Importance of Precision Shaft Alignment

—

Alignment

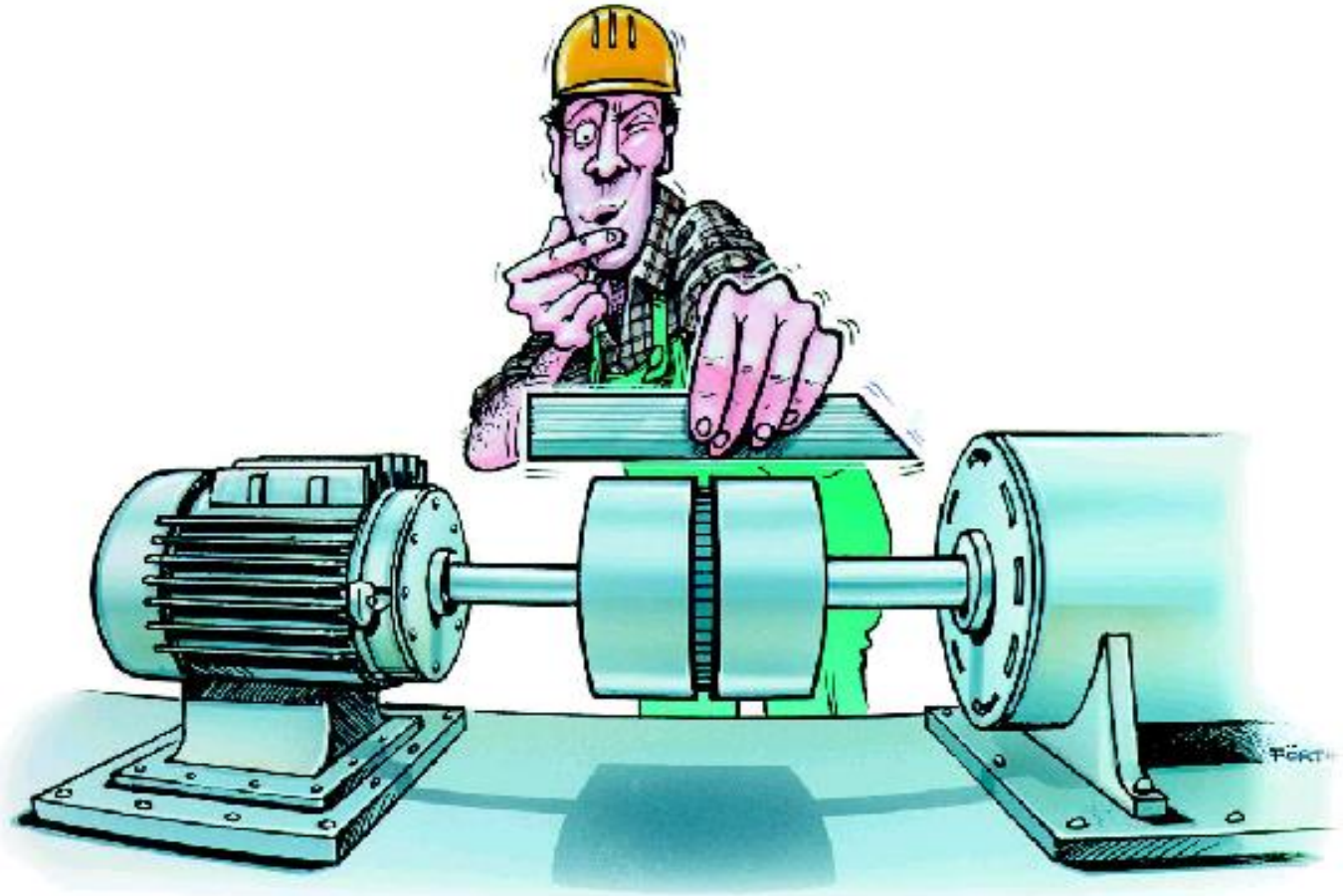


Alignment

An often quoted comment is “...**why align a machine when it is fitted with a flexible coupling designed to accommodate misalignment?**”

It is true that flexible couplings are designed to take misalignment, possibly up to max. 10mm or more radial offset of the shafts.

But the **load imposed on shafts, and thus the bearings and seals increase dramatically due to the reaction forces created within the coupling when misaligned.**

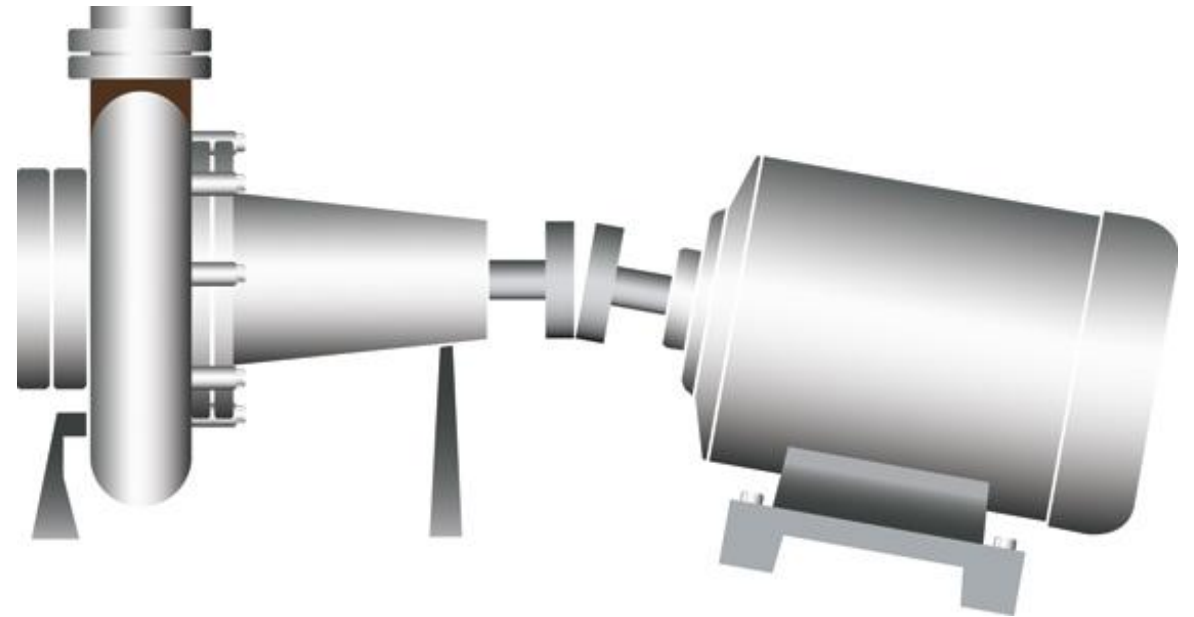


Why alignment

'Industry worldwide is losing billions of dollars a year due to misalignment of machinery'

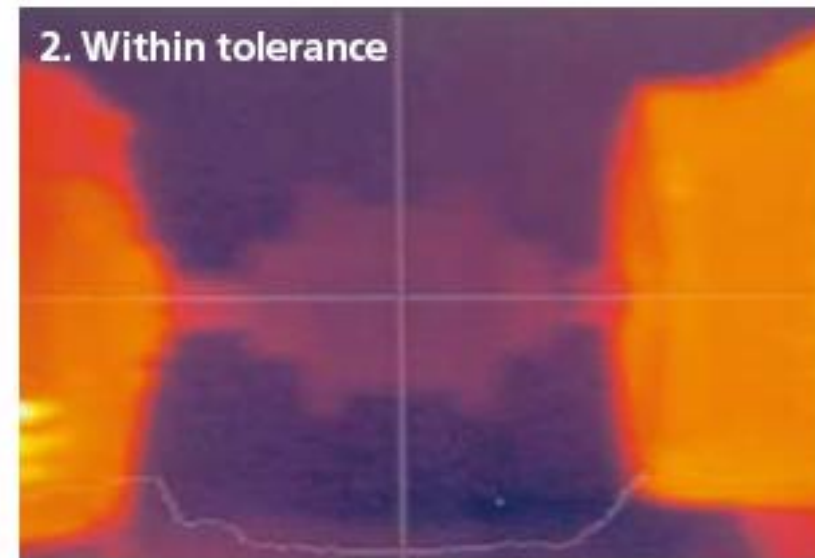
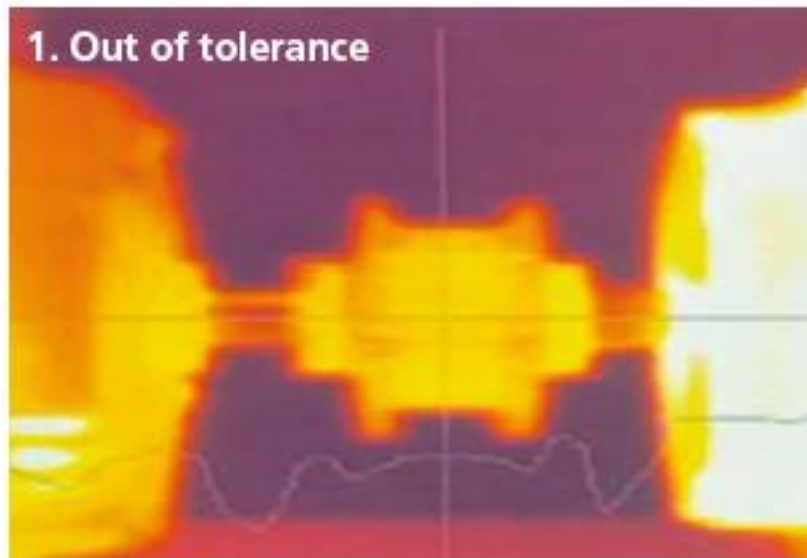
*Shaft Alignment Handbook
John Piotrowski*

- ... Rotating shafts must be aligned.
- Whenever a machine generates vibration, then alignment condition must be checked...

