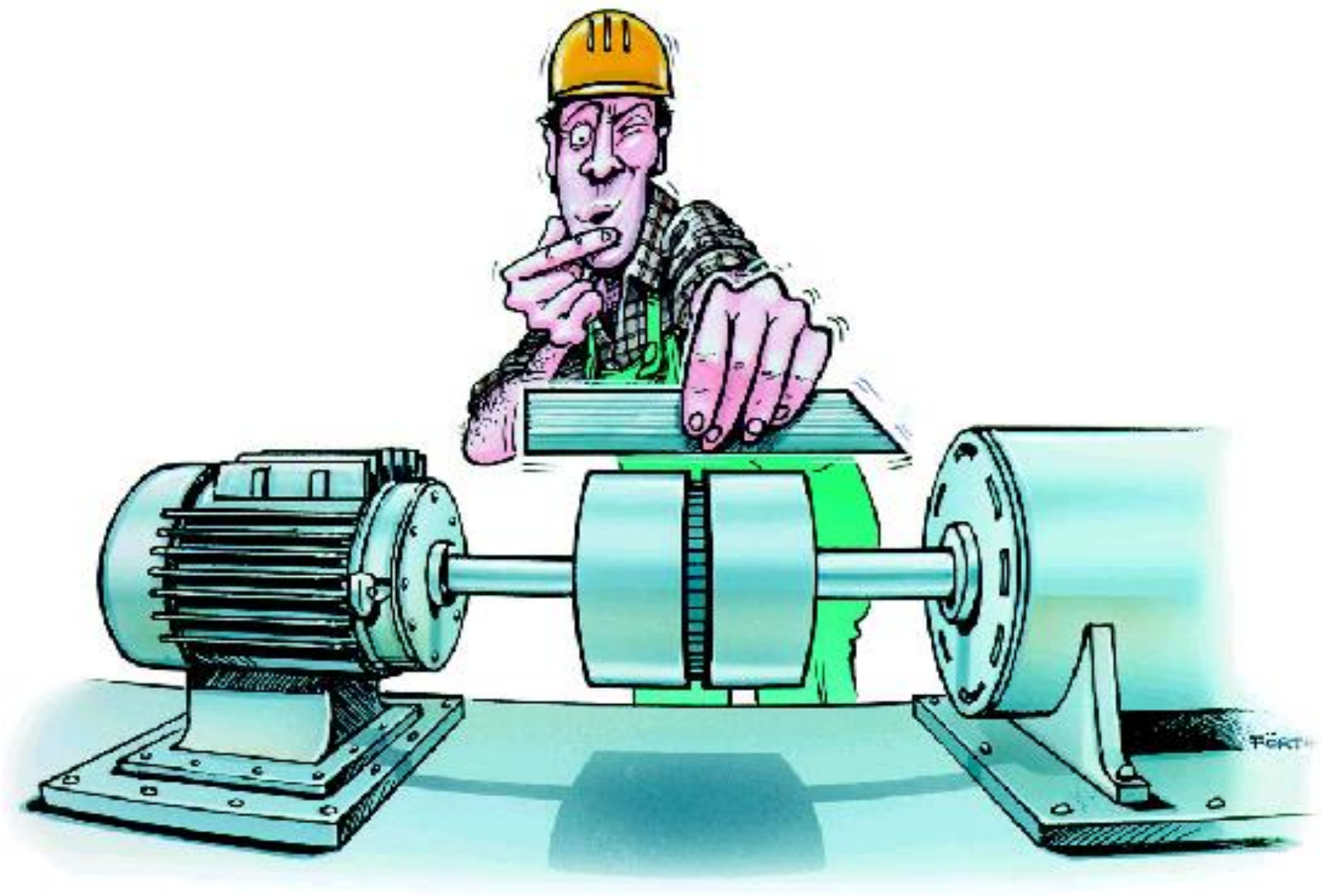
FLUKE®
Reliability

The Importance of Precision Shaft Alignment

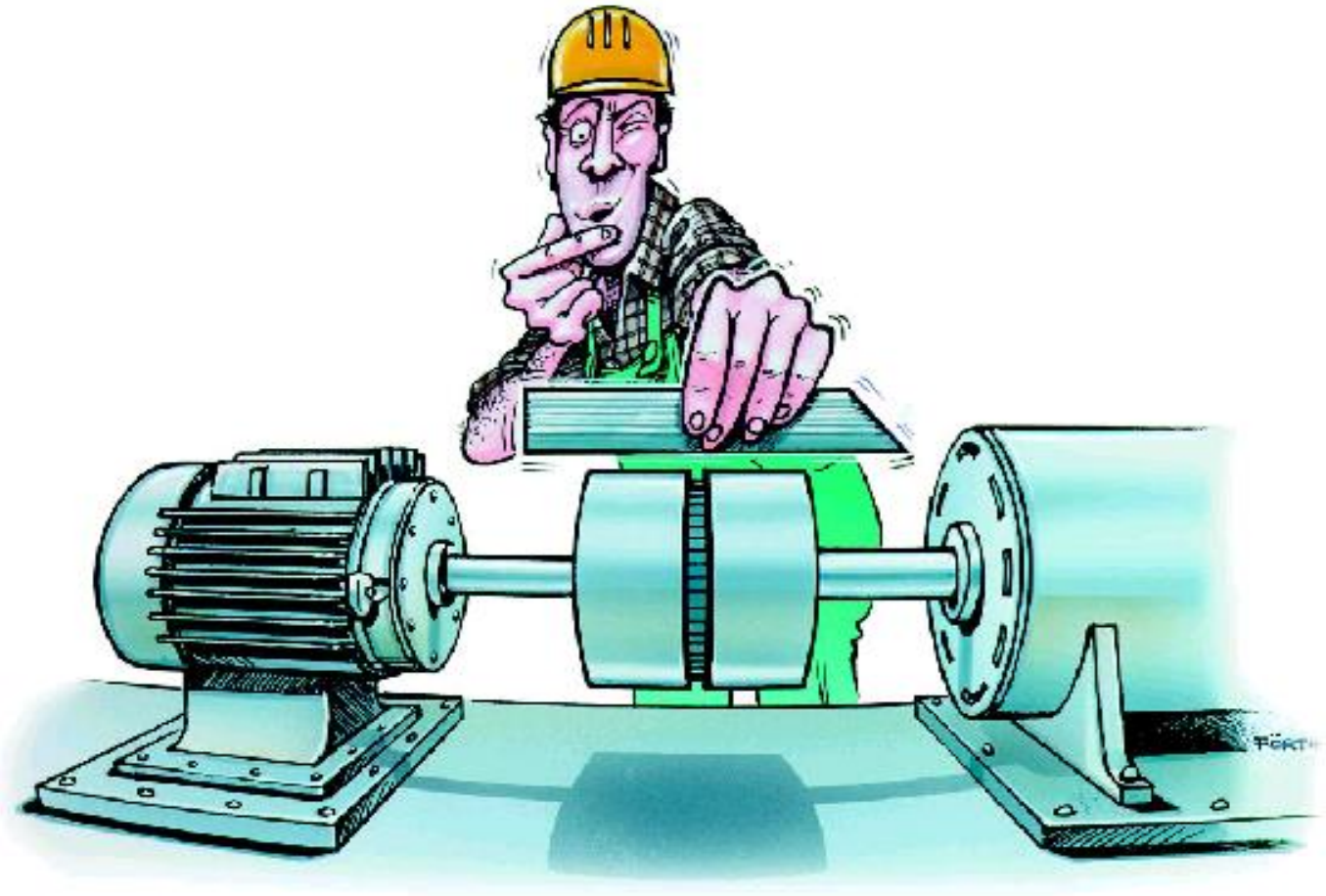
Alignment



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.**

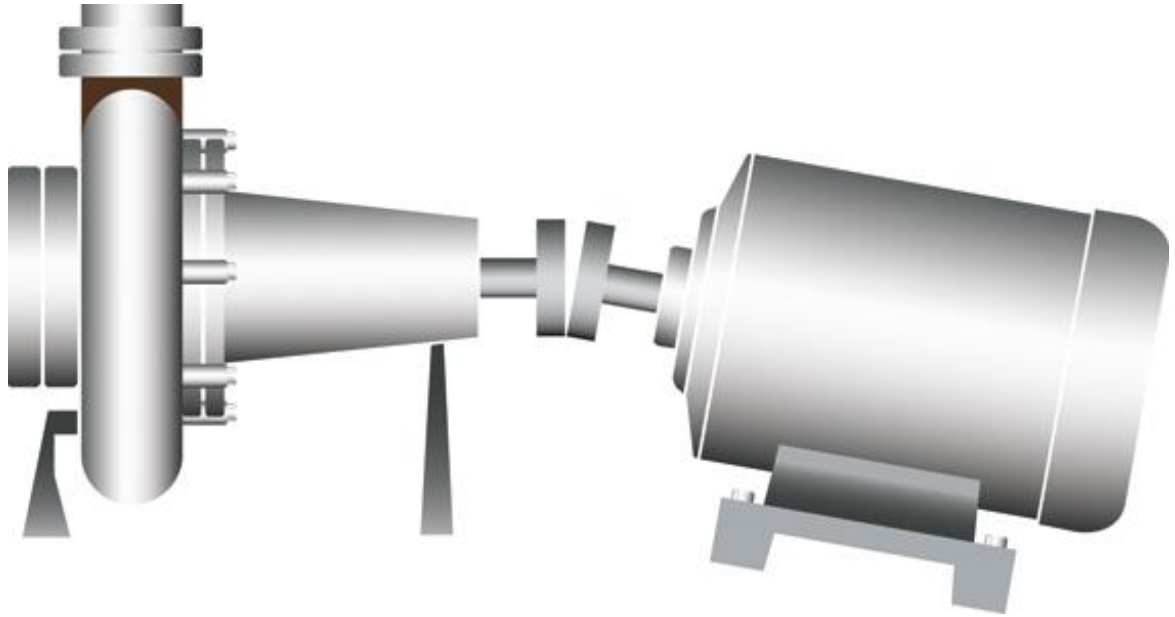


Why alignment

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

Shaft Alignment Handbook
John Piotrowski

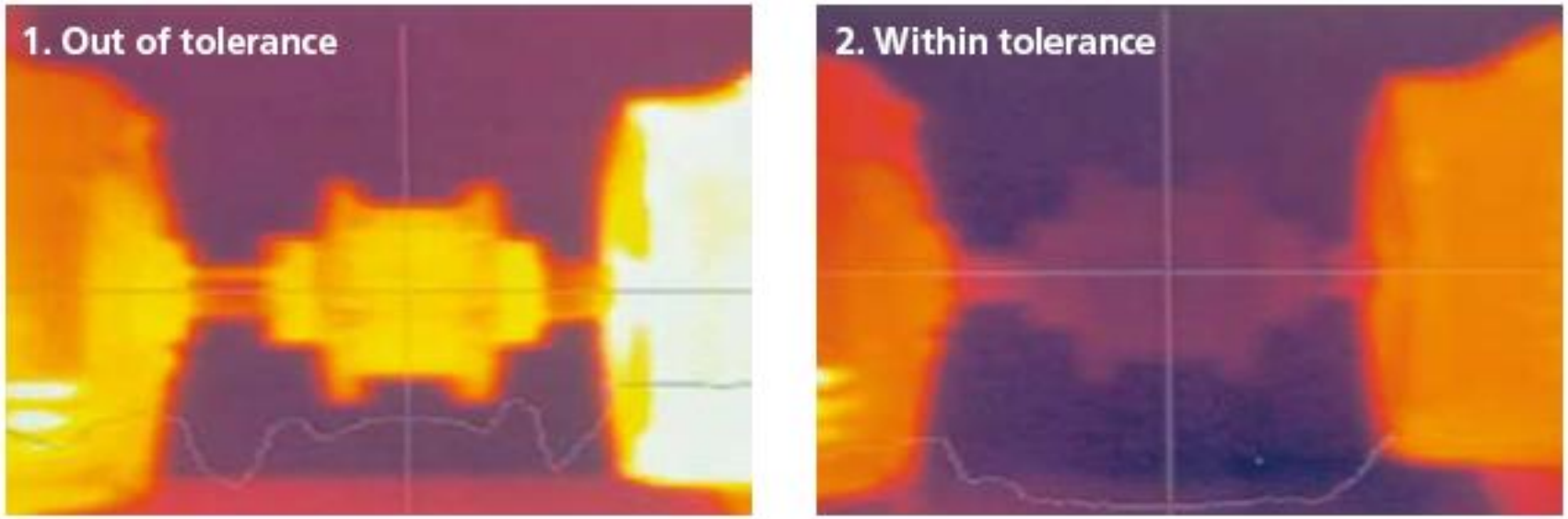
- … Rotating shafts must be aligned.
- Whenever a machine generates vibration, then alignment condition must be checked…



