RECENT CASE HISTORIES WITH COUPLING ENCLOSURES

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ABSTRACT

Coupling enclosures are oil-tight guards which serve the double purpose of protecting people from the rotating coupling and returning oil that escapes past the seals back to the oil reservoir. Enclosures were, and still are, a much-neglected component of machinery trains. When used with gear couplings they are notorious for oil leaks; when used with dry couplings they can operate so hot that they may harm people, and even cause machinery failures. Four such bad cases are discussed, the solutions used to correct the problems are reviewed, and design recommendations are provided.

INTRODUCTION

A paper on the "Design of Coupling Enclosures" was presented at the Fourteenth Turbomachinery Symposium (1985). Many enclosures were built on the basis of that paper during the last five years, and a lot has been learned from both the successes and the failures in the field.

Two facts are no longer questionable today: that the dry couplings have replaced the gear couplings in all new (and many existing) applications in turbomachinery, and that oil-tight enclosures are, and will continue to be, used in most high-speed applications. *Note:* Outside the U.S.A., gear couplings are still used in many new applications.

The last five years have also provided us with additional information on the reliability of nonlubricated high-speed couplings. A few failures related to excessive misalignment, bad installation procedures, and *incorrect enclosure design* have occurred. A failure of the latter type is discussed herein.

The "design" paper published five years ago proved beneficial in helping engineers design good enclosures. Unfortunately, in many cases, the design is still left in the hands of inexperienced draftsmen, and the fabrication is performed in the field by people who understand little about air flow, heat dissipation, and dynamic sealing. The results can sometimes be disastrous, as will be shown.

CASE 1
THE DESIGN OF A LEAK-PROOF ENCLOSURE

A fire that caused a long shutdown at a plant of Quantum Chemical Corporation prompted their safety department to search for other "fire hazards" in the plant. Such fire hazards were found to be the continuous oil leaks from the gear coupling enclosures on steam turbine to centrifugal compressor drives. The basic enclosure design, as manufactured by the OEM, is shown in Figure 1. Pounds of RTV sealant could not stop the oil leaks. In order to minimize the resulting mess, the maintenance department fabricated steel trays, which were placed under the enclosures to catch the spills. The oil was flowing from the trays into barrels placed near the compressors. These barrels had to be emptied daily of the accumulated oil. A study of the existing enclosures showed that the main leaks occurred at the connections with the compressor cases, and at the horizontal split lines. The author redesigned the enclosures; the main improvements over the original design are:

- The split lines incorporate dynamic seals, based on the design proposed in the first paper, and reproduced now in Figure 2.
- The enclosure was made to "float" at both ends, rather than being rigidly attached to the turbine. *Rigidly attached enclo-*

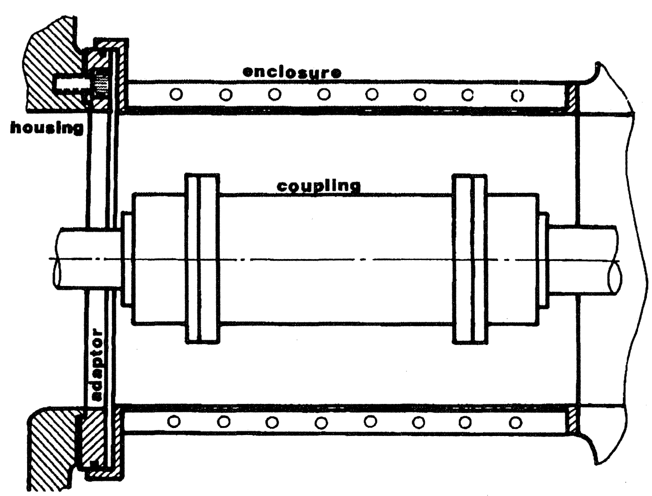

Figure 1. Rigid Enclosure, OEM Design.

