COUPLING GUARDS

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COUPLING GUARDS

1. General

All flexible shaft couplings must be surrounded by a guard, in order to comply with OHSA requirements. For Turbomachinery applications, this guard is an oil-tight enclosure and the purpose is to trap any oil escaping the machinery seals.

When couplings rotate at high speeds in oil-tight enclosures, they shear the air, and this shearing results in a significant heat generation. The temperature of the enclosure, as well as the coupling, depends on the amount of air shearing and on the ability of the enclosure to dissipate the heat. Another problem with couplings operating in oil-tight enclosures is that negative pressures are created occasionally in the vicinity of machinery seals, causing oil to be sucked in the enclosure, which is particularly detrimental for gear reducers.

Some design guides for fabricating enclosures which operate at acceptable temperatures are introduced here. Enclosures fabricated using these guidelines are successfully operating in petrochemical plants.

2. Are Coupling Enclosures Necessary?

A coupling enclosure is defined as a cylindrical container whose main function is to capture the oil used to lubricate couplings, and the oil that escapes from machinery seals and to return this oil to the reservoir. A coupling enclosure is also a guard, which must be used on all couplings for compliance with Occupational Safety and Health Administration (OSHA) regulations. To satisfy its main purpose, a coupling enclosure must be oil-tight, but not necessarily air-tight. Almost all coupling enclosures are provided with a breather.

When non-lubricated couplings were initially used on high-speed machinery, attempts were made to replace the relatively cumbersome enclosure with an open guard. These attempts ended in failures, and it is now known that enclosures cannot be eliminated. Even if the quantity of oil leaking past the seals is minimal, an installation might lose all of its oil over a period of time. The resulting oil mist surrounding the machines would then become a fire hazard. Coupling enclosures are also needed because atmospheric dust tends to accumulate in any crevices of a coupling.

3. Why Are Coupling Enclosures a “New” Problem?

Coupling enclosures were successfully used in conjunction with oil lubricated couplings for many years. Depending on their design, some worked better than others, but none were a major problem.

When the first “dry” couplings were installed in oil tight enclosures, it was discovered that these enclosures can become very hot. It also became evident that the oil flow to the gear type couplings had not only lubricated the coupling, but also cooled it. Hence, the oil lines were reconnected and dry couplings were being cooled with an oil spray. The manufacturers of dry couplings then rushed back to the drawing board to study the heat problem and how to eliminate it.

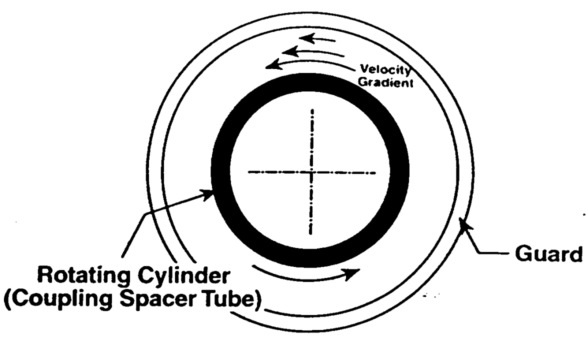
4. How Is Heat Generated In An Enclosure?

Until dry couplings were installed in oil tight enclosures, it was believed that heat was generated by the friction between the gear coupling teeth. Tests have shown, however, that this friction is very small, and it would account only for a few degrees of the total temperature rise. In fact, the heat is generated by air shearing and air turbulence.

a. Air Shearing

The air in an enclosure is contained in an annular cylinder, with the outer diameter (OD) equal to the enclosure diameter, the inner diameter (ID) equal to the coupling’s diameter, and a length equal to that of the enclosure (Figure 1). While the OD of this annular cylinder is stationary, the ID rotates with the coupling. A short time after startup, the air in the enclosure also starts rotating. The velocity of this rotation is variable, with maximum velocity in the vicinity of the coupling and the minimum in the vicinity of the enclosure. Hence, friction occurs between adjacent layers of air and this friction generates heat.