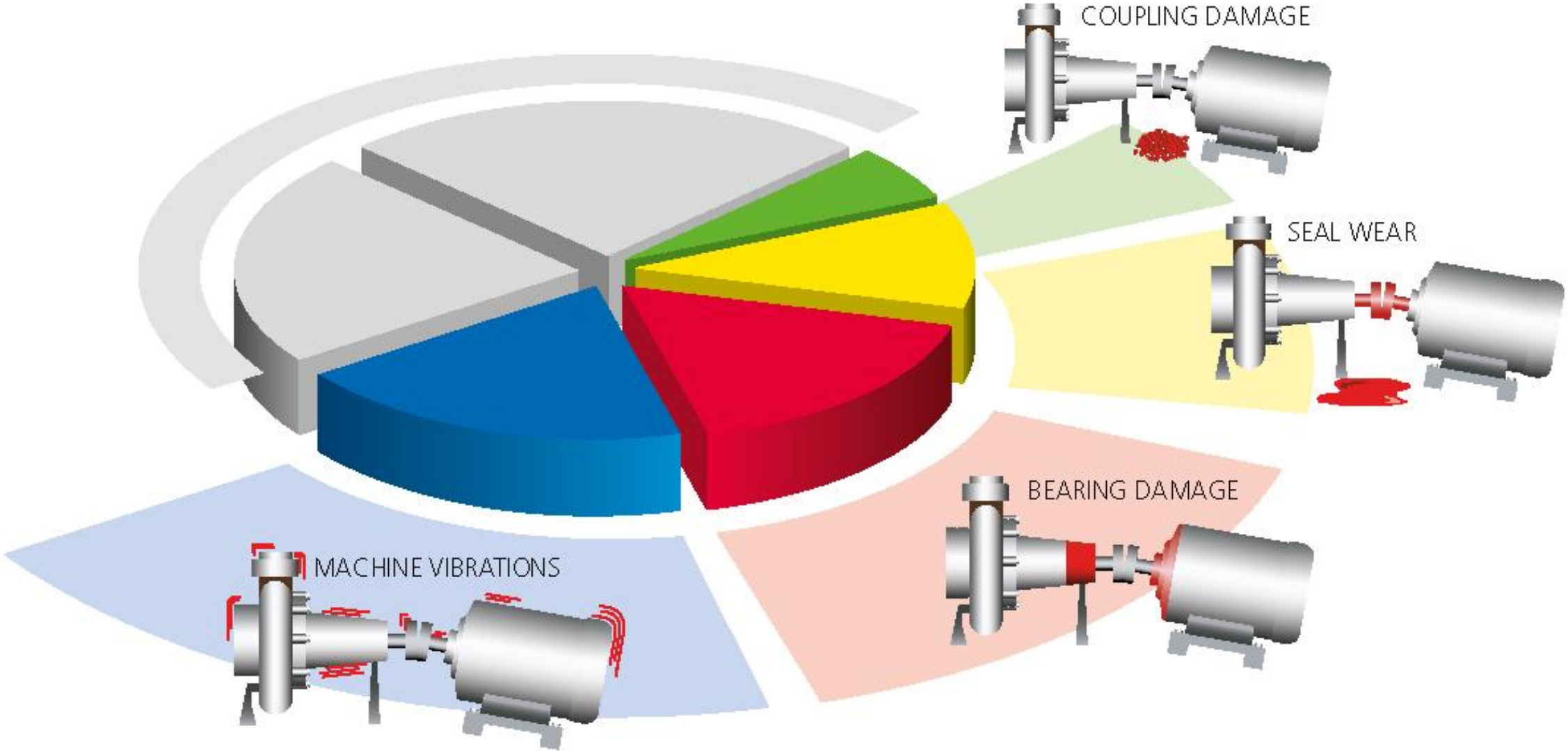
Coupling and shaft loading

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

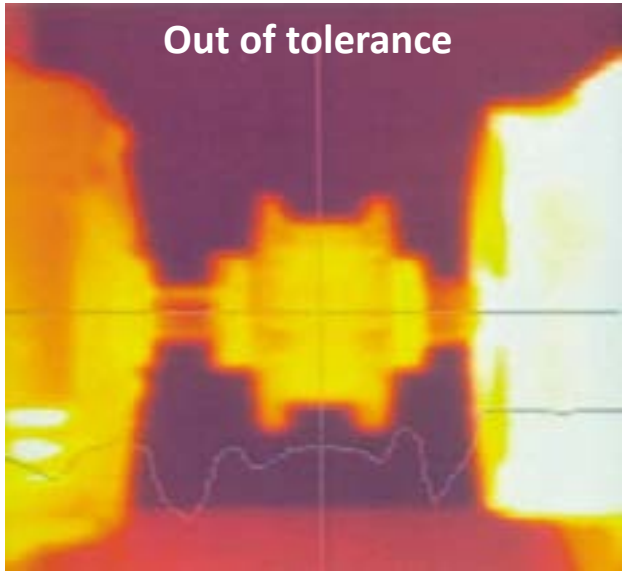
- The flexible coupling elements heats up and the machine develops elevated temperatures particularly around the bearing housings

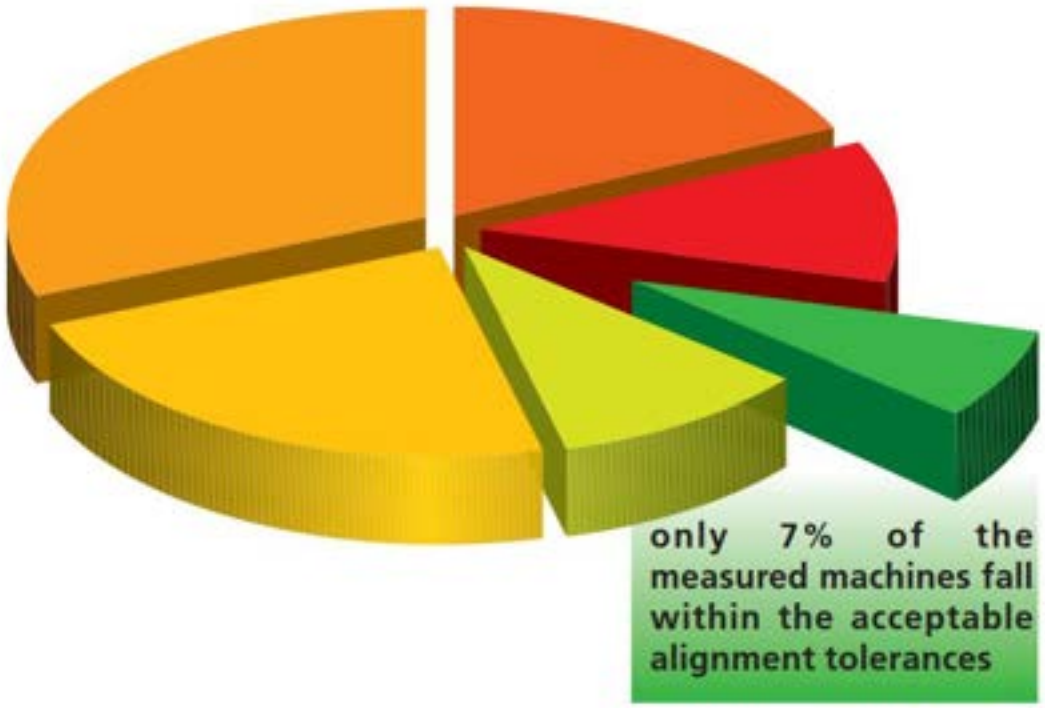


Consequences of misalignment on machine condition

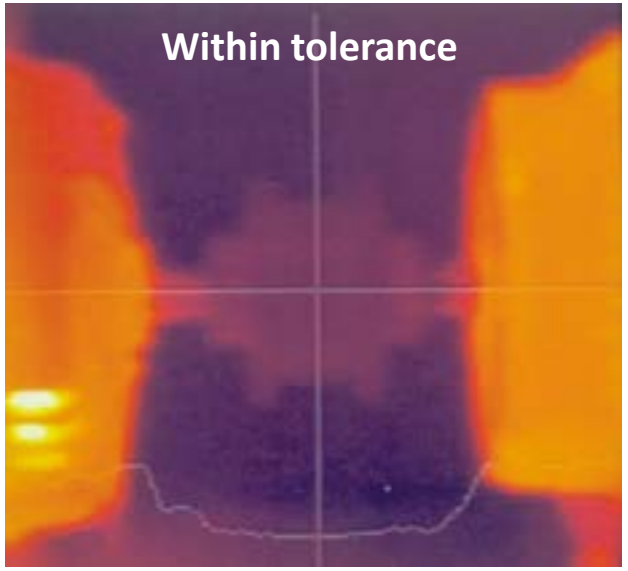


Machines within precision alignment tolerances





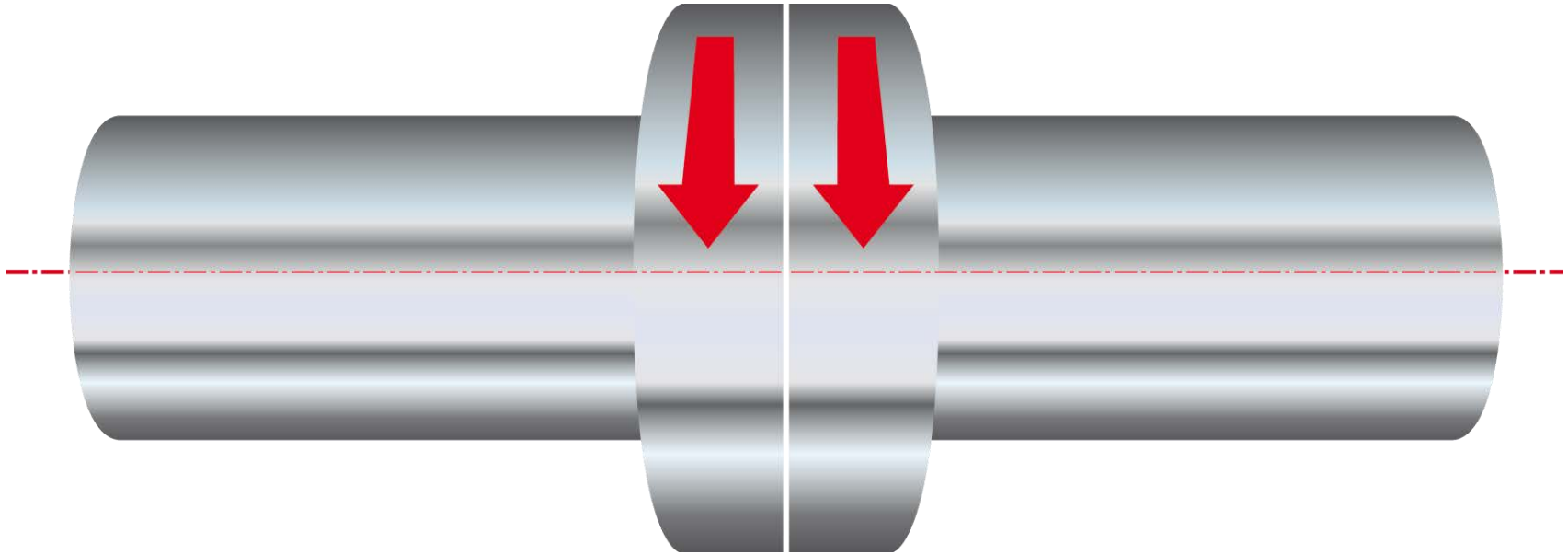
Courtesy of an UK major chemical plant



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

FLUKE Reliability

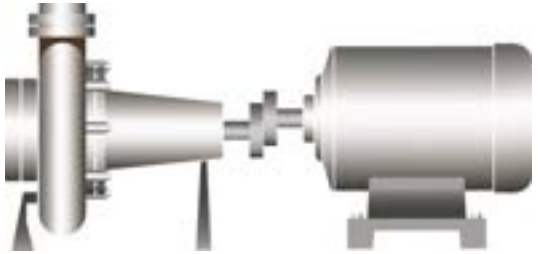
What is shaft alignment ?



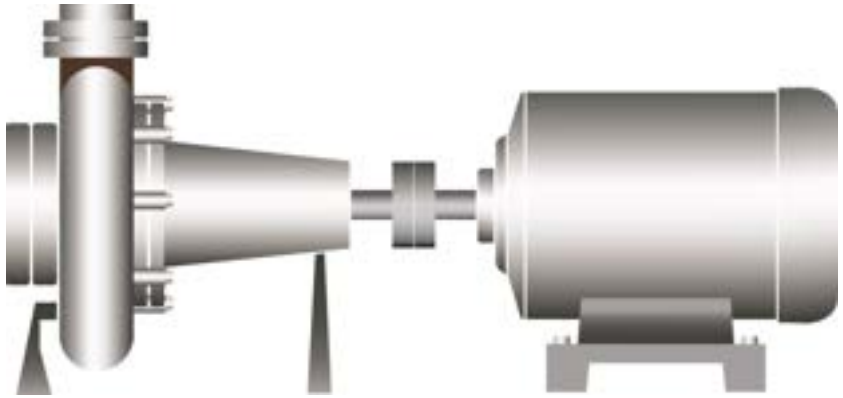
at the point of power transfer from one shaft to another, the axes of rotation of both shafts should be colinear when the machine is running under normal operating conditions

The 4 alignment parameters

Vertical angularity



Vertical offset

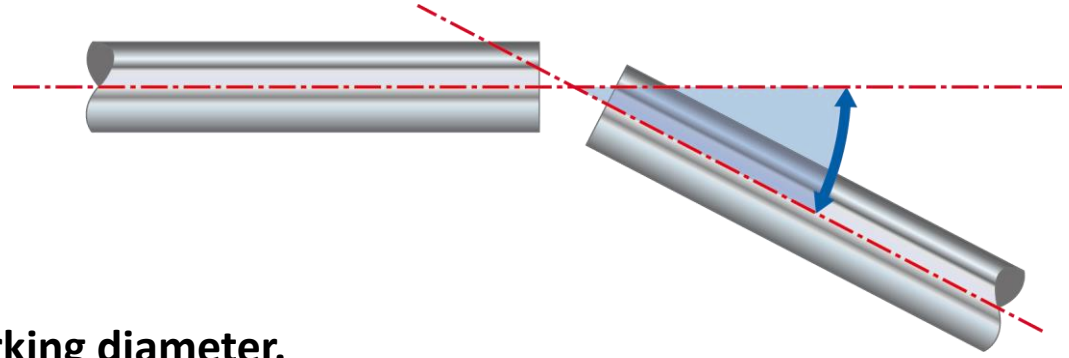


Horizontal angularity

Horizontal offset

Angularity or Gap

Angularity means the angle between two rotation axes



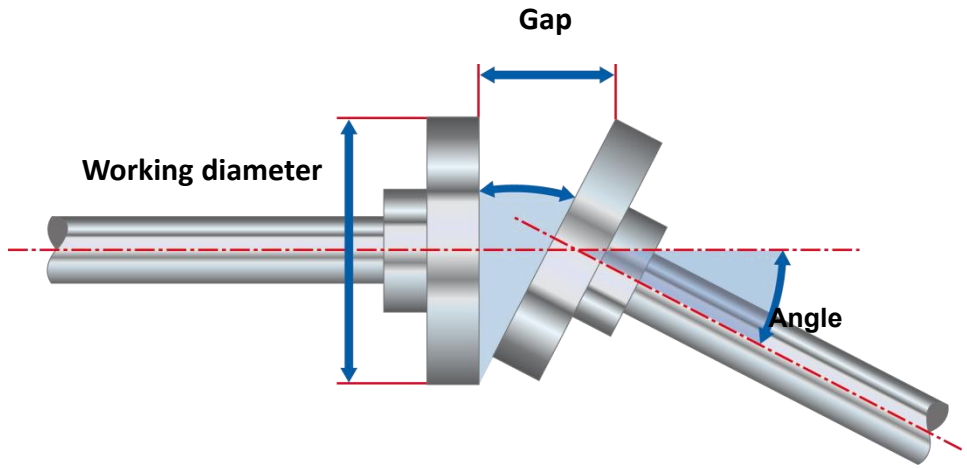
The angle is usually given as a **gap** per **working diameter.**

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 mrads.

