DO IT RIGHT THE FIRST TIME A REVIEW OF AN ETHYLENE PLANT TURBOMACHINERY COMMISSIONING TEST

by

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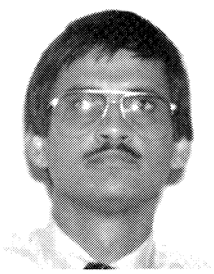

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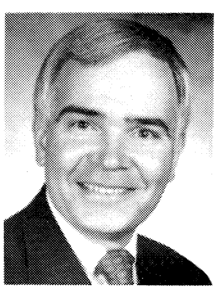

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ABSTRACT

Every user would like to check the mechanical integrity of rotating equipment in the field before startup. In the case of large compressor trains with steam turbine drives, running a mechanical string test with associated piping and auxiliaries provides positive check outs for compressor, driver, and all auxiliary equipment. The benefits of planning, preparation, and execution of such a program are described.

INTRODUCTION

When international projects such as the one described here are initiated under the partnership of two multinational companies, extensive commissioning activities optimize plant operating reliability, and also provide important training opportunities for personnel responsible for operation of the plant. The ethylene plant described here is a billion pound per year capacity ethane cracking unit with operating revenue of $250,000 or more per day. The joint venture management support was obtained early on for the commissioning program, even before the construction schedule was established and the contractor was selected. The management program support was based on the following program benefits that would maximize plant safety and revenue.

- Assure all critical equipment trains operated as designed.
- Provide on the job training for plant personnel prior to start up.
- Provide a mechanical data baseline for critical equipment and auxiliary system operation.

This plant has four compressor trains for three services (see Figure 1). The charge gas service is split into two trains, a 16,000 kW/4250 rpm and a 10,000 kW/7693 rpm unit. The other two units are a 28,000 kW/3715 rpm two body propylene refrigeration train and a 6500 kW/7821 rpm ethylene train.

Charge gas services use a separate lube oil and a seal oil consoles. The propylene and ethylene trains have an independent, combined lube/seal oil consoles. The larger (16,000 kW/4250 rpm) charge gas compressor unit and propylene refrigeration compressor units are driven by an the extraction condensing steam turbines. The steam conditions are 620 psig at 750°F inlet, 310 psig extraction, and 4.5 in HG exhaust. The ethylene refrigeration unit and the higher speed charge gas unit (10,000 kW/7693 rpm) are driven by identical straight condensing steam turbines with the same steam conditions. Each train will be described in detail in a later section.

EQUIPMENT DESIGN FEATURES AND OTHER CONSIDERATIONS

The schematic sketch of each compressor train is shown in Figure 1. Initially, options considered were running the tests with compressor flanges blanked and pulling vacuum on the casing or using nitrogen in a closed loop arrangement. In consideration of project scope and schedule, it was decided to pursue a string test arrangement using air.

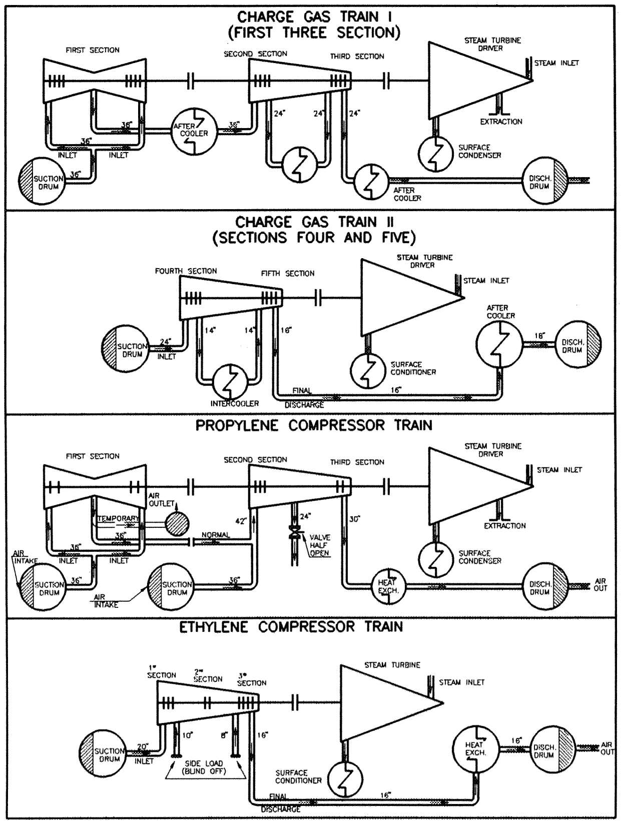


Figure 1. Compressors Piping Schematic Sketch.

