



## Alignment Eliminator Coupling:

Investigation of energy efficiency and water leakage reduction when installed on typical pump to motor system

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**Date:** 22<sup>nd</sup> February 2011

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## Abstract

The Alignment Eliminator Coupling, developed by Thompson Couplings Limited, is claimed to be more energy efficient and more effective than traditional shaft coupling in preventing water leakage from typical pump systems even when the shafts of the motor and pump are misaligned. This report compares the water leakage and energy efficiency of the Alignment Eliminator Coupling and a traditional elastomer coupling by a series of experiments. Both couplings were connected to the same pumps under the same misalignment configurations. The results show the leak rate of the motor to pump system installed with the Alignment Eliminator Coupling is much less than that installed with a traditional elastomer coupling but no discernible difference in energy efficiency is measured.

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## **Introduction**

### **Background**

Each year, billions of dollars are spent on the industry worldwide due to the misalignment of machinery. Consequences of misalignment include lubricant or pumped media leakage and premature bearing, seal and coupling failure. Shaft alignment at the same time can be time-consuming and costly.

This project is supported by a New South Wales Government funding, Water Adjustment Innovation Fund (WAIF). The objective of the project is to test the ability of a new self-aligning water pump to motor coupling, the Alignment Eliminator Coupling, which is designed to reduce water leakage at the pump, improves energy efficiency and eliminates the need for expensive regular laser alignment of the pump shaft to the motor shaft.

### **Water leakage reduction**

An initial test was done that showed the Alignment Eliminator Coupling (AE coupling) reduced water leakage from a pump. A systematic test was needed to confirm the water saving ability of AE coupling.

## **Information**

### **Shaft Misalignment**

In most industrial applications, such as motor-to-pump power transmission, a coupling is used to connect the drive shaft to the driven shaft. Shaft misalignment occurs when the centerlines of the two rotating shafts are not co-linear. When misaligned, the loading of shafts increases due to the forces generated within the coupling. This results in premature bearing, seal, shaft and coupling failure.

There are two components of shaft misalignment. For the first component, the centerlines of the shafts are parallel but with an offset between them, so the shafts do not meet at the power transfer point. This is referred as offset, lateral or parallel misalignment. The second component is angular misalignment, whereas the shafts meet at the power transfer point but one shaft is at an angle to the other. A combination of both types of misalignment often occurs in operating machinery.

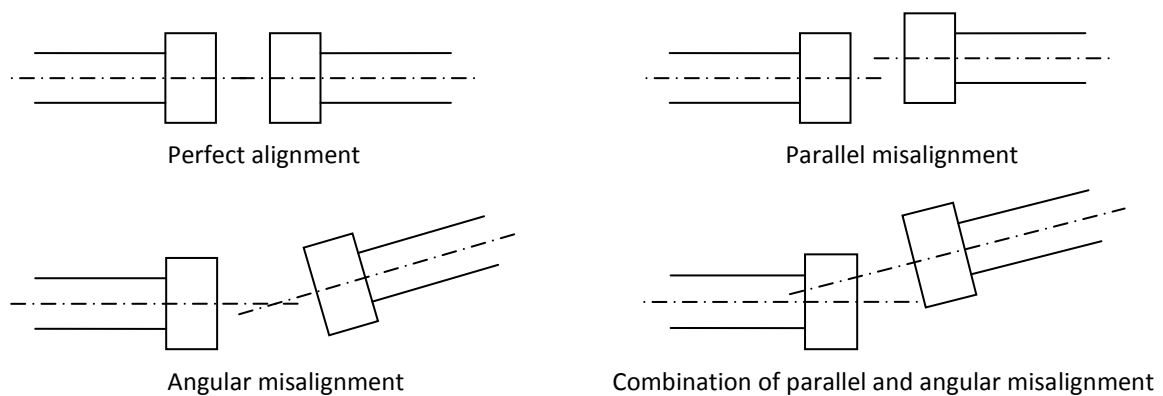


Figure 1 Types of shaft misalignment

Misalignment can occur even when the shafts are aligned accurately when the machine is not yet started (cool setting). When rotating equipment is started, the centerline of its shaft will be displaced due to thermal expansion and leads to misalignment. Some pump manufacturers provide the cold setting figures corresponding to the hot setting so the shafts run in a misaligned setting until the equipments are in the stable operating temperature.

## Alignment methods

### Straight edge and feeler gauge

This is the oldest method which a straight edge is used to measure parallel misalignment and feeler gauge is used to measure angular misalignment. This method depends on the limited resolution of the human eye therefore is inaccurate for most machinery.

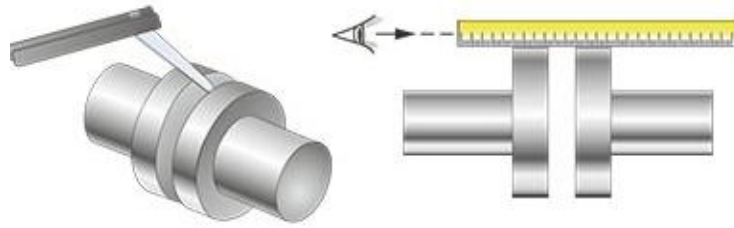


Figure 2 Straight edge and feeler gauge method

### Dial gauge

A dial gauge is a more accurate method compared to straightedge and feeler gauge. However specialist operator knowledge and precise calculation are needed. This method can also be time-consuming.

### Laser alignment

Laser alignment is the latest and the most accurate current technology for shaft alignment. Computer software is utilized to analyze all the data from the laser sensor and it is also responsible for the complicated calculation. An experienced operator is also needed for this method and equipment is expensive.



Figure 3 Dial gauge method and Laser alignment method

## Traditional Couplings

Couplings are used to connect the shafts and transmit torque. They can be divided into two categories, flexible and rigid.

Flexible couplings allow slight misalignment whereas rigid coupling require precise alignment. In this project, only flexible couplings are considered. Gear coupling, grid coupling and elastomer coupling are examples of flexible couplings.



Figure 4 Gear coupling



Figure 5 Grid coupling

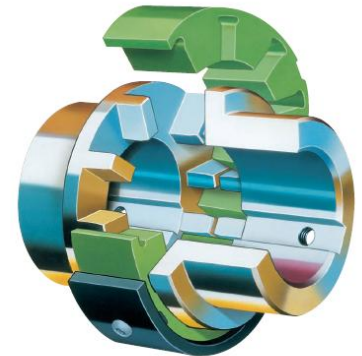


Figure 6 Elastomer coupling

## Alignment Eliminator Coupling

The Alignment Eliminator Coupling (AE coupling) is a novel product developed by Thompson Couplings Limited. Each AE coupling consists of two constant velocity joints (CV joints) and an intermediate shaft. CV joints allow parallel and angular misalignments as well as displacement of shafts in the axial direction without creating significant loading to the shafts. High torque transmission at high speed can also be achieved by the intermediate shaft.



Figure 7 Alignment Eliminator Coupling

## Water Pumps – Leakage

### Packing Gland Seal

In most of the old pumps as used in industry, the rotating shaft which drives the impeller protrudes through the pump casing. A packing gland seal is usually used to seal the protrusion. When the pump shaft is rotating at high speed, it rubs against the packing and wears off. The heat generated by friction may also cause damage to the packing. Pumps are generally designed to allow a small amount of controlled leakage along the shaft to act as a lubricant and coolant to the packing.

