Lifetime Reliability • Solutions

Phone: +61 (0) 402 731 563
Fax: +61 8 9457 8642
Email: info@lifetime-reliability.com
Website: www.lifetime-reliability.com

Towards Precision Reliability - Shaft Alignment Awareness

1. Introduction

There is no dispute between vibration and reliability trainers, practitioners and commentators that misalignment, and related problems is the principal cause of problems in rotating machinery. It is generally accepted that this in the order of 50% of adverse vibration cases, it will of course vary from industry to industry.

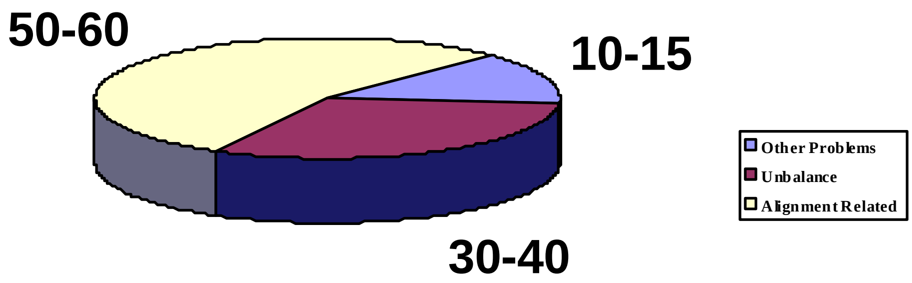

Figure 1 – Causes of Machine Failures

Attention to alignment issues alone would be a very productive place to start any reliability programme.

Unlike bearings, there are no published standards for alignment tolerances. Those that have been prepared have been by industry interest groups, such as API, or by trainers who have had access to a wide input from industry as to what is effective and produces worthwhile results.
A popular misconception is that flexible couplings will accommodate misalignment without detriment to other components in the machine, and adopt those criteria. The criteria given for couplings is related to the transmission of the rated torque.

There are numerous problems which have an influence upon the final alignment result and it is important to address these. Where these other issues have not been attended to an alignment task can take many hours longer than one where they have been, and the final result is most probably not so good or enduring.

There is a truth that correcting the contributory problems is probably more important, and ultimately profitable, than the actual alignment itself.

This session will look at these related problems and at the techniques of alignment.

2. What is Misalignment and Why is it Important?

A Definition: Shaft misalignment is the deviation of relative shaft position from a colinear axis of rotation measured at the points of power transmission when equipment is running at normal operating conditions.

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Defining Shaft Misalignment

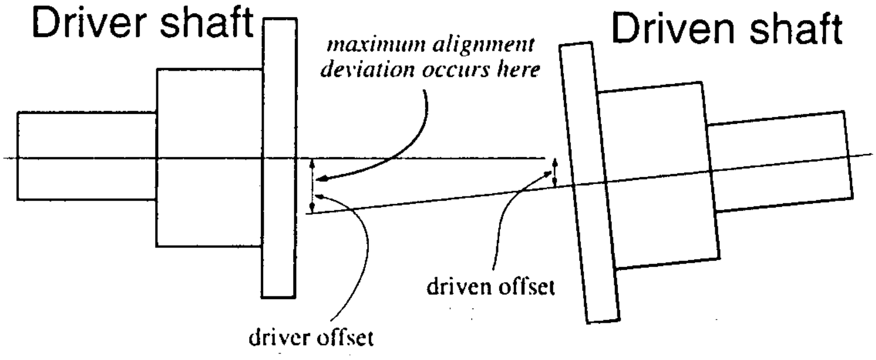

Figure 2 – Types of Shaft Misalignment

For a flexible coupling to accept both parallel and angular misalignment there must be at least two points where the coupling can flex to accommodate the misalignment condition. Measuring in the horizontal and vertical planes produces four deviations, each of which must be within the specified tolerance values.

Take the largest of these four deviations, measured in microns, and divide by the axial distance between the points of power transmission, measured in mm; this gives the maximum deviation in microns/mm. There are three factors that influence alignment in rotating machinery;

- The speed of the drive train,
- The maximum deviation at either flexing point or point of power transmission,
- The distance between the flexing points or points of power transmission.