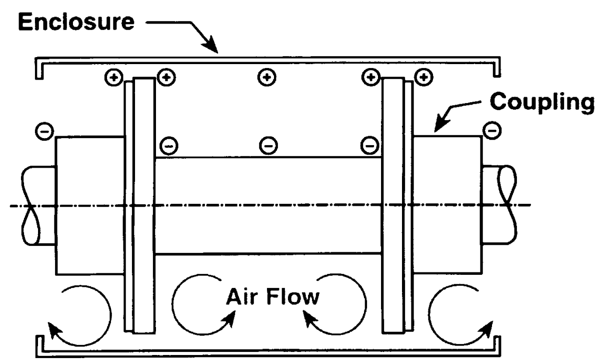
FIGURE 1 Air Shearing of a Disc



b. Air Turbulence

With few exceptions, the three elements of a coupling (two flexing elements and one spacer) have dissimilar diameters. The spacer is smaller in diameter than the rest of the coupling, being particularly evident with diaphragm type couplings (Figure 2). Due to the friction between the air and the face of the disks, a circular motion is generated, and this motion generates additional heat.

FIGURE 2 Disc Effects Inside an Enclosure



Turbulence is also generated by the heads of bolts and nuts connecting the various components of the coupling. A well designed coupling incorporates shrouds over bolt heads and nuts which are placed at high surface speed locations.

5. Predicting Coupling and Guard Temperatures

When a high speed drive is retrofitted from an oil lubricated coupling to a dry coupling, the temperature of the new coupling can be estimated. There are a number of different programs and calculation methods to predict the coupling and enclosure temperature, and they are not always accurate in all cases because of the complexity of the heat transfer equations. However, a reasonable estimate can be gained in many cases, especially where there has been actual correlation between measured guard temperatures and calculated values for specific coupling types in certain enclosure styles.

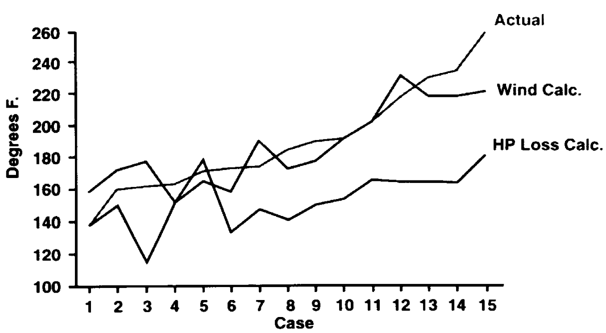
The main inputs (variables) for any of the temperature prediction methods normally used for totally enclosed guards are :

- ambient temperature
- shaft temperature
- coupling dimensions
- guard dimensions
- coupling speed

a. Temperature Prediction

As far as temperature prediction, there are several methods to predict enclosure temperatures These methods generally will predict within +/- 15% of actual measured values. An example comparison graph is shown in Figure 3)

FIGURE 3 Temperature Comparison Graph

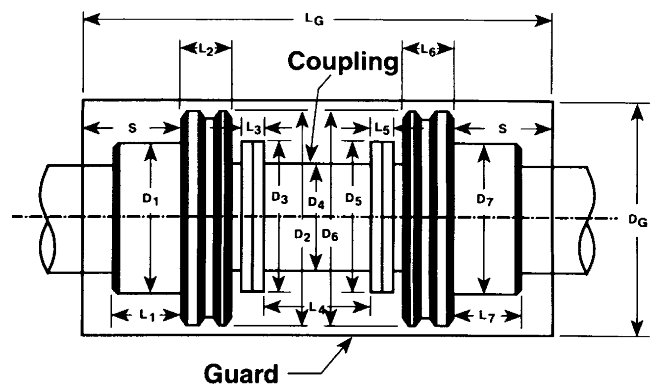


Below are examples of is two calculation methods (there are others);
"HP Loss" method
"Windage" method

b. "HP LOSS" Method

This method calculates the temperature rise of a coupling guard due to rotation of the coupling losing energy to the surrounding air in the form of heat. The algorithm used is known as the horsepower loss method which models the coupling as disks and cylindrical sections with specific diameter and lengths (Figure 4). Note: that the temperature of the air inside the guard may tend to be higher than the guard temperature due to frictional heating, but the guard temperature is assumed to be the air temperature to be conservative. Two types of losses are considered in this method.