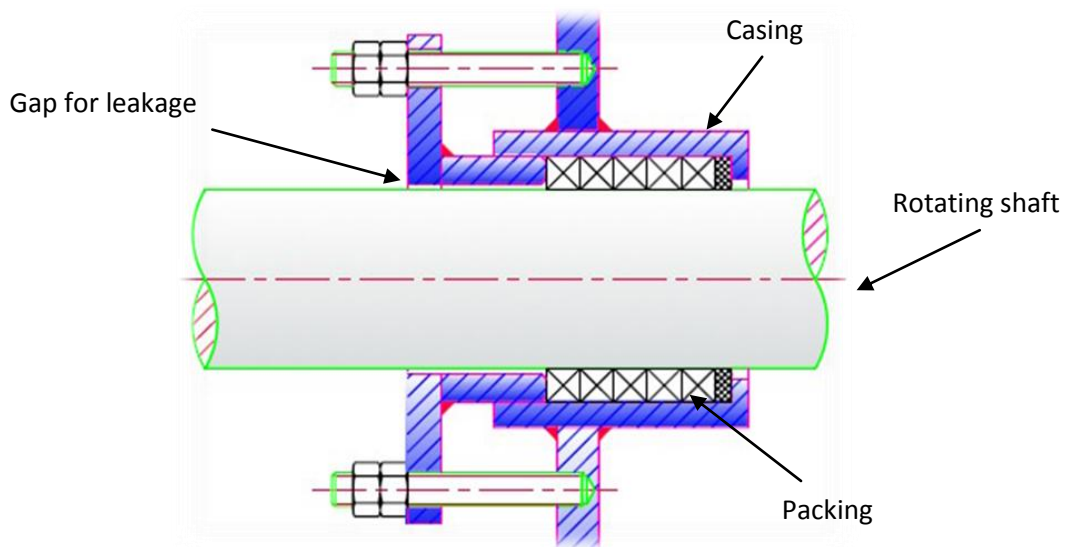


Figure 8 Packing Gland Seal

### Mechanical Seal

Pumps manufactured in more recent times are usually installed with mechanical seals instead of packing gland seals. A typical mechanical seal is shown in Figure 9. A spring, which rotates with the shaft, presses the rotating seal ring against the stationary seal ring to form a sealing gap. A small amount of water leaks through this gap due to pressure difference and acts as lubricant. If the mechanical seal works properly, no liquid should leak out of the pump since it has evaporated due to heat generated in the sealing gap.

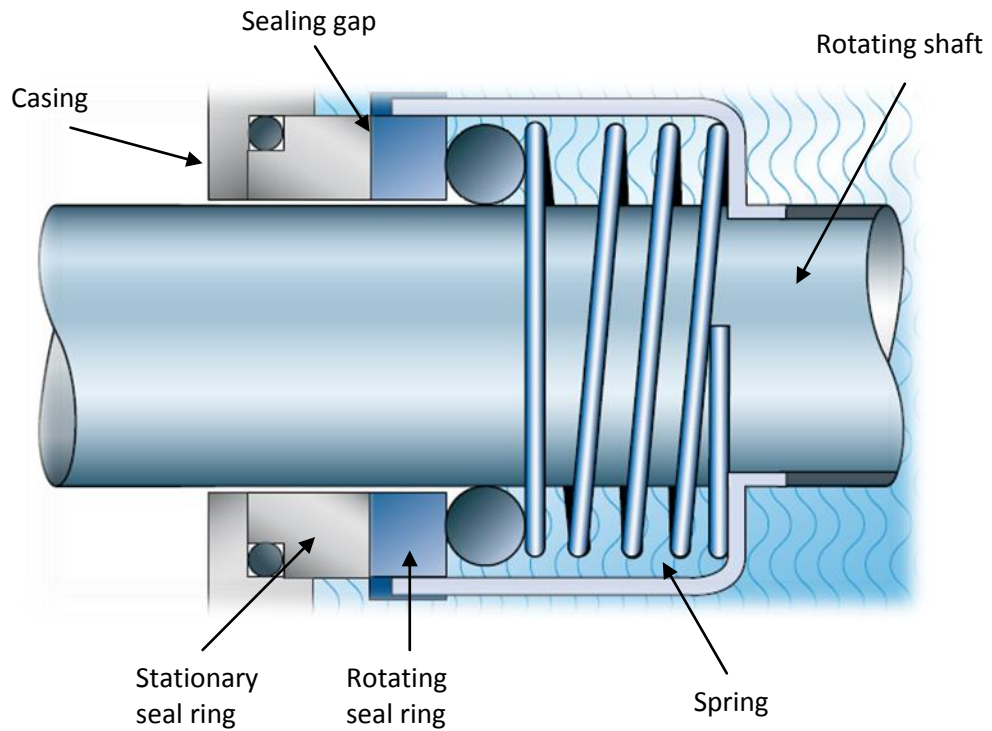


Figure 9 Mechanical Seal

## Hypothesis

### Water Leakage

Shaft alignment expert Piotrowski (2007, p. 252) suggests that when two shafts are misaligned and engaged by a coupling, they will distort as shown in the Figure 10.



Figure 10 Shaft distortion due to parallel misalignment suggested by Piotrowski

The bending of the shafts introduces lateral forces acting on the bearings and other components along the shafts of the pump and motor. The force would increase with the misalignment and the leak rate will also increase.

In the case of pumps with packing gland seals, a lateral force will be exerted on the packing due to bending of the shafts. The gap between the shaft and the packing will become larger because of the deformation of the packing, hence the leak rate increases.

The effect of misalignment with a mechanical seal is suspected to be less significant. It is because the sealing gap will be closed by the spring even when the shafts are misaligned slightly. However, a pump with mechanical seals is still prone to leak if the shafts are misaligned excessively. Figure 11 shows that the area of the sealing surface decreases due to the displacement of the shaft. It leads to leakage since the pressure difference remains unchanged but the sealing surface area decreases.

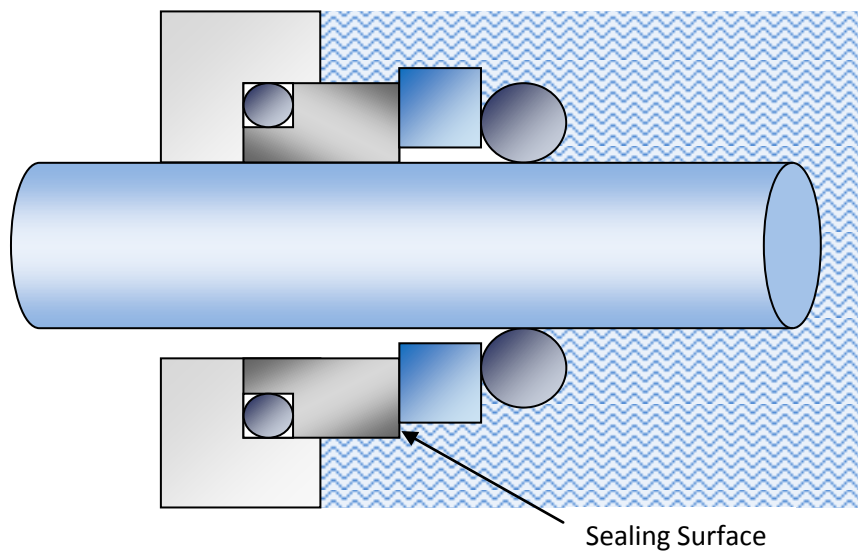


Figure 11 Decrease in the Sealing Surface area when misaligned

Based on the hypothesis, couplings with a higher ability to prevent bending of the shaft should be more capable of reducing water leakage. To avoid bending the shafts, the coupling should be deformable and flexible. Traditional couplings like elastomer and grid couplings accommodate misalignment by deformation of the interconnecting element however the element will naturally try to restore its original shape. It means that traditional couplings are deformable but not adequately flexible therefore it is expected that shaft bending can occur when they are applied.

As described earlier, an AE coupling consists of two CV joints. The CV joints conform to the shaft condition though the displacement of the balls and raceways without deforming any component. The arrangement of AE coupling enables it to flex and adapt to more significant misalignment conditions without bending the shaft.

Furthermore, the force exerted on the bearings of the pump by the coupling can be used to determine a relationship between misalignment and leakage.