The last part of the definition is probably the most difficult to achieve which is probably why it is also the most often ignored – *at normal operating conditions.*
When the machine is started the shafts will begin to move to another position, with temperature change being the most common cause. There are others such as process induced pipe forces and counter-reactions due to the rotation of the rotor.

The objective of accurate shaft alignment is to increase the operating life of the machine. To achieve this the machine components that are most likely to suffer failure must be operated within their design specifications. Those most likely to fail are the bearings, seals, coupling and shafts – and alignment has a significant influence on the life of each these, but particularly on the bearings. Accurately aligned machinery will achieve:

- Reduced axial and radial forces on the bearings to ensure longer bearing life,
- Eliminate the possibility of shaft failure from cyclic fatigue,
- Minimise the amount of wear on coupling components,
- Minimise the amount of shaft bending from the point of power transmission in the coupling to the coupling end bearing.
- Maintain proper internal rotor clearances,
- Reduce power consumption. This is a controversial issue – some studies have shown savings from 2% to 17% whist others have shown no measureable benefit.

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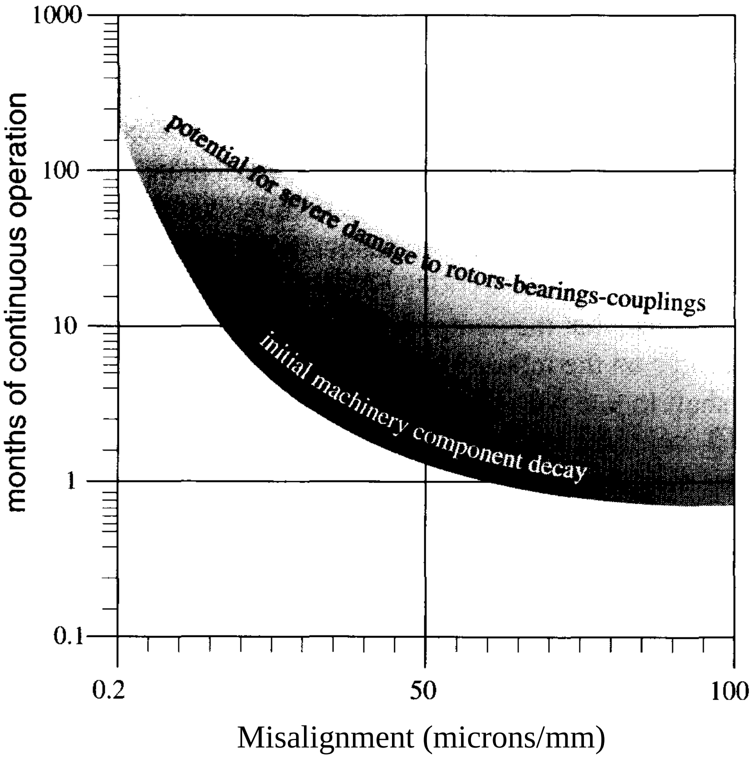
- Lower vibration levels on bearing housings, machine casings and rotors. But note that there are instance where slight amounts of misalignment have resulted in reduced vibration levels. There is a case for some caution about relating vibration amplitude to misalignment.



Typical operating lifespan of rotating machinery being subjected to various amounts of misalignment.

Figure 3 – Rapid Loss of Machine Life from Misalignment
(Source: Shaft Alignment Handbook-Pietrowski, John)