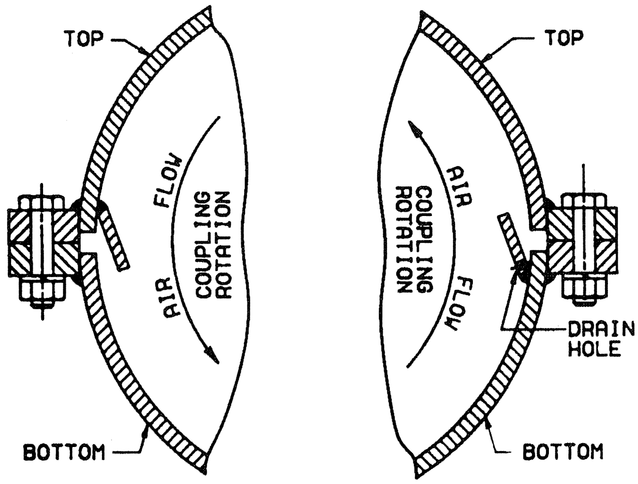

Figure 2. Dynamic Sealing for Flange Joints.

sures resist offset movement between the two machines. Evidently, the enclosure is too weak to prevent the machine movements, and the end result is the distortion of the enclosure, and inevitable oil leaks.

• The drain line was attached to the enclosure tangentially, and the vent was designed to inhale air in the enclosure. *In order to prevent oil leaks, a designer must provide good seals, and must ensure that the oil is evacuated from the enclosure as fast as possible. The oil cannot be drained if air is not freely admitted into the enclosure.*

• The side seal was moved to a radius that is smaller than the enclosure drain point, as shown in Figure 3. *The enclosure-to-compressor connections of the original design generated pools of oil that could not be drained, and which contributed to the continuous leaks.*

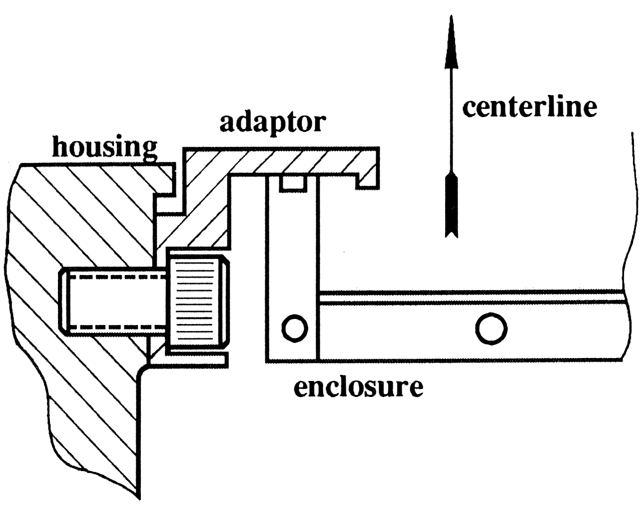

Figure 3. Redesigned Enclosure-to-Compressor Seal.

The results of these modifications were truly leakproof enclosures. Actually, because no leaks occurred, the mechanics kept observing the sight glasses in the drain lines, to make sure that oil was indeed being supplied to the couplings. The fire hazard previously created by the oil leaks was completely eliminated.

CASE 2
THE INABILITY TO DESIGN A COOL ENCLOSURE

This case involves four new compressor trains operating at 12,000 rpm. The dry couplings originally considered were so large that exception was taken to API 671, "Special-Purpose Couplings For Refinery Services," paragraph 2.1.1, and the rated continuous torque of the selected coupling was only 140 percent (rather than the specified 175 percent) of the operating torque. Even with this reduction in capacity, calculations showed that the coupling weight caused lateral resonance vibrations of the compressor shafts. The coupling manufacturer reduced the weight by scalloping all the flanges, thus creating a rather square-looking coupling. The geometry of the flanges, combined with the large peripheral velocity, created very large air shearing, and the enclosure temperature reached 350°F. None of the improvements to the enclosures that the author implemented could reduce the temperatures to an acceptable level. The possibility of the complete elimination of the oil tight enclosure was considered. Unfortunately, as is most often the case, the oil leaking past the gear box seal was about 75 gallons per day, which mandated the presence of the enclosure.