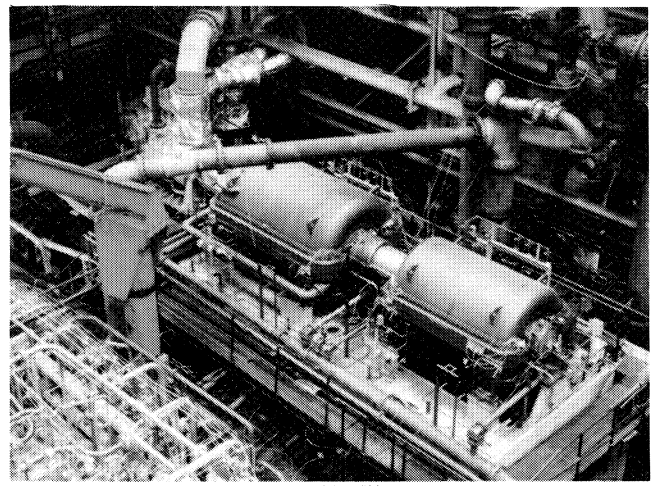


Figure 2. Propylene Compressor Unit on Shop Test Floor.

Charge Gas Compressor
(Design Gas Conditions, MW=19.5, K=1.25)

The lower pressure charge gas train is comprised of two compressor casings and three compression sections. The first compressor case (first section) is a double inlet flow unit with four balanced opposed impellers (total eight) discharging in the middle of the casing. The second compressor case is a two section intercooled unit with four impellers in each section. The high pressure charge gas train (last two sections) is an intercooled radial split casing with four impellers in each section.

Propylene Refrigerator Compressor
(Design Gas Conditions, MW=42 K=1.18)

The propylene train is comprised of two compressor casings and three sections. The first section is a double inlet casing with two balanced opposed impellers (total four). The first induction side load is introduced externally between the two casings. The second section is comprised of three impellers followed by an extraction side load. The last section has two impellers (Figure 2).

Ethylene Refrigerator Compressor
(Design Gas Conditions, MW=28, K=1.4)

The ethylene train is a single compressor casing, three section unit with three, two, and four impellers, respectively. The two side loads are induction flow into the casing.

DESIGN CONSIDERATIONS

The following considerations were taken into account to assure a safe and successful test:

Safety

During air runs, subatmospheric suction pressure will cause seal oil to flow towards the inside of the casing making an air/oil mixture, which can be ignited at high discharge temperatures (Figure 3). To prevent this occurrence, it was necessary to inject inert buffer gas into the seals. We injected nitrogen during air runs. To ensure sufficient nitrogen flow, the vent orifice in the seal contaminated oil drainers were temporarily removed (Figure 4). The piping was disconnected at the drainer vent connection, the orifice was removed, and the nitrogen was throttled, making sure that a positive nitrogen flow was continuously maintained.

