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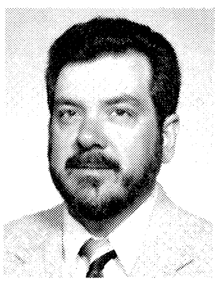
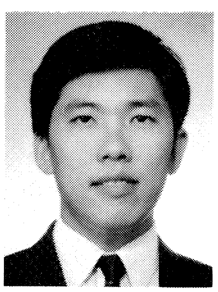
ADAPTATION OF A PROPYLENE REFRIGERATION COMPRESSOR WITH DRY GAS SEALS

by
John R. Dugas, Jr.
Senior Engineer
Bich X. Tran
Senior Area Engineer
E. I. duPont deNemours & Company, Incorporated
Orange, Texas
and
James F. Southcott
Market Segment Manager, Type 28 Product Group
John Crane Inc.
Morton Grove, Illinois



John R. (Johnny) Dugas is a Senior Engineer with Du Pont's Chemicals Department in Orange, Texas. For the past 11 years, he has been assigned to the Technical Department of the ethylene manufacturing facility where he is involved in repair, troubleshooting, redesign, and specification of turbomachinery and other process equipment. He has worked at Du Pont since graduating from the University of Southwestern Louisiana with a B.S. degree in Mechanical Engineering (1973). Previous activities with Du Pont dealt with maintenance and construction of mechanical equipment including assignments with Du Pont's Construction and Field Service Divisions.



Bich X. Tran is a Senior Area Engineer with E. I. du Pont de Nemours and Company, Incorporated. He joined Du Pont in 1981 after receiving a B.S. degree in Mechanical Engineering from the University of Missouri. He has been involved in specification, technical evaluation, redesign, troubleshooting, and maintenance of various chemical processing equipment. Currently, he is assigned to the Technical Department of Du Pont's ethylene manufacturing facility located at the Sabine River Works site in Orange, Texas.

James F. Southcott is the Market Segment Manager, Type-28 Product Group, for John Crane Inc. His responsibilities with John Crane include the application and marketing of the dry gas seal and its ancillary instrumentation/control systems to turbomachinery in the HPI, Chemical and Gas Transmission Segments.

Prior to joining John Crane, he had over 20 years of experience in a broad range of mechanical equipment applications, design installation, and troubleshooting. This included experience in fluid dynamics/turbomachinery.

Mr. Southcott has a B.S.M.E. degree from the University of Wisconsin.

ABSTRACT

The retrofit of a 35000 hp, two-case centrifugal, propylene refrigeration compressor with tandem dry gas seals in Du Pont's ethylene plant at Orange, Texas, is described. The installation of these dry gas seals is one of the first applications to propylene refrigeration service in the United States.

The new seal design eliminated seal oil contamination of the compressor and downstream heat exchangers which led to decreased efficiency, effectiveness, and subsequent loss of ethylene production. The seals also reduced the capital investment for a flare system upgrade project $1.5MM, by decreasing propylene losses during system shutdowns caused by existing seal system shortcomings.

This retrofit was unique in several ways. The original compressor manufacturer had no experience with dry gas seals installed in their equipment. They were very willing to cooperate in this venture, but only to the point of providing dimensional data and engineering review. Due to the "sold-out" condition of the ethylene market, this installation had to be accomplished during a limited shutdown. In order to minimize downtime, an innovative installation method was developed which eliminated opening compressor casings even though the new design required removing a shaft sleeve. To demonstrate the feasibility of this method, a mock up was built simulating working conditions to develop techniques and tooling to remove the shaft sleeve.

INTRODUCTION

Although the spiral groove dry gas seal technology has been fully developed for over 10 years, it has only been used extensively during the past five years. There are over 2000 of these dry gas seals in use and the petrochemical and refining industries have had excellent results with them. For example, the spiral groove dry seal has more than four million hours running time on various hydrocarbons. The longest continuous running time of a dry seal experienced to date is 43000 hr. The retrofit at the Orange facility is one of the first applications in the United States of these dry seals with propylene. The advantages of the dry gas seal over conventional oil seals are:

- Eliminating the seal oil support system including seal oil pumps, reservoirs, filters, traps, coolers and consoles.
- Eliminating the parasitic losses from the wet seal system.
- Preventing process gas contamination with seal oil.
- Reducing the process gas leaks (from 15 scfm and above for wet oil systems to one to three scfm for the dry gas seals).
- Reducing maintenance costs.
- Reducing unscheduled shutdowns and minimizing downtime.