$$\theta = gap \,/\, working\ diameter$$

θ = 0,127/152,4 = 8,33 10^{-4} rad = 0,83 mm/m

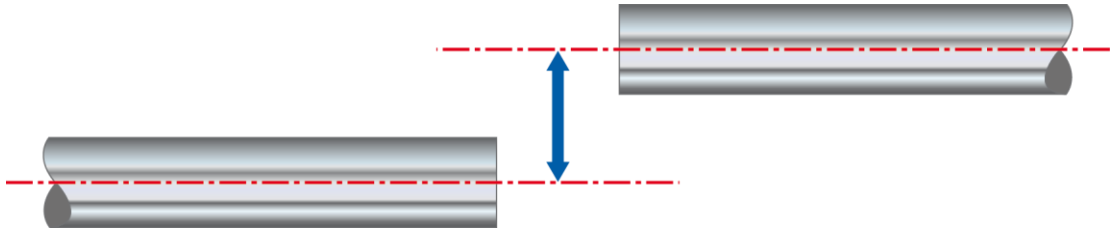


Note:
1 mrad = 1 thousandth of an inch per inch
1 mrad = 1 mm / m

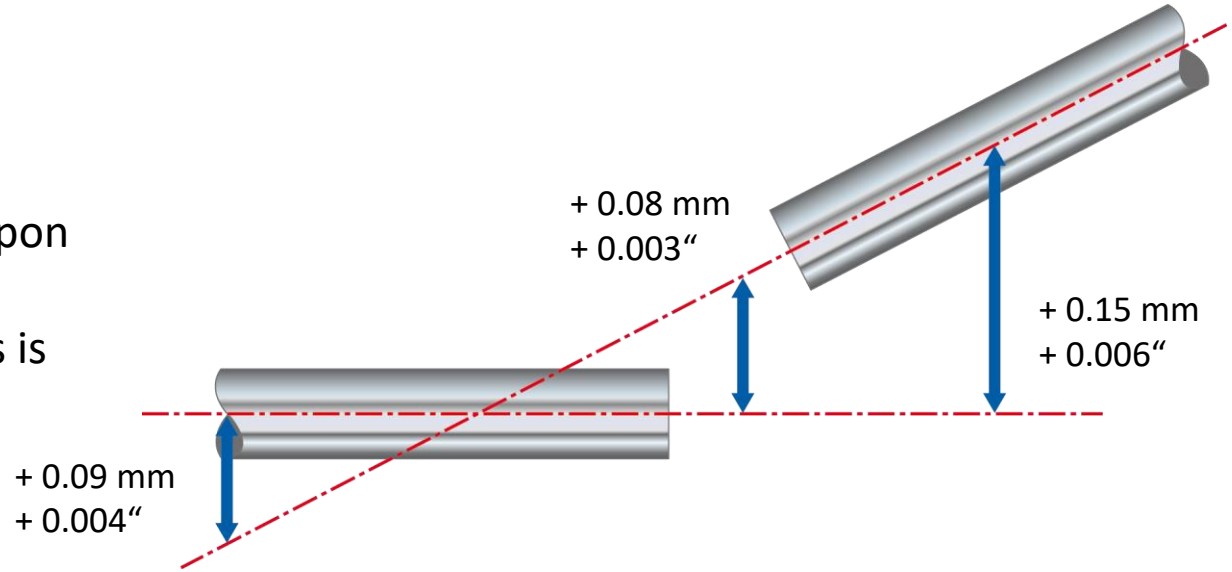
Parallelity or Offset

Offset refers to distance between shaft rotation axes at coupling center

Offset means distance between rotation axes at a given point

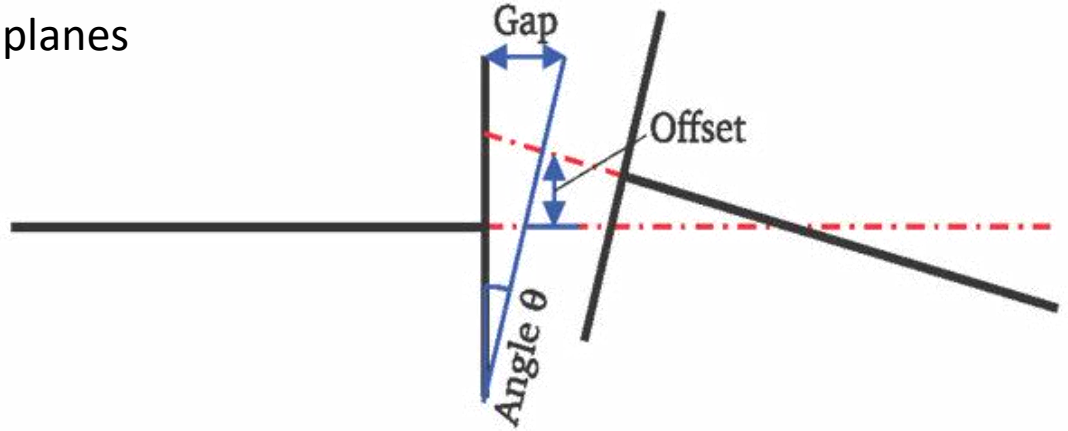


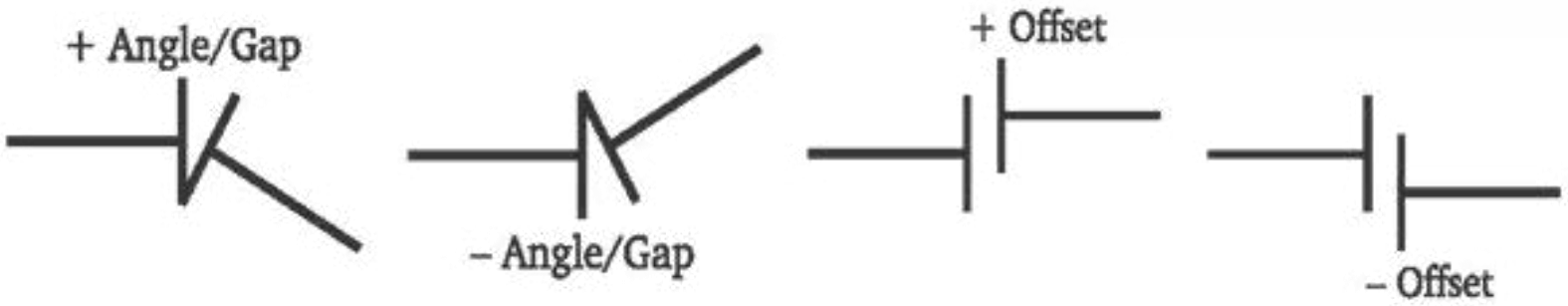
Offset value varies depending upon the location where the distance between two shaft rotation axes is measured



Alignment Condition

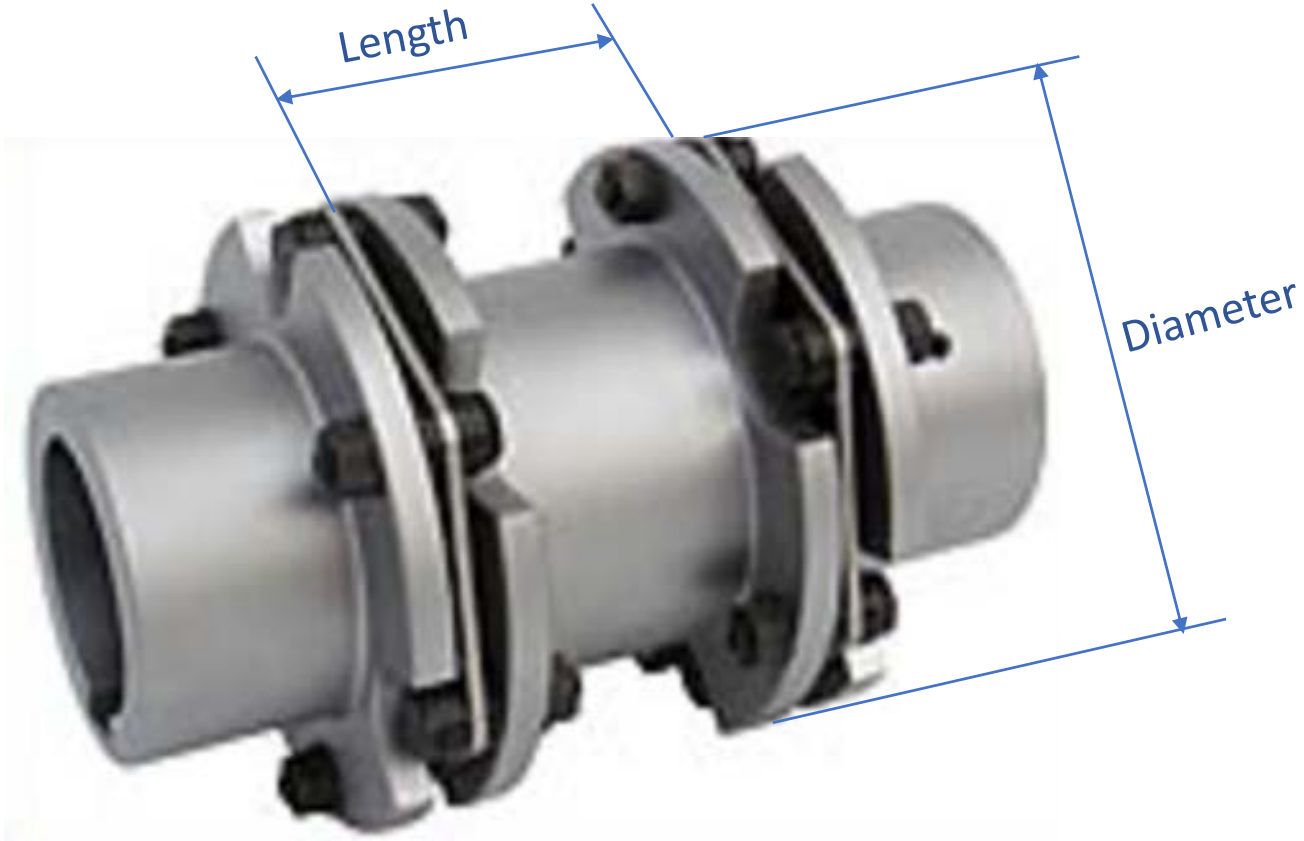
- Alignment condition is always a combination of **Gap** (or Angularity) and **Offset** (or Parallelity)
- A Machine must be corrected in both **Vertical** and **Horizontal** planes
- Alignment Sign convention:
  - + Gap (or Angularity)
  - - Gap (or Angularity
  - + Offset (or Parallelity)
  - - Offset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





Flexible couplings

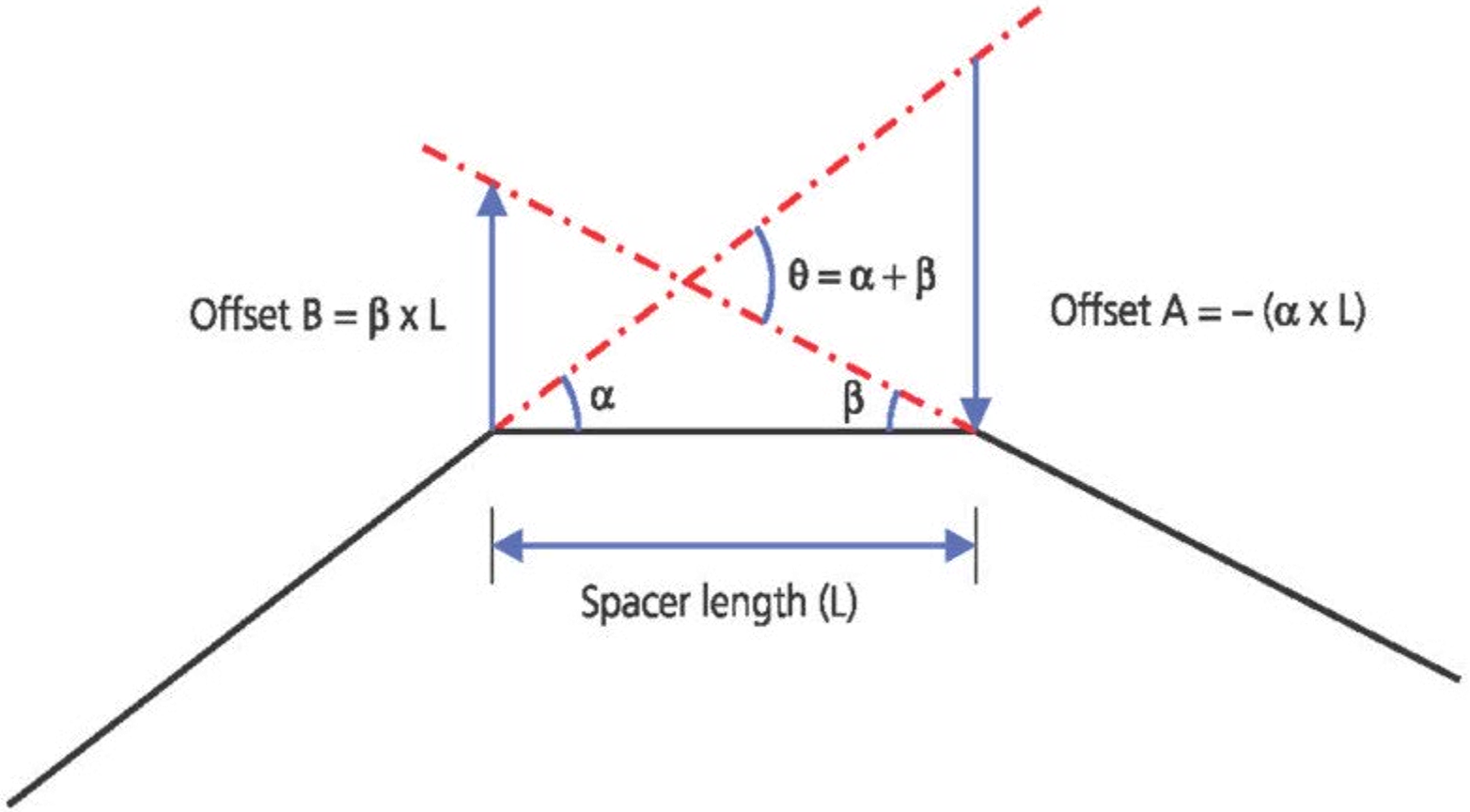
For ease of understanding we define short flexible couplings when **the axial length of the flexible element or the axial length between the flexible element is equal or smaller than the coupling diameter.**