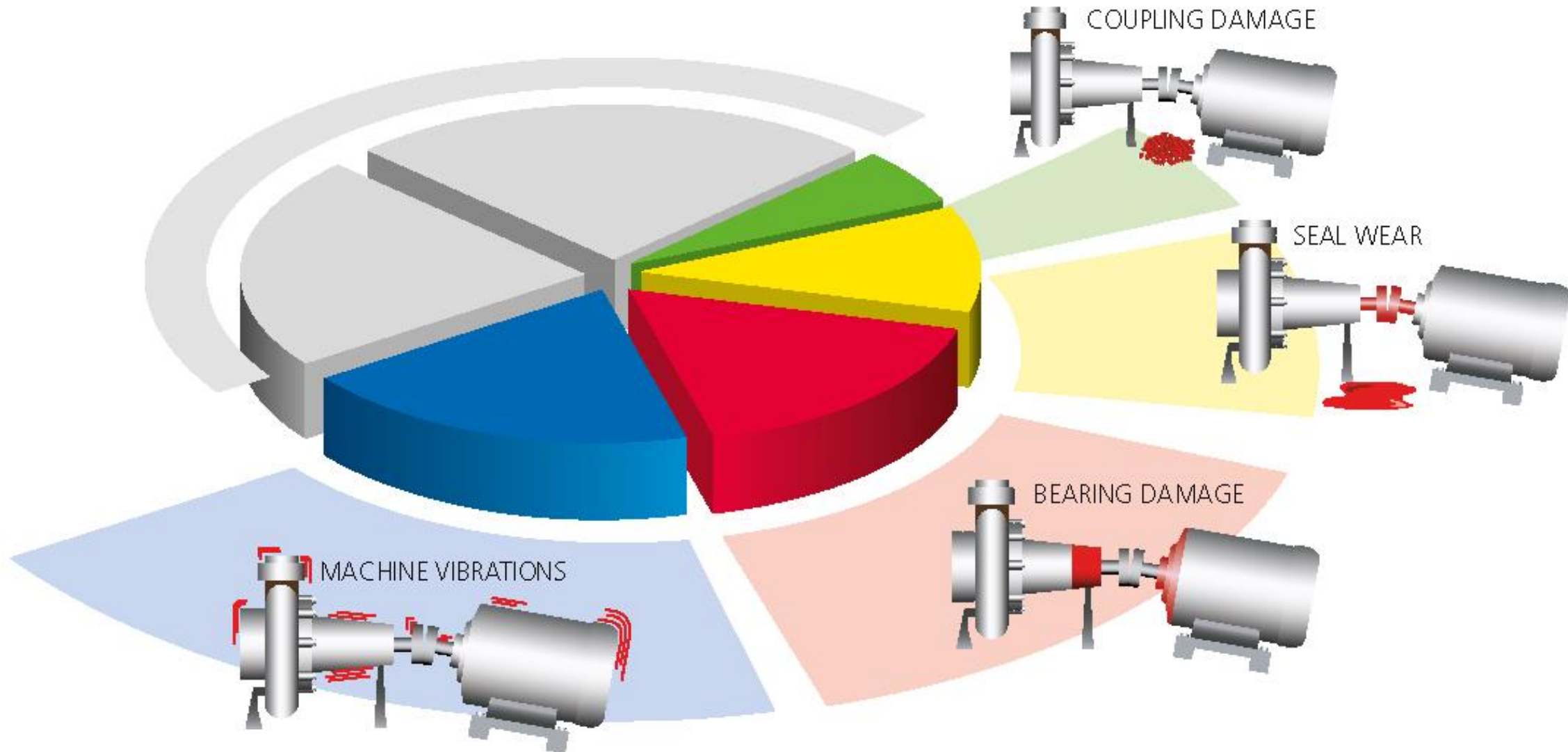


Coupling and shaft loading

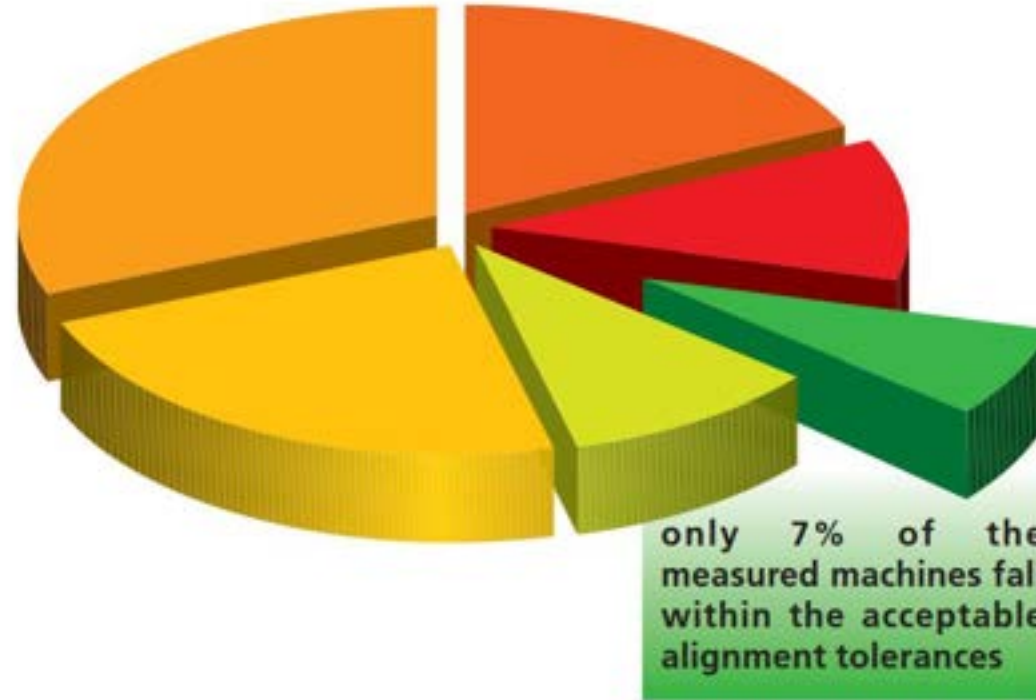
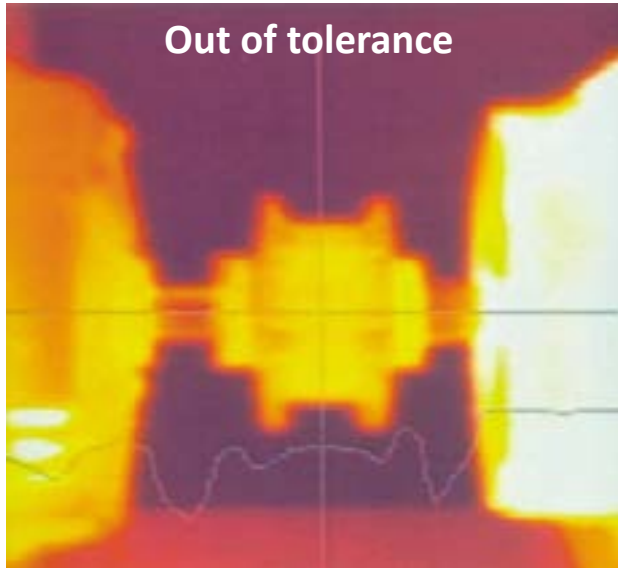
- When misaligned the loading of the shafts increases due to the reaction forces created within the coupling
- The flexible coupling elements heats up and the machine develops elevated temperatures particularly around the bearing housings



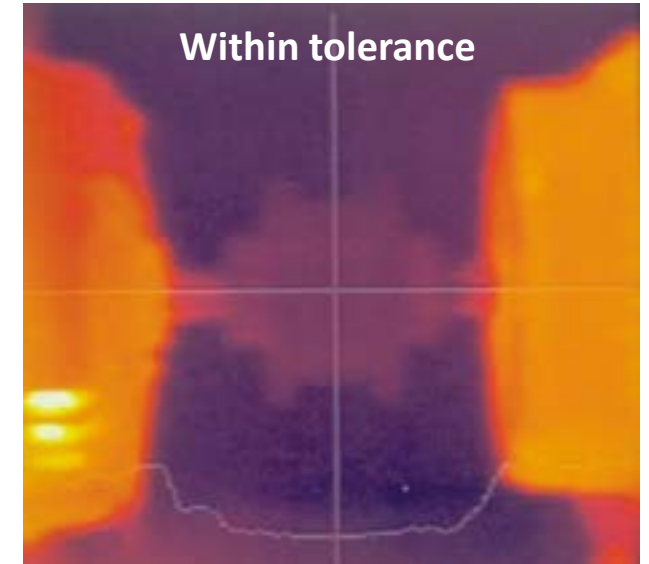
Consequences of misalignment on machine condition



Machines within precision alignment tolerances

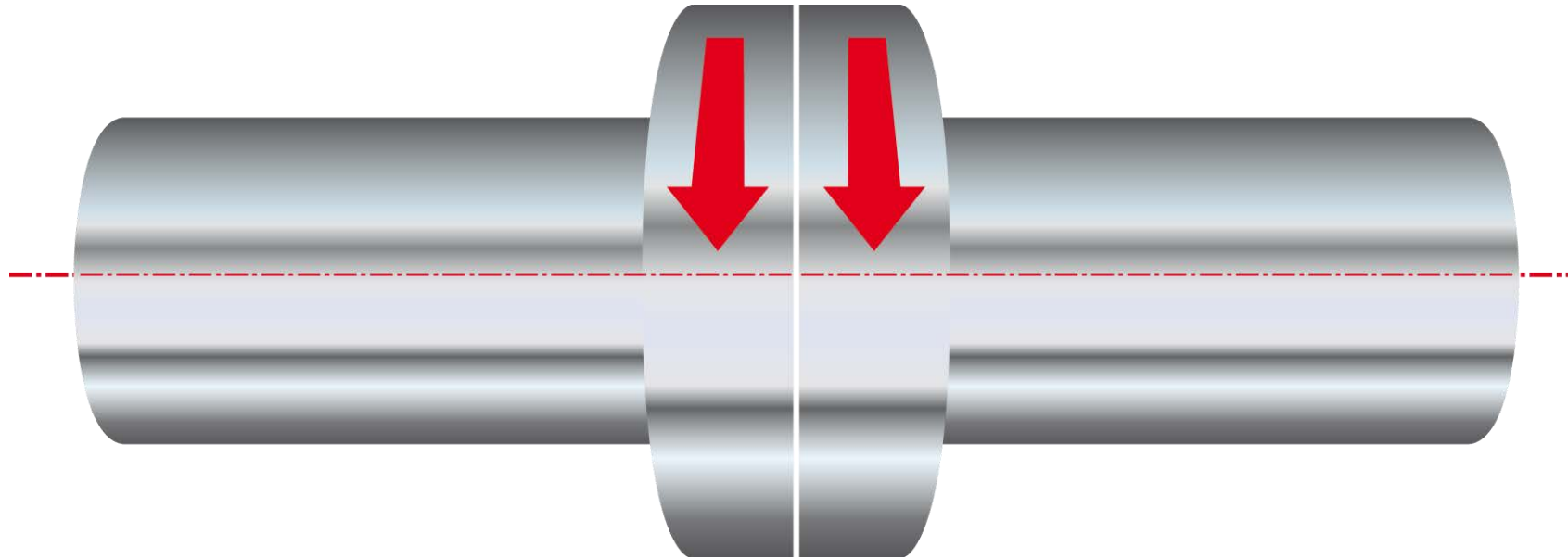


Courtesy of an UK major chemical plant



When misaligned the loading of the shafts increases due to the reaction forces created within the coupling

What is shaft alignment ?

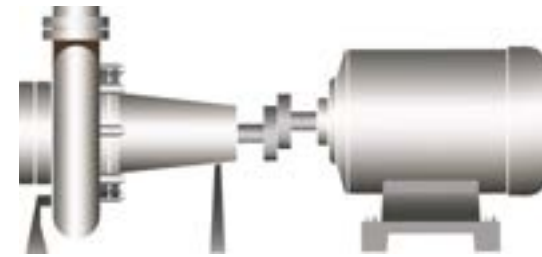


at the point of power transfer from one shaft to another, the axes of rotation of both shafts should be colinear when the machine is running under normal operating conditions

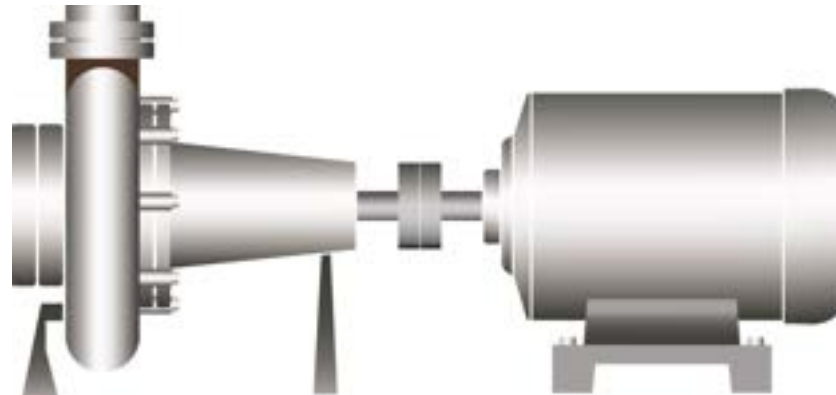
The 4 alignment parameters



Vertical angularity



Vertical offset



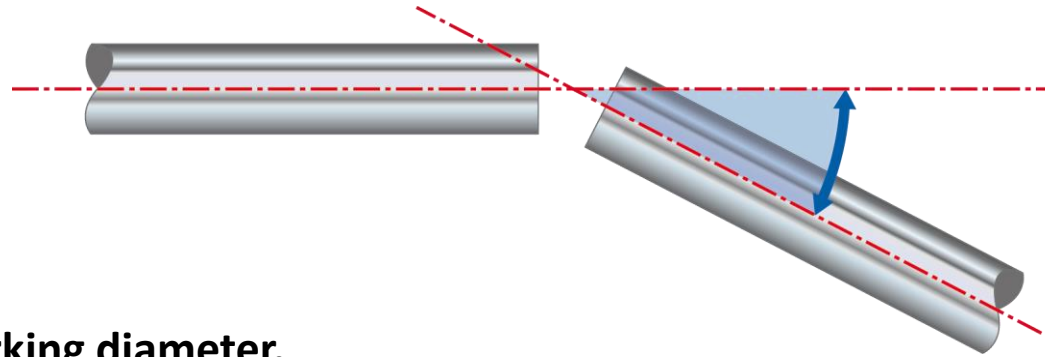
Horizontal angularity



Horizontal offset

Angularity or Gap

Angularity means the angle between two rotation axes



The angle is usually given as a **gap** per **working diameter**.

A 6" (152.4 mm) coupling open at the top by 0.005" (0.127 mm)

gives an angle between shaft axes of 0.83 mrad.

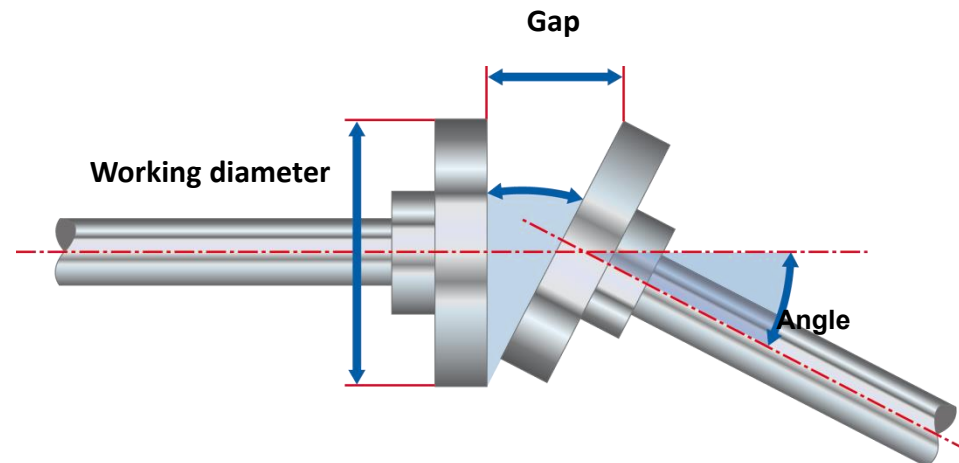
$$\theta = \text{gap} / \text{working diameter}$$

$$\theta = 0,127/152,4 = 8,33 \cdot 10^{-4} \text{ rad} = 0,83 \text{ mm/m}$$

Note:

1 mrad = 1 thousandth of an inch per inch

1 mrad = 1 mm / m

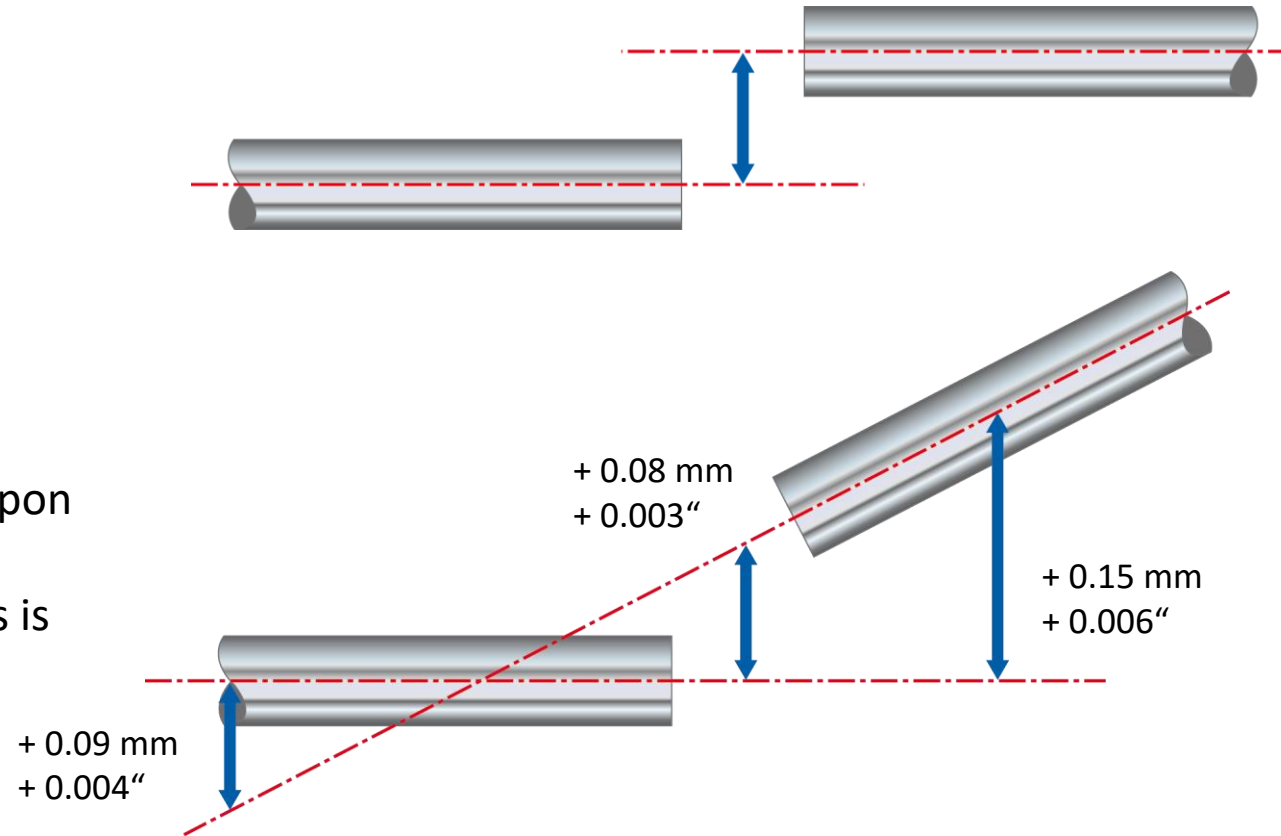


Parallelity or Offset

Offset refers to distance between shaft rotation axes at coupling center

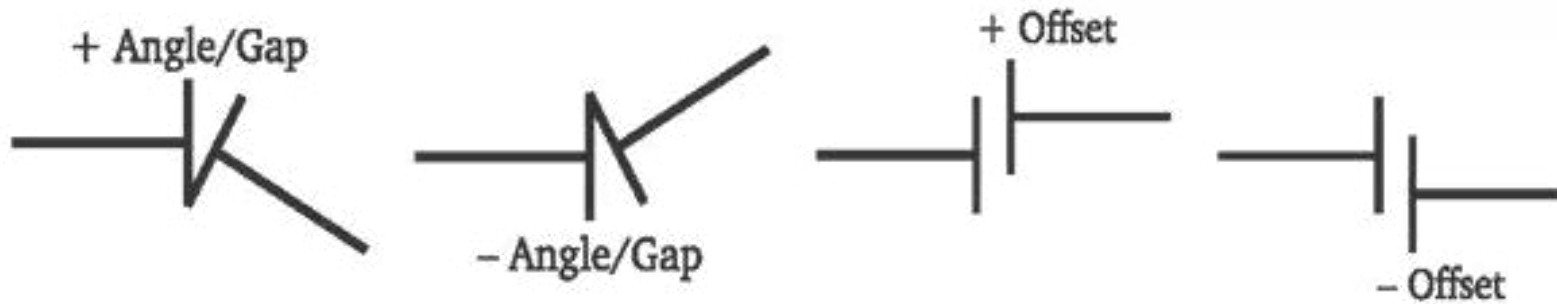
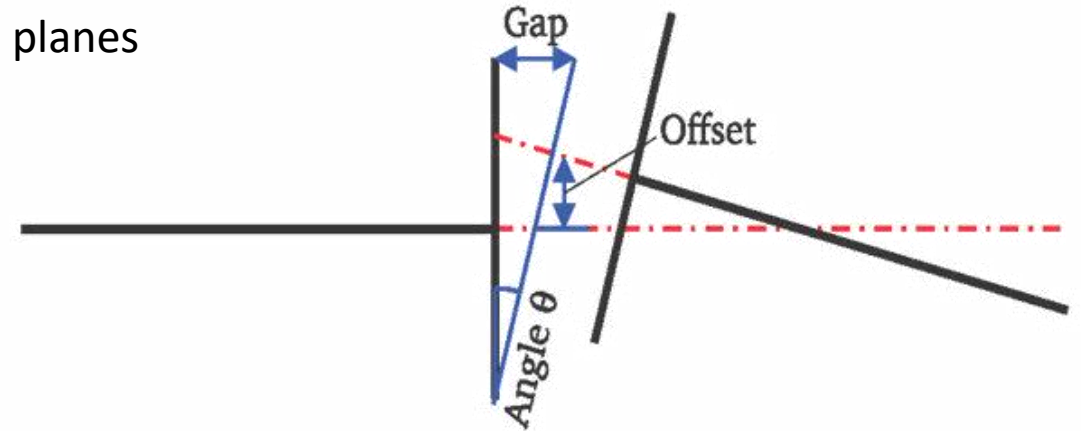
Offset means distance between rotation axes at a given point

Offset value varies depending upon the location where the distance between two shaft rotation axes is measured



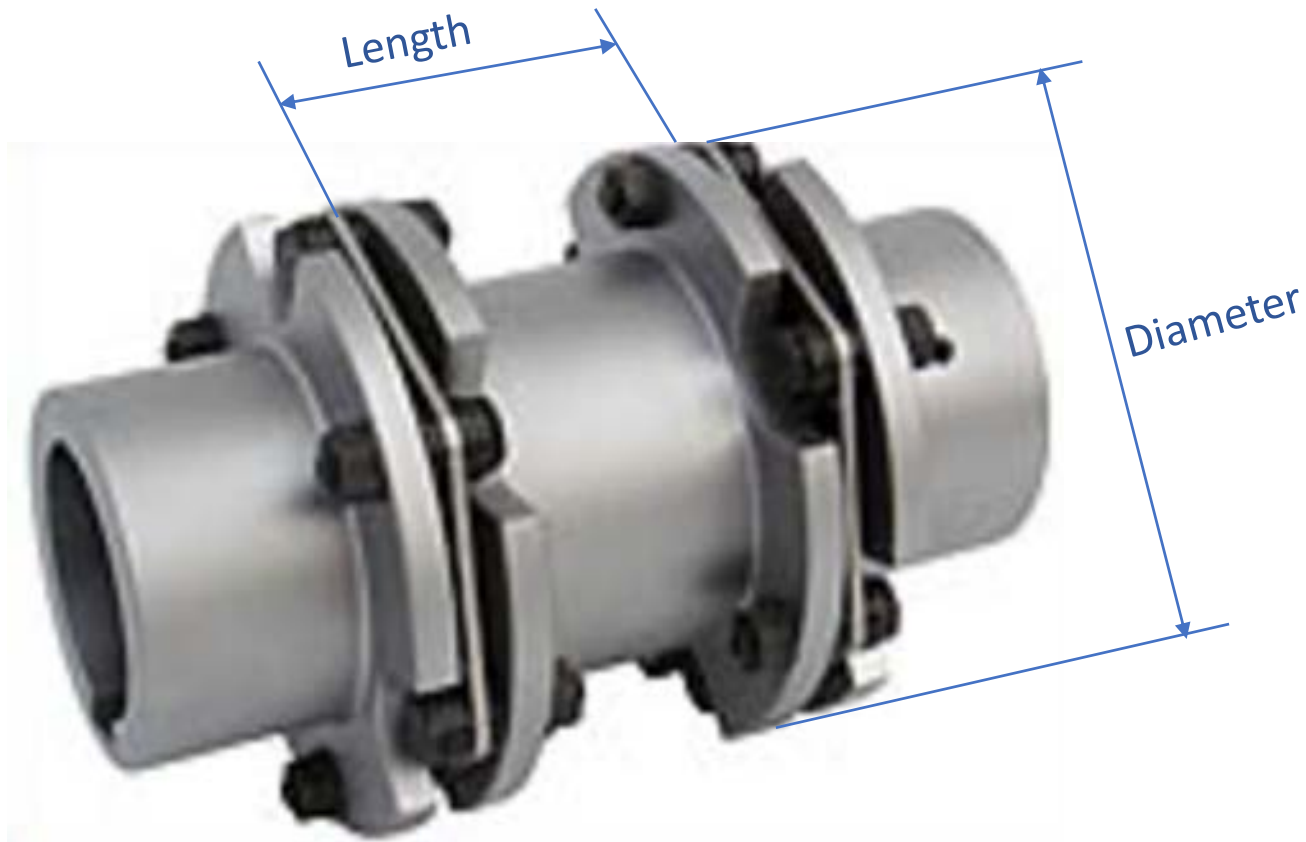
Alignment Condition

- Alignment condition is always a combination of **Gap** (or Angularity) and **Offset** (or Parallelity)
- A Machine must be corrected in both **Vertical** and **Horizontal** planes
- Alignment Sign convention:
 - + Gap (or Angularity)
 - Gap (or Angularity)
 - + Offset (or Parallelity)
 - Offset (or Parallelity)



Flexible couplings

For ease of understanding we define short flexible couplings when **the axial length of the flexible element or the axial length between the flexible element is equal or smaller than the coupling diameter.**



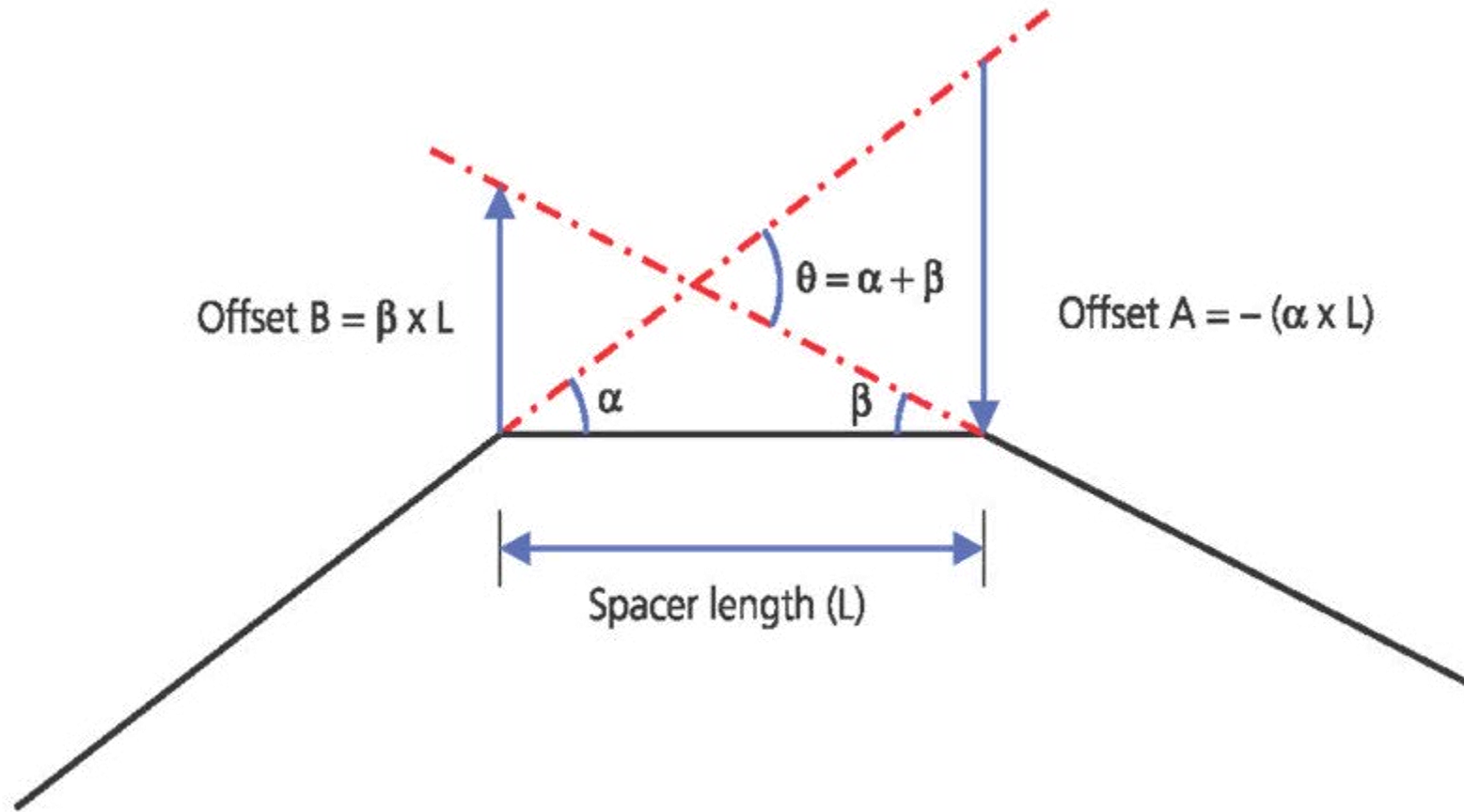
Typical short-flex couplings



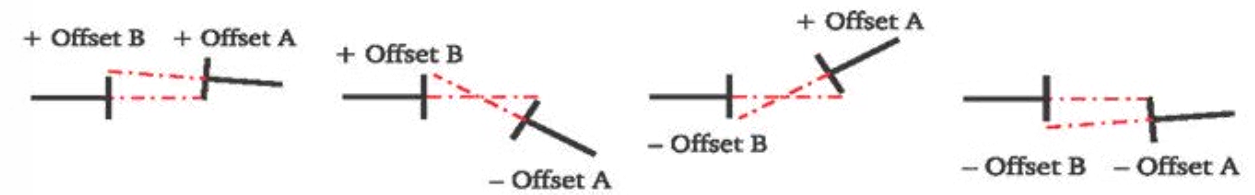
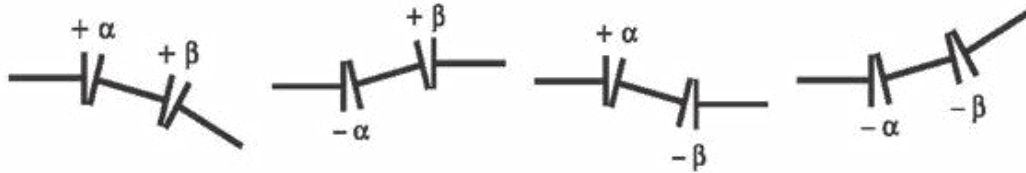
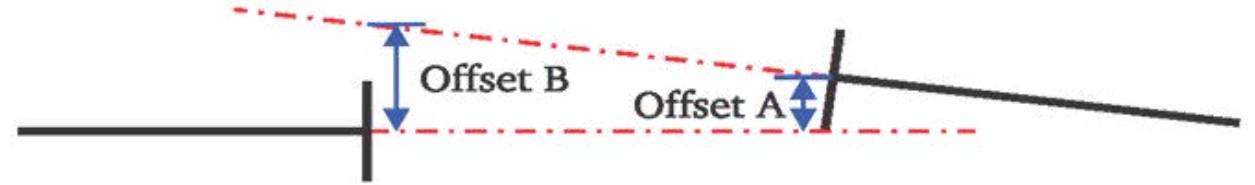
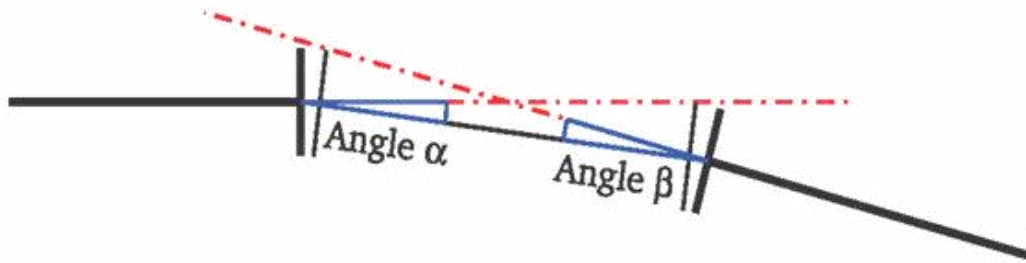
Spacer coupling type



Spacer coupling: Angularity or Offset

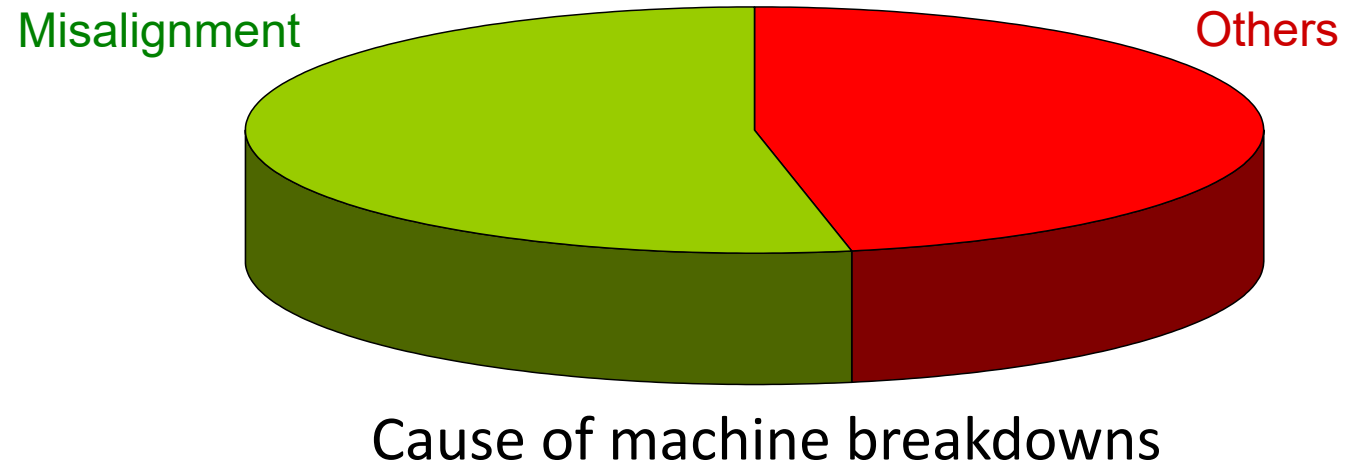


Spacer coupling: Angularity or Offset



How to recognise the symptoms of misalignment?

