

MAXIMIZING AN ETHYLENE PLANT'S TURBOMACHINERY RELIABILITY

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He has worked at Du Pont since graduating from the University of Southwestern Louisiana with a B.S. degree in Mechanical Engineering in 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.

ABSTRACT

The ethylene plant in Du Pont's major petrochemical complex in Orange, Texas was designed and built in the late 1960s, using the latest proven technology of that period. From plant startup in 1967 to 1981, there were eighteen ethylene plant shutdowns caused by problems associated with the large compressors and turbines. After two very long outages which occurred in 1980 and 1981, an extensive turbomachinery upgrading program was undertaken to improve utility.

This presentation sets forth reasons for the reliability problems experienced through 1981 and illustrates the program undertaken to increase equipment utility. This program has allowed the ethylene plant to run from 1981 to 1989 with only one turbomachinery related shutdown.

INTRODUCTION

The large rotating machinery found in the ethylene plant is tabulated in Table 1 and shown in Figure 1. All of the compressor

Table 1. Ethylene Plant Compressor Trains.

Train	Driver	Hp	Speed	# Stages
1. Charge Gas	Condensing	32,000	4000/6800	4
2. Propylene Refrigeration	Condensing Steam Turbine	32,000	4,200	3
3. Ethylene Refrigeration	Topping Steam Turbine	6,000	12,000	3
4. Purge Propylene Refrigeration	Electric Motor	3,500	7,600	4
5. Methane	Electric Motor	2,500	9,100	2

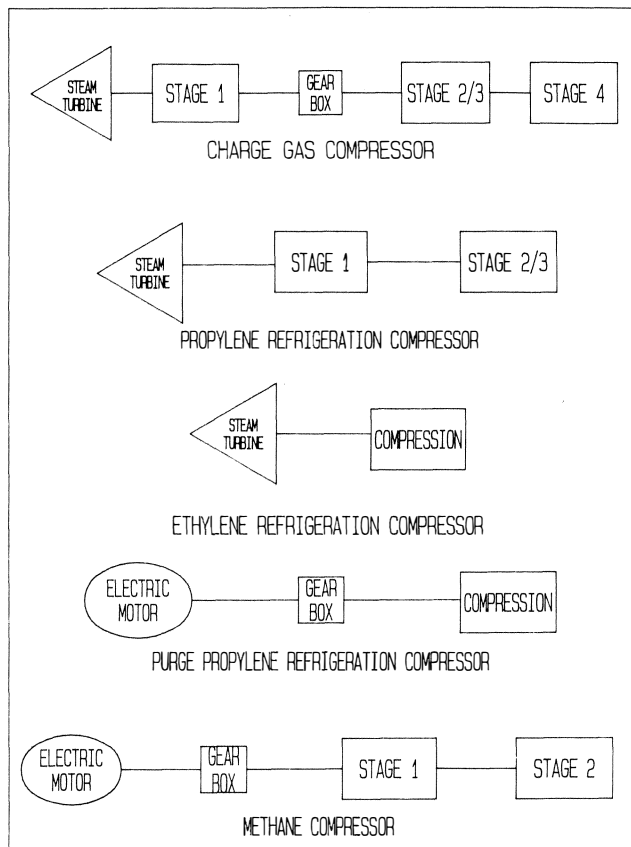


Figure 1. Block Diagram Showing Five Major Compressor Trains.

trains are single-line equipment; there are no installed spares. A shutdown of train 1, 2, or 3, consequently causes the entire ethylene plant to shut down. A shutdown of train 4 or 5 will not necessarily cause an entire unit shutdown, but will significantly restrict the ethylene plant production.

An ethylene plant shutdown, depending on the outage duration and the business climate, can cost the company millions of dollars. As previously mentioned, there were eighteen ethylene plant shutdowns caused by turbomachinery related problems. These culminated in a thirty-two day unscheduled shutdown in which three aborted start-up attempts were made before the plant could be successfully started.

BACKGROUND

The rotating machinery condition in 1981 and the causes of the 18 shutdowns can be attributed to the following three problem areas.

