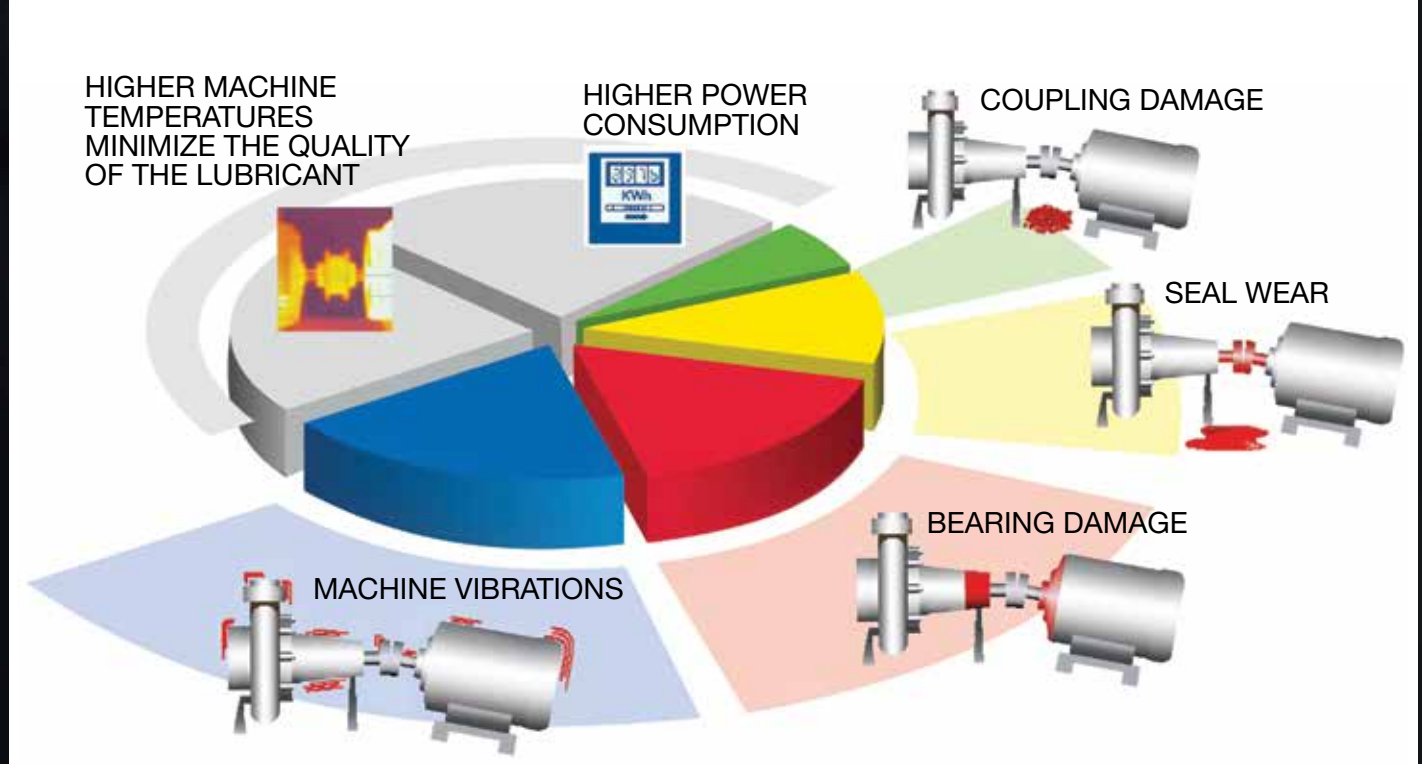


SHAFT ALIGNMENT

PRÜFTECHNIK

Negative effects of misaligned shafts and the dynamic forces at the coupling



Thermal expansion of machines



Thermal growth is the movement of the shaft centerlines due to temperature change in the machines.

The solution is to compensate the effects of thermal growth by defining alignment target values in cold condition.