FIGURE 4 Coupling Outlined in a Guard



1) "Disc Windage Loss

The disc windage power accounts for frictional losses in both ends of the guard. The correlation with rpm and diameter is

$$\textbf{Disk windage power} \approx \textbf{rpm}^3 \textbf{ x diameter}^5$$

A example equation to find disc windage loss for a coupling is

$$hp_{\text{loss disk}} = rpm^{2.85}\,\frac{1}{K_1}\left(\frac{S}{D_W}\right)^{1/10}$$

where D_W and K_1 are found on a horsepower loss constant chart (Figure 5) for the size of coupling **S** . This equation is to be applied to each end of the coupling if disc loss is present.

FIGURE 5 Typical Horsepower Loss Constant Chart

D_W (in.)	$K_1 \times 10^{10}$
6	2,460
9	372
12	67.6
16	19.3
24	4.76

2) Cylinder Windage Loss.

The cylinder windage power correlation with rpm, diameter, and length is

$$C_{losses} \approx rpm^3 \; x \; \sum diameter^4 \; x \; length$$

An equation to find the amount of horsepower loss for each cylindrical section is

$$hp_{loss\ cylinder} = E \; x \; L_c \; x \; C_f$$

where

$E = RPM^3 \; X \; D^{3.859} \; 5.5 \; x \; 10^{-15}$

D_c = diameter of section (in.

L_c = length of section (in.)

C_f = cylinder friction coefficient

$$C_f = \frac{128B + 2.075}{B(RPM)(D_c)^2} + 0.0015$$

$$B = \frac{D_g - D_c}{D_c}$$

D_g = diameter of guard section (in)

This is done for each section and all the $hp_{loss\ cylinder}$ are summed together.

3) Total Windage Loss.

Add the disc hp loss and loss for the total hp loss.

$$hp_{loss\ total} = hp_{loss\ disk} + \sum hp_{loss\ cylinder}$$

To find the temperature of the guard, take the area of the guard, $\mathbf{A_g}$ (ft^2), and divide into the hp loss total,

where

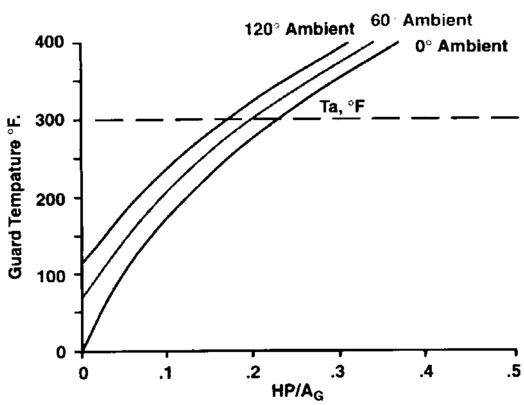
$$A_G = \frac{\pi}{144} \; x \; D_G \left(L + \frac{D_G}{2} \right) \quad (ft^2)$$

D_G = diameter of guard (ft)

L_G = length of guard (ft)

From Figure 6 for the total HP/A_g and the correct ambient temperature, T_a (^{0}F), find T_{gi} the temperature of the guard (^{0}F). ***Note:*** If T_{gi} > 175^{0}F, use the scaling technique below to find the actual HP_{ioss} and operating temperature of the guard.