4. Types of Misalignment

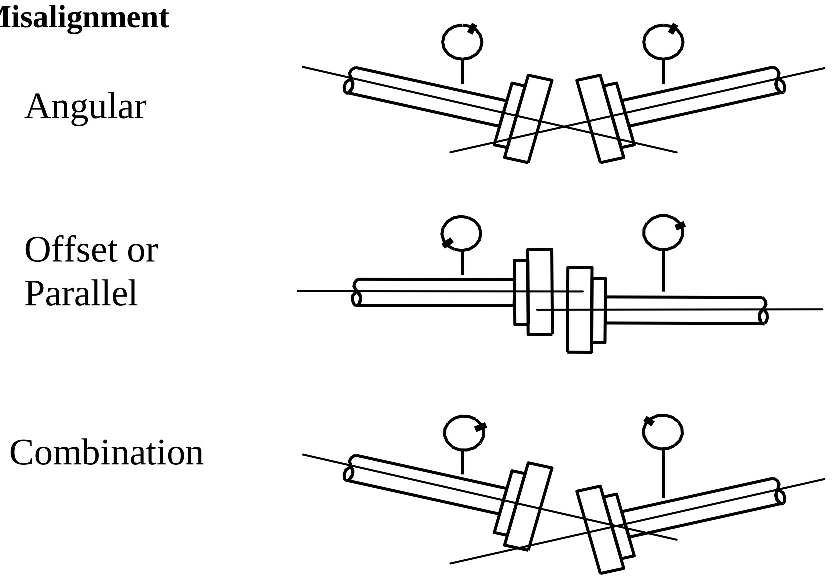


Figure 4 – Shaft Misalignment Types

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3. The Benefits of Alignment

There are now numerous recorded histories of companies who have addressed alignment issues and obtained quite dramatic results;

- improvements in vibration levels,
- reduced mean time between failures
- reduced maintenance costs.

5. Tolerances

The tolerances given in Table 1 are from a major company as part of their new equipment specification. As seen against Figure 3, they are very tight but indicate the companies drive for excellence. Their tolerance for run out is a maximum of 0.050mm, regardless of the speed.

Table 1 Alignment Tolerances

Speed rpm	**Parallel Offset** mm/100mmof coupling separation	**Angularity** mm/100mm of coupling diameter
Up to 1500	0.050	0.06
1500 to 3000	0.025	0.04
Over 3000	0.013	0.02

Table 2 gives tolerances as proposed by Universal Technologies, Inc of USA, and originate from companies who have been successful in achieving high overall reliability, giving extended life to other rotating components – seals, bearings.

Table 2 Alignment tolerances by Universal Technologies, Inc.

Machine Speed	**Maximum Offset at Machine Feet**	**Maximum Offset at Coupling Centreline**
Up to 1500 rpm	0.050mm	0.025mm
Over 1500 rpm	0.025mm	0.013mm

Misalignment Tolerance Guide for flexibly coupled rotating machinery.

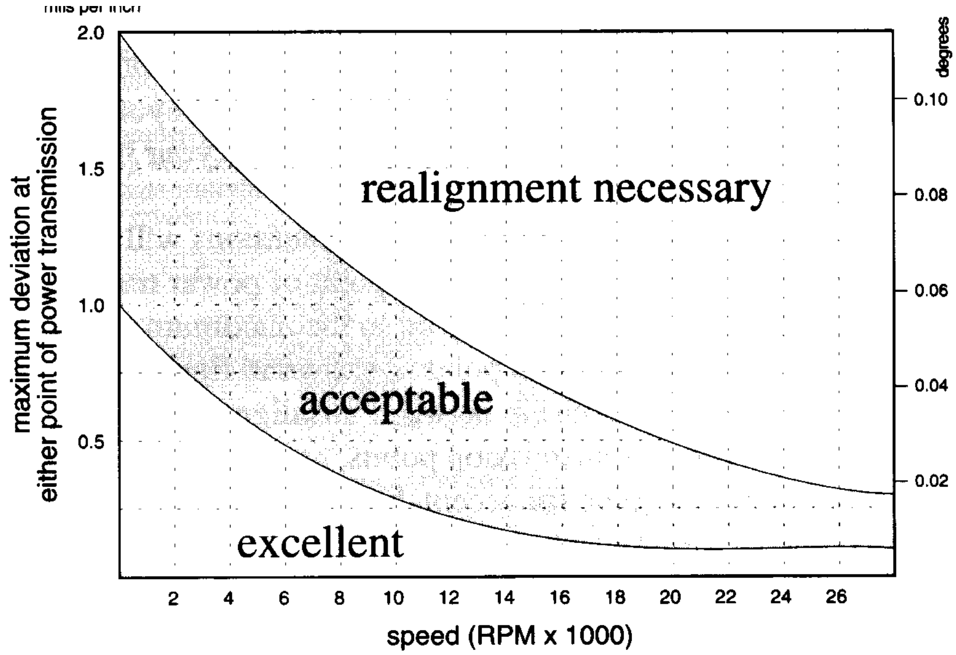

Figure 5 – Misalignment Limits

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Such tolerances should be included in maintenance department specifications for repaired and overhauled machinery.