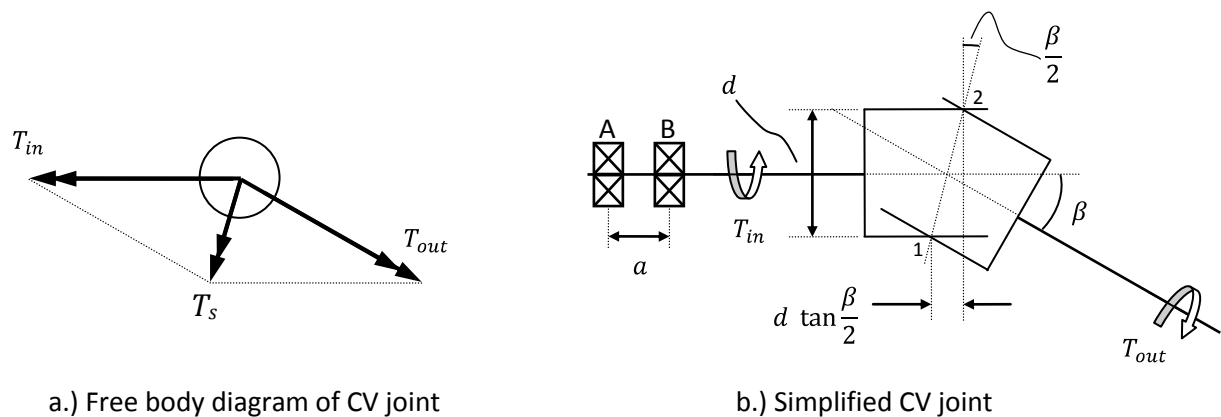


Figure 12 Simplified CV joint

Figure 12 a. shows the free body diagram of a CV joint. When the input torque  $T_{in}$  is applied to the driving shaft and resisted by an equal and opposite torque  $T_{out}$  on the output shaft, a bending moment is produced. This bending moment is called a Secondary Couple,  $T_s$ . The secondary couple reacts as forces on the shaft bearings.

Figure 12 b. shows a simplified CV joint with an angle of  $\beta$ . Points 1 and 2 represent two balls in the joint which are designed to always be in the homo-kinetic plane, a plane bisects the angle between input and output shafts. The bearing forces can be determined as follows:

By replacing  $T_{in}$  with a couple,

$$T_{in} = F_c \cdot d$$

$F_c$  is the force producing torque at balls 1 and 2. The force at point 1 is pointing out of the page and the force at point 2 is pointing into the page. As a result, the component of the secondary couple which has effect on the bearings will be,

$$C = F_c \cdot d \tan \frac{\beta}{2}$$

$$= T_{in} \tan \frac{\beta}{2}$$

Thus the reaction forces on the bearings are

$$F_{AE} = \frac{T_{in}}{a} \tan \frac{\beta}{2}$$

And the direction of force on bearing A is into the page whereas the direction of force on bearing B is out of the page. This expression shows that the bearing force is directly proportional to the input torque  $T_{in}$  and  $\tan \frac{\beta}{2}$ . Since the input torque remained steady during all experiments, the only variable for the bearing loads is  $\tan \frac{\beta}{2}$ . Expression (1) is then written.

$$F_{AE} \propto \tan \frac{\beta}{2} \dots\dots\dots (1)$$

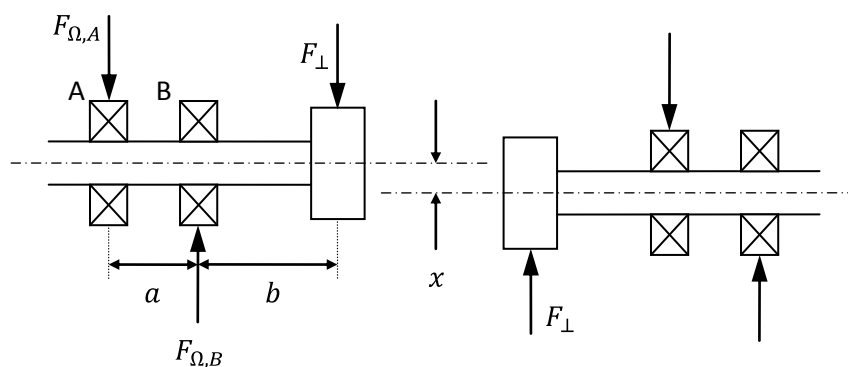


Figure 13 Free body diagram of shafts with the elastomer coupling

The elastomer coupling applies two equivalent side forces  $F_{\perp}$  to the input and output shafts as illustrated in Figure 13.  $F_{\perp}$  is expected to be a spring force due to the elasticity of the coupling and can be expressed as

$$F_{\perp} = k \frac{x}{2}$$

Where:  $k$  = Spring constant

$x$  = Parallel offset of the shafts

By taking moment about bearing B,

$$F_{\perp} \cdot b = F_{\Omega,A} \cdot a$$

$$F_{\Omega,A} = F_{\perp} \cdot \frac{b}{a}$$

$$F_{\Omega,A} = k \cdot \frac{x}{2} \cdot \frac{b}{a}$$

And by summing the force in the vertical direction,

$$F_{\Omega,B} = F_{\perp} + F_{\Omega,A}$$

$$F_{\Omega,B} = F_{\perp} \left( 1 + \frac{b}{a} \right)$$

$$F_{\Omega,B} = k \cdot \frac{x}{2} \left( 1 + \frac{b}{a} \right)$$

As  $k$ ,  $a$  and  $b$  are all constants, the only variable for the bearing loads is  $x$ .

$$F_{\Omega} \propto x \dots \dots \dots (2)$$

Expression (1) and (2) are then compared by using Figure 14.

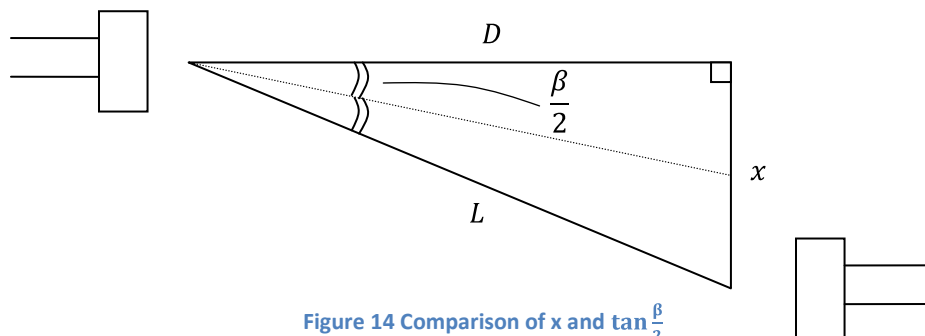


Figure 14 Comparison of  $x$  and  $\tan \frac{\beta}{2}$

In Figure 14,  $L$  stands for the length of the intermediate shaft of the AE coupling which is much longer than  $x$ . Then,

$$\tan \frac{\beta}{2} = \frac{x}{2/D}$$

$$\therefore \tan \frac{\beta}{2} \ll x$$

Therefore  $F_{AE}$  is expected to be much smaller than  $F_{\Omega}$  and the predicted bearing load vs. misalignment curves are plotted in Figure 15.