BACKGROUND

The initial propylene refrigeration compressor was installed in 1967. However, it was replaced in 1985 to take advantage of new technology for increasing compressor efficiencies (Figure 1). This compressor, manufactured by an overseas supplier, has provided excellent service with the exception of a low settle out pressure required by the seals and process gas oil contamination problems experienced, due to a fundamental seal design shortcoming. This design problem was aggravated by process seal upsets and improper operation of the seal system during unit outages.

A proposed ethylene modernization project for the plant included capital investment for modernizing the flare system. The flare system upgrade provided for handling the propylene vented from the propylene refrigeration system during a shutdown. The normal compressor settle out pressure is 70 to 80 psig, but the design limit of the oil seals mandated that propylene be sent to the flare to maintain the system pressure below 40 psig during shutdowns. A new dry flare drum, estimated at $2.0MM, would be needed to handle this additional load.

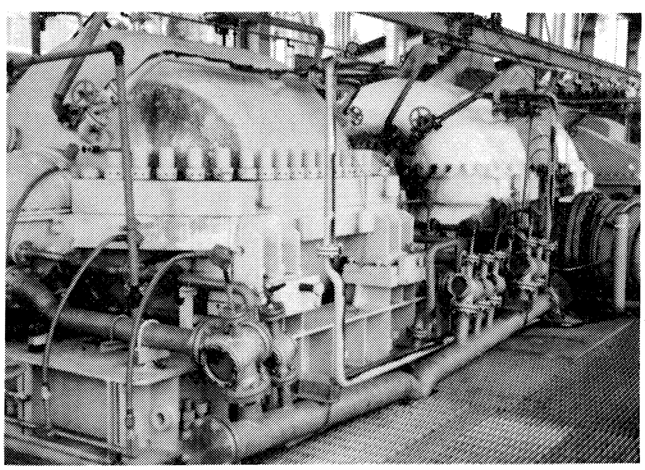


Figure 1. Propylene Refrigeration Compressor.

The modernization study also considered using High Flux™ tubing in heat exchangers downstream of the compressor to increase capacity at minimal cost. These tubes could improve heat transfer by tenfold, but they are highly susceptible to fouling. Since the propylene refrigeration system has experienced severe contamination by oil from the compressor seals, High Flux™ tubing could not be used.

Using dry gas seals eliminated both of these problems. The seals do not use oil, so oil contamination is no longer an issue. High Flux™ tubing can be used, reducing the overall modernization costs by $3.1MM. The design of the dry seal allows the propylene refrigeration system to settle-out at 70-80 psig, eliminating the need to flare propylene during system shutdowns. The new flare drum was eliminated and the project investment was reduced by $1.5MM.

In addition, oil fouling of the overhead condensers in the propylene system currently reduces their capacity by 20 percent. Installing dry gas seals and cleaning the oil from the system will return these condensers to rated capacity. Assuming conservatively that only 25 percent of this restricted capacity is recovered, $2.4MM/yr would be generated from the increased ethylene production.

The ethylene refrigeration compressor has also experienced the oil contamination problem. Dry gas seals have been ordered for this compressor to eliminate that problem and enable the High Flux™ tubing technology to be used for this modernization project.

PRINCIPLES OF OPERATION

The spiral groove dry gas seal provides a gas lubricated, self acting, noncontacting alternative to the oil seal. The main components of this seal are the stationary primary ring (usually carbon), the mating ring (usually tungsten carbide) fixed to the rotating shaft, and the multiple spring mechanism to provide axial force on the primary ring (Figure 2). These components are similar to conventional mechanical seals, except for the wider sealing faces and spiral grooves added to the mating ring.

Figure 2. Dry Gas Seal Cross Section.

When the compressor is not running, the two rings are held in contact by mechanical springs, allowing a minimal amount of leakage. When the shaft is rotating, the rings separate, forming a gap as the pressure rises in the spiral grooves.