The only solution available on short notice was the replacement of the dry couplings with gear couplings. These couplings are still in satisfactory and *cool* operation, three years since the modification.

It is likely that a more aerodynamic, nonlubricated coupling with even a smaller overhung moment could be found today for these particular applications. However, after months of inability to start a large and expensive installation strictly because of a dry coupling, the management of the plant is reluctant to experiment with a new type of coupling to replace something that, so far, operates satisfactorily.

CASE 3
A BELATED, BUT SUCCESSFUL DESIGN

This case was reported three years ago at a Vibration Institute meeting by Mr. David Galster of Quantum USI Division. The gear couplings in an ethylene plant were replaced with diaphragm couplings, and the immediate results were high enclosure temperatures and oil leaks into the enclosure connecting the gear increaser to the high speed compressor. The combination of 11000 rpm and a disk diameter of 13 in created a peripheral velocity of 624 ft/sec (425 mi/hr!), which in turn generated enough heat to increase the enclosure temperature to over 300°F.

In an attempt to reduce this high temperature, which could have caused the deterioration of the oil leaking from the compressor seals into the enclosure (at the rate of 150 gal/day!), a new enclosure was fabricated. The idea behind the new design was to significantly increase the enclosure's surface area in order to improve the heat radiation. The new enclosure design is shown in Figure 4. In hindsight, it is easy to see that the odd-looking birdhouse design could not have worked. The boiler type tubes intended to increase the heat transfer were at the same time impeding the smooth air flow inside the enclosure, aggravating the turbulence. The end result was a slight drop in enclosure temperature, which still ranged between 250 and 300°F. The oil that continued to leak from the machines was exiting the enclosure at the same temperatures, and was not allowed to go back to the reservoir because of possible degradation.

Eventually, Quantum contracted the OEM to manufacture an enclosure based on the guidelines described in the 1985 paper. Problems occurred in two areas:

• Oil continued to be sucked into the enclosure by the coupling. The problem was eventually solved through the introduction of a one psig nitrogen purge in the oil labyrinth seals.

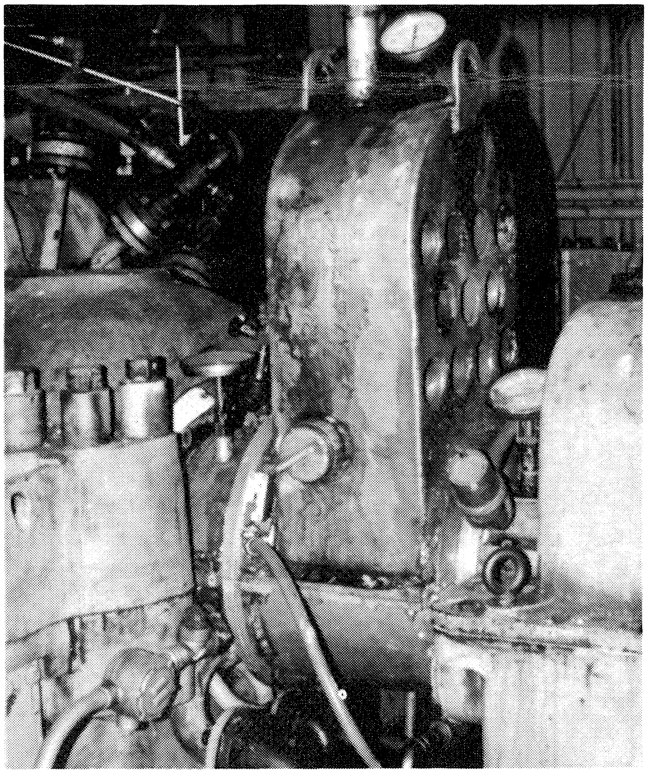

Figure 4. Increased Surface Area Enclosure Design.