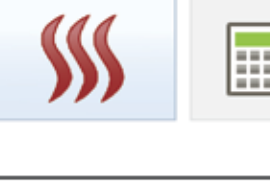
	Coupling targets or thermal foot growth values from OEM (Original Equipment Manufacturer)
	Thermal growth values calculated using change in machine temperature
	Taking a "Live Trend" measurement from cold (ambient) to hot (operating/working) condition using sensors mounted on the machine housing

Table with coefficient of thermal expansion (CTE) values of standard materials

Material	CTE Coefficient of Thermal Expansion [α]	
	[mils] per [inch] per [°F]	[mm] per [m] per [°C]
Aluminium alloys	0.0125	0.0220
Brass (Cu 70%, Zn 30%)	0.0110	0.0198
Carbon steel	0.0063	0.0113
Cast iron	0.0590	0.0106
Concrete	0.0720	0.0130
Invar	0.0007	0.0012
Nickel steel	0.0073	0.0131
Stainless steel	0.0098	0.0176
Bronze (Cu 90%, Sn 10%)	0.0102	0.0184

Formula: $L_{\Delta} = (T_w - T_a) \times L \times \alpha$

L_{Δ} = change in length
 T_w = working temperature
 T_a = ambient temperature
 L = length
 α = CTE Coefficient of Thermal Expansion

Example: Pump with hot liquid at 248 °F (120 °C)

	Sign	Imperial	Metric
Ambient temperature	T _a	68°F	20°C
Pump working temperature	T _w	248°F	120°C
Change in temperature of machine	T _Δ	180°F	100°C
Cast iron CTE value	α	0.0059	0.0106
Length from base to shaft centerline	L	12 inch	315 mm
Thermal growth calculation	L _Δ	12.7 mils	0.33 mm

Alignment procedure

1 PRE-ALIGNMENT

SAFETY

- Lock-out and tag-out the machine
- Close all valves
- Remove coupling guard

MACHINE DATA

- Thermal growth or targets
- Movement of the machine rotating axis in operating condition (sleeve bearings, gearbox)

COUPLING

- Define tolerances
- Axial spacing / coupling gap value from the data sheet

FOUNDATION

- Visual inspection of the baseplate, frame, and machine physical appearance
- Visual inspection of the coupling elements
- Hold-down bolts are tight

EQUIPMENT

- Laser shaft alignment system
- High quality shims
- Digital caliper
- Feeler gauges
- Tools for lifting and moving machines
- Torque meter

2 ALIGNMENT

DIMENSION

- Mount the chain brackets and measuring components onto the shaft and/or coupling
- Enter dimensions into the measurement device
- Enter coupling target or thermal growth values if necessary

MEASURE

- Select the required measurement mode (depends on type of machine)
- Rotate the shafts in normal operating direction
- Take a minimum of at least two measurement sequences then check the repeatability of the measurements

RESULT

- Results within tolerances?

SOFT FOOT

- Clean the contact surfaces of the machine feet
- Replace bent bolts and curved washers
- Clean the bolt threads and bolt holes, then lubricate lightly
- Measure and eliminate any soft foot

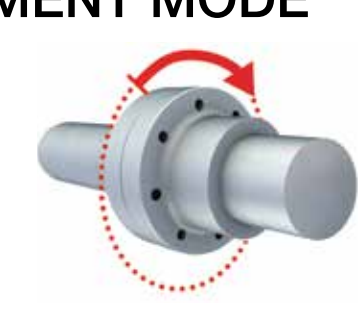
MACHINE CORRECTIONS

- Perform vertical corrections with precision shims
- Undertake machine movements with hydraulic jacks, jacking bolts or lifting bolts
- Adjust the axial spacing / coupling gap as recommended in the data sheet
- Avoid shocks or jerky machine movements that can damage bearings