5. The Alignment Process

The alignment process can range from a simple periodic alignment check through to the full procedure required when installing a new or rebuilt machine. The complete process may be considered as a three part exercise;

- Pre-Alignment
- Rough In Alignment
- Precision Alignment

5.1 Pre-Alignment Checks and Corrections

There are numerous problems which have an influence upon the final alignment result and it is important to address these. An alignment task where these other issues have not been attended to can take many hours longer than one where they have been, and the final result is most probably not so good or enduring.

There is a truth that correcting the contributory problems is probably more important, and ultimately profitable, than the actual alignment itself.

5.1.1 Pre-Alignment checks focus on the following area:

- unstable or deteriorated foundations and baseplates
- damaged or worn components on the rotating elements; bearings, shafts, seals, couplings
- excessive runout conditions; bent shafts, incorrectly bored coupling hubs
- soft foot; machine casing to baseplate interface problems
- excessive forces on attachments; pipework, ductwork, conduits
- preparing machine for movement; hold down & jacking bolts, shims

5.1.2 RunOut describes eccentric(radial run out) or non-perpendicular (face run out) conditions that exist between shafts and coupling hubs, impellers or other components rigidly fixed to the shaft.

Run out is typically measured with a dial indicator and at several points along the length of a rotor. Note that the amount of face run out will vary depending upon the radius of measurement. The table below can be used as a guideline for acceptable amounts of run out.

Recommended Maximum Radial Run Out

Machine speed RPM	Maximum Allowable Total Indicator Run Out (TIR)
0 – 1500	0.125mm
1500 – 3000	0.050mm
3000 and above	Less than 0.050mm

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Check that the high spot and the low spot are 180^{o} apart, otherwise there may be confusions with localised hills and valleys.

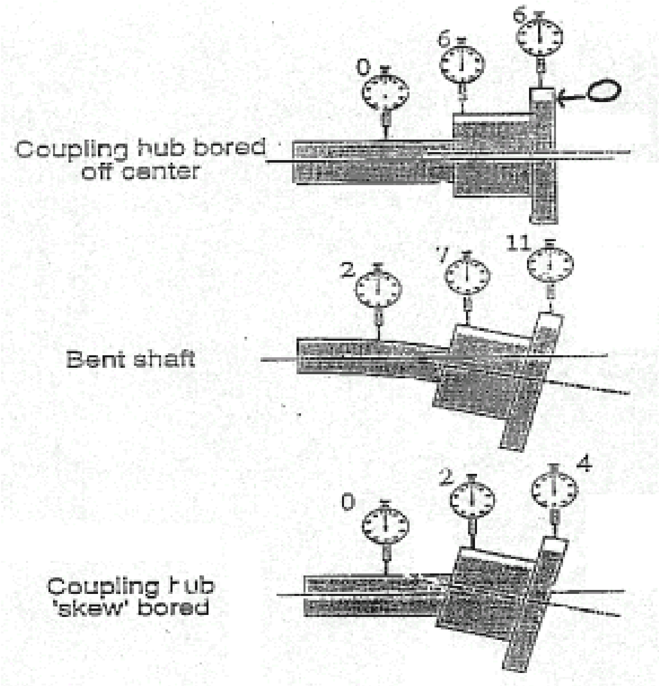

Figure 6 – Measuring Shaft Run-Out

5.1.3 Soft Foot occurs when one or more of the feet are not making intimate contact with its base/soleplate/frame. It is one of the more prevalent problems associated with alignment and can be attributed to warped or bowed frames or machine cases, improper machining of equipment feet or the baseplate, or any combination of these. It is more complex than the simple short leg on a four legged chair analogy. The feet of a chair make point contact; machine feet are a (supposedly) flat area and they have to make good contact with four (supposedly) flat surfaces on the baseplate. The chances of all four feet and all four surfaces being truly flat and in the same plane are not good.