- Excessive radial and axial vibrations
- Premature bearing, seal, coupling and shaft failures
- Oil leakage at the bearing seals
- High bearing and coupling temperatures
- Shafts are cracking or breaking
- Loose foundation bolts
- Increased energy consumption
- and more....(direct and indirect quantifiable costs)



Consequences of misalignment on rotating machinery

BEARINGS



COUPLINGS



SEALS





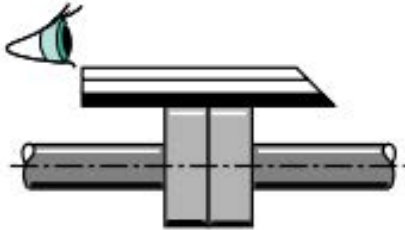


Typical Motor-Pump application



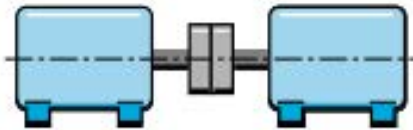
Shaft Alignment methods

STRAIGHT EDGE

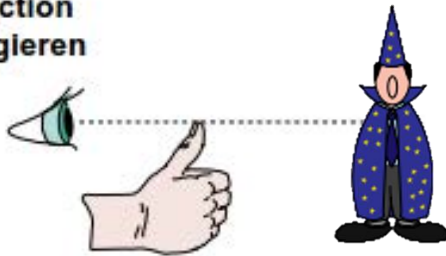


Measurement
Messen

5 mils
 $\frac{1}{10}$ mm



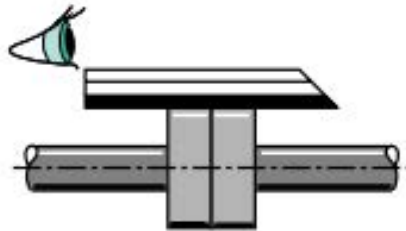
Correction
Korrigieren



THE WIZARD

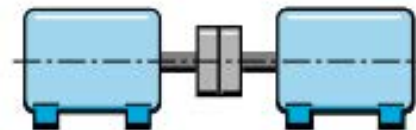
Shaft Alignment methods

STRAIGHT EDGE

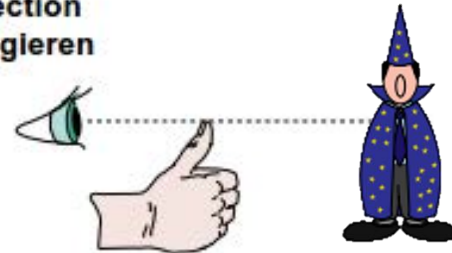


Measurement
Messen

5 mils
 $\frac{1}{10}$ mm

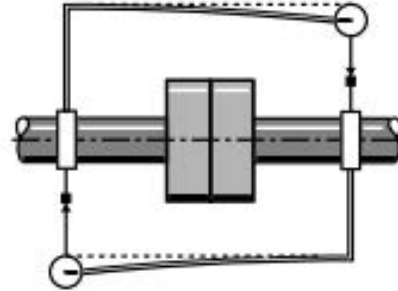


Correction
Korrigieren

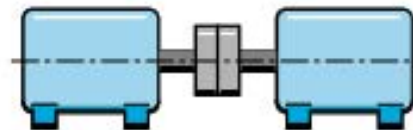


THE WIZARD

DIAL INDICATOR

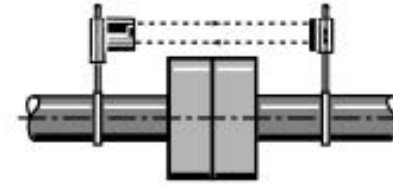


0.5 mils
 $\frac{1}{100}$ mm

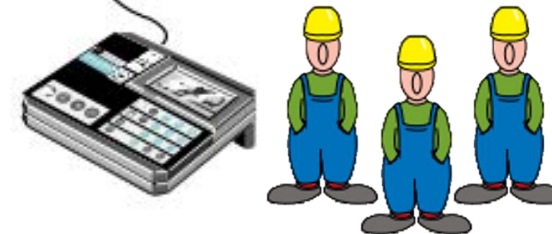
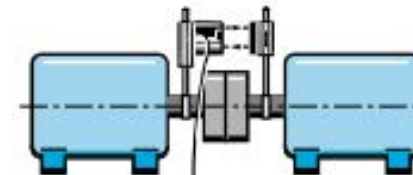