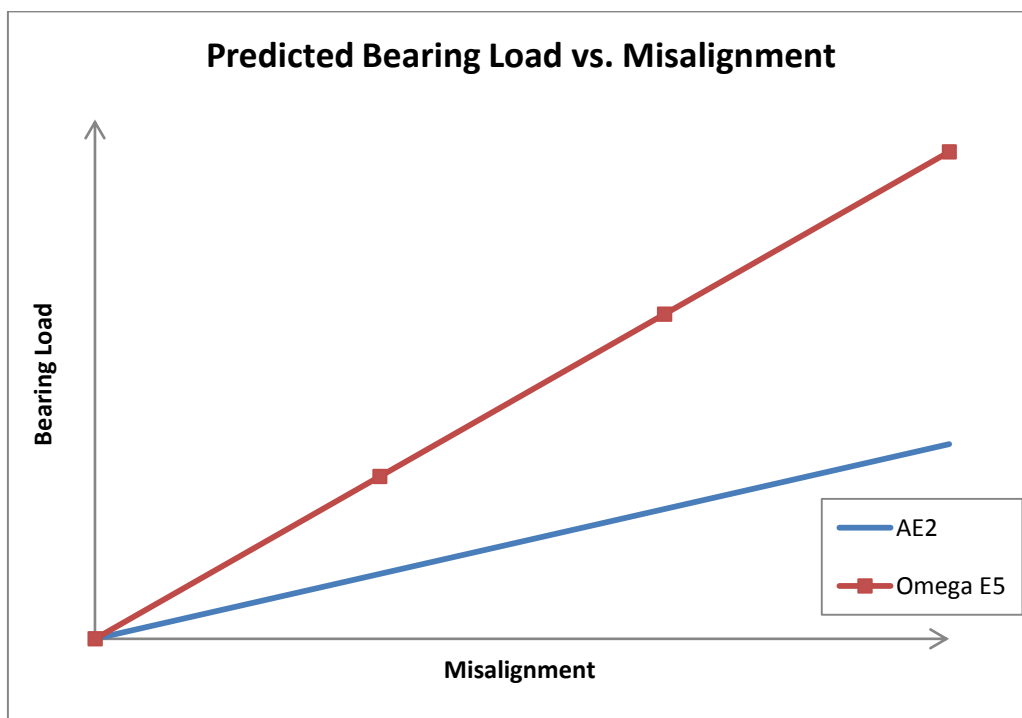


Figure 15 Predicted Bearing Load vs. misalignment

In a pump, the shaft is normally supported by the bearings and the seals.  $F_{AE}$  and  $F_{\Omega}$  can then be treated as the forces exerted on the seal by the AE coupling and the elastomer coupling respectively. As discussed earlier, the force on the seal causes leakage therefore it is believed that AE couplings can improve the water leakage problem of a pump system.

## **Energy Efficiency**

Coleman (2005, p. 116) stated that precision alignment leads to an increase in energy efficiency in pump to motor applications. It is believed that energy is lost at the bearings and the coupling due to increased bearing load by misalignment. According to this notion, the AE coupling should be more energy efficient given that the bearing loads are predicted to be much smaller.

However a study conducted by the University of Tennessee (Hines & Jesse 1997) showed no quantifiable difference in motor efficiency related to motor shaft misalignment when the couplings were operated within the allowable range provided by the manufacturer. Power consumption and power output remained unchanged regardless of shaft misalignment.

These notions opposed each other thus experiments were conducted during this project to determine the influence of the coupling on energy efficiency of the pump system.

## Experiment

The first aim of the experiment was to determine the difference in the water leakage rate of two different pumps when both pumps were connected to the motor with the same coupling and were tested under the same experimental configuration. The second aim was to compare the leak rate from the same pumps when they were installed with different couplings. During all the experiment, the efficiency of the system was also measured.

### Couplings

The two types of coupling used are

1. Elastomer Coupling

- Manufacturer: Rexnord
- Series: Omega
- Model: E5

2. Alignment Eliminator Coupling (AE Coupling)

- Manufacturer: Thompson Couplings Limited
- Model: AE2



Figure 16 Elastomer Coupling, Omega E5

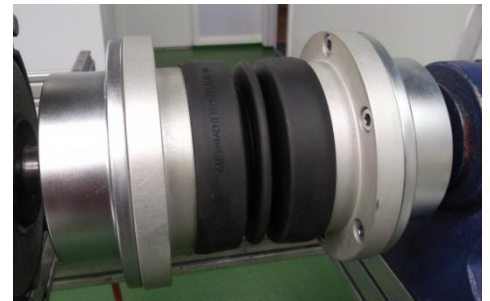


Figure 17 Alignment Eliminator Coupling, AE2

**Table 1 Properties of the couplings**

Coupling	Max Speed (RPM)	Outer diameter (mm)	Max angular misalignment (°)	Max parallel misalignment(mm)
Omega E5	7500	241	4*	1.6*
AE2	3500	148	5	7.5

\* For Omega E5, maximum angular and parallel misalignments cannot be combined. Please refer to the allowable misalignment chart in the catalogue of Omega Elastomer Coupling.

## **Pumps**

Two different pumps were used. One of them was in a used condition and installed with packing gland seals. The other one was a brand new pump with mechanical seal. In order to determine the difference in leak rates of the seals, the same misalignment configurations were applied to both pumps when the same coupling is installed.

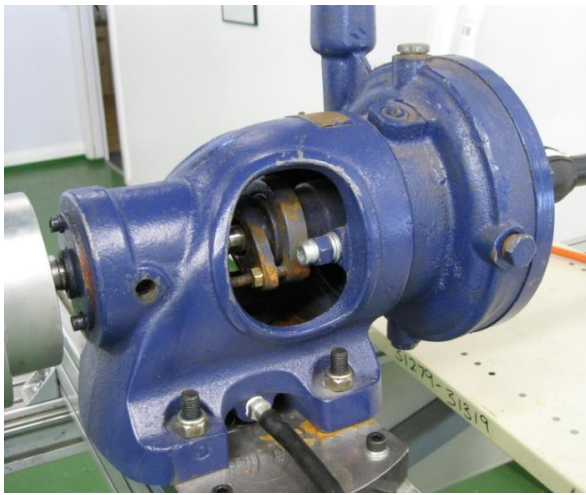


Figure 18 Old pump with packing gland seal



Figure 19 New pump with mechanical seal

### **Information of the pumps:**

#### **1. Old pump**

- Manufacturer: Kelly & Lewis
- Model: 50
- Condition: in various state of operation for approximately 20 years

#### **2. New Pump**

- Manufacturer: Davey
- Model no: 5150P-0
- Condition: Brand new

## Test rig

A 2.2 kW three phase induction motor was connected to the pump through a coupling. During all experiments, the motor ran at 50 Hz controlled by a frequency controller. The frame supporting the induction motor was driven by a linear actuator thus offset misalignments were induced by moving the motor sideways. The pump was mounted onto another frame which was bolted on two tracks. By adjusting the position of the tracks, various angular misalignment configurations were induced.



Figure 21 Test rig

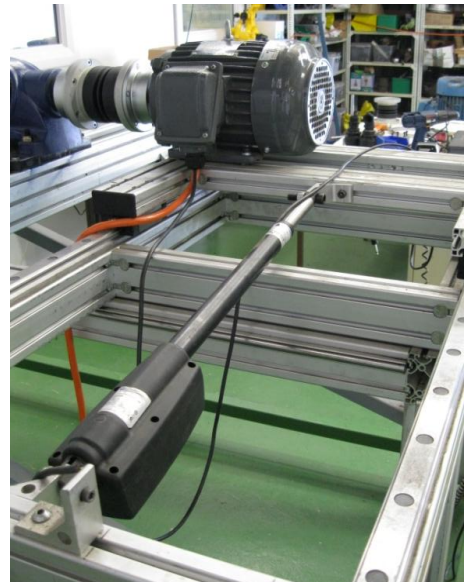


Figure 20 Linear actuator



Figure 22 Frequency controller

## **Measurement Method**

### **Leak rate**

The volume of water leaked per hour was measured by using a stop watch, a balance and a container. The weight of the empty container was first measured before any experiment. The weight of the water, hence the volume, was calculated by subtracting the weight of the empty container.

### **Misalignment method**

All the misalignment configurations were measured by using a dial gauge with good accuracy to 0.1mm. Figure 23 illustrates the misalignment methods that were used.