Choose the correct measurement mode for horizontal machines

CONTINUOUS SWEEP MEASUREMENT MODE

- Smoothly rotatable shafts
- Coupled shafts
- Machines with roller bearings



MULTIPOINT / ACTIVE CLOCK MEASUREMENT MODES

- Difficult to rotate shafts (external forces influence centerline of shafts)
- Shafts with high breakaway torque
- Uncoupled shafts
- Machines with thin shafts and soft frames
- Machines with sleeve/journal bearings (floating oil film)
- Combustion engine (diesel, compressor) with force on the crank shaft
- Non rotatable shafts (sliding bracket)



Lack of measurement repeatability

- Dynamic forces at the coupling
- Backlash between the shafts
- Loose components (coupling, bracket, sensors)
- Brackets and sensors touch stationary parts during rotation
- Change of rotational direction during the measurement
- Excessive vibration from nearby equipment and personnel
- Direct sunlight
- Thermal influence on laser beam (over long distances)
- Sliding brackets on uneven surface

Alignment procedure

3 POST-ALIGNMENT

MACHINE

- Re-tighten all machine hold-down bolts with the recommended torque
- Remove all lifting and jacking bolts at the machine feet

MEASURE

- Take a final measurement

RESULT

- Coupling values within tolerances?

REPORTING

- Save the measurement file for reporting
- Measurement file saved with date, time, machine id, and operator name

SAFETY

- Remove all brackets and measuring equipment from the machine
- Mount the coupling guard
- Unlock the machine

Soft foot

Why measure and eliminate soft foot?

- Influences the machine position in both vertical and horizontal directions during loosening and tightening of the hold-down bolts
- May cause cracks in the machine feet and housing
- May result in increased radial load on the bearing
- May cause increased machine vibrations

Soft foot tolerance on standard frames

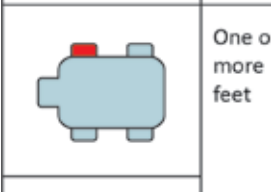
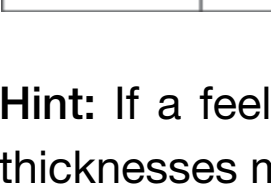
< 0.05 mm / 2 mils

> 0.5 mm / 2 mils

Parallel soft foot

Angular soft foot

Induced soft foot

Foot schema	Result	Solution
	Parallel air gap found on two diagonally opposed feet	Shim one foot by the amount of the measured air gap or divide this value by two, then shim both feet by the divided amount
	Gap found at the inside or outside of the foot/feet	Clean the surfaces Replace worn out or bent shims Minimize the number of shims Re-machine feet, base or both
	Parallel air gap found at two feet on the same side	External forces from coupling, piping or flexion

Hint: If a feeler gauge is not available, shims of different thicknesses may be used to measure the gap between the machine foot and the baseplate surface.
Maximum number shims → 4-5.