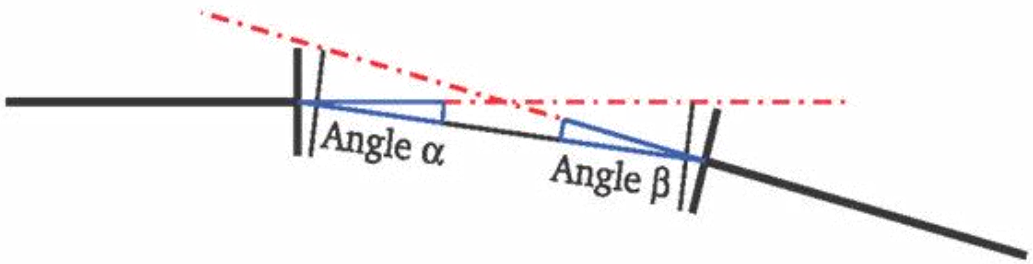
Typical short-flex couplings

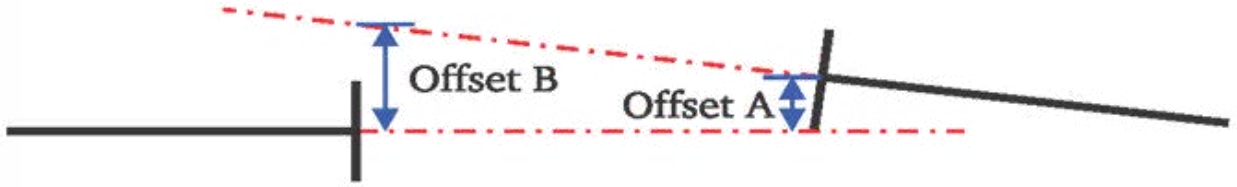
Spacer coupling type

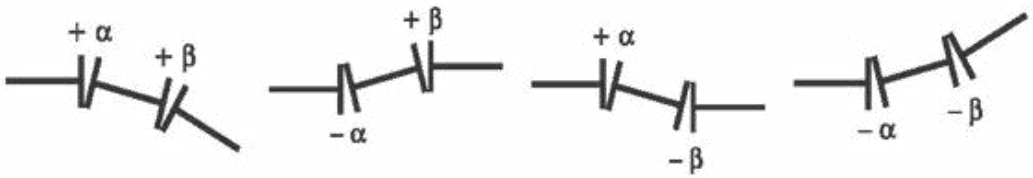
Spacer coupling: Angularity or Offset

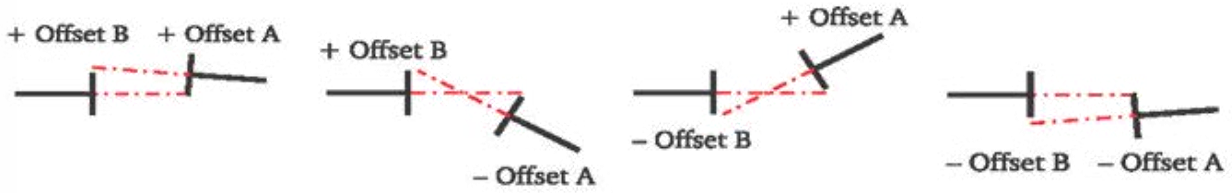


Spacer coupling: Angularity or Offset



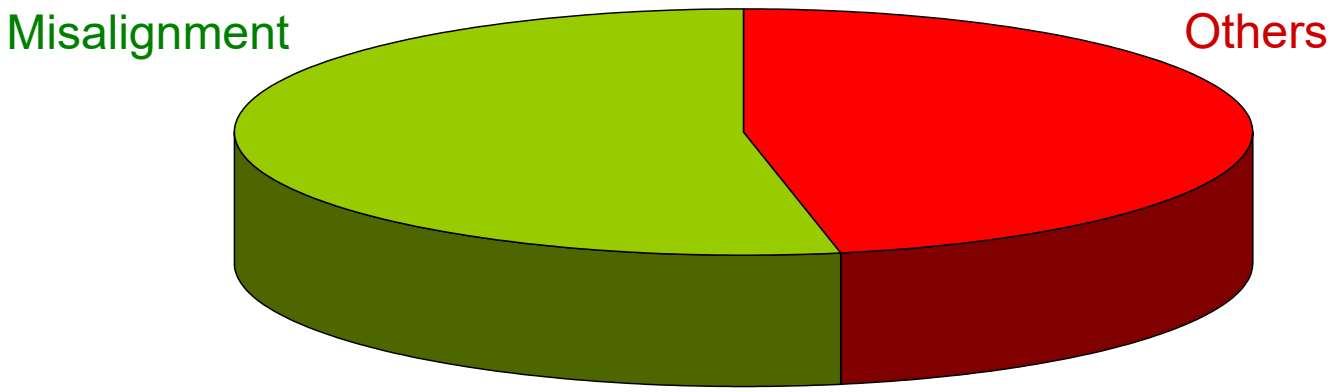






How to recognise the symptoms of misalignment?

- 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)



Cause of machine breakdowns

Consequences of misalignment on rotating machinery

BEARINGS

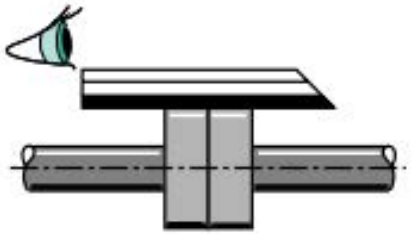
COUPLINGS

SEALS

Typical Motor-Pump application

Shaft Alignment methods

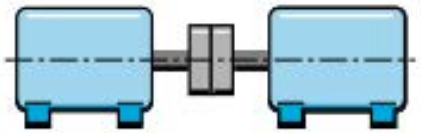
STRAIGHT EDGE



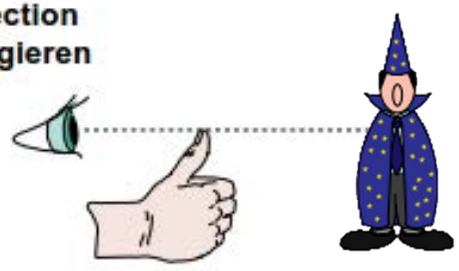
Measurement
Messen

5 mils

$\frac{1}{10}$ mm



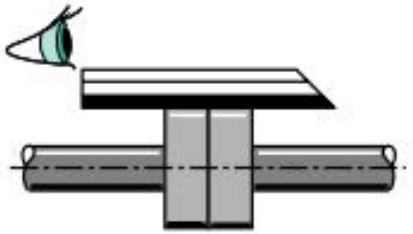
Correction
Korrigieren



THE WIZARD

Shaft Alignment methods

STRAIGHT EDGE



Measurement
Messen

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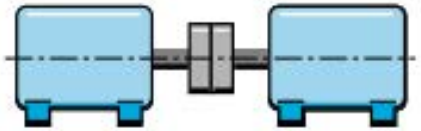
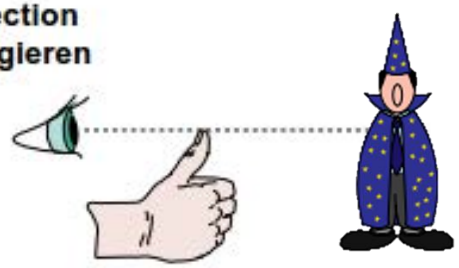
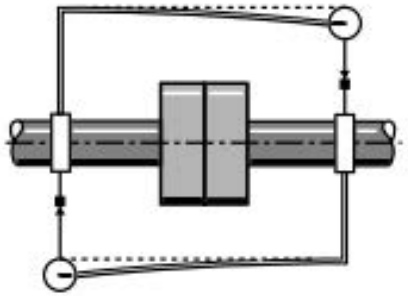


Correction
Korrigieren



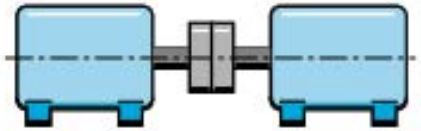
THE WIZARD

DIAL INDICATOR



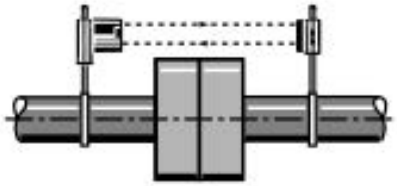
0.5 mils

$\frac{1}{100}$ mm



THE SPECIALIST

LASER SHAFT ALIGNMENT



0.05 mils

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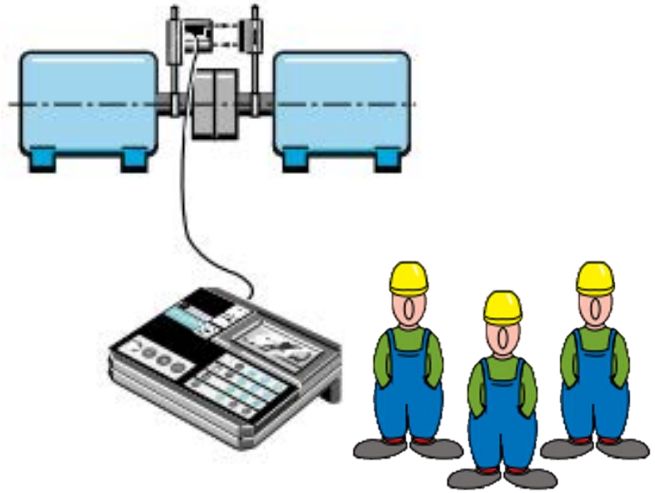
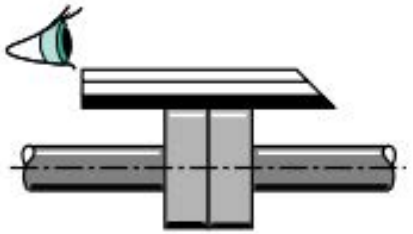