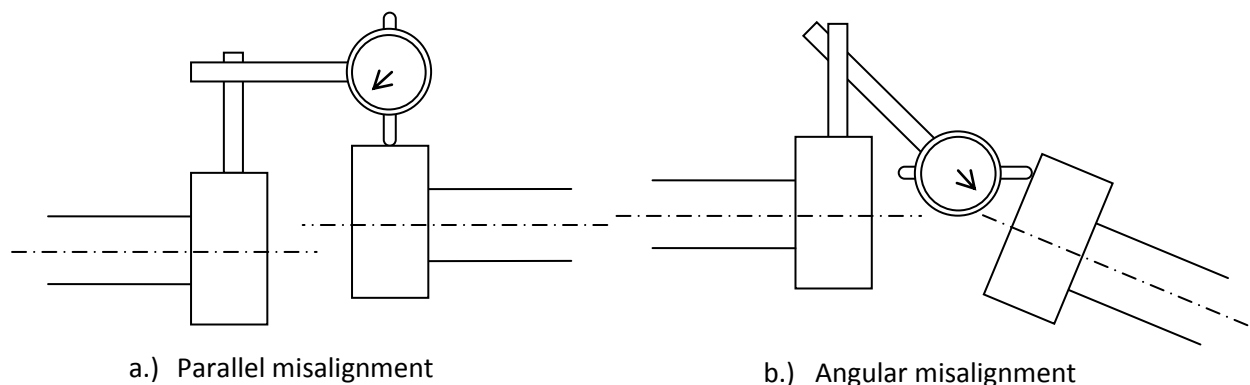


Figure 23 Method of misaligning the shafts by dial gauge

Parallel misalignment can be easily induced as revealed. To measure angular misalignment, the dial gauge was mounted onto the hub of the coupling as shown above on in Figure 23 b. Then by measuring the maximum difference in dial gauge reading and the diameter of the circle drawn by it, the slope and angle was then calculated.

## Energy efficiency

A signal recorder was connected to the power input of the motor to measure the input voltage. The data was recorded and transmitted to a PC for further analysis.

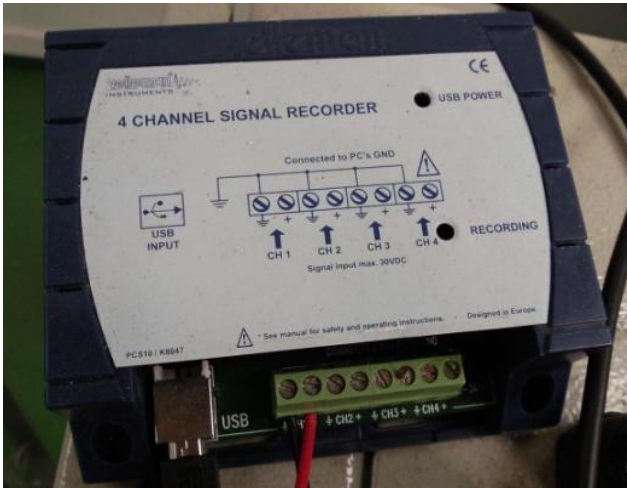


Figure 24 Signal Recorder

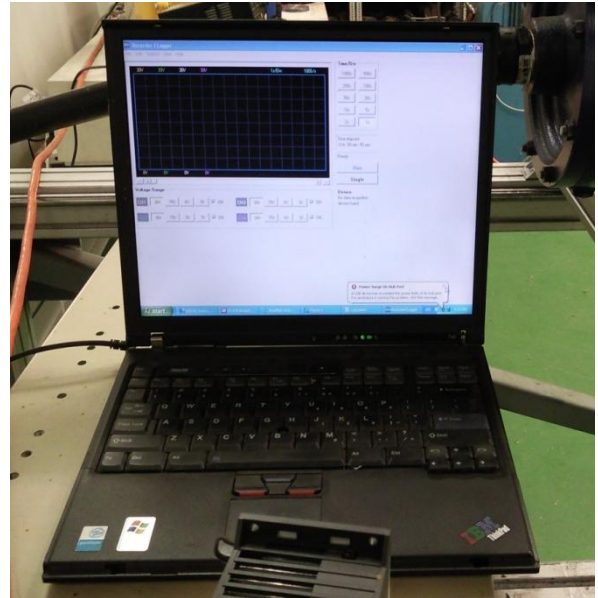


Figure 25 Personal computer for data collection

## Experiment Configurations

In this report, the misalignment configuration is described as  $(x \text{ mm}, \alpha^\circ)$ , where  $x$  and  $\alpha$  are the parallel and angular misalignment values respectively. Due to the difference in maximum allowable misalignment, different configurations were applied to the two couplings as listed below. For each configuration, three experiments were conducted and the mean value of the results was used in the analysis.

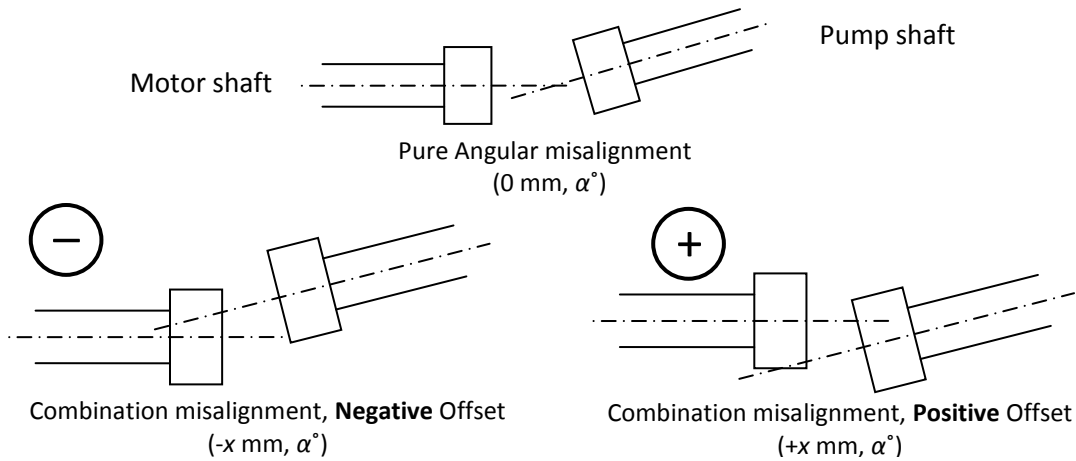
**Table 2 List of misalignment configuration for the Omega coupling**

Pure Parallel Misalignment	Pure Angular Misalignment	Combination
(0 mm, 0°)	(0 mm, 0°)	(±1 mm, 1° - 3°)
(1 mm, 0°)	(0 mm, 1°)	(±2 mm, 1° - 3°)
(2 mm, 0°)	(0 mm, 2°)	(±3 mm, 1° - 3°)
(3 mm, 0°)	(0 mm, 3°)	

**Table 3 List of misalignment configuration for the AE2**

Pure Parallel Misalignment	Pure Angular Misalignment	Combination
(0 mm, 0°)	(0 mm, 0°)	(±0.5 mm, 1°)
(0.5 mm, 0°)	(0 mm, 1°)	(±1 mm, 1°)
(1 mm, 0°)	(0 mm, 2°)	-
(1.5 mm, 0°)	(0 mm, 3°)	-

(-x mm,  $\alpha^\circ$ ) is a combination misalignment with a negative offset whereas (+x mm,  $\alpha^\circ$ ) is one with positive offset and their definitions are shown in Figure 26. In all cases in the figure, motor shaft is on the left and pump shaft is on the right.



**Figure 26 Explanation of Positive and Negative Offset**

## Results and Discussion

In general, the results confirm the initial hypothesis and the details are stated here.

### 1. No water leakage from the brand new pump with mechanical seal

The first critical finding of the experiment is that no water leakage was obtained from the brand new pump with mechanical seal regardless of which coupling was used during the entire period of experiment. Some results are presented in Table 4.

**Table 4 Some results of the new pump**

offset (mm)	Angle (°)	Leak rate (mL/hour)	
		AE2	Omega E5
0	0	0	0
1	0	0	0
2	0	0	0
3	0	0	0
0	1	0	0
1	1	0	0
2	1	0	-
3	1	0	-
0	2	0	0
1	2	0	-
2	2	0	-
3	2	0	-

### 2. Leak rate of the old pump is reduced when AE coupling was used under pure offset and angular misalignment

The results of the leakage of the old pump with packing gland seal leaked and the results are plotted on graphs. Figure 27 shows both leak rates increase when offset increases. As indicated, an exponential growth in leak rate occurred during the use of the Omega E5 whereas the AE2 provided a reduced linear growth. This finding confirms the hypothesis that AE couplings are more flexible and will cause less bending and will exert smaller forces on the seals. The result in Figure 27 also confirms the prediction of forces in Figure 15. Note

that experiments using the Omega E5 were conducted up to 1.5 mm offset due to its maximum allowable parallel misalignment being 1.6mm.