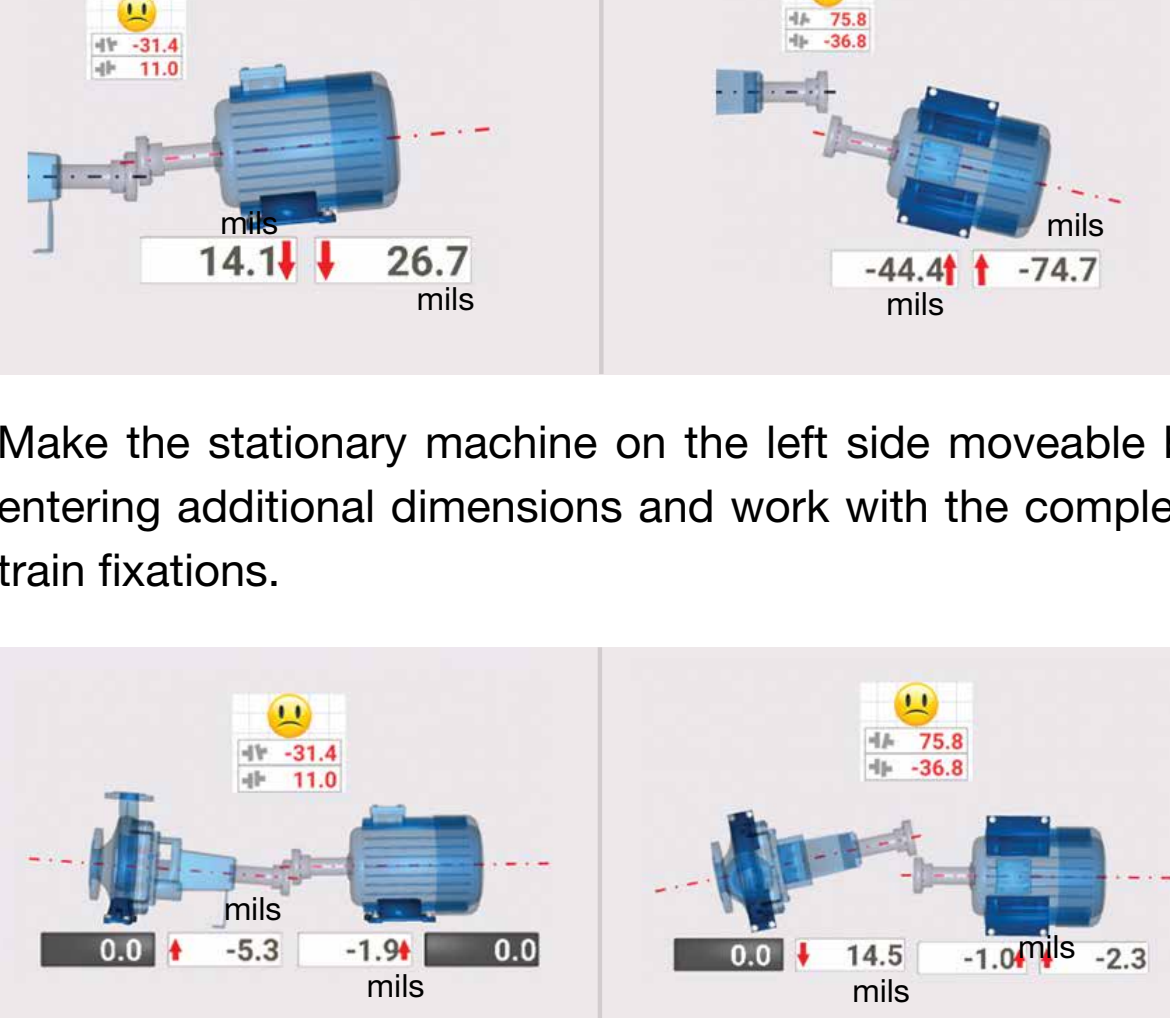
Movement restrictions



Traditionally the motor was the MTBM (machine to be moved). In many cases the centerline of the stationary machine shaft is not properly parallel aligned to the surface of frames and the bolt holes.

1st Example
Motor is high and has no shims under the feet

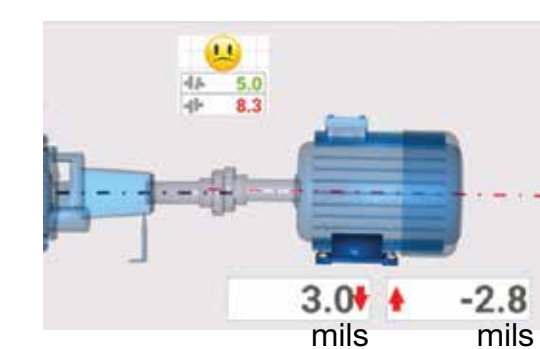
2nd Example
Motor is bolt-bound and therefore cannot move horizontally.