Original Inherent Design Problems

The charge gas and propylene refrigeration compressor steam turbine drivers experienced turbine blading failures shortly after initial plant startup due to resonance excitation of the ninth stage buckets (Figure 2). By working in conjunction with the original equipment manufacturer (OEM), the turbine blading problem was identified and solved by redesigning the ninth stage blades so that the resonant frequency was effectively moved outside of the turbine operating speed range. This correction was made in 1968 and is detailed in a technical service letter issued by Turbodyne [1]. This incident increased sensitivity to turbine blade problems and all future modifications to turbines were studied thoroughly before implementation. This attention resulted in no further turbine blade problems to date.

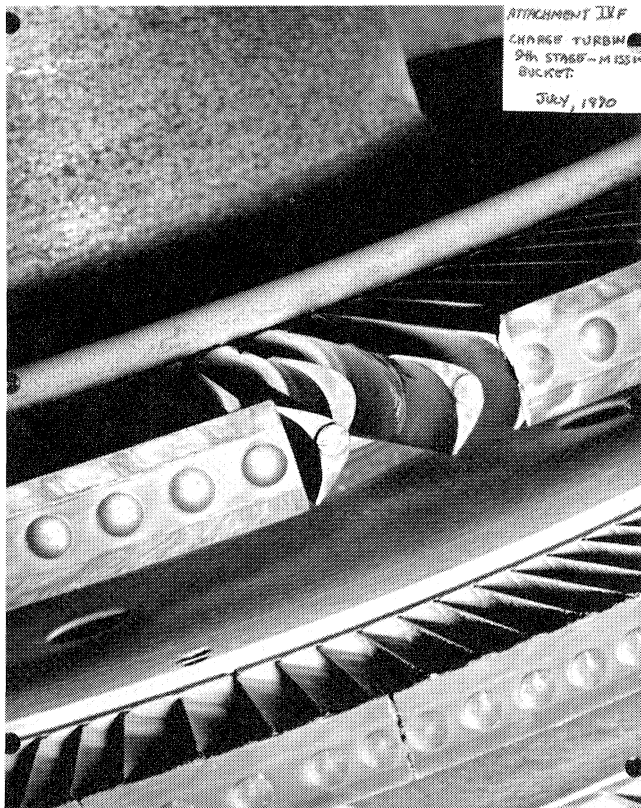


Figure 2. Turbine Rotor with Broken Blade and Shroud.

The charge gas compressor train experienced reverse rotation during several shutdowns, due to unbalanced flow conditions in the compressor minimum flow system. In addition, the charge gas compressor train, along with the propylene and ethylene refrigeration compressor trains, exhibited numerous bearing instability problems (Figure 3). In October 1981, an unscheduled shutdown resulting from an electrical power failure resulted in a plant outage, which eventually extended to 32 days because three successive plant startup attempts had to be aborted because of bearing instability. The second/third stage case of the train was assembled and disassembled three times before the problem was finally corrected.

Machinery Degradation

Over the years, the ethylene plant rotating machinery suffered a gradual loss of machine fits, rotor balance, internal alignment, etc., due to normal wear and abuse from process fouling

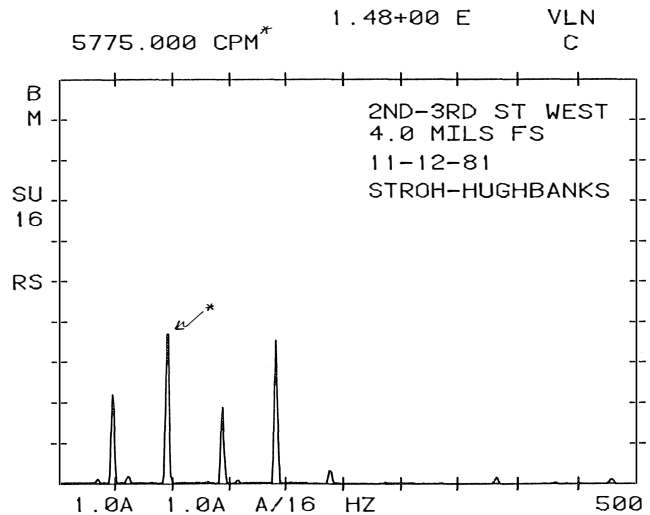


Figure 3. Frequency Spectrum of Bearing Stability Problem.

and abnormal operation. Poor spare part control contributed to this situation.