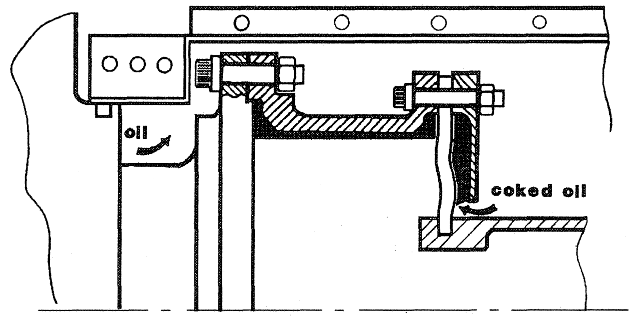

Figure 5. Fabricated Enclosure and Locked Coupling.

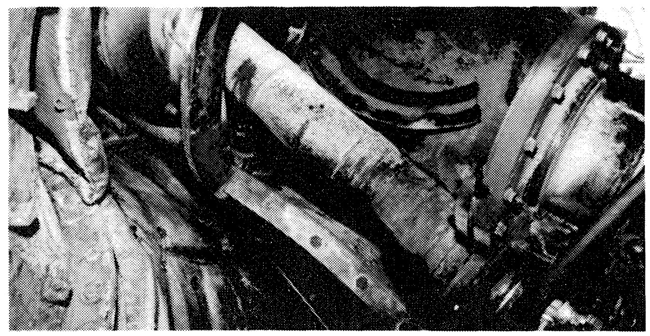

Figure 6. Equipment Failure Caused by an Improperly Designed Enclosure.

• No significant reduction was initially seen in the enclosure temperatures. It was, however, noticed that very little air was being discharged, so that the intake filters and the exhaust demister were replaced with wire mesh screens. The air flow at the exhaust tube increased rapidly, and was measured at 235 cfm. The result of the increased air flow was that the enclosure temperature dropped to 180°F.

CASE 4
A CATASTROPHIC COUPLING FAILURE CAUSED BY THE ENCLOSURE

The failure occurred on a large compressor train, driven by an industrial gas turbine, in tandem with a 5,000 hp steam helper-starter turbine. The gear coupling that originally connected the two turbines was replaced with a multiple diaphragm coupling at the time the whole system was upgraded. The author would like to emphasize from the beginning that the failure was in no way caused by the coupling.

This is a very difficult application for any dry coupling, which connects the discharge ends of both turbines. In addition to the operation at high temperatures, the coupling has to accommodate a significant axial shaft movement. Because the OEM was late in delivering a new enclosure, the maintenance department fabricated a new one *onsite*. A partial sketch of the fabricated enclosure is shown in Figure 5. It incorporated a few significant mistakes, which eventually caused the diaphragms at the steam turbine end to rupture, the failed coupling to rip the enclosure, and the steam turbine shaft to bend. The appearance of the coupling after failure is shown in Figure 6.

The enclosure features that caused these failures were:

• The enclosure side wall was very close to the coupling bolts. This configuration made the coupling operate as a blower, causing a large negative pressure at the steam turbine oil seal. Oil flowed into the enclosure from that bearing.

• The drain line was fabricated from a ¾ in electrical conduit, in the belief that a *dry* coupling enclosure would operate *dry*. In addition, the drain line was perpendicular to the enclosure wall, and no baffle was added.

• No breather was provided. The enclosure was intentionally made air tight as, at the time of the retrofit, a vacuum (5.0 in of water) pump was installed at the oil tank, in order to improve the flow of the oil returning from the bearings.

The temperature of the enclosure must have been *very high*. After the accident, coked oil was found inside the enclosure, as well as inside *and outside* the coupling. Lubrication experts estimated the coupling temperature at about 700°F! It is amazing that the coupling continued to operate for three years. Eventually, it failed during a cold December.

The condition of the coupling immediately before the failure is sketched in Figure 5. The dark area represents coked oil. The density of this substance was amazingly high. The author had to use a screwdriver and a hammer to break it into pieces (Figure 7). This high density was caused by the large centrifugal acceleration (4,500 g) in the coupling, which tightly packed every particle of coked oil as it entered the coupling. Eventually, the space between the first diaphragm and the guard disk was completely filled with rock-solid coke.