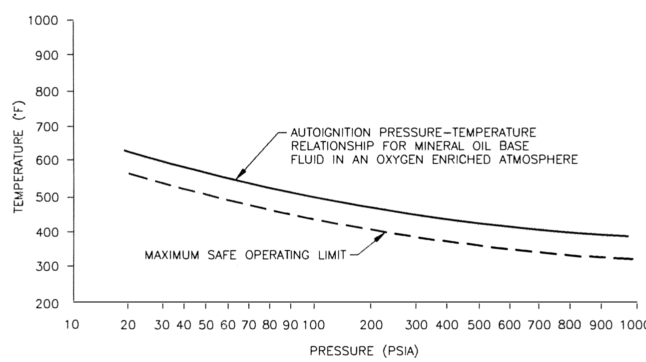
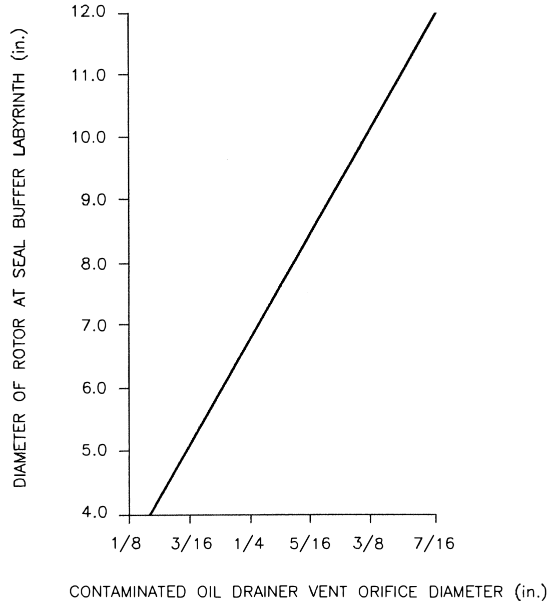


Figure 3. Safe Operating Limit for Oil in Air Environment.

Discharge Temperature Limitation

During air runs, discharge temperatures should never exceed the maximum allowable for the casing. In our compressors, 350°F was the limit, which is a typical number based on the balance piston material temperature limit. High discharge temperature can be expected if the design gas "mole weight" and/or "K" values are lower than for air (MW = 29, K = 1.4). In the case of side load compressors, high discharge temperatures are encountered if side loads are blanked off and air is flowing straight through the unit. During the test, high discharge temperatures can restrict the speed of compressor and the length of the air run. Our ethylene compressor was designed for –150°F inlet temperature. The casing internal discharge temperature was monitored throughout the duration of the test (more on this in a later section).



BASIC ASSUMPTIONS:
1) 50 f/s VELOCITY THRU LABY
2) LABY DIA. CLEARANCE = .002 in/in + MAX. BRG. C.
3) ORIFICE ΔP = 2 PSI

Figure 4. Curve for Resizing Drainer Vent Orifice for an Air Mechanical Test Run.

Steam Limitation

During the air run, suction throttling is desirable, since throttling reduces gas density, inlet mass flow and the power requirement. Turbine horsepower was limited for these tests since the main steam producers (cracking furnaces) were not in operation at the time of the air run. The steam demand and variations were estimated and communicated it to the utility people well before the actual test. The startup team was careful not to surge the units and observed the suction pressure gage during the tests. The delta pressure was calculated across the inlet and the startup team confirmed that they did not force an excessive pressure ratio, that would surge the compressors.

Atmospheric Seal Limitation

During the air run, it is likely that high seal oil drain temperature will be experienced due to the low Delta P across the outboard (atmospheric) seal. The seal oil bypass orifice size may have to be adjusted (if incorporated in design) or seal oil pressure may have to be increased to ensure adequate oil flow through the outboard seal. In planning, the seal oil throw off temperature was limited to 200°F, based on shop test data and a simple orifice calculation. A compressor seal oil system that is designed for high pressures may become unstable during an atmospheric air run. To supply the same seal oil flow at reduced pressure, the seal oil regulators may have to be adjusted to avoid chattering during the air runs. It may be necessary to bypass the regulator and control seal oil pressure with a hand valve to maintain the required seal oil to reference gas delta pressure (50 psi for mechanical contact type seals).

PROGRAM PLANNING

General Comments

The importance of preplanning the procedures for the program cannot be over emphasized. The first step is to have a brainstorming meeting with the equipment vendors regarding testing. The best time to have this meeting seems to be after all shop testing is complete and field construction is well underway. As a preparation for this meeting, a thorough review of the project piping and instrumentation drawings (P&ID) was conducted along with "walking" through the lines in the field. This was necessary to establish the compressor inlet and outlet points and the feasibility of making any piping modifications that may be required for the air runs. The system resistance was determined for these modifications. This information was used to determine approximate test operating points. The curves were prepared for following information showing maximum/minimum speeds (Figure 5 and 6).