Static Obsolescence

Failure to keep abreast of improved technology and maintenance techniques over the years contributed to the poor mechanical utility. A reluctance to utilize outside resources compounded the situation.

COMPRESSOR UTILITY UPGRADE PROGRAM

In 1982, an extensive program was instituted to improve the ethylene plant turbomachinery reliability. This program was implemented by a committee consisting of technical engineers, maintenance technicians and supervisors, production supervisors and technicians, and engineering department consultants. The committee focused on four major areas for long-term utility improvement.

Technological Improvements

Utilizing resources internal to Du Pont as well as outside consultants, rotordynamics analyses were performed for all 12 compressor and turbine rotors. This work was presented at the 14th Turbomachinery Symposium by Stroh [2]. The latest techniques available were used to determine optimum bearing design with respect to rotor response. Based on these results, which showed the potential for $10\times$ improvement in rotor stability for some cases, the charge gas compressors, propylene refrigeration compressors, and the ethylene refrigeration compressor and steam turbine were converted to tiltpad bearings. Tiltpad bearings were included as part of the original equipment on the purge propylene refrigeration compressor and the methane refrigeration compressors installed in 1974. The analysis has recently been completed for the two 32,000 hp steam turbine drivers and the tiltpad bearings are on order. With the completion of these bearing installations, all critical ethylene plant rotating machinery will have the most stable systems possible by retrofitting. In addition, all compressor trains have been retrofitted to dry couplings to eliminate problems associated with gear-type couplings, such as lockup and greater misalignment forces.

The rotor balance philosophy was based on the deteriorated condition of the rotors and the findings of the rotordynamics analysis work done by Stroh [2]. In the past, all rotors had been conventionally low-speed balanced, with the exception of two problem rotors, which were high-speed balanced during the 32

day outage in 1981. The rotors were first returned to OEM balance specifications or better by stripping the wheels from the rotors and then performing individual mandrel balancing, followed by progressive balancing. Subsequently, it was determined that the balance criteria could be maintained on each rotor by using the latest low-speed balance techniques. High-speed balance would be used as required, in particular on new rotors. To date, performance of the rebalanced rotors has been excellent.

The original equipment installed in 1967 did not include proximity probes for vibration monitoring. An attempt was made to retrofit the machinery with proximity probes in 1969, but the installations were misapplied. Initial vibration data was questionable and the monitors were mostly ignored by the operating technicians in favor of seismic data which was also questionable. In 1982, x-y proximity probes (Figure 4), dual axial position probes, and dual embedded bearing thermocouples were installed with associated monitors. This provided accurate data, which when used in conjunction with real-time analyzers and oscilloscopes, helped return confidence to the operating technicians and provided early detection of equipment problems. A computerized, online monitoring system (Figure 5) was added in 1985.

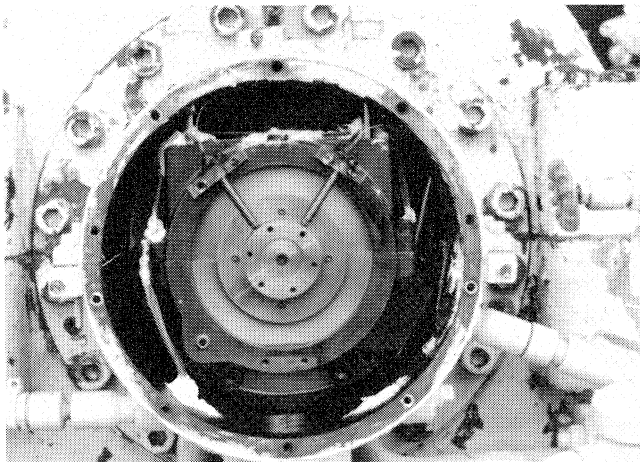


Figure 4. Proximity Probe Installation.