The failure was triggered by large axial shaft movements, which demanded from the coupling a flexibility it no longer had. The axial movements were caused by freak winter conditions in South Texas. The temperature variations during the six days before the failure is shown in Figure 8. Adding to the 45° temperature variations in the air, the machines and the skid were also heated by the sun during the day. The resulting thermal movements caused the breaking of one diaphragm after another.

To prevent the reoccurrence of the failure, the author and the plant engineers designed a new enclosure, in which:

• The side walls were moved as far as possible from the coupling bolts.

Figure 7. Coked Oil that Blocked Coupling Movements.

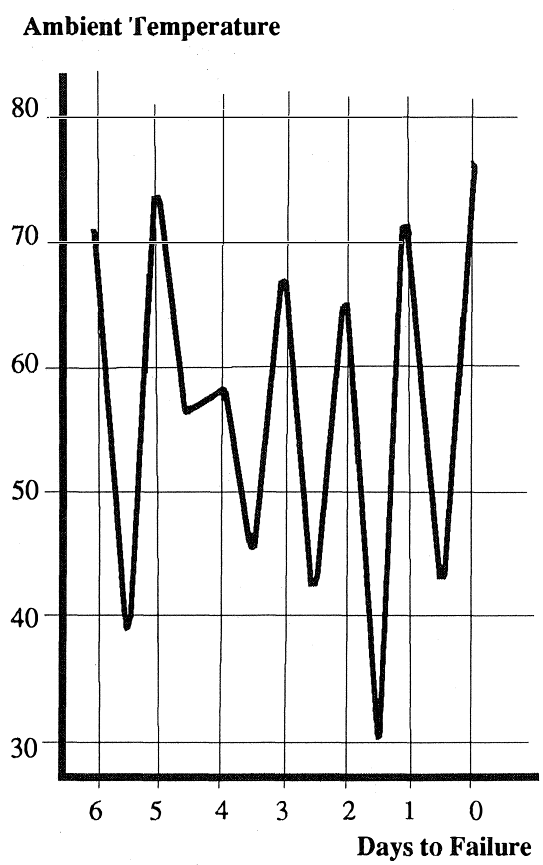

Figure 8. Ambient Temperature Variations before the Failure.

- Two drains and *two breathers* were incorporated. The drains were provided with air escape piping (Figure 9), and provisions were made to increase the air flow, if necessary, by connecting the breathers to the plant air supply.
- A 10 in trap was built in the drain line, ensuring the oil return *without* breaking the vacuum in the oil reservoir.

A drawing of the new enclosure is shown in Figure 10, and a piping diagram is shown in Figure 11. With all these improvements, the enclosure still operated hot because of heat radiated toward it. An air blower was added to move the hot air that surrounds the enclosure, which has now operated satisfactorily for close to two years.