THE SPECIALIST

LASER SHAFT ALIGNMENT



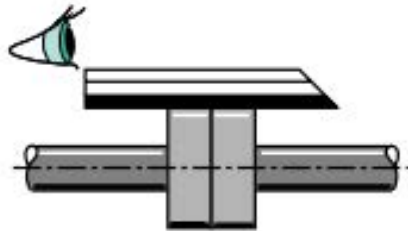
0.05 mils
 $\frac{1}{1000}$ mm



THE TECHNICIAN

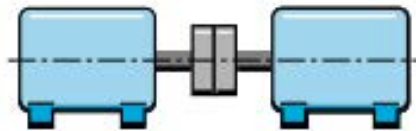
Shaft Alignment methods

STRAIGHT EDGE

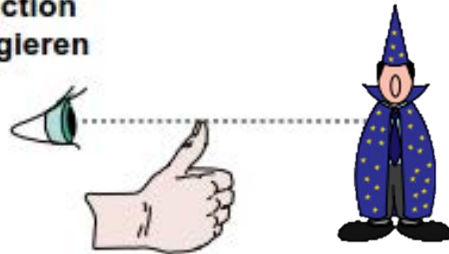


Measurement
Messen

5 mils
 $\frac{1}{10}$ mm

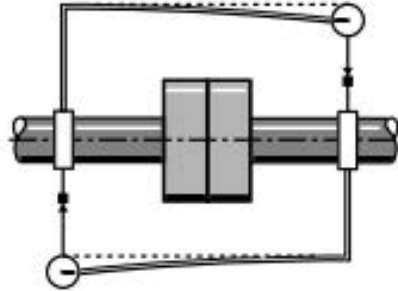


Correction
Korrigieren

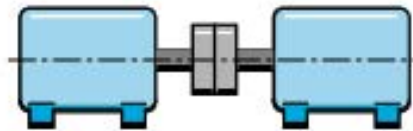


THE WIZARD

DIAL INDICATOR

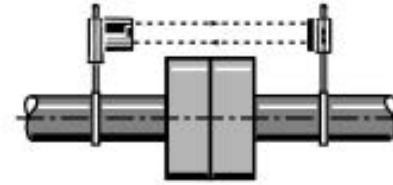


0.5 mils
 $\frac{1}{100}$ mm

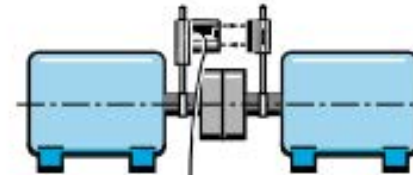


THE SPECIALIST

LASER SHAFT ALIGNMENT



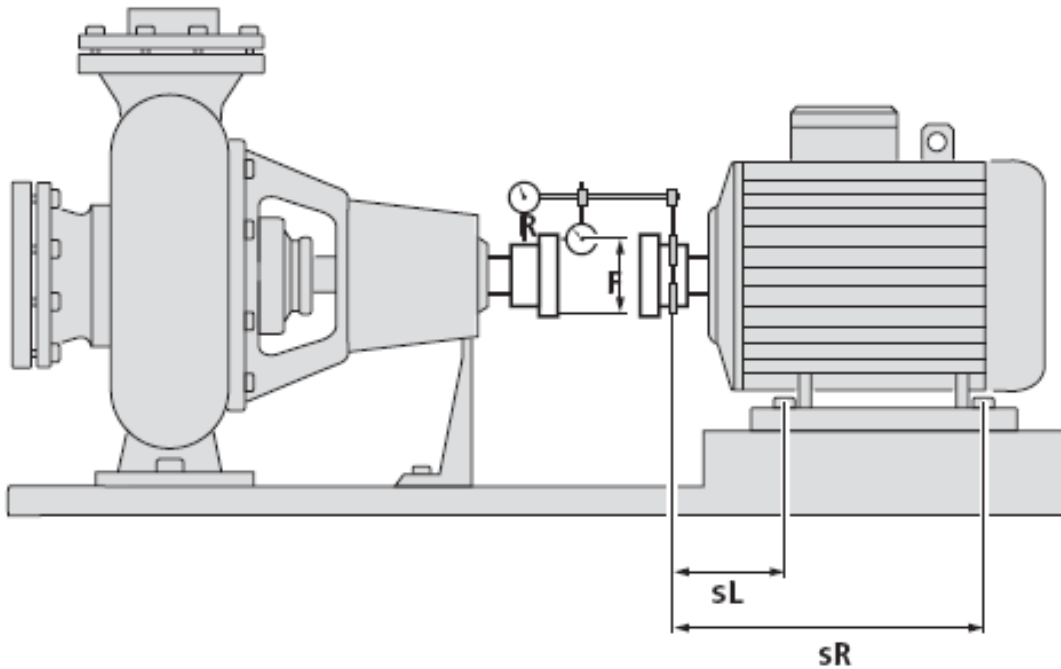
0.05 mils
 $\frac{1}{1000}$ mm



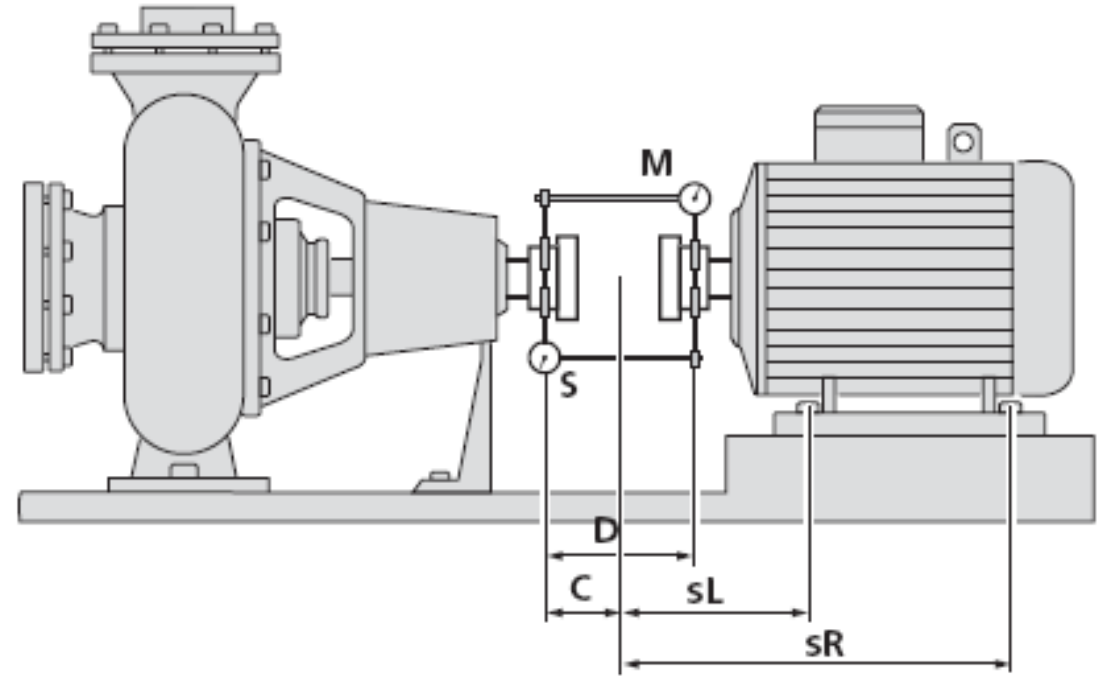
THE TECHNICIAN

Alignment of machines: Dial gauges

Rim and Face method



Reverse indicator method



Laser Shaft Alignment tool

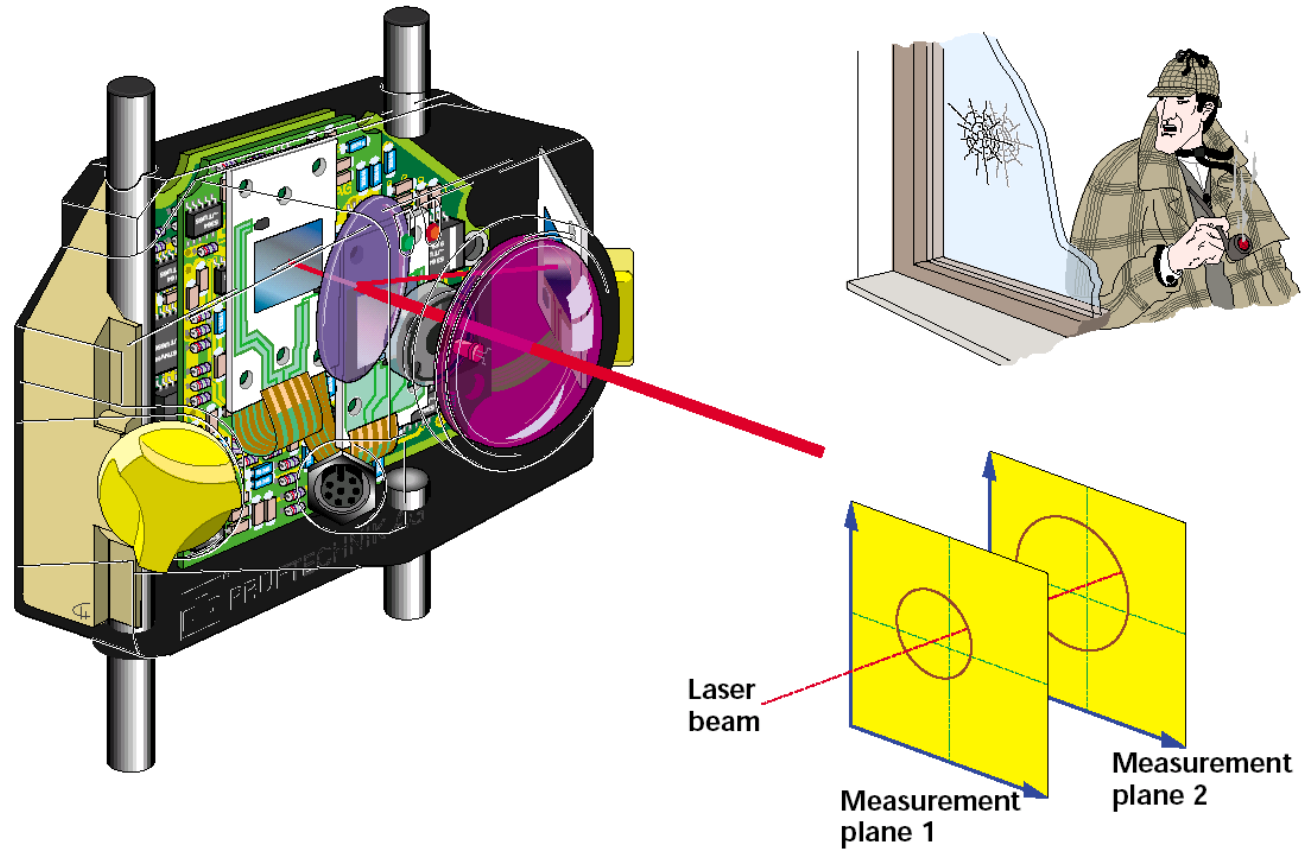


Introduction to hardware

- The three main components



OPTALIGN smart RS measurement principle



Laser Shaft Alignment tool



Enter front foot-to-back foot dimension then tap or .

DIMENSIONS			
/	*	C	
-	+	←	
7	8	9	
4	5	6	
1	2	3	
.	0	π	



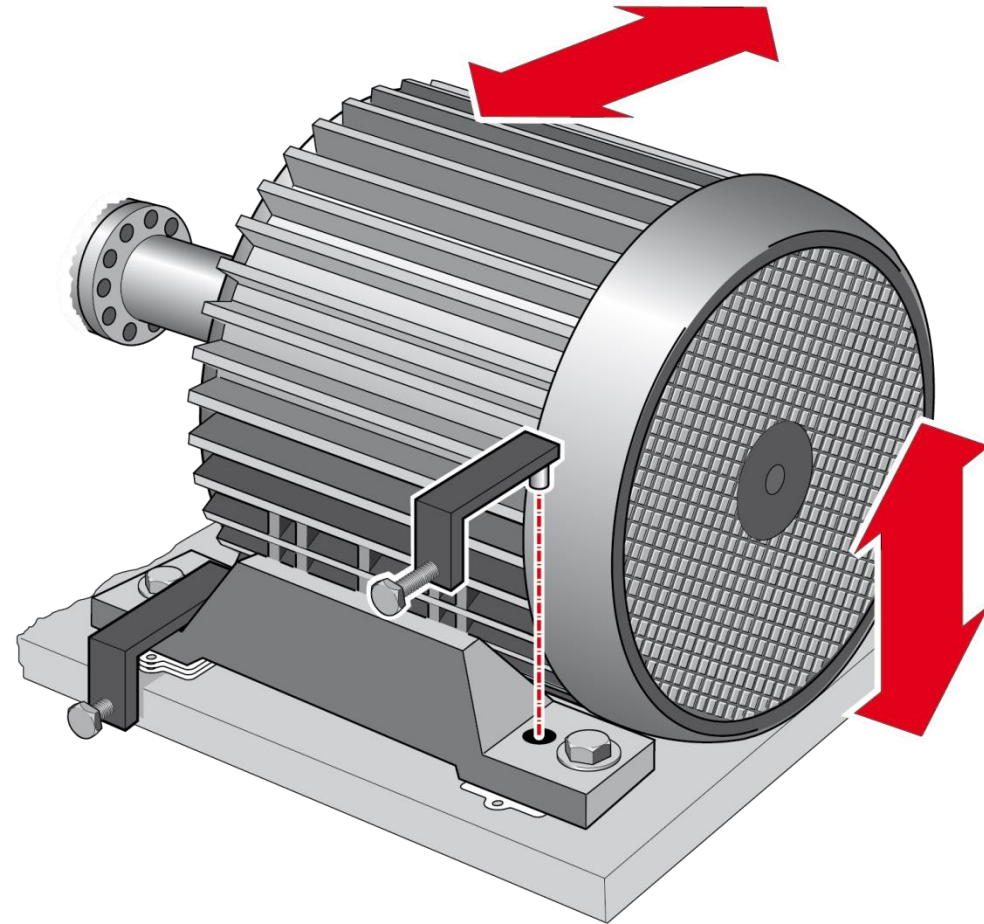
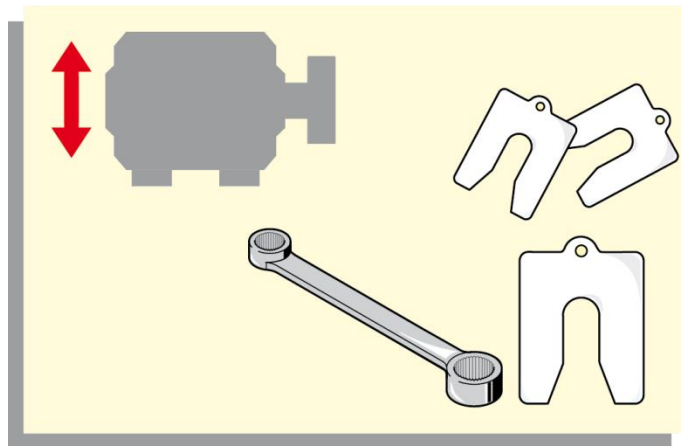
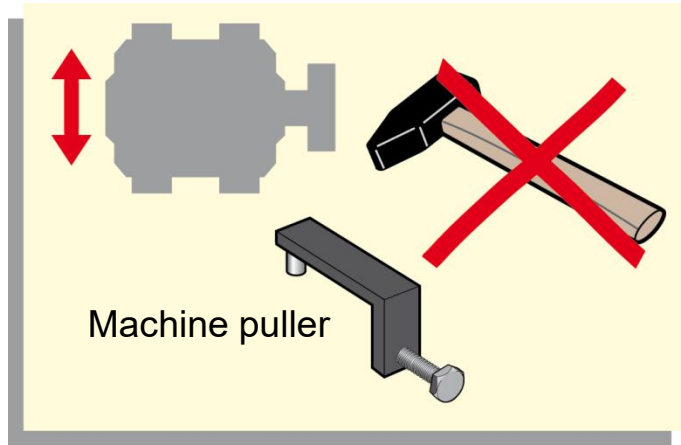
Tap to view results or to re-measure

ACTIVE CLOCK				
Laser On				
	V	H	V	H
	0.94	-0.24	-0.00	0.02
	0.94	-0.23	-0.00	0.02
	0.94	-0.24	-0.00	0.01
	↔	0.94		
	↔	-0.24		
	↕	-0.00		
	↕	0.01		



Tap to start Live Move.

RESULTS				
SAVE				
REPORT				
	↔	0.94		
	↔	-0.24		
	↕	-0.00		
	↕	0.01		

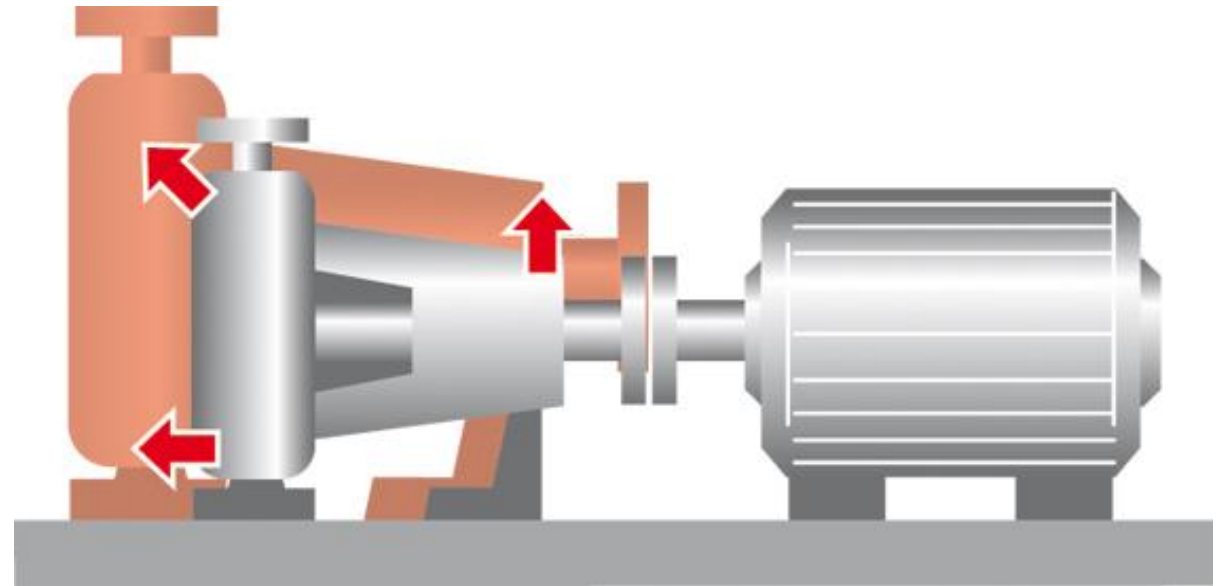


Once alignment condition found, a correction is recommended

Thermal growth and Target Pre-sets

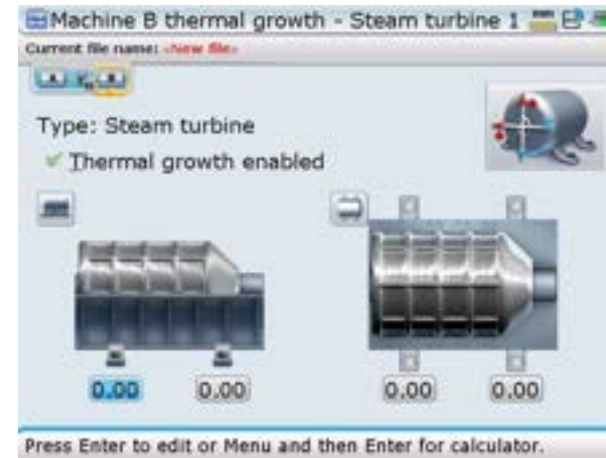
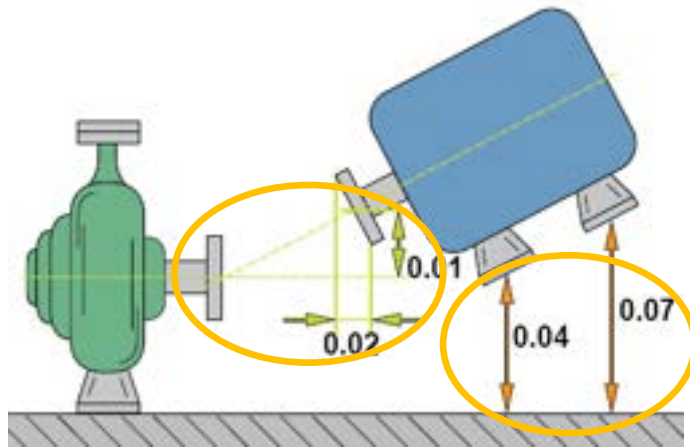
The specifications can be input to take into account the expected positional change of the machine during operation.

- The parameters are provided by **machine manufacturers**
- They can be **calculated**
- It is also possible to determine the compensation values by **monitoring the machines positional changes while the machines are running**

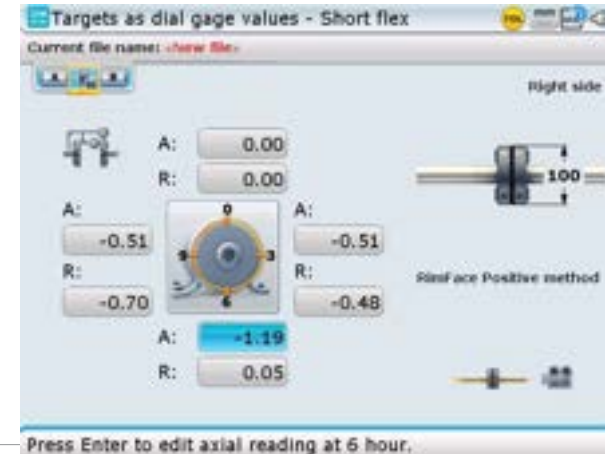
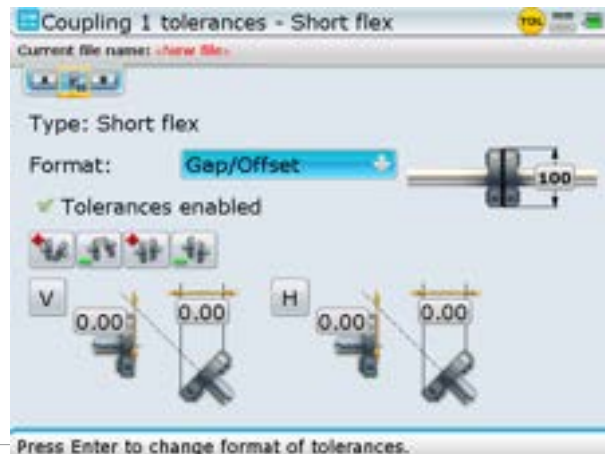


Thermal growth and Target specifications

Thermal growth parameters – at machine feet



Target values – at coupling (as gap/offset or dial indicator readings)




Thermal Growth

- Thermal growth calculator

THERMAL GROWTH CALCULATOR mm

Thermal growth enabled:


0.10 0.20

Cast iron

10.610⁻⁶ / °C

Initial temperature°C

Final temperature°C

Lengthmm

The thermal growth coefficient is calculated using the temperature difference and change in length of selected material.