- Flow (CFM) vs power
- Flow (CFM) vs discharge pressure
- Flow (CFM) vs discharge temperature

As a result of the meeting, the following decisions were made for each train (See Table 1 and 2).

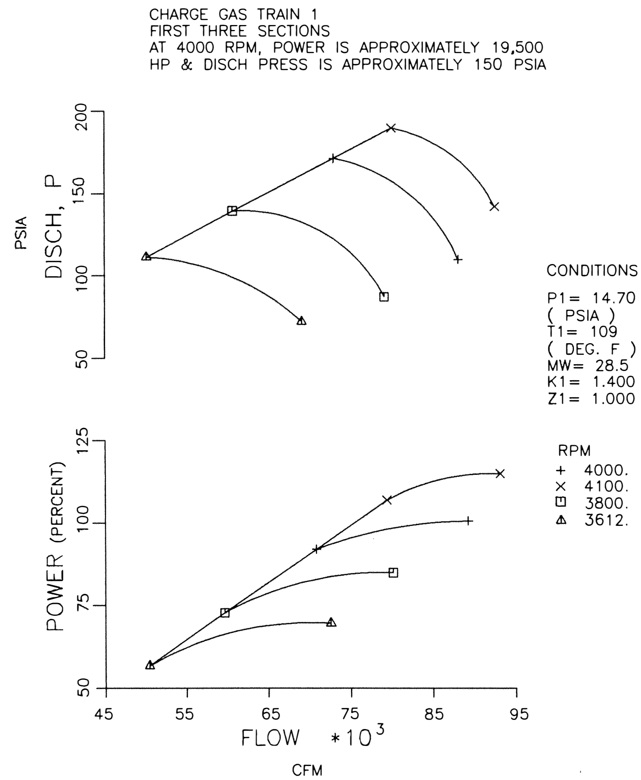


Figure 5. Air Operation Performance Curve (Power).

EQUIPMENT TEST CONFIGURATIONS

Charge Gas (Low and High Pressure) Train

Both casings for the low pressure train could be run in series with the manway to the first casing suction drum open to atmosphere for suction. The outlet was the second case discharge drum manway. The team checked the pressure drop in the exchangers between the compressor and the discharge drum to assure positive pressure in the last impellers of the string. This is necessary to avoid the condition where impeller suction pressure is higher than discharge pressure resulting in gas expansion, which can cause damage to compressor internal hardware. Seal oil drain pot vent

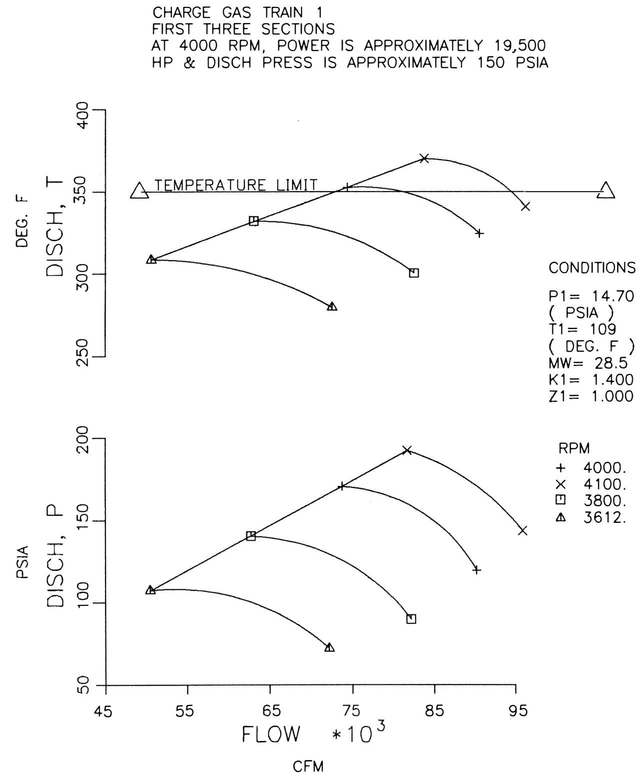


Figure 6. Air Operation Performance Curve. (Discharge temperature).

orifices sizes were increased for both cases. The seal oil bypass orifice design sizes were found to be adequate for the air run (Table 2). Thrust conditions were well within design during the air run (Table 3). Similar decisions were made for the higher pressure charge gas train. These are summarized in the Tables 1 and 2.