THE TECHNICIAN

Shaft Alignment methods

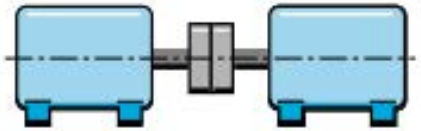
STRAIGHT EDGE



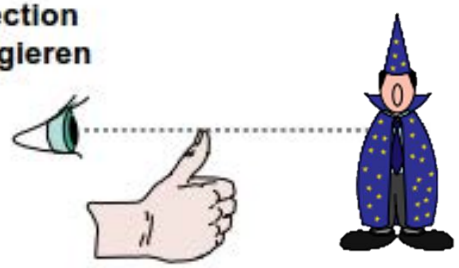
Measurement
Messen

5 mils

$\frac{1}{10}$ mm

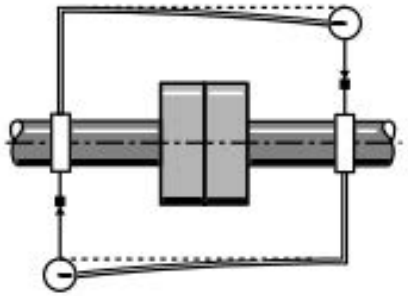


Correction
Korrigieren



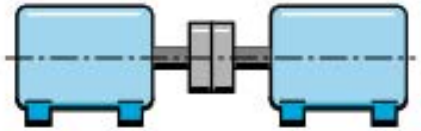
THE WIZARD

DIAL INDICATOR



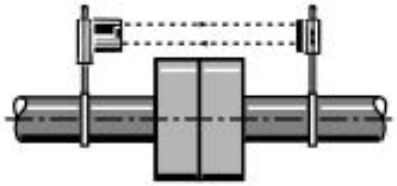
0.5 mils

$\frac{1}{100}$ mm



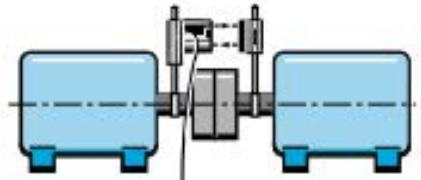
THE SPECIALIST

LASER SHAFT ALIGNMENT



0.05 mils

$\frac{1}{1000}$ mm

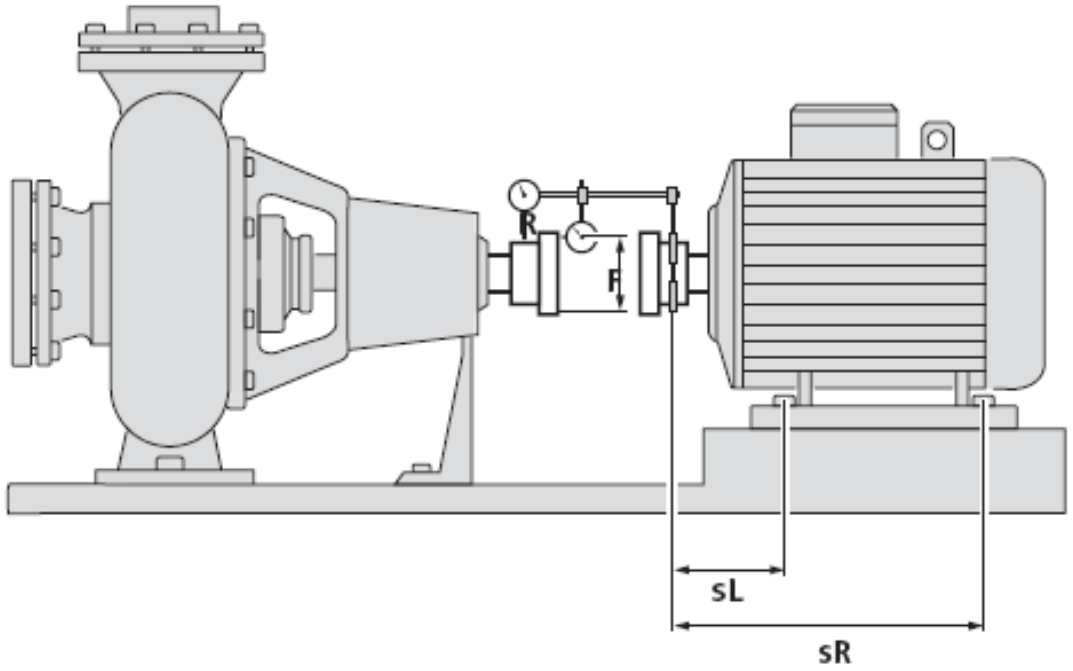


THE TECHNICIAN

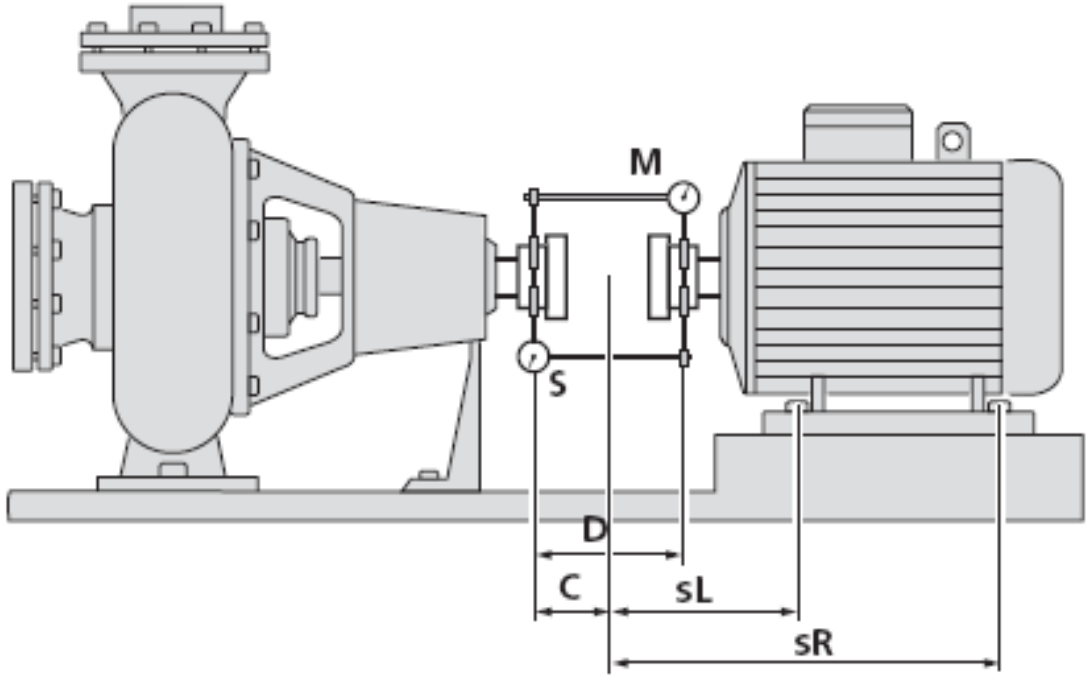
FLUKE Reliability

Alignment of machines: Dial gauges

Rim and Face method



Reverse indicator method



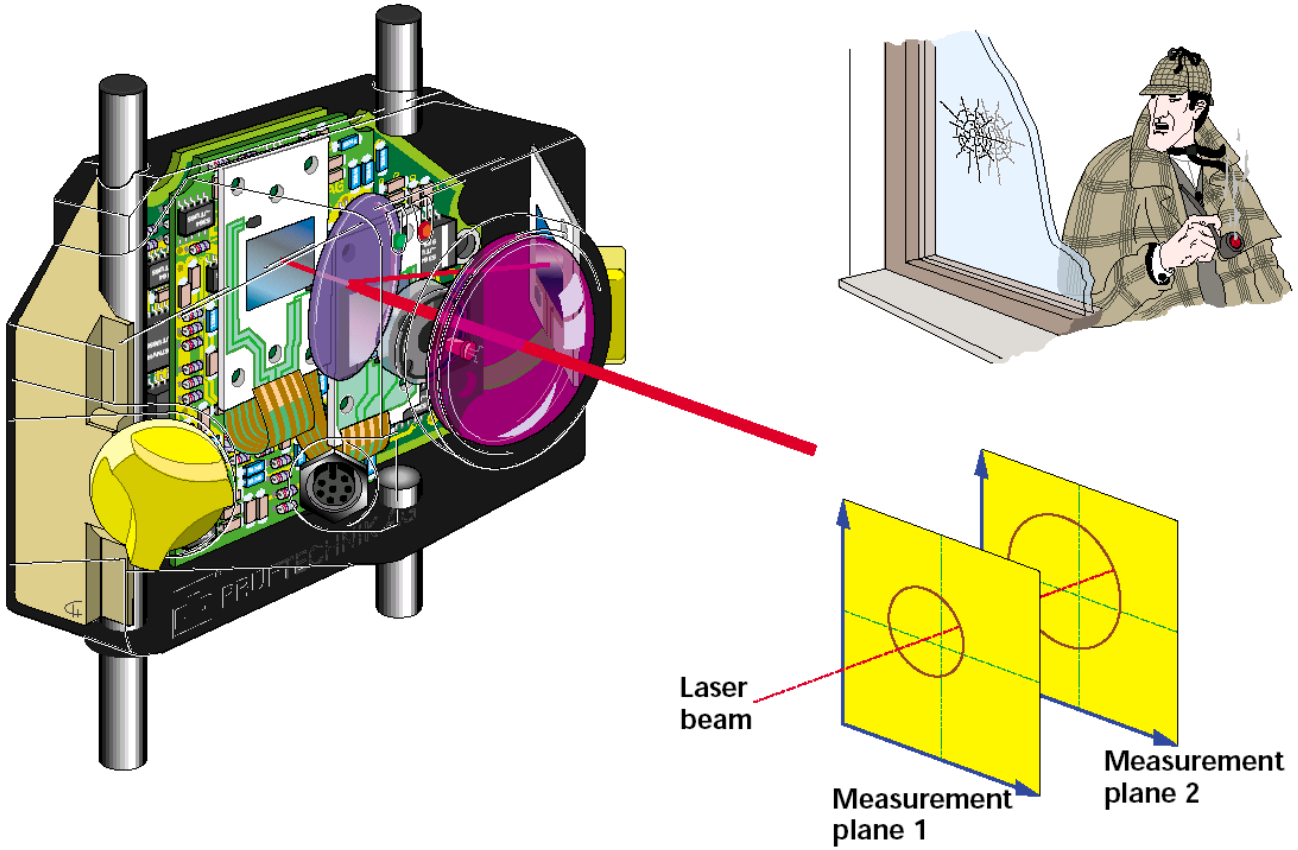
FLUKE Reliability

Laser Shaft Alignment tool

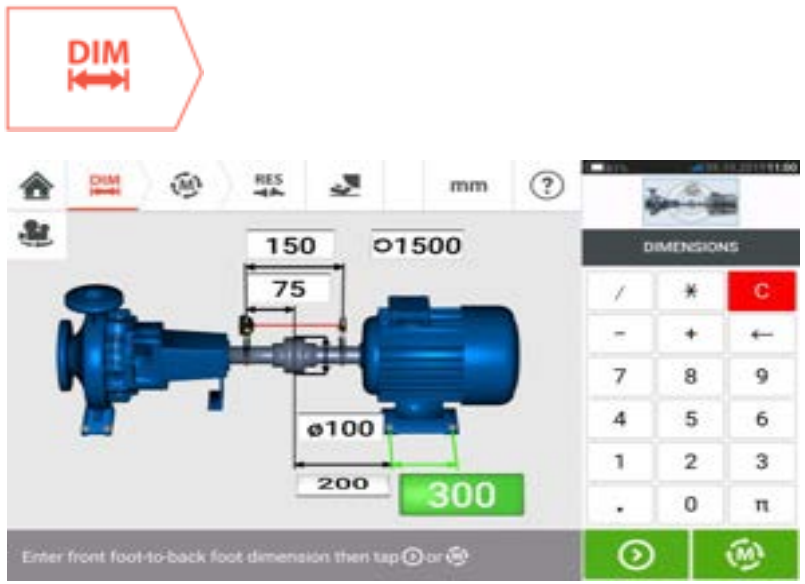
Introduction to hardware

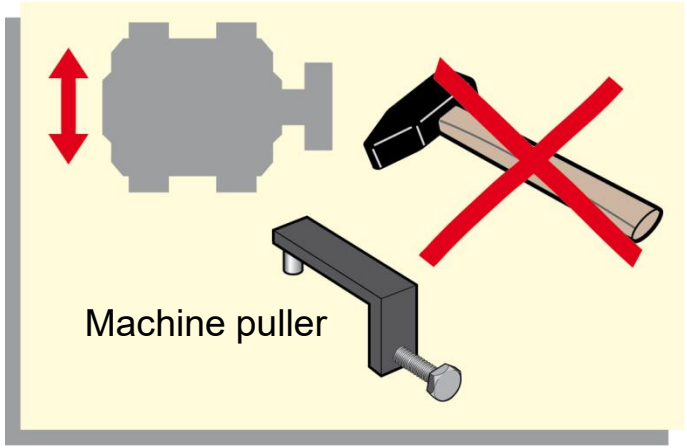
- The three main components

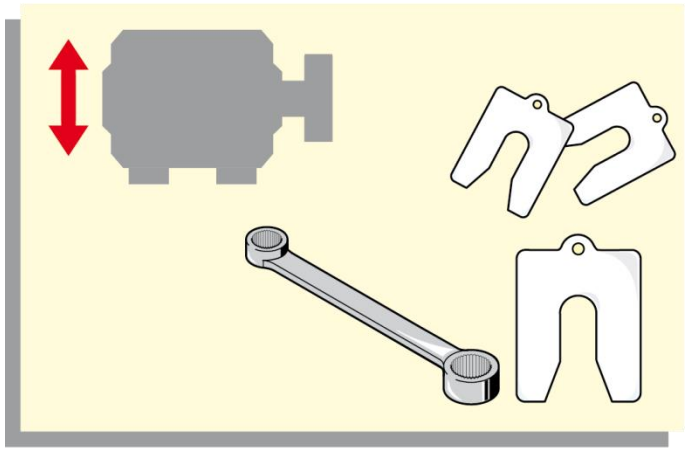
OPTALIGN smart RS measurement principle

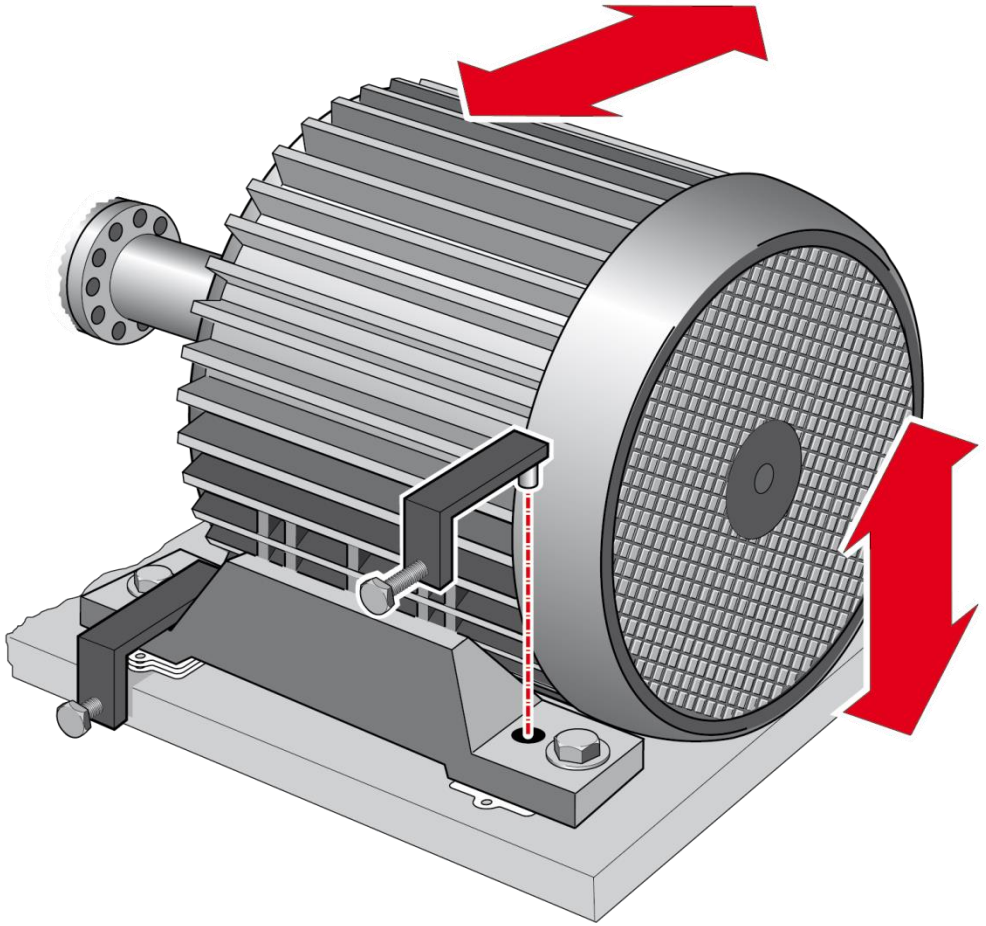


Laser Shaft Alignment tool







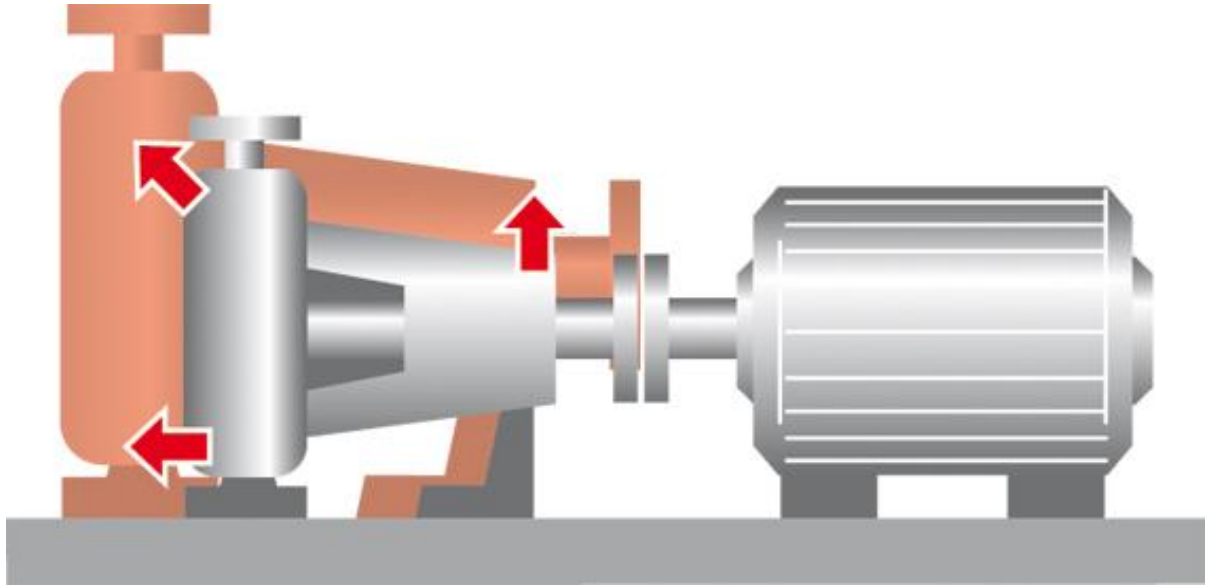


Once alignment condition found, a correction is recommended

Thermal growth and Target Pre-sets

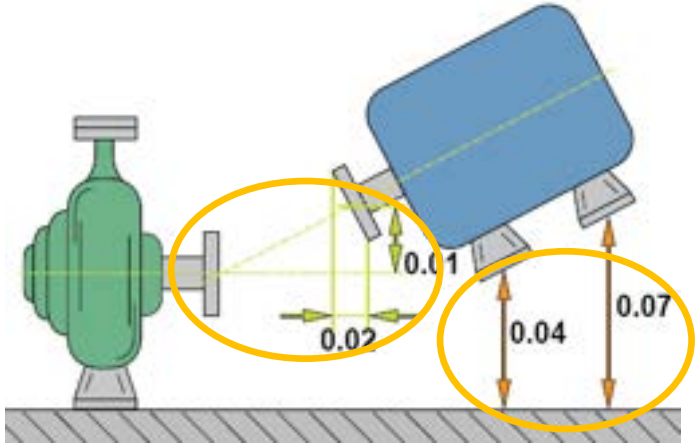
The specifications can be input to take into account the expected positional change of the machine during operation.