CALCULATOR

Thermal growth calculator

Thermal growth is calculated from the material characteristics, expected temperature difference and height of the shaft centerline above the shim plane.

➤✔

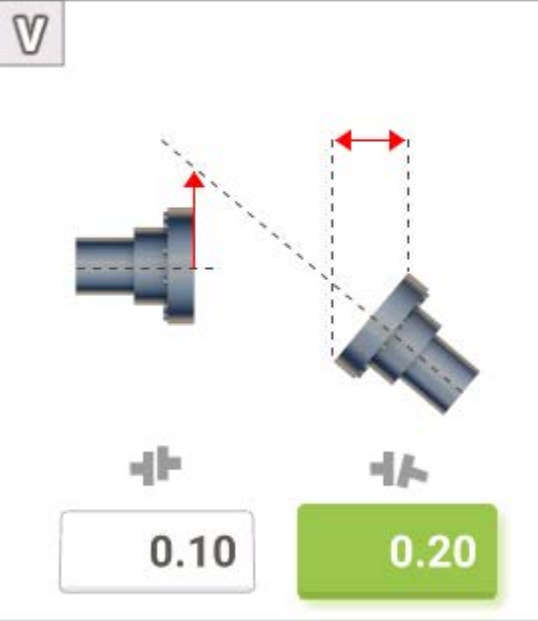
Thermal Growth

- Target values – at coupling
 - as gap/offset or dial indicator readings

TARGETS mm

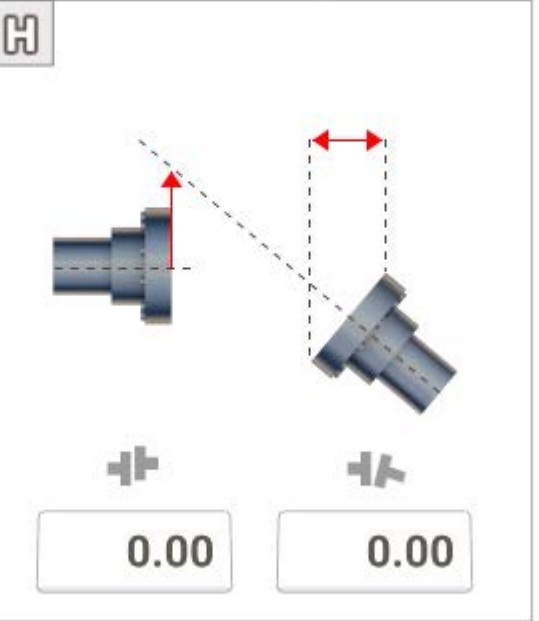
Targets enabled:

V



0.10 0.20


H



0.00 0.00

Targets represent the amount of misalignment in cold conditions needed to reach a "zero" alignment in operating conditions.

58% 18.07.2018 09:33



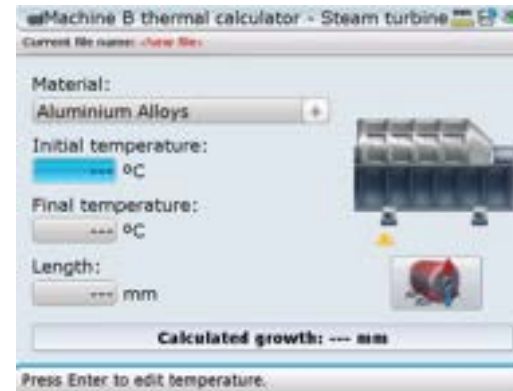
COUPLING TYPE

/	*	C
-	+	←
7	8	9
4	5	6
1	2	3
.	0	π

→ ✓

Thermal growth and Target specifications

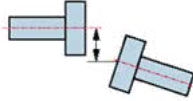
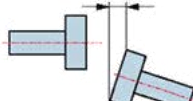
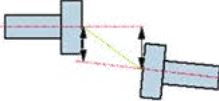
Thermal growth :calculated



Thermal growth : measured (Live Trend)

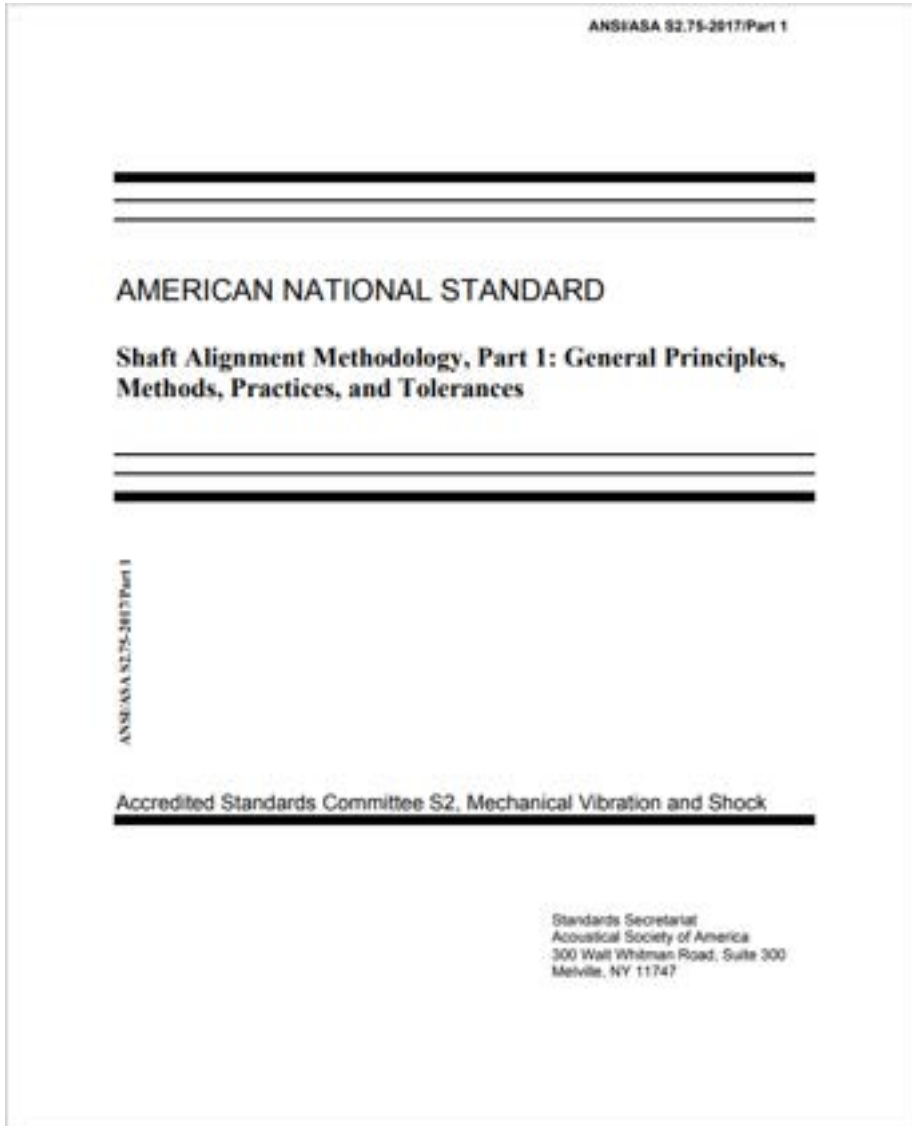


Tolerances

Soft foot	any	0.06 mm		2.0 mils	
		Acceptable	Excellent	Acceptable	Excellent
Short "flexible" couplings		OK	😊	OK	😊
Offset	600			9.0	5.0
	750	0.19	0.09		
	1500	0.09	0.06	3.0	2.0
	1800			1.5	1.0
	3000	0.06	0.03		
	3600			1.0	0.5
	6000	0.03	0.02		
	7200				
Angularity (gap difference at coupling edge per 100 millimeters diameter)	600			15.0	10.0
	750	0.13	0.09		
	1500	0.07	0.05	5.0	3.0
	1800			3.0	2.0
	3000	0.04	0.03		
	3600			2.0	1.0
	6000	0.03	0.02		
	7200				
Spacer shafts and membrane (disk) couplings Offset (per 100 millimeters spacer length or per inch of spacer length)	600			3.0	1.8
	750	0.25	0.15		
	1500	0.12	0.07	1.0	0.6
	1800			0.5	0.3
	3000	0.07	0.04		
	3600			0.3	0.2
	6000	0.03	0.02		
	7200				

- Tolerance table:** the suggested tolerances are RPM dependent values based upon decades of shaft alignment experience

ANSI (American National Standards Institute) Shaft Alignment Tolerances: S2.75-2017/Part 1



Three acceptance levels are described as Minimal AL4.5, Standard AL2.2 and Precision AL1.2. The tolerance angle T is the maximum angle in units of Offset/Span (mils/inch or mm/m) at each flex plane, and is calculated as:

$$T = \frac{AL}{\sqrt{\frac{RPM}{1000} + 1}}$$

Where: AL is the selected Alignment Quality Grade, and

RPM is the maximum machine operating rotating speed

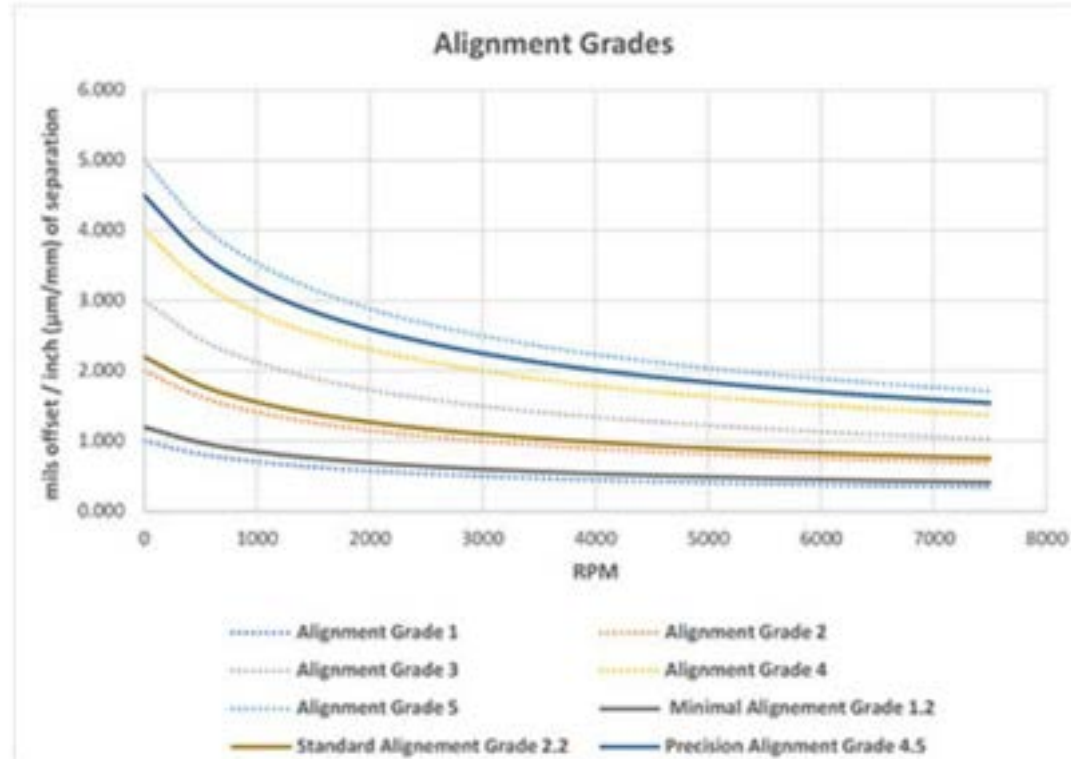


IMAGE 1: Alignment grade chart (Images courtesy of EASA)

Shaft Alignment ROI (Return On Investment)

https://prototypes.fluke.com/roi_calculator/v1_01/#

https://prototypes.fluke.com/roi_calculator/v1_01/#

Purchase justification for laser alignment Best case example

Settings Restore default values


Currency: € USD GBP

Business format: 123,456.78 | 123,456.78 | 123,456.78

Power saving | Seal replacement cost | Bearing replacement cost | Pump repair cost

Power saving calculation

	Alignment Data	4th Rating	Cost of seals
Measured misalignment	675 mm	19 mm	0
Power loss	146%	21 mm	0
Cost of power per kWh	0.134	75 mm	1
Operating hours per day	24	123 mm	2
Operating days per year	365	300 mm	3



Total additional cost of power consumed across plant: 1,575,311 €

% increase Type coupling

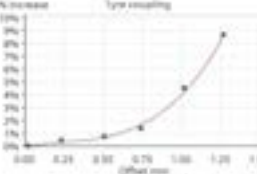


Figure 1 The effect on power consumption of misalignment

% increase Type coupling

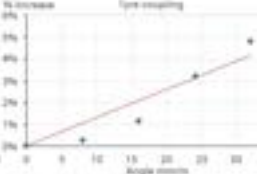


Figure 2 Mechanical seal life in future due to shaft misalignment

The graphs are generated from a report of the investigation into the effects of misalignment of power consumption on the case carried out at the 10 Powerhouse One System from 04 July - 14th August 1994.

The pump was installed to receive water through a closed loop of piping with the motor running at 3000 rpm. The motor rating was 7.5 MW. Run-to-run misalignment and angular misalignment were introduced into the machine set, and the current drawn by the motor was recorded.

Purchase justification for laser alignment Best case example

Settings Restore default values

Currency: € USD GBP

Business format: 123,456.78 | 123,456.78 | 123,456.78

Power saving | Seal replacement cost | Bearing replacement cost | Pump repair cost

Seal replacement cost (for cartridge seals at average costs from seal manufacturers)

	Alignment Data	4th Rating	Cost of seals
Measured misalignment	675 mm	19 mm	340.00 €
Failure interval in months	12.00	25 mm	420.00 €
		75 mm	480.00 €
		123 mm	540.00 €
		300 mm	670.00 €



Total additional cost of seals consumed across plant per year: 306,541 €

In this graph, the lower threshold values are taken from the Soudanese paper. Failure is defined when the seal starts to leak. In practice, the seals are not replaced immediately but continued to be used for some time. Based on data from AEG seals, the upper threshold values show seal life based on typical failure practice. For the purposes of this purchase justification, the more conservative upper limit is used.