FIGURE 6 Temperature Rise vs HP/Ag



$$HP_{loss\ total} = \frac{590}{T_{g1} + 560} = HP_{loss\ actual}$$

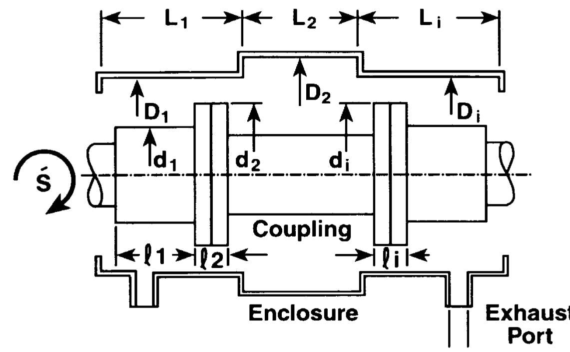
Again from Figure 6, use $HP_{loss\ actual} / A_G$ and ambient temperature: to find the operating temperature of the guard (^{0}F).

c. Windage Method

This method is mainly empirical and derived from R&D testing

1) Coupling Temperature with air cooling. All dimensions are in inches and the temperatures are in degree F (see Figure 7)

FIGURE 7 Inputs for Windage Method



For enclosures with air cooling, the coupling temperature is given by the equation:

$$T_c = K_2 \, x \, K_3 \, x \, K_4 \, x \left[S/1000\right]^{(K_{4e}/K_1)} + \left(T_A + T_S\right)/2$$

T_c = coupling temperature

K_1 = air shear factor = (enclosure mean dia. ./ max. coupling dia.)$^{0.27}$

K_2 = area factor = (coupling surface area factor / enclosure surface area)

K_3 = coupling circulation factor = (max. coupling dia. / min. coupling dia.)$^{0.2}$

K_4 = (1/1000) x (enclosure surface area / exhaust port area) and the exponent factor K_{4e} is given by the empirical formula:

$$K_{4e} = \left(1/K_4\right)^{0.27} + 0.65$$

S = application speed (rpm)

T_A = ambient temperature

T_S = shaft temperature

2) Observations

The coupling surface area factor (K_{ac}) used to determine K_2 can be evaluated with the formula:

$$K_{ac} = \sum_{i=1}^{N_c} d_i^{2.8} \, l_i$$

where

K_{ac} = coupling surface area factor

N_c = number of coupling cylinder surfaces

l_i = length of cylinder i

d_i = diameter of cylinder I

The enclosure surface is:

$$A_e = \pi \sum_{i=1}^{N_e} L_i \, D_{i_i} \quad \text{(sq. in)}$$

Where

A_e = enclosure surface area

N_e = number of enclosure cylindrical surface

L_i = length of cylinder i

D_i = diameter of cylinder i

The enclosure mean diameter to use to determine K_1 is given by:

$$Dem = \left(\sum_{i=1}^{N_e} L_i \right) \Big/ \left(\sum_{i=1}^{N_e} \left(L_i / D_i \right) \right)$$

where

Dem = enclosure mean diameter

The maximum value for K_4 is 0.6 (case of no air flow) while a properly designed enclosure will exhibit an air flow factor K_4 = 0.1 to 0.2.

Mathematically, the exponent factor K_{4e} must be situation in the domain 1.8 (for K_4 < 0.2) to 2.2 (for K_4 = 0.6)

The exhaust ports area is given by the equation:

$$A_{cp} = (\pi/4) \times \sum_{i=1}^{N_p} D_{pi}^2$$

A_{cp} = exhaust ports area

N_p = number of exhaust ports

D_{pi} = diameter of exhaust ports i

6. Dissipating The Heat

The heat generated within the enclosure is normally dissipated by it's outside surface into the surrounding air. To increase this dissipation, common engineering sense should be used:

- increase the surface area, either by making the enclosure large or by adding radiator fins
- allow air circulation over the enclosure
- shade the enclosure from exposure to the sun or from other hot components, such as turbine exhausts and steam lines

7. Oil Cooling

If the enclosure cannot be modified, and it's temperature is unacceptably high, spraying the coupling or the inside of the surface of the enclosure will dissipate the heat.

To calculate the temperature drop that can be achieved by using oil cooling, the following are needed:

- cooling oil temperature
- cooling oil flow rate
- surface which is being sprayed

8. Air Cooling

If the air heated by friction is allowed to escape from the enclosure, and if outside air is allowed to replace the heated air, the enclosure's temperature can be significantly reduced. However, venting the air out of the enclosure could create the problem of oil mist escaping into the atmosphere. Through proper enclosure design, this problem can be eliminated.