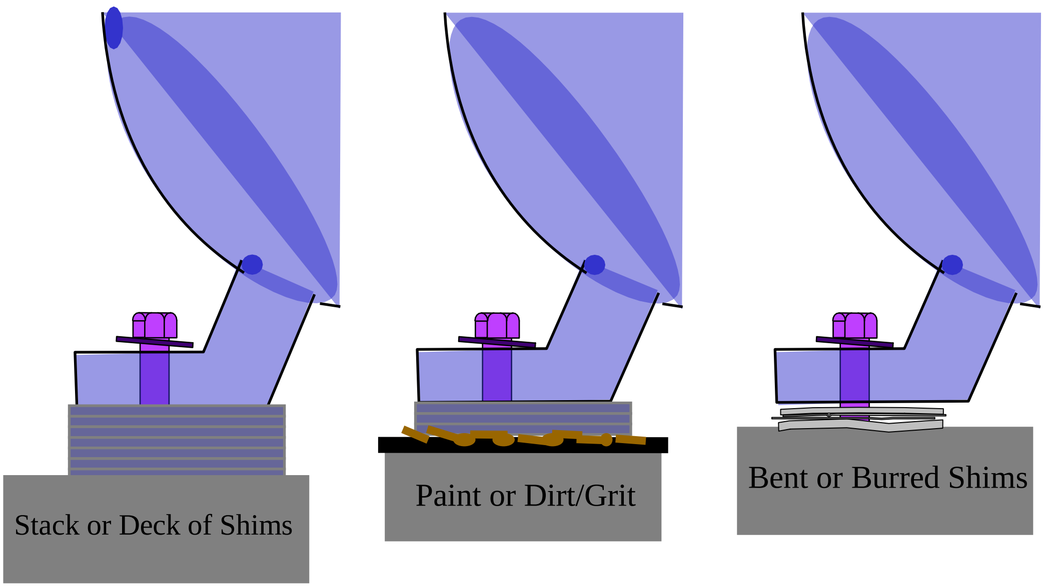

Figure 7 – Machine Soft Foot Causes

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It is possible to have all four feet "soft"; this does not mean the machine is suspended in mid air. It is quite likely that one or more feet are not parallel and that they are making only a point or edge contact; in such a situation it will be necessary to make up a shim wedge to properly support the foot.

There are three important reasons why this problem must be corrected:

- The centre line of rotation of the shaft will move in a way that is dependant upon the sequence of tightening the hold down bolts and will cause considerable frustration when trying to achieve alignment.

- Tightening down any of the hold down bolts that are not making good contact will cause the machine case to warp upsetting critical clearances on components such as bearings, shaft seals, mechanical seals, pump wear rings, compressor staging seals, motor stator/armature air gaps etc, and inner alignments such as in gearing.

- A situation of stress induced resonance can occur, giving rise to excessive vibration levels.

5.2 Rough-In Alignment

At this stage the centrelines of the machines are brought into close proximity. There are no set rules for this but as a general guide line they should be within 1mm offset at the coupling and 1mm/100mm angularity vertically and horizontally. Much depends upon the type of machine and the experience of the person doing the job.

At the commencement of this work it is a good practice to commence with;

- a 3mm shim under each foot so that there is good provision for adjustment vertically
- hold down bolts in the centre of their holes so that there is good provision for adjustment horizontally.

Methods used for the rough-in alignment;

- Straight edge across the coupling
- Straight edge across the coupling with feelers

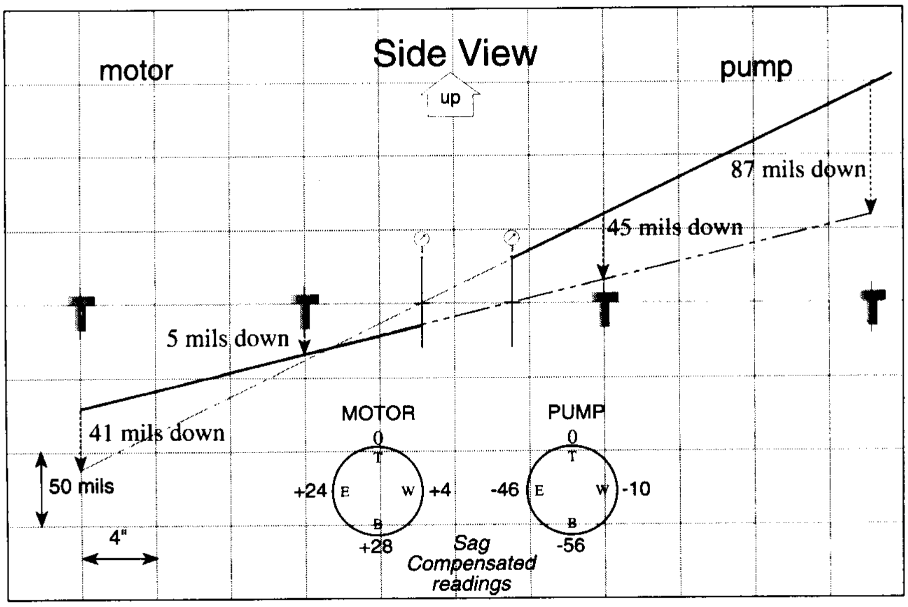
Unfortunately, this is so often where the job ends.