The logarithmic spiral grooves on the outside portion of the mating ring face, shown in Figure 3, serve to "pump" the gas from the outer diameter (O.D.) to the inner diameter (I.D.) of the faces. The inner surface of the ring acts as a sealing dam, providing a barrier to gas flow. This forms a restrictive plane at the apex of the spiral grooves across which the gas begins to decrease in pressure and expand (O.D. to I.D.). The gap stabilizes when the hydrostatic and hydrodynamic forces are equal. The face geometry is extremely critical and must provide a gas film thick enough to prevent the rings from physical contact, but thin enough to prevent excessive gas leakage. The gas leakage from these seals is less than 2 scfm while the leakage from the oil seal systems is 15 scfm or greater.

The seal for this application is a tandem type, 9 5/8 in cartridge seal with a continuous face velocity of 185 ft/sec. The maximum axial float capability for transient conditions is ± 0.100 in. Rotor position tolerance for seal installation is ± 0.015 in, well within typical compressor thrust bearing float.

Figure 3. Spiral Grooves in Dry Gas Seal Hardface.

SEAL MANUFACTURER

The seal manufacturer was selected based on the follow criteria:

- Dry gas seal engineering experience
- Manufacturing capabilities
- Number of satisfied users

The spiral groove dry gas seal was developed in the 1970s and the manufacturer has successfully engineered and designed these seals for 14 years.

The seal manufacturer has committed several million dollars at its facility, shown in Figure 4, for state-of-the-art equipment. The manufacturing facility has the capability of machining extremely tight toleranced part geometries from difficult, high temperature alloy materials. They use four or five axis CNC machines that have machine position repeatability of 80 to 160 millionths of an inch (Figure 5). These machines are combined into machining cells that use distributed numerical control (DNC).

The manufacturer's quality assurance facility has the capability to check and certify any component part to 100 millionths of an inch and flatness to within one light band or 11.6 millionths of an inch (Figure 6). In addition, QA records very critical component dimension and surface finish are available for complete traceability if required.

The seal manufacturer provided estimates and guaranteed the seal would not exceed predicted leakages. Each seal is tested both statically and dynamically at operating conditions. The manufacturer has molecular weight simulation capabilities with air and helium mixing. The test cell setup also includes state-of-the-art software for pressure, temperature, speed, and leakage printouts (Figure 7).

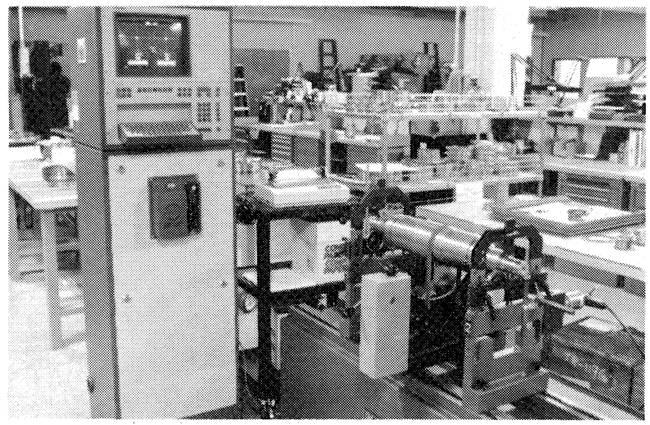


Figure 4. Dry Gas Seal Manufacturing Facility.

Figure 5. Seal Manufacturing Area—DNC Machines.

EXECUTION

The initial project of retrofitting the compressor with dry gas seals involved an engineering contractor, an overseas OEM, the seal manufacturer, and the plant. The contractor insisted that the OEM guarantee the compressor performance with the dry gas seal. However, the OEM had no previous experience with these seals

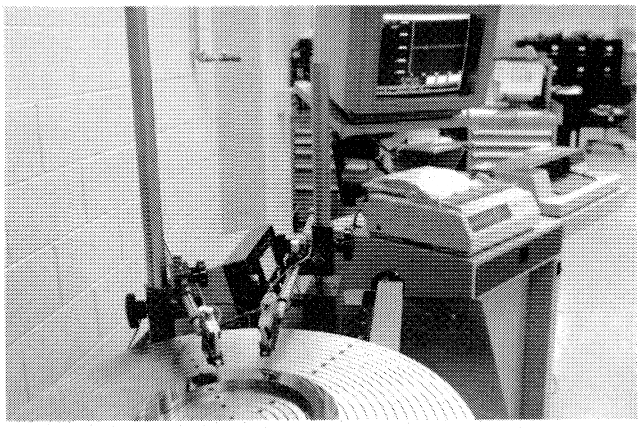


Figure 6. QA Check During Seal Assembly.