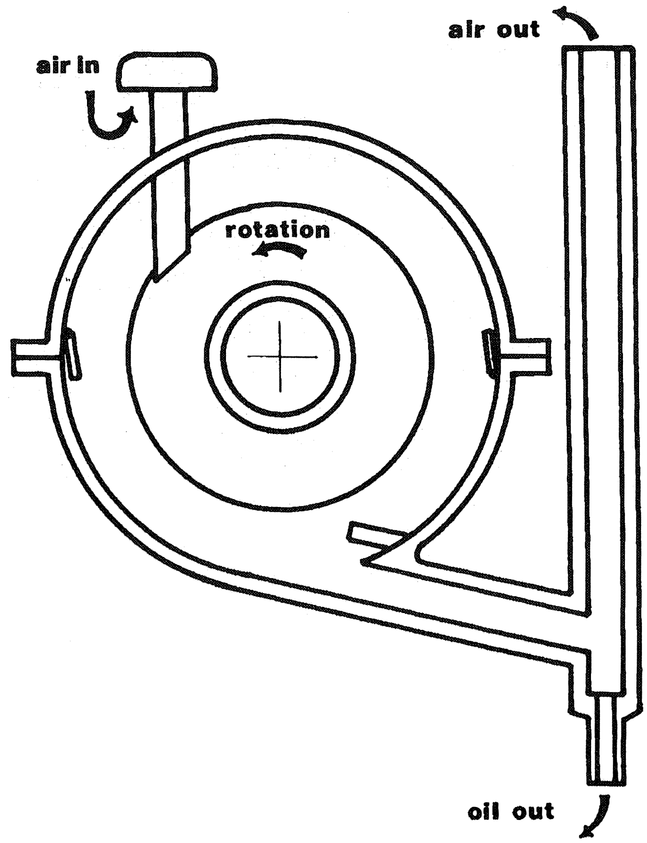

Figure 9. Enclosure with Air Cooling.

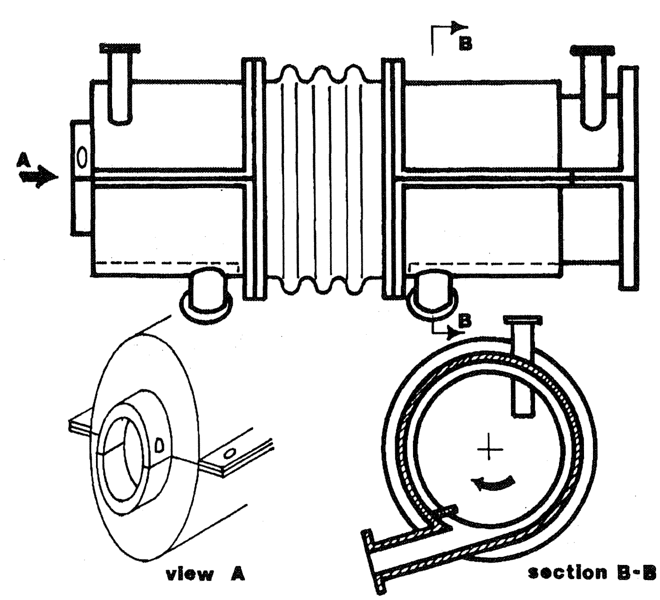

Figure 10. Redesigned Enclosure.

NEW DESIGN GUIDELINES

The experience gained in recently designed enclosures, and the experimental work performed by a manufacturer since the first paper was presented, allow the suggesting of additional design guidelines.

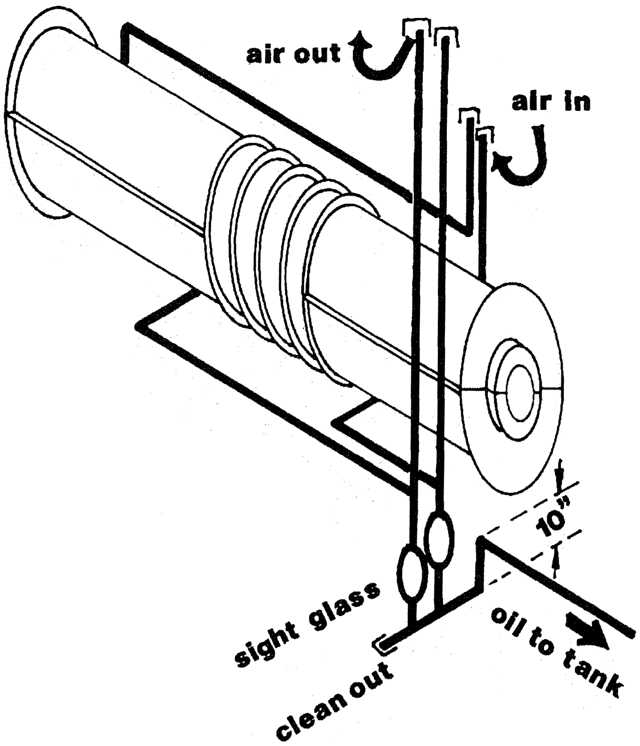

Figure 11. New Enclosure Piping Diagram.