Figure 5. Computerized Online Monitoring System.

The three steam turbine drivers were retrofitted with electronic governors to improve operability, particularly during startup. In addition, electronic governors eliminated numerous linkages and gears which were sources for mechanical problems.

Inhouse consultants were contracted to perform computer modelling of the charge gas compressor minimum flow system to eliminate the reverse rotation problem. By modifying the minimum flow control valves to increase response time during shutdown conditions, this problem was effectively eliminated.

Machine-to-machine alignment was accomplished in the past using the reverse indicator method of alignment. While this is a proven method which will provide adequate results, the path chosen was to upgrade to optical alignment, which gives additional data in the form of hot casing movement data. This service is now provided inhouse, but outside vendors will probably be utilized in the future.

Torque meter couplings were installed on the two large trains to assist in determining performance of the turbine and compressors. The torque meter is used mainly to help determine whether the turbine or compressor is fouled and when attention is necessary.

Electrical discharge machining (EDM) was first observed in 1985 on the propylene refrigeration steam turbine thrust bearing. EDM was also seen on the propylene refrigeration compressors in 1988 in the squeeze film seal area. All compressors and turbines have been retrofitted with grounding brushes to prevent recurrence.

Balance seal damage was observed during several overhauls. In the past, used balance seals were routinely reclaimed by re-babbitting. To prevent failures, it was decided to discard all used seals and replace them with new seals from the OEM. Used balance seals will be reclaimed only in an emergency. All balance seals are now inspected, upon receipt, for bond integrity using angle beam ultrasonic techniques. In addition, balance seal leakage monitoring systems have been installed on all compressors.

Maintenance Training and Procedures

Individual maintenance procedures had been developed over the years for each compressor and turbine. These procedures were reviewed thoroughly and updated based on input from the OEM and industry consultants. An example is the addition of internal alignment checks as standard procedures for all major overhauls. In addition, check sheets were developed so that all critical checks and measurements could be documented and deviations from specifications could be controlled.

The mechanical technician's experience level began deteriorating both because of personnel cutbacks to increase productivity and because of early retirement offers. This caused a significant emphasis to be placed on training. The scheduled ethylene plant outage in 1983 was filmed in its entirety and then edited into individual video tapes showing assembly and disassembly of the various compressors and turbines. Full scale models of bearings (Figure 6), seals (Figure 7), and couplings were built to assist in training. In addition, the company has begun to share mechanical technicians and supervisors between plant sites during equipment overhauls. This has served a dual purpose of maintaining the technicians' skill level and providing the sites with a larger pool of experienced personnel. Also, participation in outside technical informational meetings, such as the Texas A&M Turbomachinery Symposium, was encouraged at all levels and it has paid good dividends in the information that has been returned.

Shutdown Preparation, Implementation, and Coverage

The most critical aspect of preparing for a scheduled overhaul is to ensure that necessary spares are available and in top condition. Spare rotors probably receive the most attention and deservedly so. Rotor repair techniques are developed jointly with the OEM and company inspectors oversee the repair at selected critical points, such as witnessing blue contact of taper fits with ring and plug gauges specially fabricated for the company for