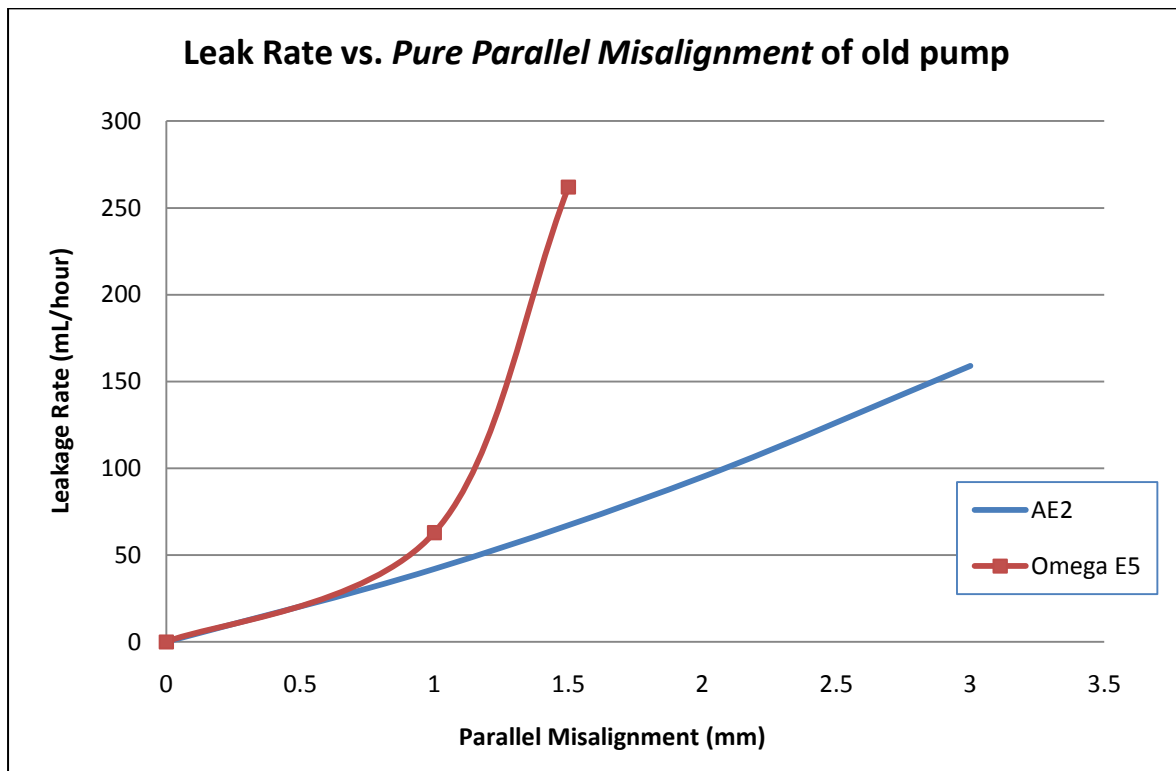


Figure 27 Leak Rate vs. Pure Parallel Misalignment of the old pump

It was also found that, when linked to the motor through an AE coupling, there was no observable leakage from the old pump with angular misalignment up to 3°. Conversely, an increased amount of water leakage was recorded from the same configurations while the Omega E5 was being used. It has to be clarified that the experiments of Omega E5 with angular misalignment were the last to be performed and it was suspected that the bearing of the pump had started to fail at that time due to the constant bending load. It may have led to inconsistent results. However the ascending trend of the results is not deniable and should be taken as a valid finding.

CV joints were originally designed for transmission of torque between two angled shafts. An AE coupling, composed of two CV joints, therefore has high ability to accommodate angular

misalignment with significantly reduced bending of the shafts and provides no leakage with pure angular misalignment. In contrast, the Omega E5 is not as flexible as the AE2 so it results in leakage.