• The original paper gave formulae for the calculation of the *coupling's* temperature. Engineers were interested in the calculation of enclosure temperatures. The following formula can be used:

$$T_{enclosure} = 0.85 \times T_{coupling} + 10°F$$

Actual tests have shown that this formula has an error of ± 15°F.

• The method recommended in Figure 7 of the 1985 paper for the reduction of oil being sucked out of the machine seals proved ineffective at high speeds or when couplings with abrupt diametral changes are used. A more effective method to break the vacuum present in the vicinity of the bearing seals is shown in Figure 12. The baffle must have a small clearance at the shaft, and about one inch clearance at the enclosure.

• The original paper stated that "spraying the *coupling* or the inside surface of the enclosure with oil" will help in maintaining an acceptable temperature. The statement is in error, inasmuch as the *coupling* should not be sprayed, only the inside of the enclosure, and only in the direction of the coupling's rotation. Rather than performing oil flow calculations, the author recommends the installation of an oil valve in the circuit, as shown in Figure 13, and the adjustment of the flow until an acceptable temperature is achieved. Two nozzles must be used, at the ends of the enclosure, with one drain at the center.

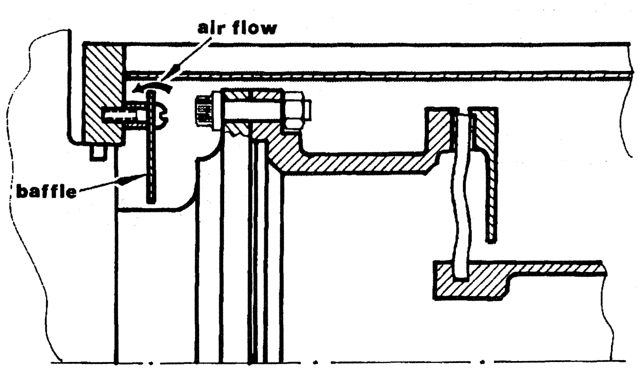

Figure 12. Vacuum-Breaking Baffle.

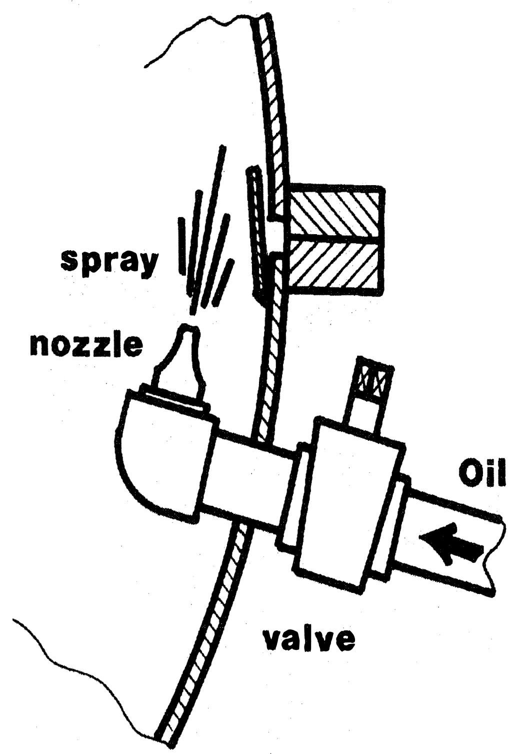

Figure 13. Enclosure Cooling with Oil Spray.

CONCLUSIONS

Experience has shown that not all dry couplings can operate at high speeds in an oil-tight enclosure. High speed couplings must be designed to generate as little windage as possible; such designs require a smooth profile. The largest windage generators are scalloped flanges, and exposed bolts and nuts, particularly the ones placed at large diameters.

Experience has shown that enclosures can be designed to be oil-tight, and such designs require more good sense than good gaskets or sealants. It is apparent that air cooling cannot always be used, particularly when the enclosures must also be air tight (such as when dangerous gases can penetrate the enclosure). Oil cooling, combined with a continuous nitrogen purge, is a viable solution.

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