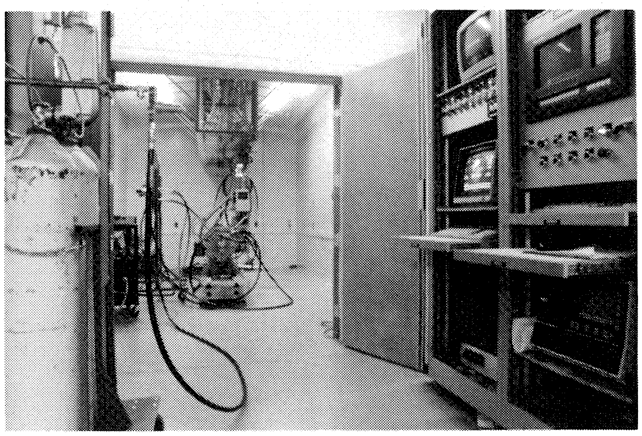


Figure 7. Dry Gas Seal Testing Facility.

and refused to guarantee the compressor performance. The plant had to assume responsibility for managing the project and had to work directly with the supplier.

The OEM provided the drawings and performed the bearing stability and rotordynamic analysis based on using dry seals. They provided the plant with sufficient information to conduct an independent audit. The plant also used their company's worldwide resources by developing a task team to work on the dry gas seal project.

To ensure the quality and performance of the dry gas seals, all seal components were inspected by the seal manufacturer and the results reviewed by the plant. All seals were shop tested to provide a baseline reference for seal leakages. The tandem seal cartridges were first tested statically and had very low leakage. Dynamic tests followed, where the seal chamber pressure and speed were varied to simulate the maximum expected seal operating conditions. Leakages measured across seal faces were significantly less than the guaranteed leakages rate. After testing, the seals were disassembled and the seal components inspected. No problems were found. The seals were then reassembled and shipped to the plant site.

The utilization of the OEM to provide dimensional drawings and review the seal design provided benefits when it was discovered that a shaft O-ring was located incorrectly. Even though the seals had already been shipped, an alternate design was developed, the seals were returned to the seal vendor for modifications, and then reshipped in time for the shutdown. This prevented the plant from having to correct the problem during the limited shutdown timing available.

MOCK UP

A cross section is shown in Figure 8 of one compressor case and the oil seal components which were removed to accommodate the new dry gas seal cartridge are illustrated. Limited availability of the compressor for installing the dry gas seal during the shutdown necessitated developing a method to remove a shaft sleeve without splitting the compressor case. This sleeve needed to be removed in order to provide a means of driving the seal. A mock up was developed which simulated the working conditions on the compressor floor. It consisted of a spare compressor rotor and a seal bushing simulating the limited space for removing the shaft sleeve and is shown in Figure 9.

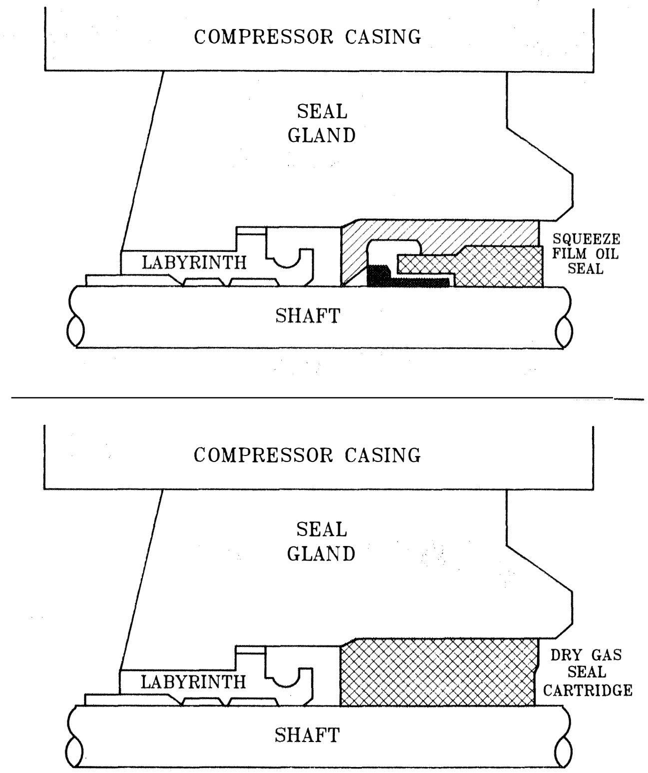


Figure 8. Compressor Cross Section of Seal Area.