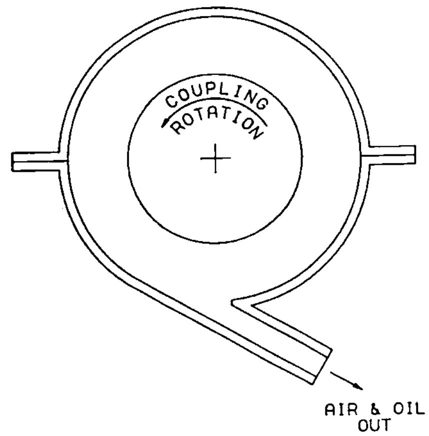
The following items must be considered when designing an enclosure with air cooling:

- sizing the air ports
- separating the oil from the air
- avoiding negative pressures

9. Sizing the Air Ports

The exhaust port should be tangential to the enclosure's outside diameter and directed with the coupling's rotation, as shown in Figure 8. This port (or ports) can have any profile; however, a tubular port is the most convenient to use. The larger the port in comparison with the enclosure, the lower the enclosure's temperature. A large exhaust port, on the other hand, can create problems in separating the oil from the air.

FIGURE 8 Exhaust Porting



The intake and exhaust ports should be placed so that no "dead zone" is left in the enclosure. Hence, if one exhaust port is placed in the middle of the enclosure's length, one intake port should be used at each end of the enclosure. Conversely, if two exhaust ports are used (this is desirable for enclosures longer than 36 inches), then one intake port should be placed halfway between the exhaust ports.

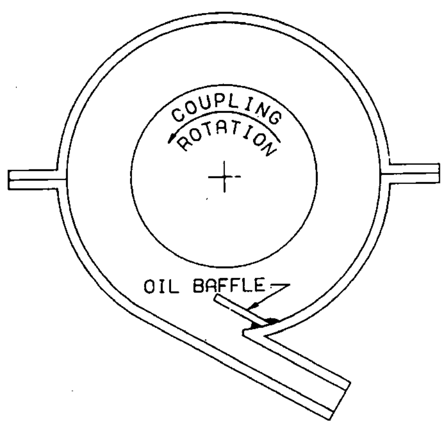
The total intake port area should be half the total exhaust area to make sure that the air leaves through the exhaust and not the intake.

10. Separating the Oil From the Air

The amount of oil that escapes past a seal is usually very small. Some compressor manufacturers, however, decided to eliminate the seals completely and to recapture the bearing oil from the coupling enclosure rather than from the compressor housing. It is therefore possible that a high flow of oil is still going into the enclosure, even when the couplings are nonlubricated. This is hot oil and does not normally provide much cooling.

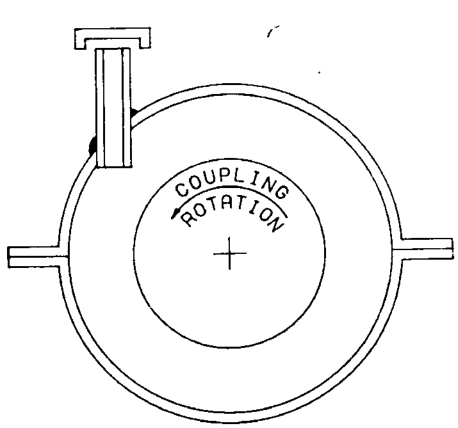
To prevent this oil from becoming a mist, many enclosures rely on the centrifugal effect created by the rotation of air, similar to the working of a cyclone separator. To get the oil out of the enclosure, a baffle should be installed, over the exit port, as shown in Figure 9. This baffle will force the oil out of the enclosure and prevent it from rotating more than one revolution before exiting.

FIGURE 9 Baffle Plate Installation



The actual separation between air and oil is done outside the enclosure as shown in Figure 10. All ports should have breather caps, provided with a coarse wire mesh filter.