Table 1. Compressor Mechanical Data and Air Test Arrangement.

SERVICE	COMP CASING/SECTION	SPEED RANGE RPM	FIRSTCRITICAL RPM	AIR RUN CASING ARRANGEMENT	COMP. CASING MAX ALLOWABLE DISCH. TEMP. T2
LOW PRESSURE CHARGE GAS TRAIN	60MD4–4/FIRST 60M8I/SECOND & THIRD	3400 – 4462 3400– 4462	1800 2000	TWO CASE STRING (FIRST, SECOND AND THIRD SECTION)	350°F
HIGH PRESSURE CHARGE GAS TRAIN	38MB8I/FOUR & FIVE	6154 – 8078	3000	ONE CASE STRING (4TH AND 5TH SECTION)	350°F
PROPYLENE REFRIG. TRAIN.	60MD2 –2/FIRST 70M6–5/SECOND & THIRD	2972 – 3900 2972 – 3900	2200 1900	ONE CASE (FIRST SECTION) ONE CASE (2ND AND 3RD SECTIONS)	350°F
ETHYLENE REFRIG. TRAIN.	38M10–9/FIRST,SECOND & THIRD	6257 – 8212	3300	ONE CASE (STR. THRU)	350°F

Table 2. Seal Modifications for Air Test.

SERVICE	COMPRESSOR CASING	ROTOR DIAMETER RPM	SEAL OIL DRAINER VENT ORIFICE NORMAL (DESIGN)/AIR RUN	SEAL OIL BYPASS ORIFICE (DESIGN)/AIR RUN
LOW PRESSURE CHARGE GAS TRAIN.	60MD4–4	9.5	(15/64")/ 9/32"	(5/32")/ NO CHANGE REQUIRED
	60M8I	9.5	(15/64")/ 9/32"	(4/32")/ NO CHANGE REQUIRED
HIGH PRESSURE CHARGE GAS TRAIN	38MB8I	6.78	(11/64")/ 7/32"	(4/32")/5/32"
PROPYLENE REFRIG. TRAIN.	60MD2–2	9.5	(1/4")/ 9/32"	(4/32")/ NO CHANGE REQUIRED
	70M6–5/B108027	11.7	(19/64")/ 3/6"	(4/32")/5/32"*
ETHYLENE REFRIG. TRAIN.	38M10–9	6.78	(3/16" INLET)/ 7/32" INLET (5/32" DISCH.) / AND DISCH.	(5/32"0)/ NO CHANGE REQUIRED

Table 3. Compressor Mechanical Data and Air Test Thrust Range.

SERVICE	COMPRESSOR CASING	COMP. CASING MAX. ALLOWABLE DISCH. PRESS. PSIG	DURING AIR TEST THRUST RANGE PSI	JOURNAL BEARINGS SIZE INCH	THRUST BEARINGS SIZE INCH	BALANCE PISTON DIAMETER (INCH)
LOW PRESSURE CHARGE GAS TRAIN	60MD4–4	60	0	6" X 3"	31.8	–
	60M8I	125/218	38–59 (575 Allowable)	6 x 3	72	24.75
HIGH PRESSURE CHARGE GAS TRAIN	38MB8I	700	40–17	5 x 2 1/8	32	14.75
PROPYLENE REFRIG. TRAIN.	60MD2–2	250	–	6 x 3	31.8	–
	70M6–5	250/340	71–15	7 x 3.68	91.1	27.25
ETHYLENE REFRIG. TRAIN.	38M10–9	609	121–21	5 x 2 1/8	32	15.0

Propylene Refrigeration Train

Due to much higher design mole weight gas (mw = 42) compared to air (mw = 29), problems were encountered in the existing impeller line up for the air run. In the situation where the first few impellers are in surge and others in last stages in stone wall (overload), it is difficult to run all impellers in series with air. It was established that both casings could not be run in series at any reasonable speed. The first case (double inlet) suction drum was open to atmosphere. Discharge piping was modified to achieve atmospheric discharge for this casing.