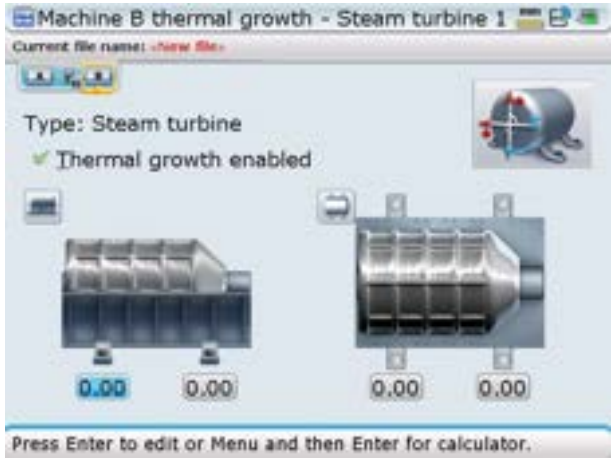
- The parameters are provided by **machine manufacturers**
- They can be **calculated**
- It is also possible to determine the compensation values by **monitoring the machines positional changes while the machines are running**



Thermal growth and Target specifications

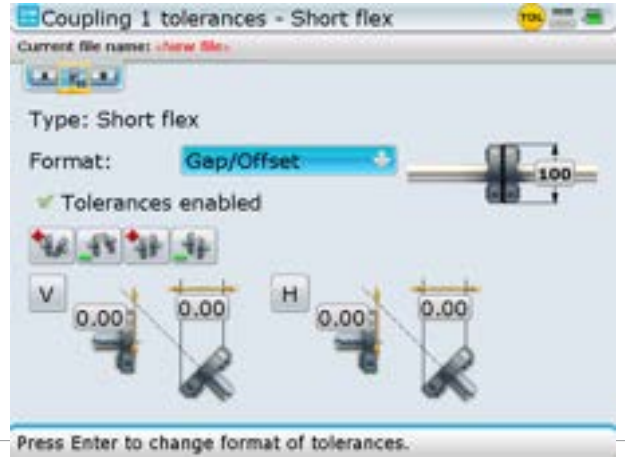
Thermal growth parameters – at machine feet





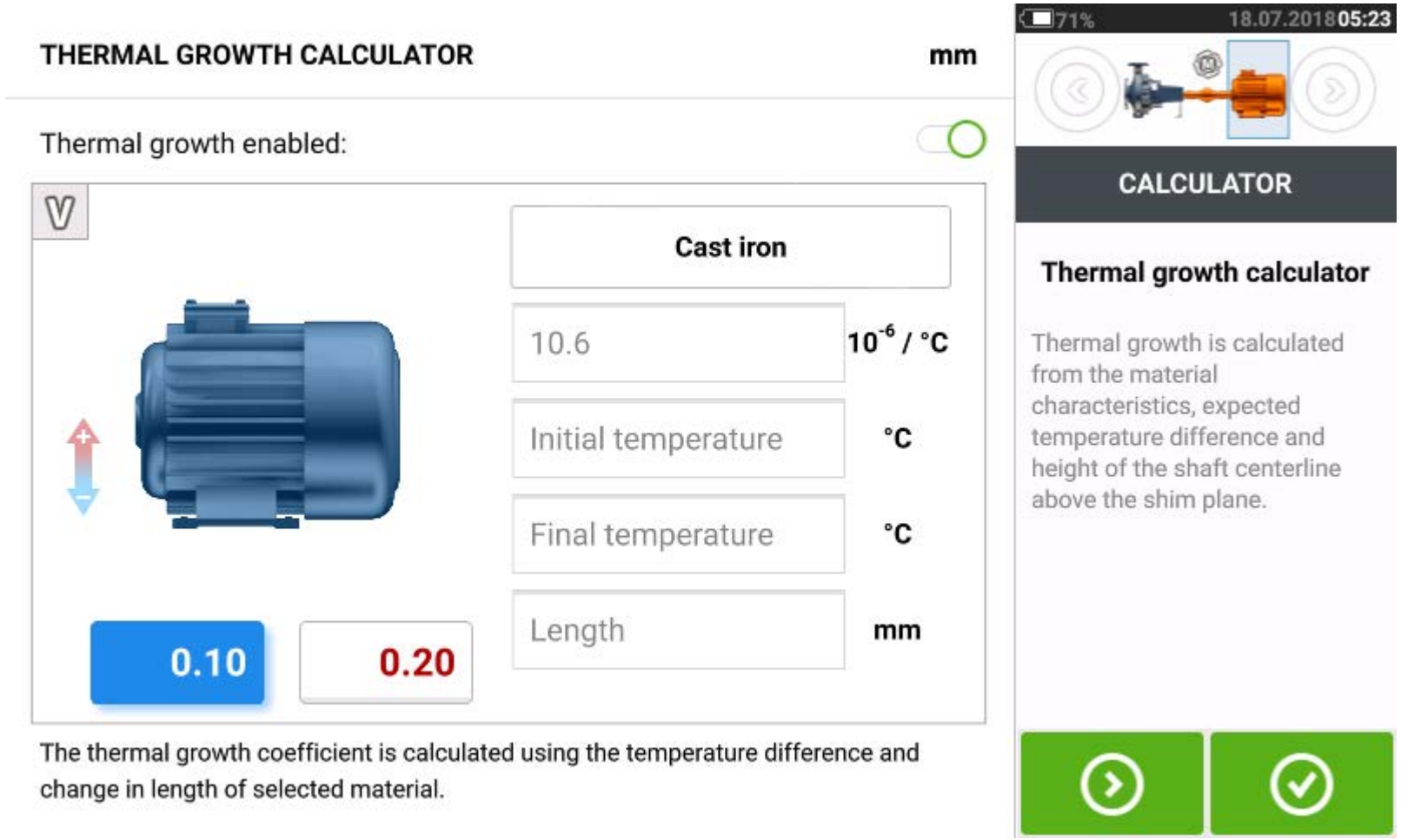
Target values – at coupling

(as gap/offset or dial indicator readings)



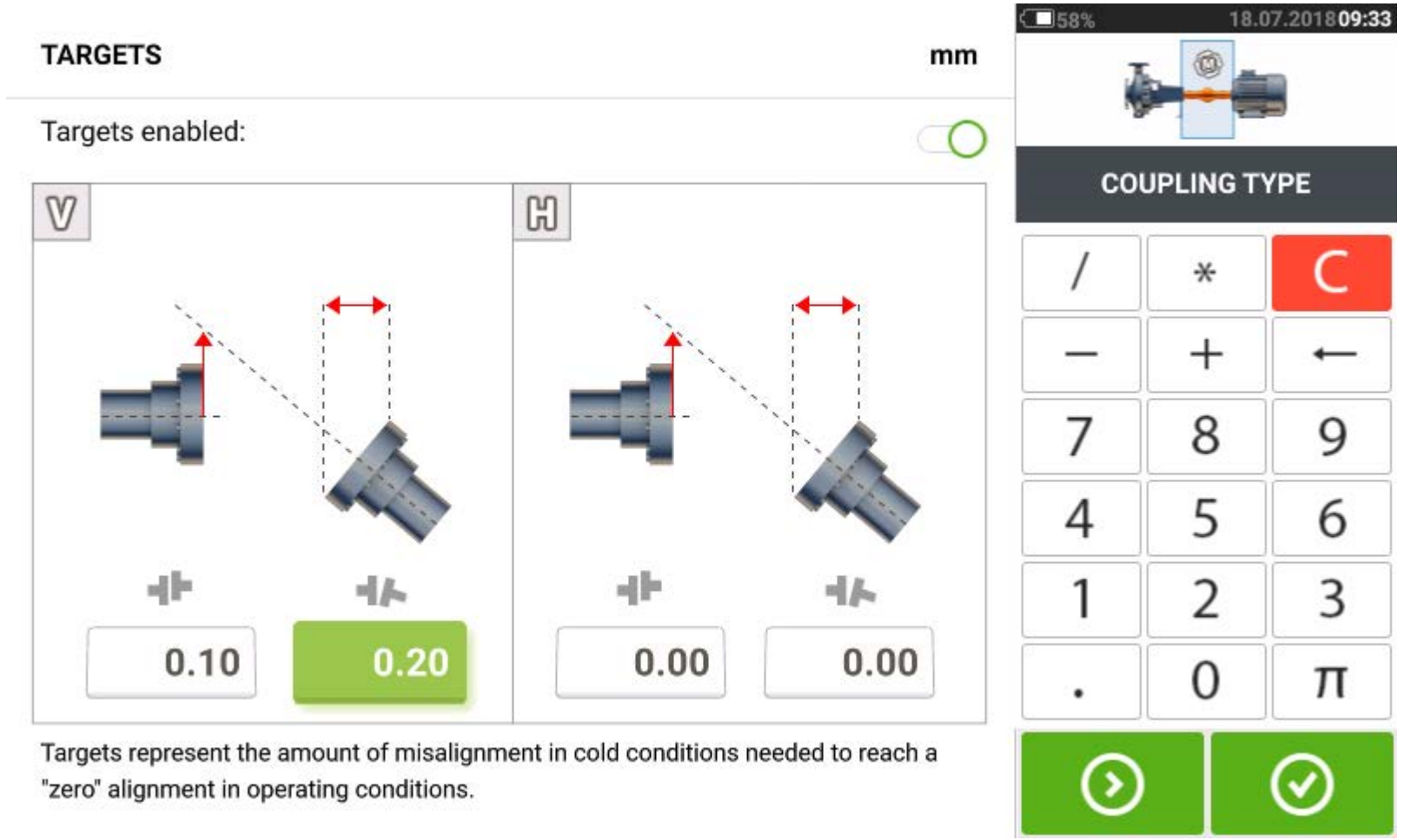
Thermal Growth

- Thermal growth calculator



Thermal Growth

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

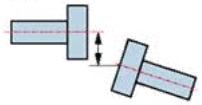
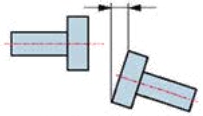
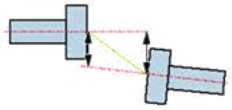


Thermal growth and Target specifications

Thermal growth :calculated

Thermal growth : measured (Live Trend)

Tolerances

Soft foot	any	0.06 mm		2.0 mils	
Short "flexible" couplings		Acceptable	Excellent	Acceptable	Excellent
		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
	6000	0.03	0.02		
	7200			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
	6000	0.03	0.02		
	7200			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
	6000	0.03	0.02		
	7200			0.3	0.2

- **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

ANSI/ASA S2.75-2017/Part 1

AMERICAN NATIONAL STANDARD

Shaft Alignment Methodology, Part 1: General Principles, Methods, Practices, and Tolerances

ANSI/ASA S2.75-2017/Part 1

Accredited Standards Committee S2, Mechanical Vibration and Shock

Standards Secretariat
Acoustical Society of America
300 Walt Whitman Road, Suite 300
Melville, NY 11747

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

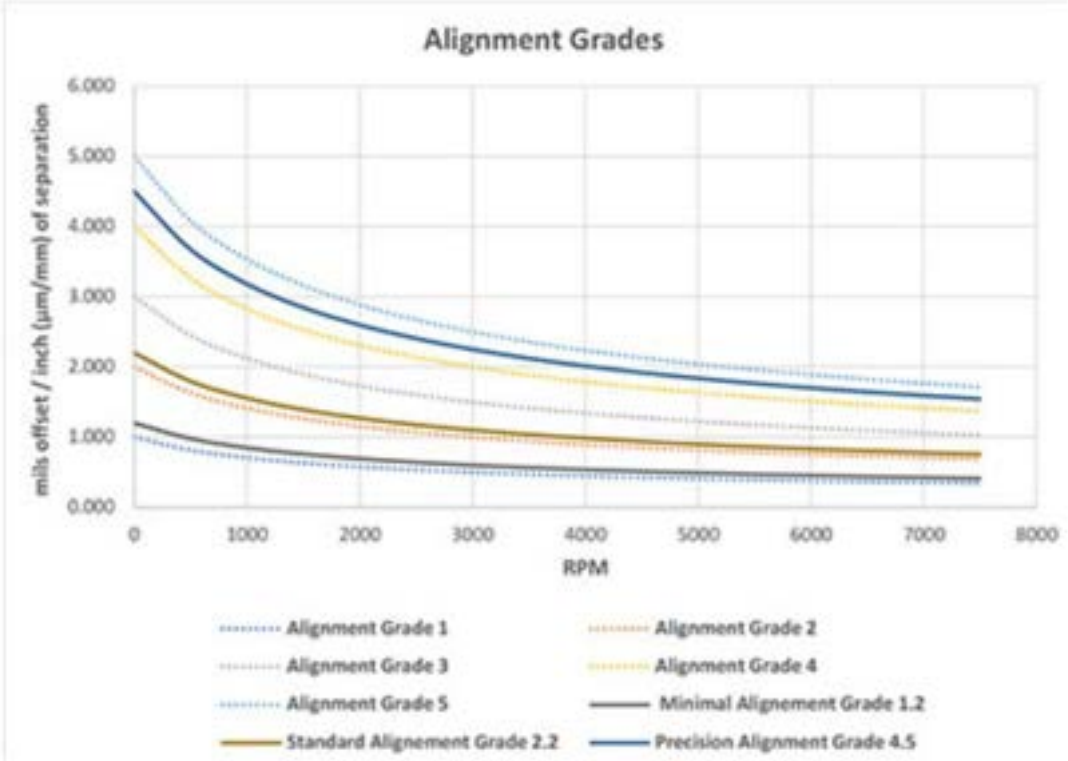
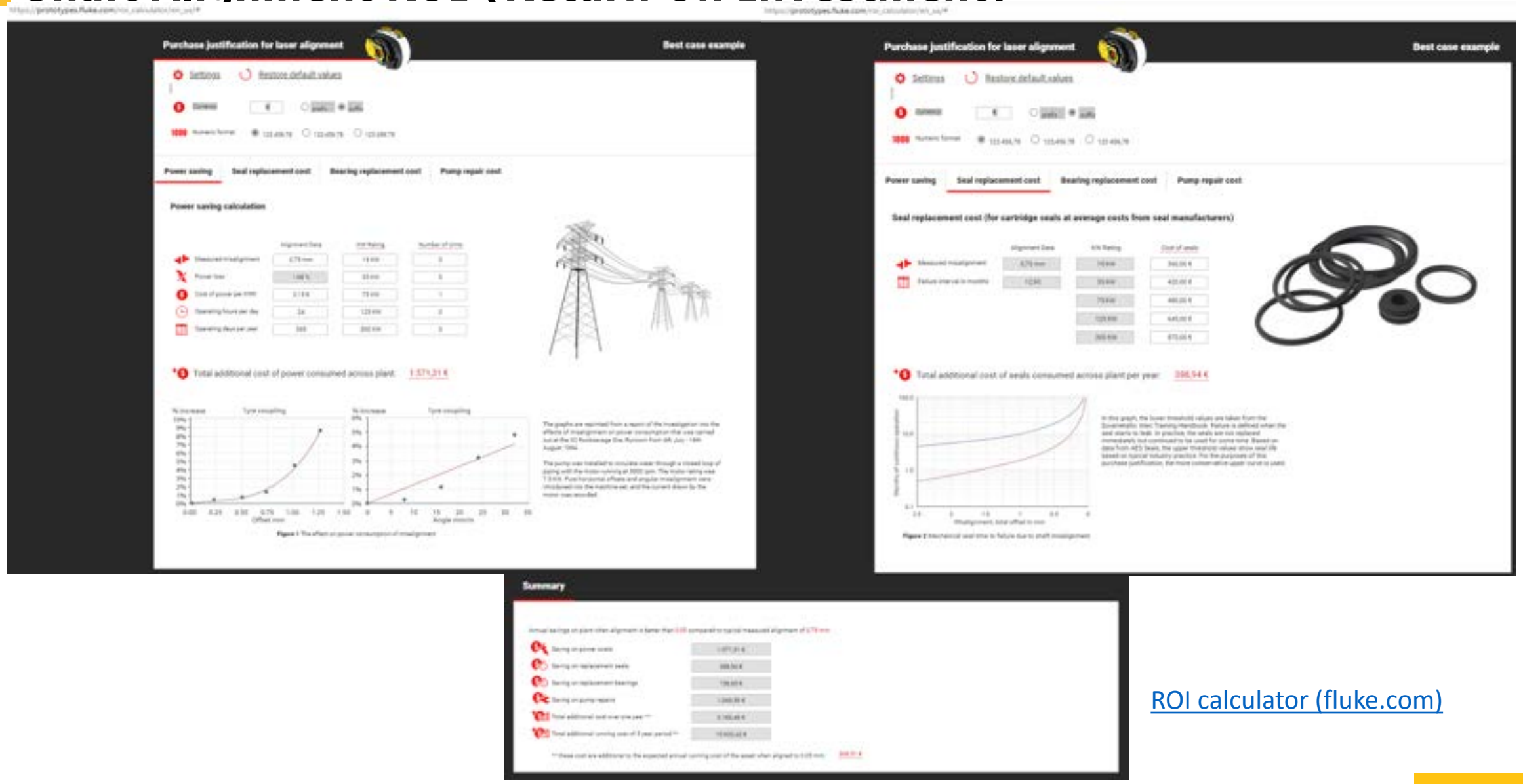