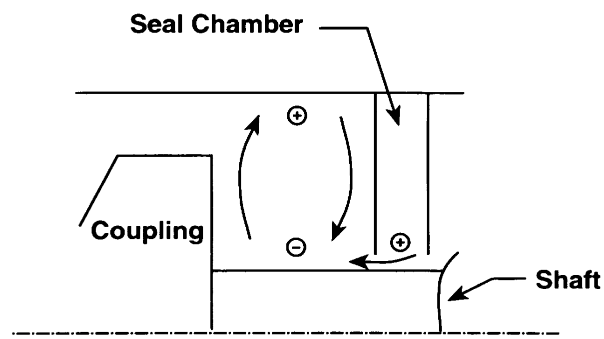
FIGURE 10 Separation of Oil from Air



11. Avoiding Negative Pressures

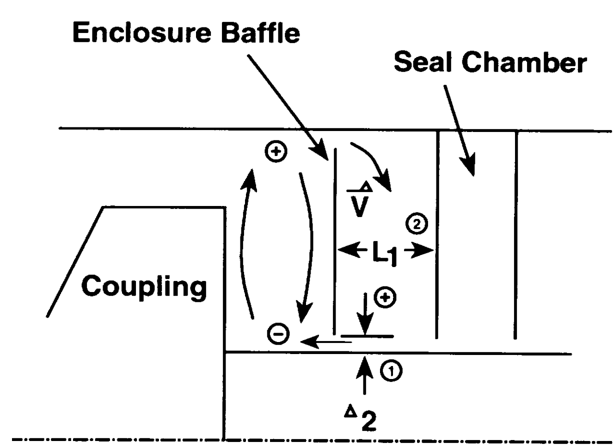
In reduced moment coupling applications especially, the spinning coupling produces a vacuum at the shaft that can "suck" oil past seals (Figure 11).

FIGURE 11 Compensation for Negative Pressure



A baffle plate between the face of the coupling and the seal face of the machine can eliminate the effects created by the vacuum (Figure 12).

FIGURE 12 Means for Pressurizing the Seal Area



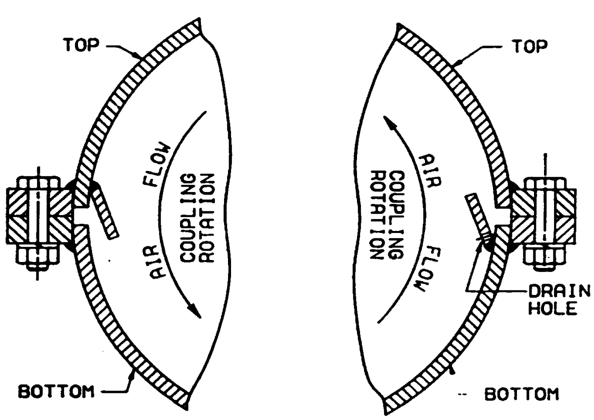
12. Basic Enclosure Design Features

Usually, couplings enclosures are cylindrical and split on a diametral plane. The two half cylinders are connected by bolted flanges. A few basic design rules should be followed.

A coupling enclosure should be free to float at both ends. Some designs are bolted to one machine and free to move axially at the other end. Such a design allows for axial motion between machines, but the enclosure is rigid with respect to any offset motions.

A coupling enclosure should be oil-tight. Even though all enclosures are usually welded construction, oil still can still leak out, usually at the flanges. Gaskets and caulking seldom can stop the leaks. A simple design, shown in Figure 13, can help eliminate these leaks.

FIGURE 13 Sealing of Flanges



Breathers are required on enclosures in order to prevent the formation of an “oil plug” and prevent the possibility of filling the enclosure with oil. Breathers should be designed so that oil cannot escape. In designing the enclosure, the direction of rotation of he coupling should be considered. A baffle should prevent the air from flowing out the breather, as shown in Figure 14.

FIGURE 14 Baffle of Intake Port