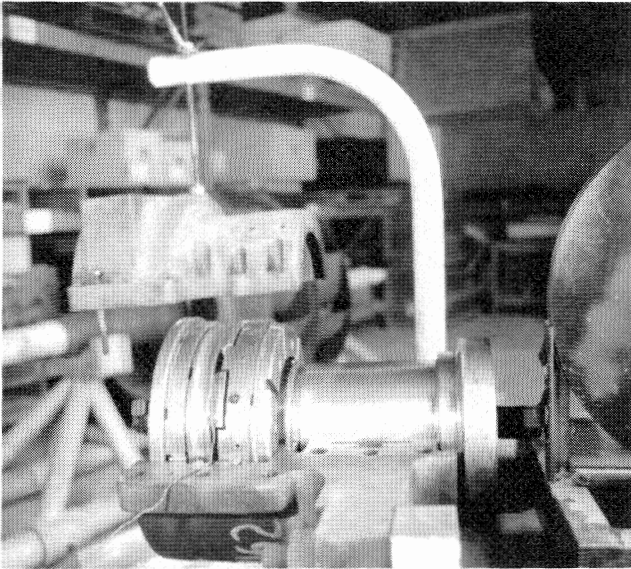


Figure 6. Compressor Bearing Training Model.

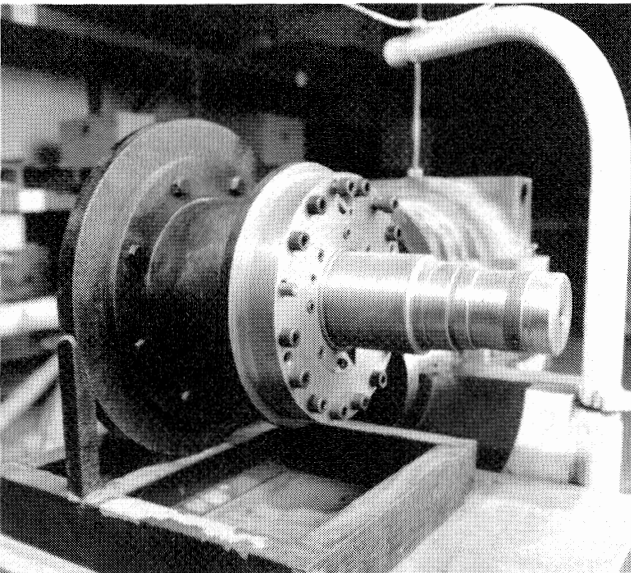


Figure 7. Compressor Seal Training Model.

this purpose. In addition to utilizing the OEMs, a list of proven repair vendors has been developed. This was based on a local survey of qualified vendors conducted by personnel experienced in machinery repair.

After overhaul, rotors must be maintained in the overhauled condition until needed. Rotor storage prior to 1982 was questionable. They were stored in wooden crates in a warehouse with a leaky roof at the port in Orange. In 1982, it was decided to return the spare rotors to the OEM for repair and subsequent storage at his dedicated, humidity controlled storage facility. The company's philosophy now is to store spare rotors at the OEM facility where the repairs will be made if the correct storage facilities are available.

Control and storage of other spare parts necessary for machinery overhauls is equally important. There is a mechanical technician dedicated solely to maintaining critical compressor and turbine spare parts. In 1982, the criticality of his position was reemphasized and he was provided with inspection tools for per-

forming quality assurance of incoming parts (Figure 8). In addition, his dedicated, humidity controlled storage (Figure 9) was enlarged to accommodate all critical compressor and turbine spare parts which were previously stored under noncontrolled conditions. All of these parts were surveyed and the questionable parts discarded and replaced.



Figure 8. Optical Flat for Quality Assurance Inspection.



Figure 9. Humidity Controlled Parts Storage Facilities.

Implementation of the machinery overhaul is enhanced by the use of "shutdown boxes." These boxes are clearly labeled as to the contents and placed at strategic locations during the overhaul. One box contains all the special tools which were developed in conjunction with the OEM. Other boxes contain seals (Figure 10), couplings, bearings, etc. There are also empty boxes for storing parts removed during the overhaul. All boxes have lids and are waterproof.



Figure 10. Shutdown Box Containing Compressor Seal.

Davit installation (Figure 11) on the compressor floors and fabrication of rotor stands (Figure 12) have significantly improved machinery overhaul logistics. The davits allow the mechanics to work on bearings and seals without having to wait on the single overhead crane. A second overhead crane is being considered to help alleviate this situation. Special rotor stands were fabricated to correctly support the rotors once they are removed from the casing and also for transportation.