When aligning machinery, do not insist that one machine will be stationary; look for the common line that gives minimal movement by each machine.

In working with trains of more than two units it is important to identify the line of the whole train so that the best axis common to all may be selected. If consideration is not given to this it is quite conceivable that after aligning the first two units the third will require corrections beyond its physical limits.

Once the centrelines of rotation have been determined and the allowable movement envelope illustrated on the graph, identify the most efficient solution for movement

Here are the two different Stationary / Movable solutions for this arrangement of shafts ...
If you keep the motor stationary, the pump must be lowered 45 mils at the inboard feet and 87 mils at the outboard feet.
If you keep the pump stationary, the motor must be lowered 5 mils at the inboard feet and 41 mils at the outboard feet.



Stationary movable choices.

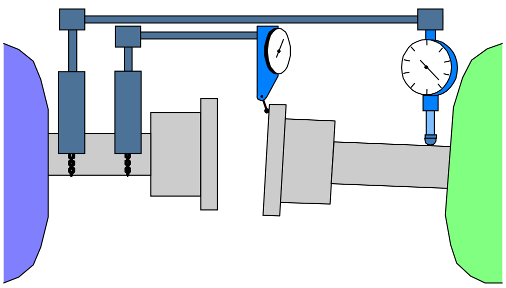
Figure 8 – Stationary / Movable Machine Choices

5.3 Precision Alignment

A precision alignment will only be achieved with dial indicators or laser. If the preceding work has been done well this final stage should be free of difficulties and for most machines take only a few hours.

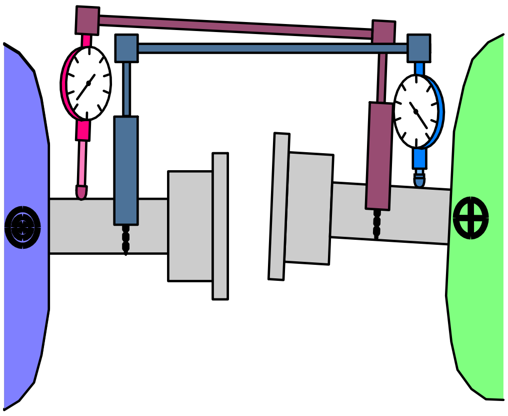
The alignment methods available at this stage include;

- Rim and Face Dial Indicator
- Reverse Dial Indicator
- Laser



- Loose Fixtures, no repeatability
- Indicator set at angle
- SAG
- Correct Readings
  - Positive or Negative
  - Did it start one way and go back
  - Did it go all the way around
  - Parallax

Figure 9 – Rim and Face, and potential problems



- Bearing Looseness
- Loose fixtures, repeatability
- Correct Indicator Mounting/Reading right
- Sticking Indicators
- Correct Clock Position
- Sag
- Parallax

Figure 10 – Reverse Dial Indicator and potential problems

6. Contractors and Alignment

As a minimum, require your contractors to provide you with the “as found” alignment data, soft foot conditions and the corrections made, shaft and coupling hub run-out information, the final alignment data, the moves made on the machinery, and the final alignment tolerances.

You must be satisfied that the contractor does have the skills and equipment you expect of him.

Do not be satisfied with an answer like, “We used dial indicators and lasers.*” Dial indicators and lasers do not move machinery, - people do!!*

By ITA Industrial Training Associates