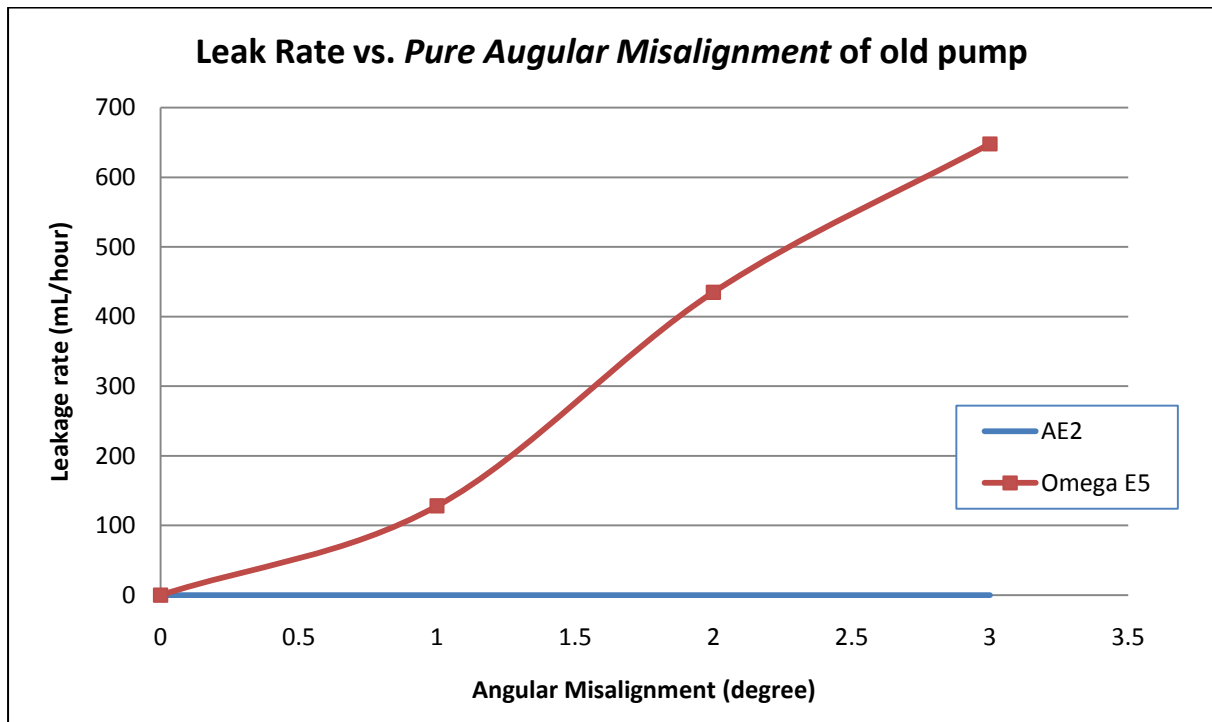


Figure 28 Leak Rate vs. Pure Angular Misalignment of the old pump

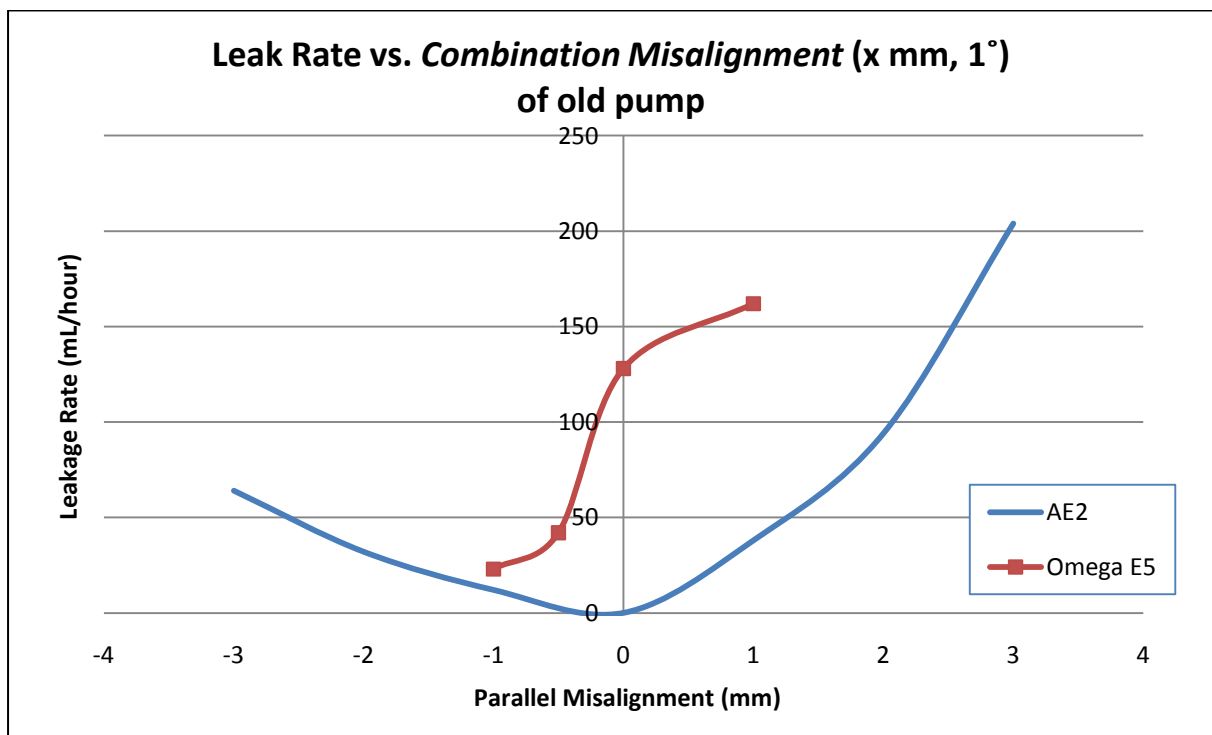


Figure 29 Leak Rate vs. Combination Misalignment, 1° angular and varying offset misalignment, of the old pump

### 3. Combination misalignment can sometimes reduce leakage

Figure 29 demonstrates the leak rate of the pump when it was coupled to the motor with a combination misalignment of ( $x$  mm,  $1^\circ$ ); parallel misalignment varied from -3mm to 3 mm and a fixed angular misalignment of  $1^\circ$ . For the AE coupling, it can be seen that the pump leaked more with a larger offset whereas positive offsets were more contributive.

In his book, Piotrowski (2007, p. 252) only suggests how the shafts will bend under pure parallel misalignment. Distortion of the shafts in other cases are deduced and shown in the Figure 30. This figure clearly illustrates that combination misalignment with positive offset produces more bending than that with negative offset hence a greater leakage rate.

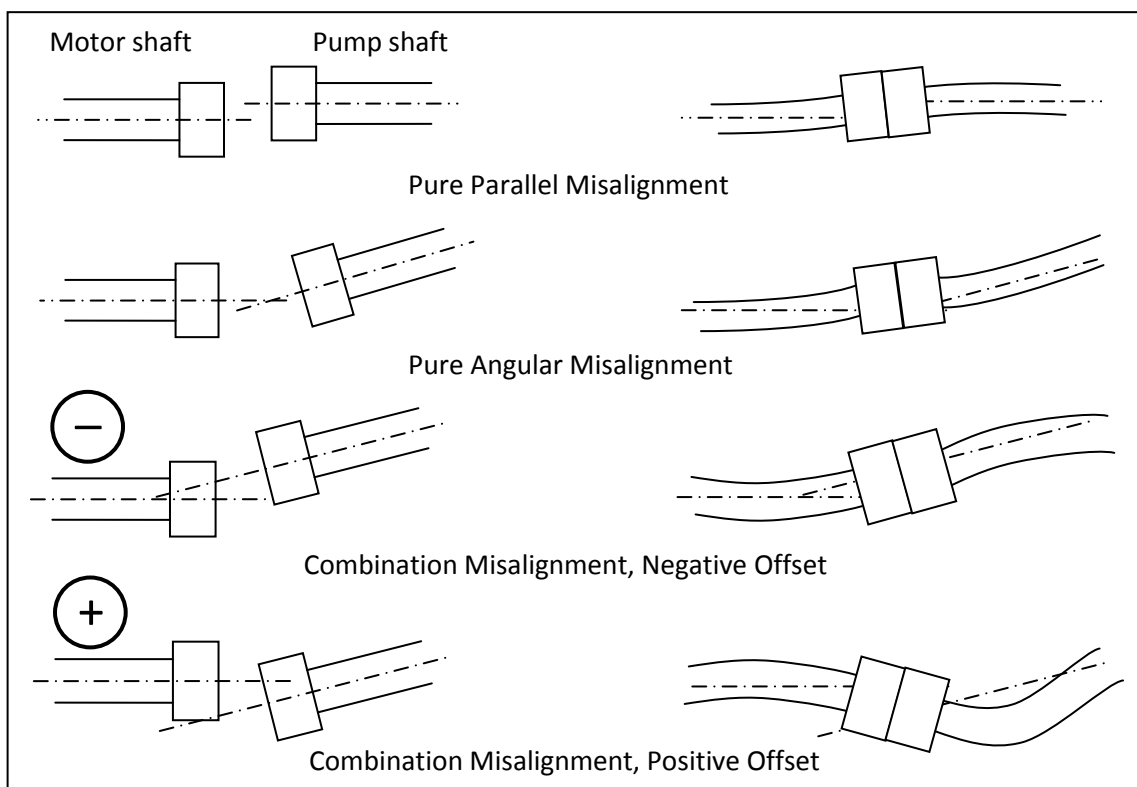


Figure 30 Bending of the shafts due to different misalignment combination

The Leakage vs. Combination curve (Figure 29) also illustrates a rise in leakage rate from negative offset to positive offset of the Omega E5. It is speculated the combination of parallel and angular

misalignments may relax shaft distortion at a certain offset and angle. Despite this finding, the leakage rate curve of the Omega E5 is always greater than the leakage rate curve of the AE2.

The results of all the combination misalignment for the AE coupling is illustrated in Figure 31. The curves also reveal the relaxation effect of combination misalignment. For example pure parallel misalignment, (x mm, 0°), induced a higher leak rate when compared with leakage induced by combination misalignment with an angle of 2°, i.e. (x mm, 2°).