Summary

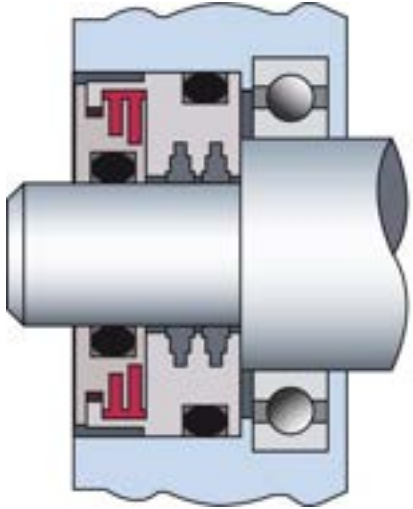
Annual savings on plant when alignment is better than 100 compared to typical measured alignment of 675 mm

Saving on power costs	1,575,311 €
Saving on replacement seals	306,541 €
Saving on replacement bearings	196,800 €
Saving on pump repairs	1,260,000 €
Total additional cost over time cost**	2,338,652 €
Total additional saving over 3 year period**	10,600,641 €

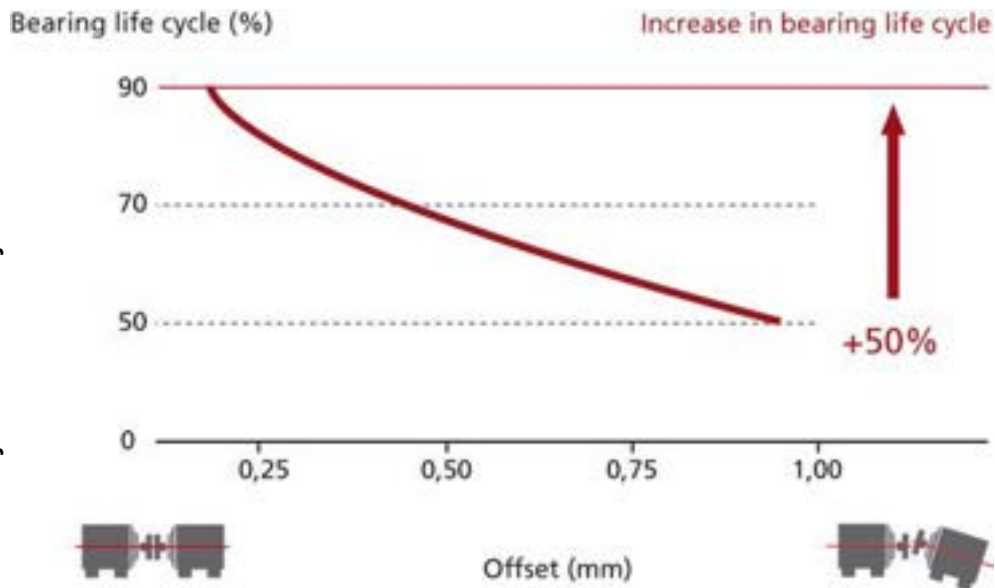
** these costs are additional to the expected annual running cost of the asset when aligned to 100 mm. **306,541 €**

[ROI calculator \(fluke.com\)](https://www.fluke.com/roi-calculator)

Bearing life cycle: Bearing repair costs



The smaller the offset misalignment, the higher the expected bearing life cycle, increasing by up to 50%



Annual bearings repair costs on a 75 KW pump

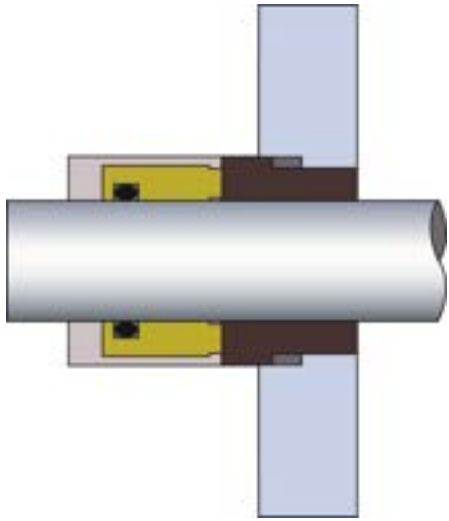


misaligned offset 0.2 mm
 additional cost of bearings per year
35.- €

misaligned offset 0.75 mm
 additional cost of bearings per year
124.- €

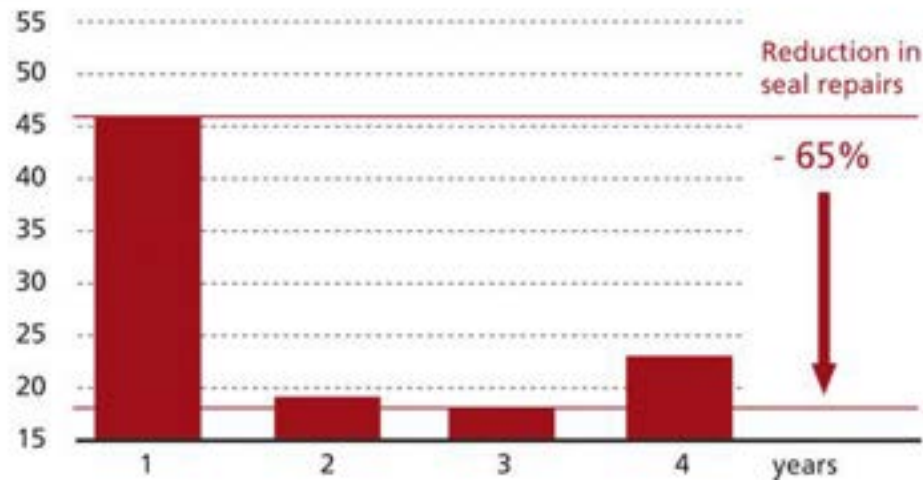
- The additional cost of bearings per year for the motor only, when compared to a perfect alignment of 0.05 mm

Pump Mechanical seal repairs: When precision alignment performed



Precision alignment can reduce the number pump mechanical seal repairs by 65%

Number of mechanical seal repairs



Annual mechanical seal repair costs on a 75 KW pump



misaligned offset 0.2 mm

additional cost of seals per year

51.- €



misaligned offset 0.75 mm

additional cost of seals per year

235.- €

- The additional cost of seals per year, when compared to a perfect alignment of 0.05 mm, are to be added to the costs of bearings

Pump repairs: When precision alignment performed



Precision alignment can reduce the number of pump repairs by 30%

Annual pump repair costs on a 75 KW pump



misaligned offset 0.2 mm

additional cost of pump repairs

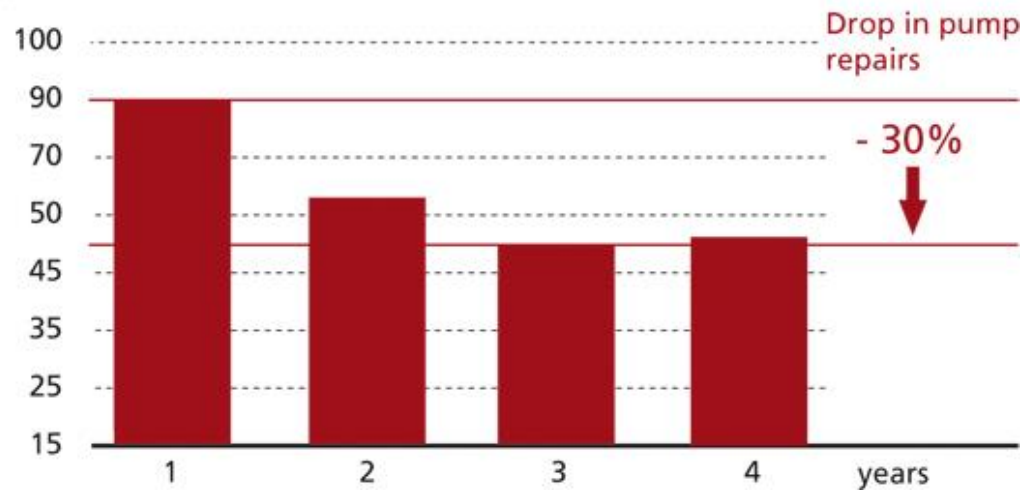
145.- €

misaligned offset 0.75 mm

additional cost of pump repair

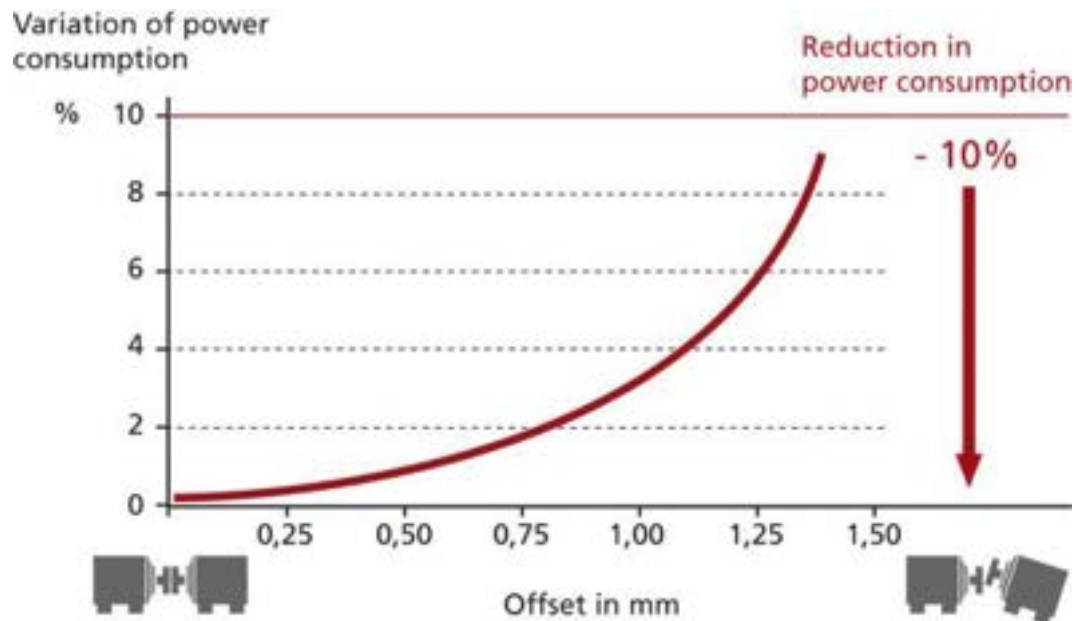
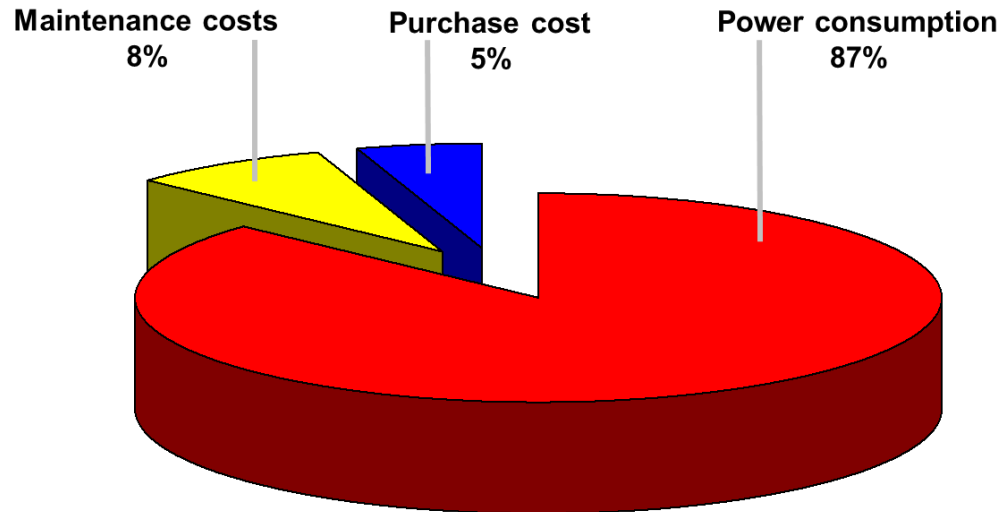
670.- €

Number of pump repairs



- The additional cost of pump repairs per year, when compared to a perfect alignment of 0.05 mm, are to be added to the costs of bearings and seals

Power consumption



Precise alignment eliminates reaction forces and reduces energy consumption by up to 10%

Annual power consumption costs on a 75 KW pump



- The additional cost on power consumption per year, when compared to a perfect alignment of 0.05 mm, are to be added to the costs of bearings, seals and repairs

Total annual costs: Return On Investment

Annual costs on a 75 KW pump summary



With fifty 75 KW pumps and 0.2 mm offset, the annual costs can easily ascend to € 22,050.- or even higher

Using precision alignment with 0.05 mm offset, the annual cost could be lowered to € 8,250.- which would be a direct annual saving of € 13,800.-



Total annual costs: Return On Investment

Annual costs on a 75 KW pump summary

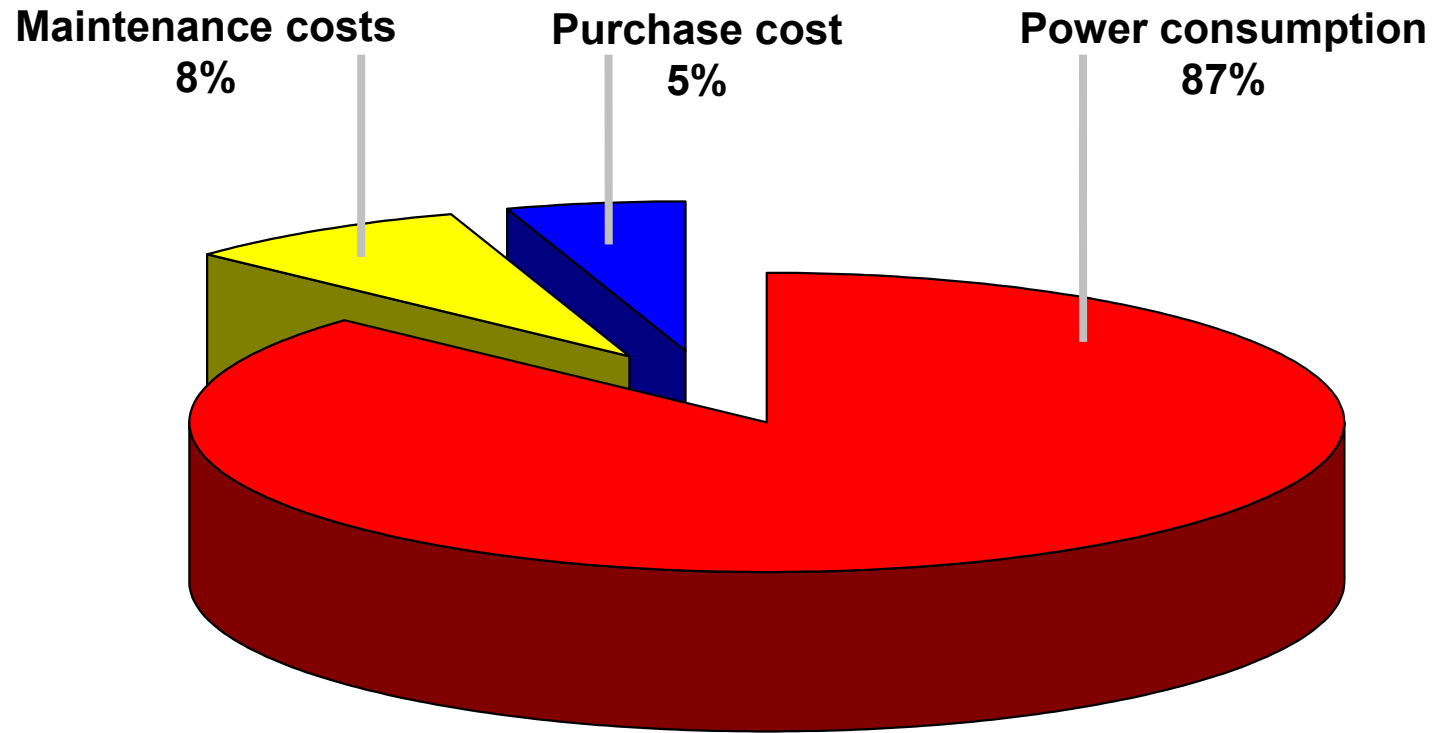


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Using precision alignment with 0.05 mm offset, the annual cost could be lowered to € 8,250.- which would be a direct annual saving of € 13,800.-