IMAGE 1: Alignment grade chart (Images courtesy of EASA)

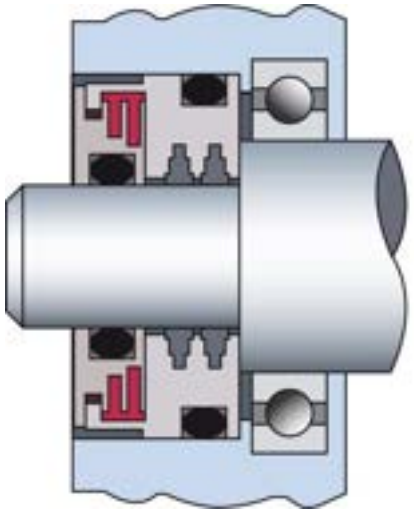
FLUKE Reliability

Shaft Alignment ROI (Return On Investment)

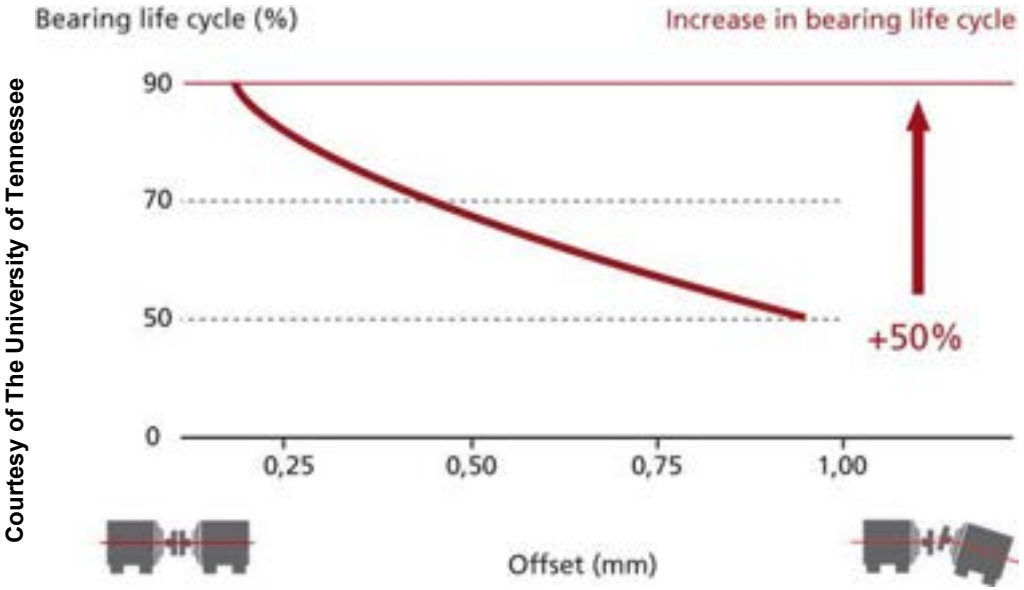


[ROI calculator (fluke.com)]

Bearing life cycle: Bearing repair costs



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



Courtesy of The University of Tennessee

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

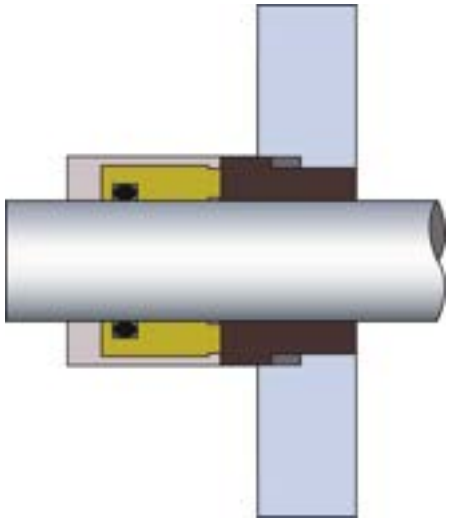
additional cost of bearings per year

124.- €

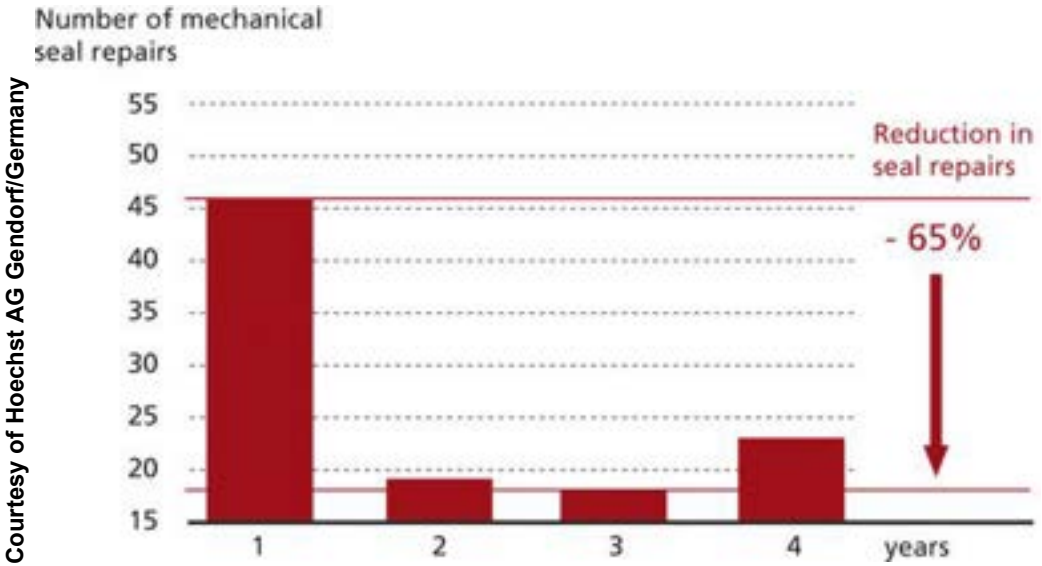
- The additional cost of bearings per year for the motor only, when compared to a perfect alignment of 0.05 mm