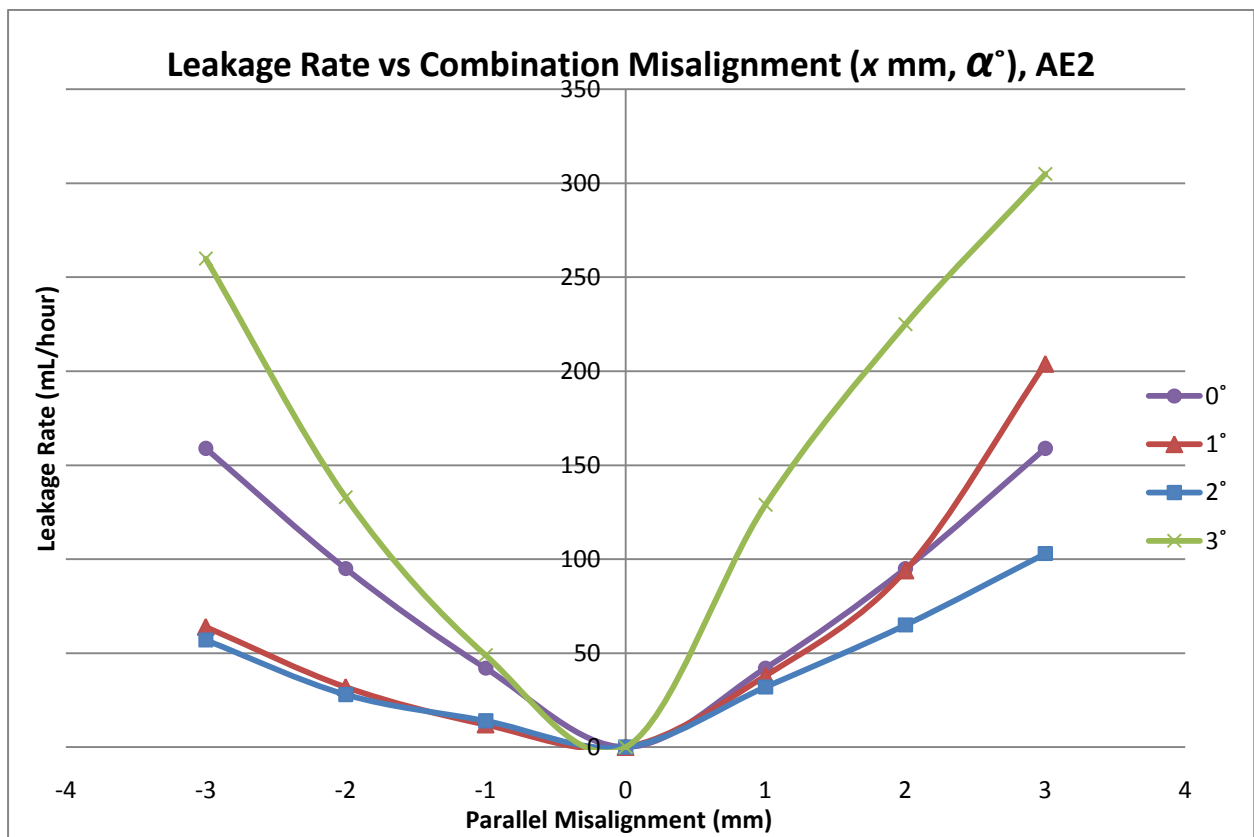


Figure 31 All combination misalignment results of AE2

#### 4. Vibration of Omega E5

Although vibration measurement was not an objective of this experiment, serious vibration was observed when the Omega E5 was used with misalignment conditions due to stiffer resistance. In comparison, the AE coupling operated in a relatively more stable condition. Vibration can cause premature mechanical failure of the pump and motor so it should be prevented.

## 5. No observable change in input voltage

Figure 32 and 33 illustrate the variation of voltage over approximately thirty minutes of operation while the motor and pump shafts were misaligned at 3mm offset and 0°. Regardless of shaft misalignment or which coupling was connected, there was no discernible difference in input voltage throughout the experiments when the couplings were operated within the manufacturer's recommended range.

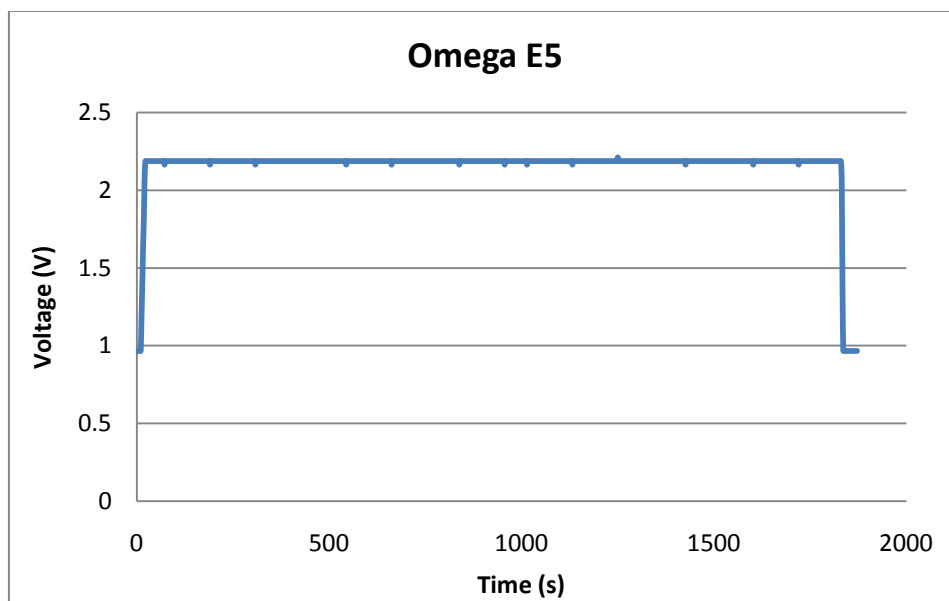


Figure 32 Input Voltage vs. Time of Omega E5

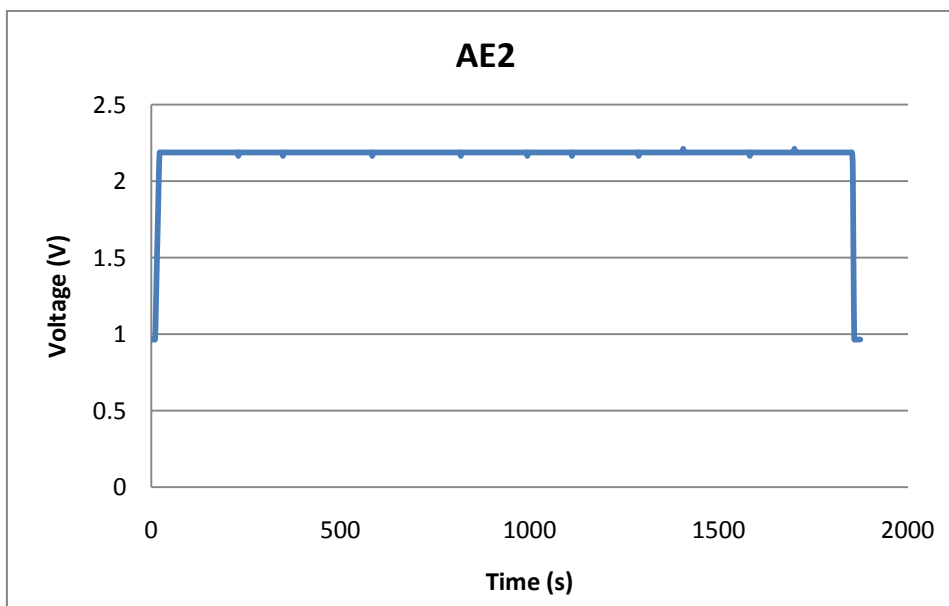


Figure 33 Input Voltage vs. Time of AE2

## Conclusion

The Alignment Eliminator Coupling demonstrably decreases the leakage of an old pump installed with packing gland seal. The study has illustrated that under the same configurations of misalignment, a significant amount of water can be saved by using AE coupling when compared with a traditional elastomer coupling. Although negative offset misalignment configuration decreased leakage, this finding did not deny the advantage of AE couplings to save more water. In addition, use of the AE coupling reduced vibration during the experiments leading to potential savings in bearing life.

It was also found that no leakage occurred from the brand new pump, with a mechanical seal, using either coupling. It is suggested that another series of experiments should be conducted on an older pump with a mechanical seal. Another suggestion is to compare the AE coupling with other types of traditional couplings. Moreover, it is more desirable to measure the energy efficiency with a power generator or dynamometer rather than a pump since the output energy can also be measured.

## Summary of Benefits of the AE coupling

### For the old packing gland sealed pump users:

1. Water leakage reduction
  - For the tested packing gland sealed pump, up to 3800 liters of water per year can be saved if an AE coupling is used instead of the elastomer coupling when the shafts are misaligned at 2°. Table 5 lists the leakage reduction per pump corresponded to the operation condition. The figures from the actual pumping industry are expected to be larger since bigger pumps are being used.

Table 5 Water leakage reduction corresponding to the operation condition

Operating Condition	24 hours, 7 days 14 days shutdown	24 hours, 5 days	16 hours, 5 days 50 weeks per year
Leakage reduction per pump	3800 L/year	2800 L/year	1800 L/year

2. Vibration reduction
  - Reducing vibration can eliminate premature mechanical failure of the bearings in the pump and motor
3. Life extension of the pump and the motor

### For the new mechanical sealed pump users:

1. Eliminate the downtime and cost for the laser alignment.
  - An average time of approximately 3 hours is needed for expensive laser alignment. Installation time for an AE coupling is approximately 3 minutes and no specialist operator skill is needed.

## Reference

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