Life cycle costs of a water pump

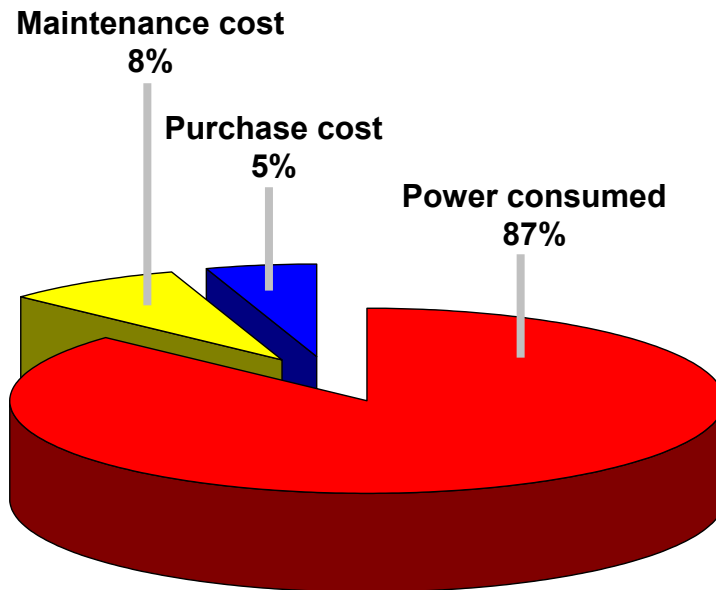


Source: UK pump association

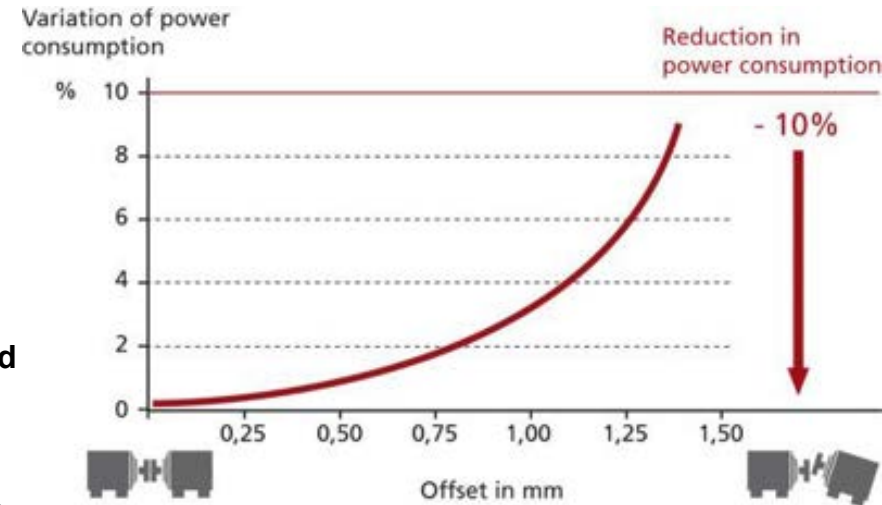
Effects on power consumption

- Significant power savings can be made through accurate alignment
- Precise alignment eliminates reaction forces and reduces energy consumption by up to 10%

Life cycle costs of a water pump



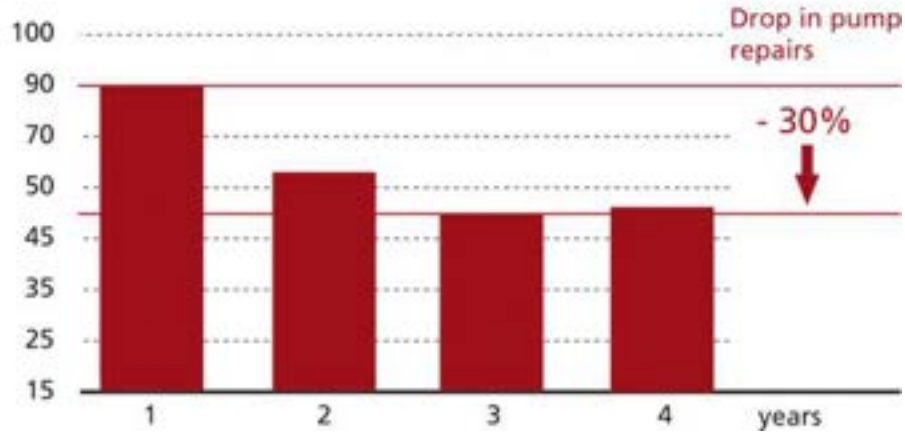
Source: UK pump association



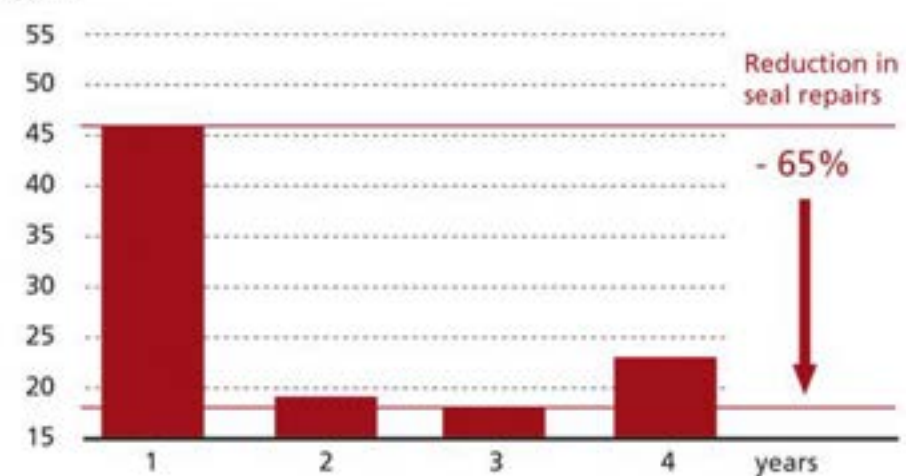
Courtesy of an UK major chemical plant

Benefits promised by laser alignment

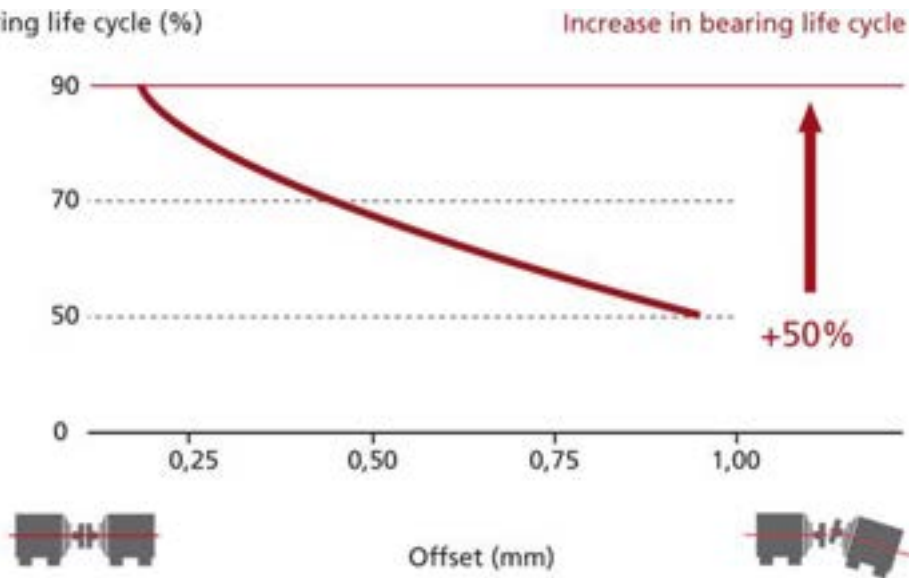
Number of pump repairs



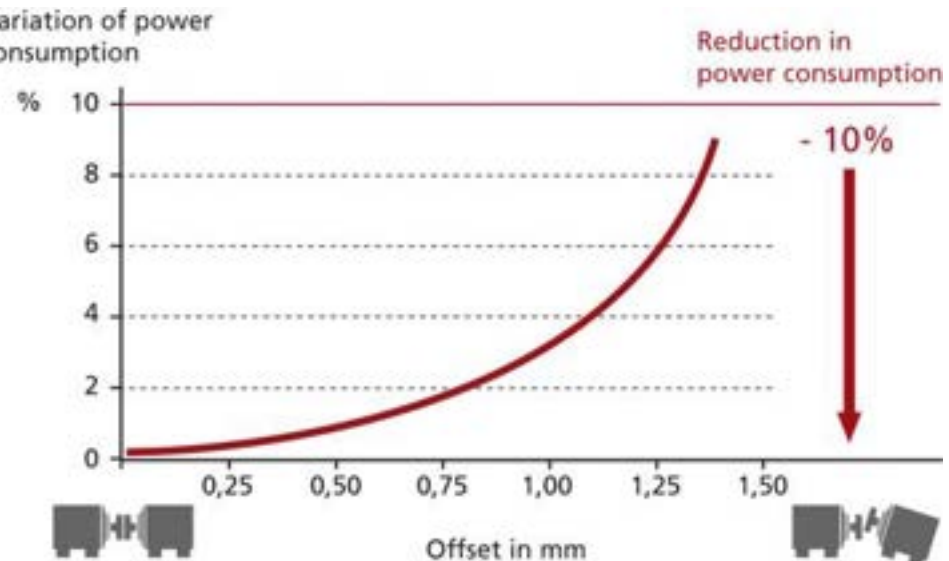
Number of mechanical seal repairs



Bearing life cycle (%)



Variation of power consumption



Precision Laser Shaft Alignment Benefits

- Reduced costs of spare parts, i.e., bearings and mechanical seals
- Reduced maintenance labour costs and improved planning
- Reduced costs on brackets and documentation issues
- Reduced power consumption of the plant
- Increased life cycle from the operating machines
- Increased plant availability
- Improved plant operation and reliability
- Improved plant operating safety
- A contribution to a cleaner environment



FLUKE®

Reliability

THANK YOU!

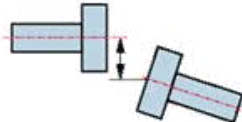
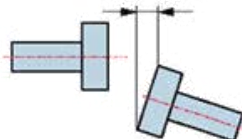
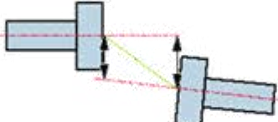






Q&A

Tolerances

- Tolerance table:** the suggested tolerances are RPM dependent values based upon decades of shaft alignment experience

Soft foot	any	0.06 mm		2.0 mils	
		Acceptable	Excellent	Acceptable	Excellent
Short "flexible" couplings		OK	😊	OK	😊
Offset 	600			9.0	5.0
	750	0.19	0.09		
	1500	0.09	0.06		
	1800			3.0	2.0
	3000	0.06	0.03		
	3600			1.5	1.0
	7200	0.03	0.02	1.0	0.5
Angularity (gap difference at coupling edge per 100 millimeters diameter) 	600			15.0	10.0
	750	0.13	0.09		
	1500	0.07	0.05		
	1800			5.0	3.0
	3000	0.04	0.03		
	3600			3.0	2.0
	7200	0.03	0.02	2.0	1.0
Spacer shafts and membrane (disk) couplings Offset (per 100 millimeters spacer length or per inch of spacer length) 	600			3.0	1.8
	750	0.25	0.15		
	1500	0.12	0.07		
	1800			1.0	0.6
	3000	0.07	0.04		
	3600			0.5	0.3
	7200	0.03	0.02	0.3	0.2

The following table shows the consolidated (50 Hz and 60 Hz) tolerances

	RPM	metric (mm)		imperial (mils)	
		Acceptable OK	Excellent 😊	Acceptable OK	Excellent 😊
Short flexible couplings Gap (per 100 mm or 10" diameter) 	600	0.15	0.10	14.9	10.0
	750	0.12	0.08	12.3	8.2
	900	0.10	0.07	10.5	7.0
	1000	0.10	0.06	9.6	6.4
	1200	0.08	0.05	8.2	5.4
	1500	0.07	0.04	6.7	4.5
	1800	0.06	0.04	5.7	3.8
	3000	0.04	0.02	3.7	2.5
	3600	0.03	0.02	3.1	2.1
	6000	0.02	0.01	2.0	1.3
	7200	0.02	0.01	1.7	1.1
	Offset 	600	0.23	0.13	9.0
750		0.18	0.10	7.3	4.1
900		0.16	0.09	6.1	3.4
1000		0.14	0.08	5.5	3.1
1200		0.12	0.07	4.6	2.6
1500		0.09	0.05	3.7	2.1
1800		0.08	0.04	3.1	1.8
3000		0.05	0.03	1.9	1.1
3600		0.04	0.02	1.6	0.9
6000		0.02	0.01	1.0	0.6
7200		0.02	0.01	0.8	0.5

	RPM	metric (mm)		imperial (mils)	
		Acceptable OK	Excellent 😊	Acceptable OK	Excellent 😊
Spacer shaft and membrane (disk) couplings Offset (per 100 mm spacer length or per 1" of spacer length) 	600	0.30	0.18	3.0	1.8
	750	0.24	0.14	2.4	1.4
	900	0.20	0.12	2.0	1.2
	1000	0.18	0.11	1.8	1.1
	1200	0.15	0.09	1.5	0.9
	1500	0.12	0.07	1.2	0.7
	1800	0.10	0.06	1.0	0.6
	3000	0.06	0.04	0.6	0.4
	3600	0.05	0.03	0.5	0.3
	6000	0.03	0.02	0.3	0.2
	7200	0.02	0.01	0.2	0.1