FLUKE Reliability

Pump Mechanical seal repairs: When precision alignment performed



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



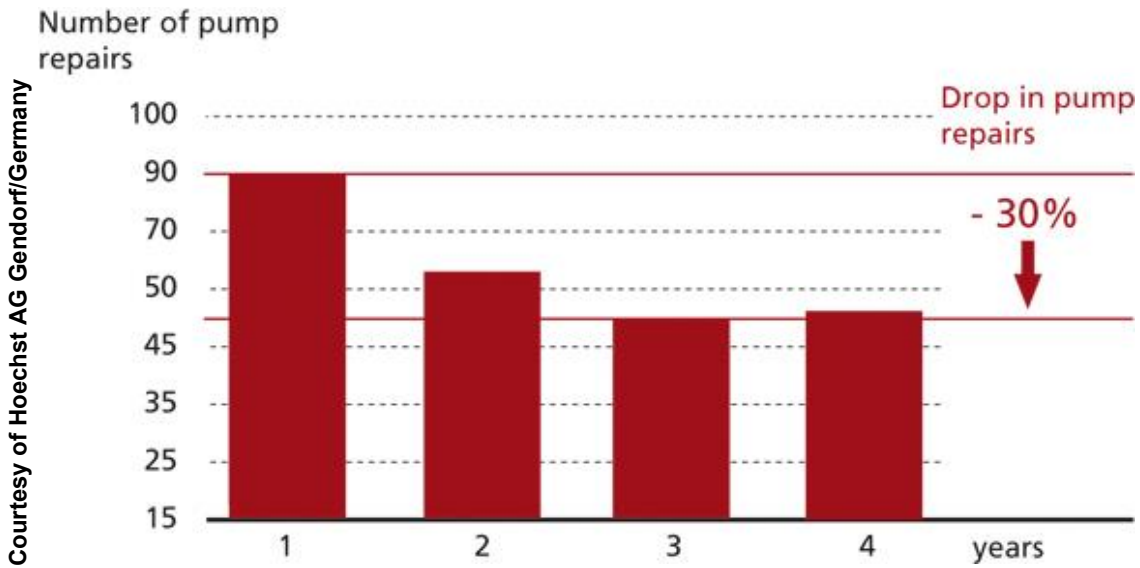
Courtesy of Hoechst AG Gendorf/Germany

Annual mechanical seal repair costs on a 75 KW pump

- 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%



Courtesy of Hoechst AG Gendorf/Germany

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

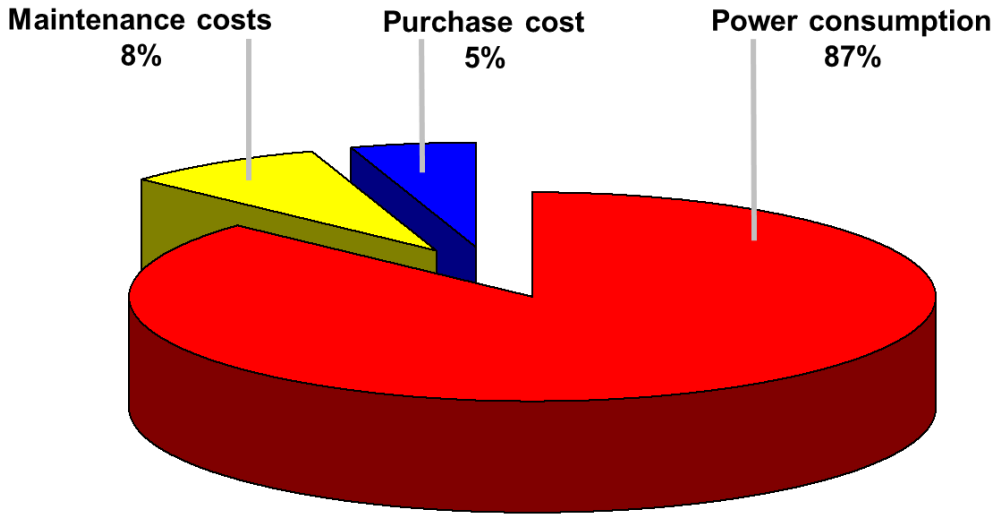
additional cost of pump repair

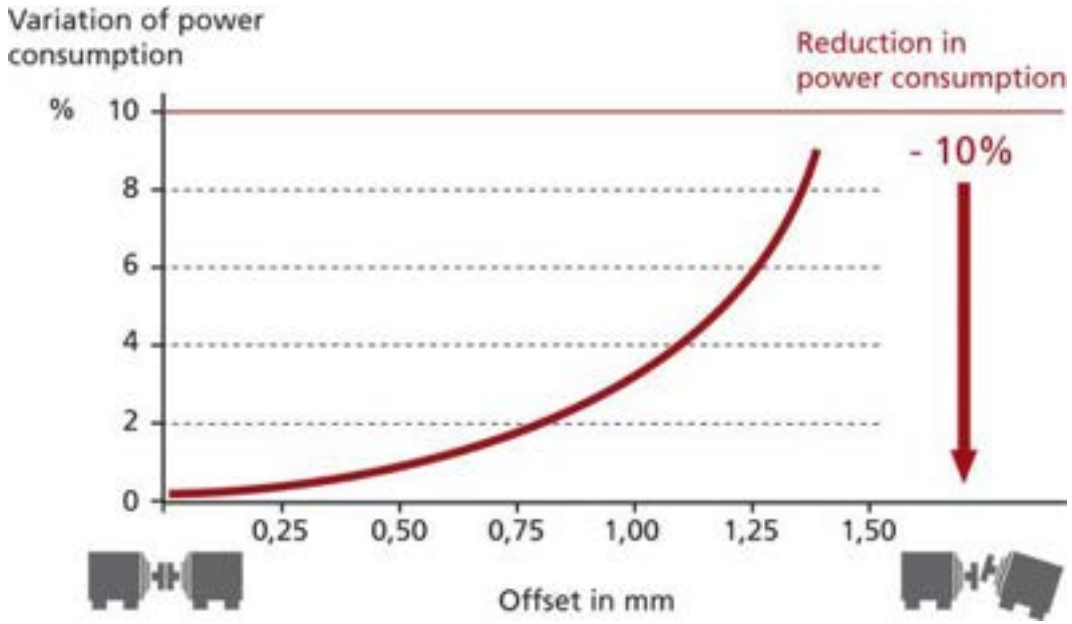
670.- €

- 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

FLUKE Reliability

Power consumption





Courtesy of an UK major chemical plant

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.-

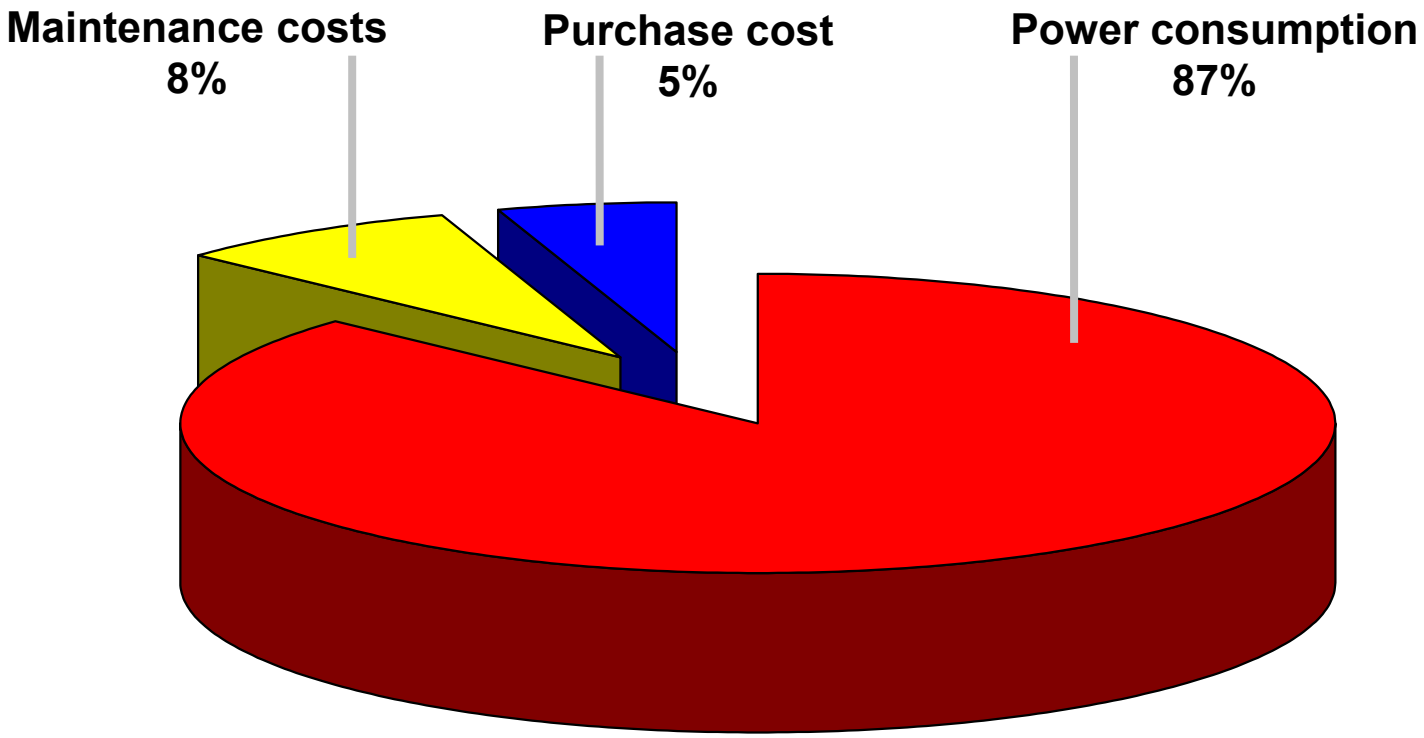
Total annual costs: Return On Investment

Annual costs on a 75 KW pump summary

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.-

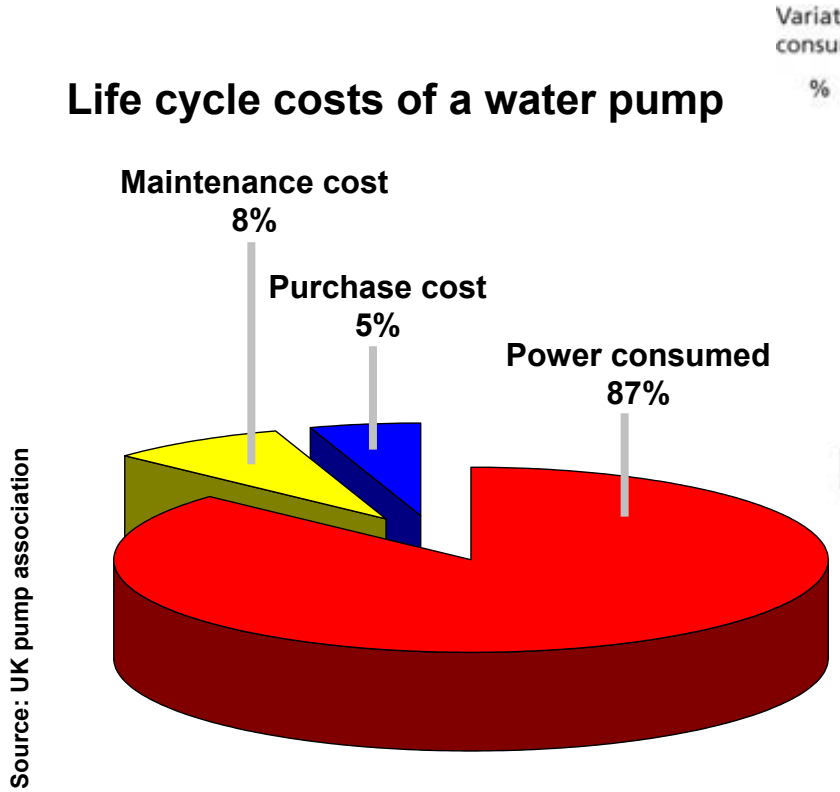
Life cycle costs of a water pump

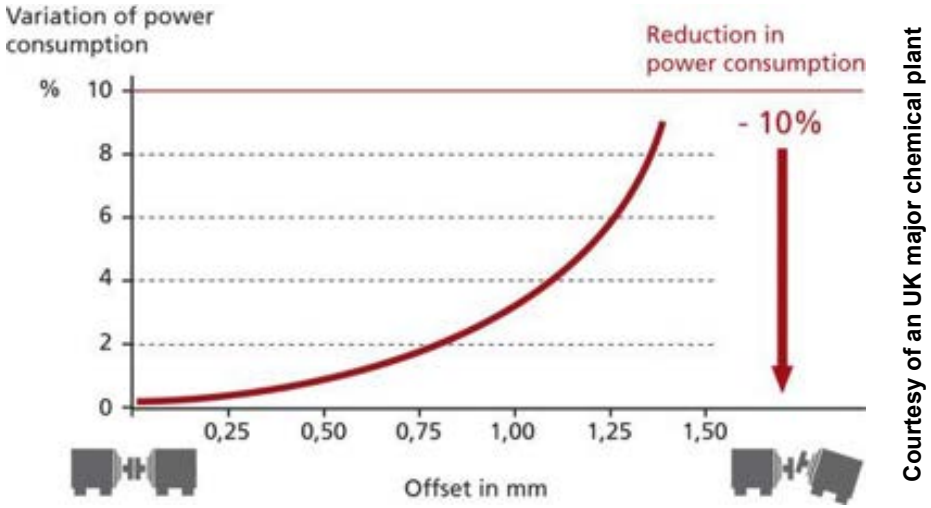


Source: UK pump association

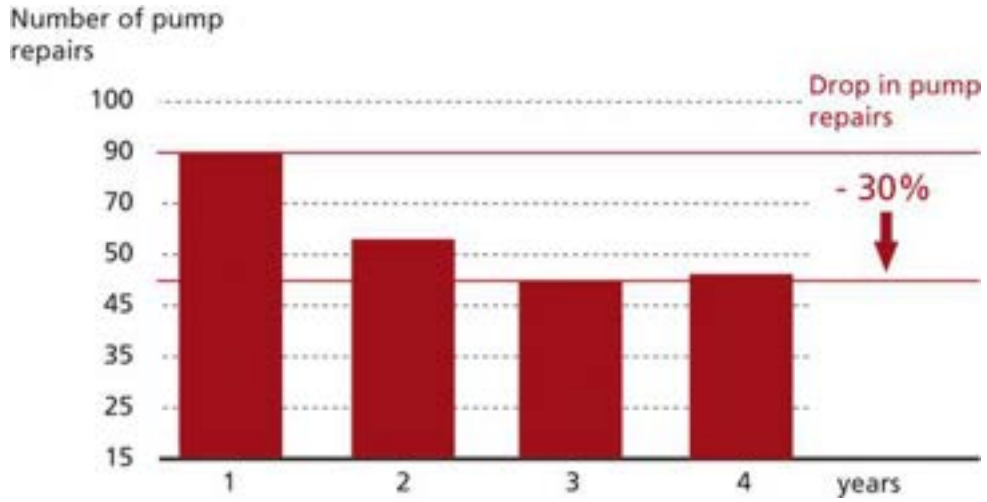
Effects on power consumption

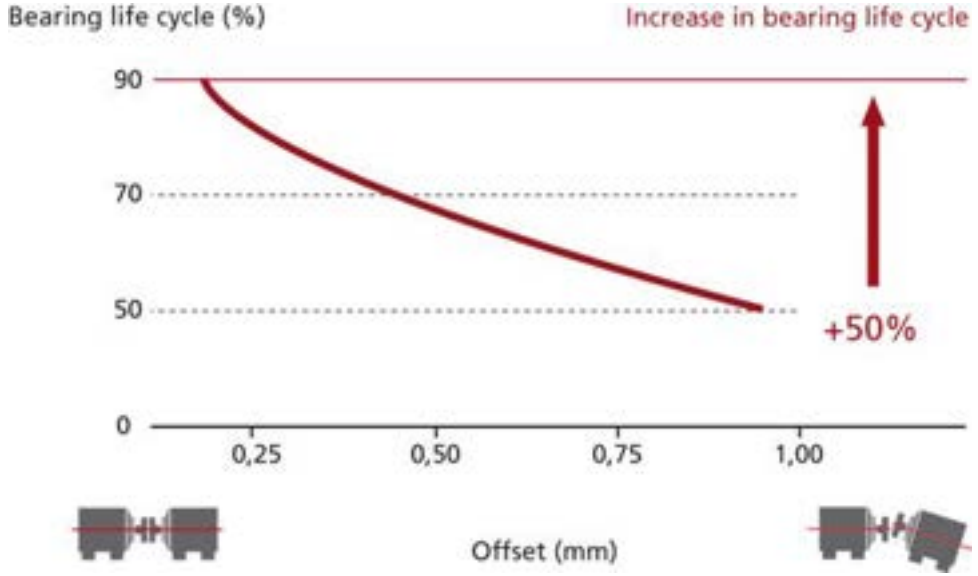
- Significant power savings can be made through accurate alignment
- Precise alignment eliminates reaction forces and reduces energy consumption by up to 10%

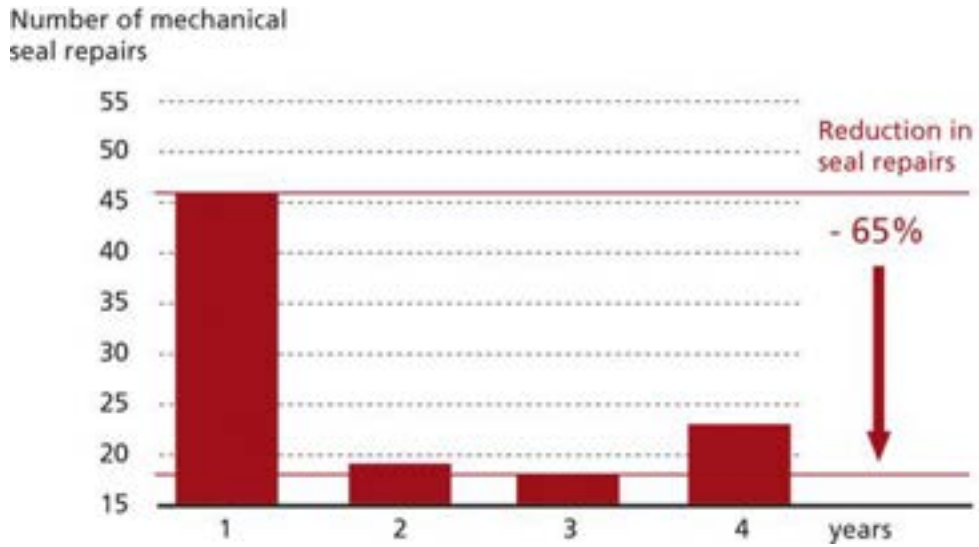


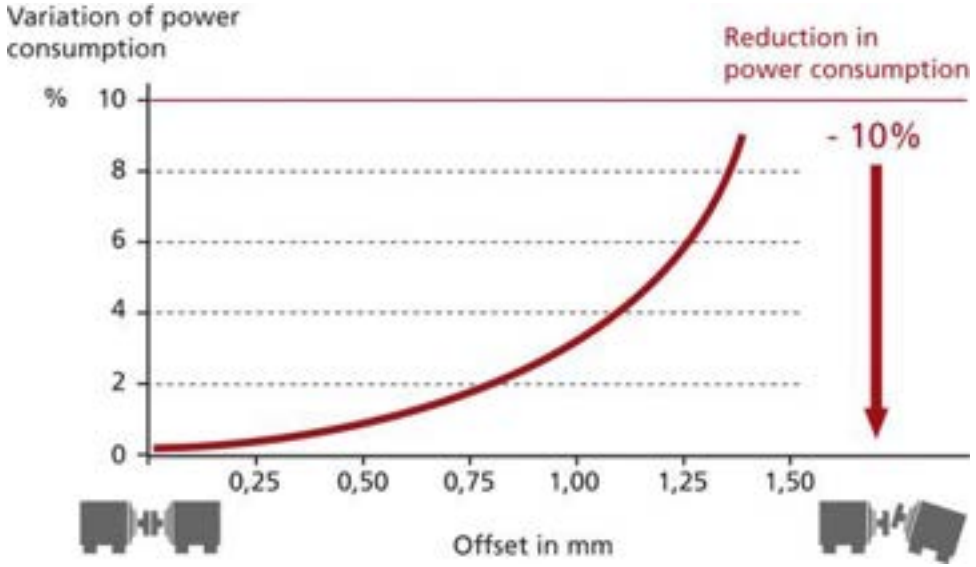


Benefits promised by laser alignment









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

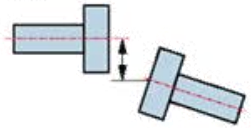
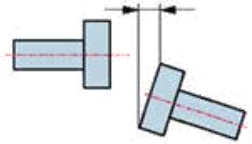
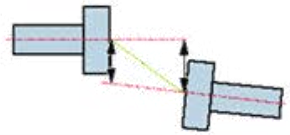
FLUKE®
Reliability

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	
Short "flexible" couplings		Acceptable	Excellent	Acceptable	Excellent
		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
	6000	0.03	0.02		
	7200			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
	6000	0.03	0.02		
	7200			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
	6000	0.03	0.02		
	7200			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	5.1
	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