Special fixtures and tooling were fabricated to facilitate removal of the shaft sleeve which included drill bits and 2.0 ft long taps. Guiding rings were used to control the drill bits and taps and then to secure the shaft sleeve with four bolts while two 19 in, 3/8 in all-thread studs were attached to a clamp ring puller. The first attempt at removing the sleeve was successful, but revealed some shortcomings with the technique and tooling. The 1/2 in thick guide was too flimsy and distorted badly. Using four all thread studs for pulling the sleeve, rather than two studs, would have helped prevent this distortion. In addition, heat had to be applied to the shaft sleeve for final removal.

After review of the first mock up procedure, the tooling was modified and the trial was repeated. The guide tooling thickness was increased from 1/2 in to 1 in, and additional tooling was used to provide guidance for the drill bits. An "old man" was designed and fabricated to assist in the drilling procedure. The hole depth in the sleeve was increased from 1/2 in to 1-1/4 in. The greater hole

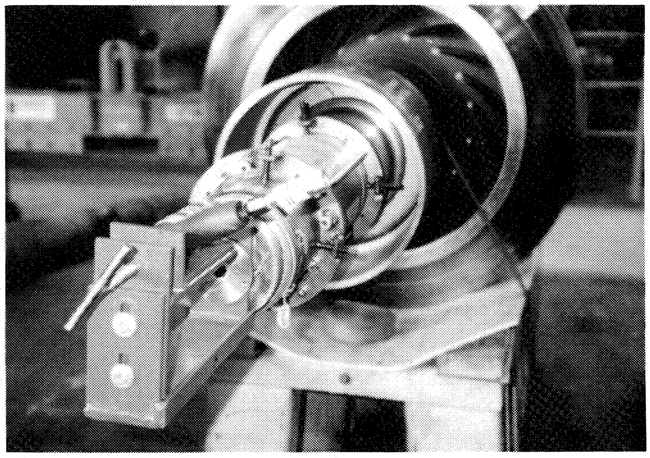


Figure 9. Mock Up for Removing Shaft Sleeve.

depth appeared to relieve the sleeve and enabled it to be removed easily without being heated. This trial was very successful and convinced the team that the sleeve could indeed be removed during the shutdown without splitting the compressor case.

INSTALLATION

The ethylene plant shut down on May 30, 1991, for 21 days to install the flare modernization project. The dry gas seals were installed during a 10 day "window" in the middle of this shutdown. After the propylene refrigeration compressor was blocked in and the system cleared of explosiveness, the existing oil seals were removed. All four shaft sleeves were successfully removed, using the procedure and tooling developed and proven by the mock up prior to the shutdown. This procedure went very smoothly, taking only eight hours to complete. The alternative procedure, which involved removing the compressor case, would have taken four to six days.

The new dry gas seal installation was routine. The only special tools required for installation in the field were two threaded rods and a backer plate. All four seals were installed and tested by the tenth day of the shutdown. Representatives from the compressor manufacturer and seal manufacturer participated in the installation of the dry gas seals. Startup of the propylene compressor was routine and operation of the seals has been excellent to date.

SUMMARY

The retrofit of the propylene refrigeration compressor with dry gas seals was an enormous success. The original objectives of eliminating oil contamination and correcting an inherent design flaw in the existing seals were accomplished providing annual savings of $2.4MM/yr and avoiding capital investments of $4.6MM. By utilizing an innovative seal removal procedure, the seals were installed on schedule, during the required shutdown timing constraints. In addition, by contracting with the compressor manufacturer to provide dimensional data and an engineering audit, by conducting our own engineering audit, and by using the seal manufacturer's experience and quality assurance capabilities, the seals were manufactured and installed with minimal problems encountered and are providing outstanding performance.

Based on the success of this adaptation, dry gas seals will be installed on the ethylene refrigeration compressor. Several additional applications of this technology are being evaluated within Du Pont. The success of this application has opened the door for newer technologies, particularly combining dry gas seals with magnetic bearing technology to achieve totally dry, oil free compressor train systems.

REFERENCE

Sedy, J., "Improved Performance of Film Riding Gas Seals Through Enhancement of Hydrodynamic Effects," ASLE-78-LC-3B-1 (1978).

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