Coupling results vs. foot values

- Alignment out of tolerances
- Small foot correction values
- High coupling results values outside tolerance values
- Alignment within tolerances
- Relatively high foot correction values
- Coupling results values within tolerance

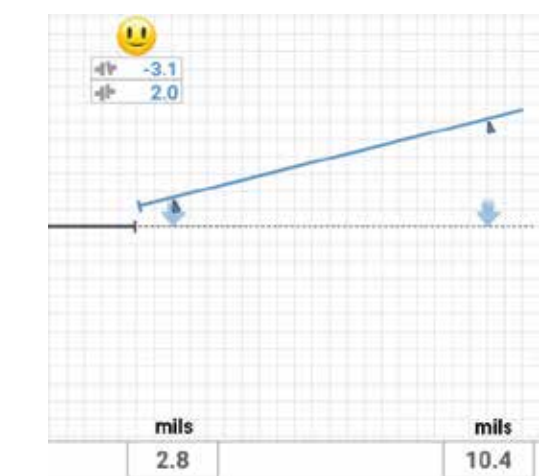
Side view (3D)





Side view graphical representation (2D)





Bolt torque

Why tighten hold-down bolts using the recommended torque?

Excessive torque results in:

- Damage to the machine feet
- Damage to the hold-down bolts, fasteners and washers

Less torque results in:

- Machine looseness

Standard bolt torque specifications
Key to table
TPI = Thread per inch
K = Torque coefficient
1 Newton meter [Nm] = 0.7375 foot-pound force [ft lb]
1 foot-pound force [ft lb] = 1.3558 Newton meter [Nm]

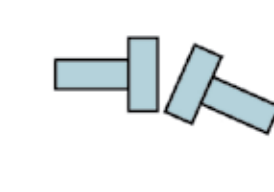
Bolt Size	TPI	Standard Bolt Torque Specifications									
		SAE Grade 5					SAE Grade 8				
		Lubricated K=0.15		Dry & Plain K=0.20		Lubricated K=0.15		Dry & Plain K=0.20		Lubricated K=0.15	
[inch]		[ft lb]	[Nm]	[ft lb]	[Nm]	[ft lb]	[Nm]	[ft lb]	[Nm]	[ft lb]	[Nm]
1/4	20	6.3	9	8	11	9	12	12	16		
1/4	18	7.2	10	10	14	10	14	14	19		
5/16	18	13	18	17	23	18	24	25	34		
5/16	24	14	19	19	26	20	27	25	34		
3/8	16	25	31	30	41	35	47	45	61		
3/8	24	25	34	35	47	35	47	50	68		
7/16	14	35	47	50	68	55	75	70	95		
7/16	20	40	54	55	75	60	81	80	108		
1/2	13	55	75	75	102	80	108	110	149		
1/2	20	65	88	90	122	90	122	120	163		
9/16	12	80	108	110	149	110	149	150	203		
9/16	18	90	122	120	163	130	176	170	231		
5/8	11	110	149	150	203	170	231	220	298		
5/8	18	130	176	170	231	180	244	240	325		
3/4	10	200	271	260	353	280	380	380	515		
3/4	16	220	298	300	407	320	434	420	569		
7/8	9	320	434	434	588	450	617	605	820		
7/8	14	350	475	475	644	500	678	670	908		
1	8	480	651	651	883	645	875	860	1146		
1	12	530	719	720	976	745	1010	995	1349		
1-1/8	7	600	814	813	1102	965	1308	1290	1749		
1-1/8	12	660	895	895	1214	1085	1471	1445	1939		
1-1/4	7	860	1159	1140	1546	1365	1851	1815	2461		
1-1/4	12	930	1247	1247	1691	1510	2047	2015	2714		
1-1/2	6	1100	1492	1491	2022	1780	2420	2385	3214		
1-1/2	12	1260	1708	1708	2316	2030	2751	2705	3608		
1-3/2	6	1460	1980	1979	2683	2370	3214	3165	4292		
1-3/2	12	1640	2224	2224	3016	2665	3614	3555	4820		