Split-line leaks have been experienced numerous times. Special procedures were developed for testing of split-line sealant used in each application by using test flanges. Sealant shelf life is stringently observed and photographs of correct sealing procedures are available to assist the mechanics.



Figure 11. Compressor Floor Lifting Davits.

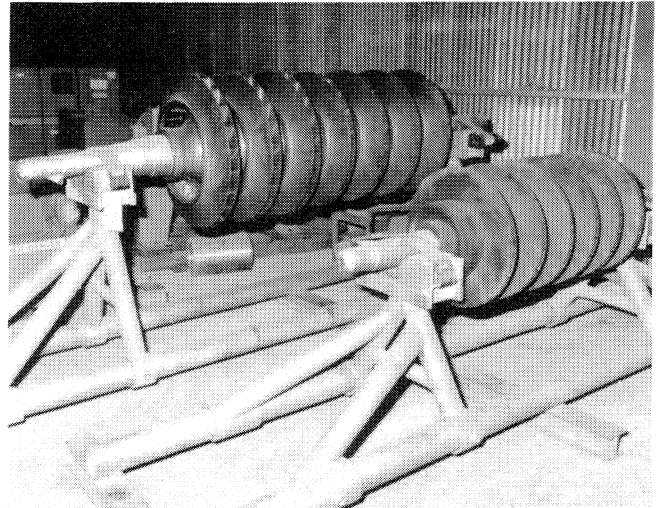


Figure 12. Rotor Stands for Temporary Storage and Transportation.

As mentioned previously, the experience level of the mechanical technician was a concern. While this was primarily addressed with improved procedures and training, it is being reinforced with increased technical and supervisory coverage during overhauls. OEM service representatives are being fully utilized, along with both company and industry consultants. Preshutdown meetings to discuss job scope and overhaul techniques are now conducted prior to each overhaul. Also, a critique of each overhaul is done soon after the equipment has been returned to service. A technique of working two shifts, with each shift working its own equipment, has been instituted for continuity.

Process Improvements

A contributing factor to turbine blade failures was the poor steam quality which caused blade corrosion. In addition, poor quality steam fouls the turbines and necessitates on-line turbine water washing to improve effectiveness. Online water washing was a common occurrence prior to 1982, and was performed as frequently as one to two times per month in the first few years of operation. It is a risky operation and has caused one turbine thrust bearing failure. Major improvements were made in steam quality, mainly by using demineralized water as boiler feedwater, and by installing an additional inline steam separator in the waste heat steam system to remove entrained liquid in the saturated steam prior to super heating. Steam quality has improved to the point that only two water washes have been required since 1982.

Process fouling of the charge gas compressor contributed to the deteriorated condition of the compressors found in 1981. Improvements in wash oil and antifoulant selection and optimization of the quantity required have resulted in greatly reduced fouling.

CONCLUSION

Program results have been outstanding with only one ethylene plant shutdown related to a turbomachinery associated problem since 1981. If the utility had not been improved, lost earnings would have been enormous, especially considering the bullish business climate of the past several years. Fortunately, the problem was recognized and addressed with enough emphasis and priority to achieve the results shown.

The utility improvement program will remain at a high priority to maintain the current level of turbomachinery reliability.

Information learned from this program has been applied to several machinery upgrade and rerate projects with excellent results. Improvements will continue to be sought in all areas and major technological improvements will be implemented where applicable.

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ACKNOWLEDGEMENTS

The author would like to acknowledge the contribution of Bob Campbell, E. I. du Pont de Nemours & Company, Incorporated, Orange, Texas, and Jerry Wilkerson, E. I. du Pont de Nemours & Company, Incorporated, Beaumont, Texas, for their help in preparing this paper. In addition, the author wishes to acknowledge Chet Stroh, Dick Hughbanks, Jerry Swalley, E. I. du Pont de Nemours & Company, Incorporated, Wilmington, Delaware, and the members of the Sabine River Works Compressor Utility Committee, Orange, Texas, for their contributions to the reliability improvement program which made this presentation possible.