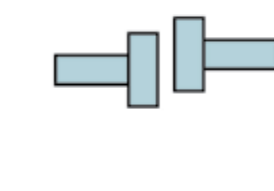
Bolt Size	Pitch	Standard Bolt Torque Specifications									
		Property Class 8.8					Property Class 10.9				
		Lubricated K=0.15		Dry & Plain K=0.20		Lubricated K=0.15		Dry & Plain K=0.20		Lubricated K=0.15	
[mm]		[ft lb]	[Nm]	[ft lb]	[Nm]	[ft lb]	[Nm]	[ft lb]	[Nm]	[ft lb]	[Nm]
4	0.7	1.7	2.3	3.1	4.1	3.3	4.3	2.4	3.3	3.6	4.9
5	0.8	4.4	6.0	8.1	10.9	6.5	8.6	5.7	7.7	7.8	10.6
6	1	7.9	10.7	14	19	11	15	9.7	13	13	18
8	1.25	14	19	26	35	27	37	24	33	31	42
10	1.5	28	38	50	68	40	54	35	47	44	59
12	1.75	49	66	86	116	69	93	62	83	78	105
14	2	78	106	134	181	111	150	101	136	127	170
16	2	121	164	211	285	173	235	162	219	209	281
18	2.5	167	226	292	397	239	324	218	295	278	374
20	2.5	236	320	414	558	337	457	304	414	385	517
22	2.5	321	435	568	770	460	624	413	557	518	693
24	3	407	552	716	972	582	789	517	699	650	872
27	3	507	689	796	1079	654	891	584	796	733	985
30	3.5	609	827	1079	1463	781	1060	684	928	853	1146
33	3.5	1201	1640	2146	2901	1374	1860	1041	1416	1305	1760
36	4	1415	1919	2506	3387	1614	2184	1269	1716	1584	2127

Shafts and couplings sign convention

Positive coupling values

+





Machine view

V = vertical (side) view
H = horizontal (top) view

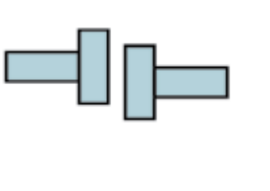




Negative coupling values

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Tolerances for standard machines

SHORT FLEX COUPLING											
OFFSET						ANGLE					
Recommended tolerance table						Recommended tolerance table					
RPM	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
60 Hz	50 Hz	[mils]	[mm]	[mils]	[mm]	[mils]	[mm]	[mils]	[mm]	[mils]	[mm]
600	750	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
900	1000	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
1200	1300	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
1800	2000	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
3600	4000	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
7200		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

ANSI / ASA S2.75-2017 / Part 1 for Coupling separations 3" (75 mm) or less											
OFFSET						ANGLE					
Recommended tolerance table						Recommended tolerance table					
RPM	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
60 Hz	50 Hz	[mils]	[mm]	[mils]	[mm]	[mils]	[mm]	[mils]	[mm]	[mils]	[mm]
600	750	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
900	1000	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
1200	1300	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
1800	2000	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
3600	4000	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
7200		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

SPACER COUPLING

RPM		Offset A / B		mils per 1 inch square length mm per 100 mm square length		Angle α / β		angle per transmission plane	
		OK	OK	U	Excellent	OK	OK	U	Excellent
60 Hz	50 Hz	[mils]	[mm]	[mils]	[mm]	[mils/lin]	[mm/lin]	[mils/lin]	[mm/lin]
1000	750	2.4	0.24	1.4	0.14	2.40	0.24	1.44	1.44
900	600	2.0	0.20	1.2	0.12	2.00	0.20	1.20	1.20
1000	1000	1.8	0.18	1.1	0.11	1.80	0.18	1.10	1.10
1200	1500	1.5	0.15	0.9	0.09	1.50	0.15	0.90	0.90
1800	3000	1.2	0.12	0.7	0.07	1.20	0.12	0.70	0.70
1800	3000	1.0	0.10	0.6	0.06	1.10	0.10	0.60	0.60
3600	6000	0.6	0.06	0.4	0.04	0.60	0.06	0.35	0.35
3600	6000	0.5	0.05	0.3	0.03	0.50	0.05	0.30	0.30
7200	12000	0.3	0.03	0.2	0.02	0.30	0.03	0.17	0.17
7200	12000	0.2	0.02	0.1	0.01	0.24	0.02	0.14	0.14