Suction throttling was required, which was achieved by closing the suction valve and/or by partially covering the manway on the suction drum. The second compressor casing suction drum was left open to atmosphere. To prevent surging of the first two impellers in this case, the motor operated valve (MOV) in the extraction side load piping was positioned to discharge 65-75 weight percent of flow. It was noted that adjustment to this valve setting may be required to prevent choking of the third section. In the field, this MOV was set at half travel and no adjustment was required. The third section discharge was through the two heat exchangers and exited through the discharge drum manway. The required changes to the seal oil by pass orifice and drainer vent orifice are noted in the Table 2.

Ethylene Refrigeration Train

As noted earlier, the ethylene compressor has nine impellers with two induction side loads. It was established that two side loads would have to be blanked out making it a straight through case. It was noted that this would severely limit the amount of operating time at full speed during the air run. During this run, the temperature of the discharge side was closely monitored by inserting a thermocouple in the casing cavity. The thermocouple was in contact with the outer diameter of the stationary balance drum seal.

The first section suction drum manway was partially left open to atmosphere (Figure 7) for suction throttling.

The last (third) section discharge drum manway was left completely open for final discharge to atmosphere. The startup team also discharge throttled to prevent gas expansion in the last stage impellers.

PROCESS PIPING MODIFICATIONS

The preceding piping modifications were established with the philosophy of minimizing changes to the piping system close to the compressor flanges and, at the same time, achieving the test objectives. The team was dealing with very large pipe sizes and equipment alignment had been attained by this time. They did not want to make any changes to the piping systems to upset the equipment alignment. They tried to run the test by breaking minimum piping connections as far away from the machines flanges as possible. The benefits of this approach were to observe the effects of the piping forces on the equipment and at same time to air blow the process lines. Breaking flanges right at the suction of the equipment does not give this information. Many times spring

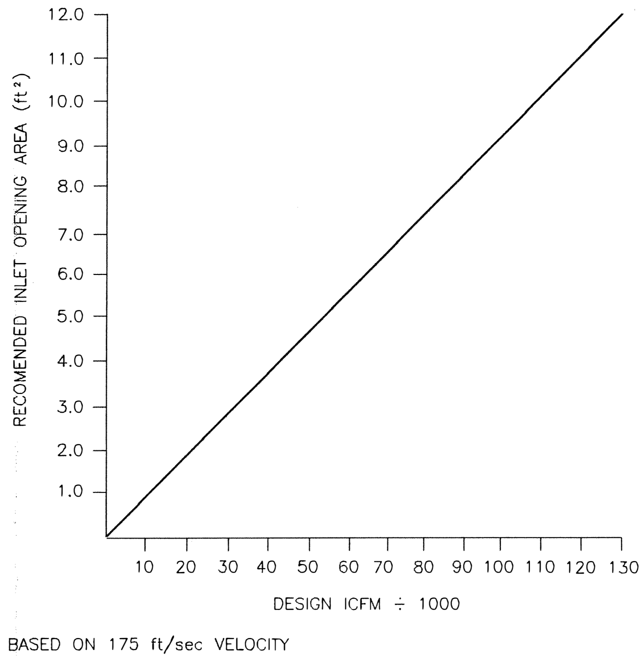


Figure 7. Recommended Inlet Area for Suction throttling During a Mechanical Air Test.

hangers are not set correctly. Running an air test within the limitation of maximum temperatures will demonstrate the effect of thermal movement of the piping. Consequently, an operator will have some indication of the effectiveness of the spring hangers and the piping arrangement by observing any changes of equipment vibration signature (misalignments, significant 1×, 2× changes).

Another consideration in the piping modifications was to carefully direct the air discharge away from personnel and construction structures. The volume of air being discharged was enough to create a small sand storm in the area. During the testing, noise was excessive and hearing protection was required. The team roped off the area for noise and safety reasons. They applied the heavy grating (clamped or bolted) to the air intake and discharge points to avoid having debris enter the system. Where required, they covered part of the opening by clamping heavy sheet metal on top of the grating to achieve suction throttling.

PROGRAM EXECUTION

General Comments

After obtaining management support, performing detailed planning with both the equipment vendors and the engineering contractor, the testing program was ready for execution. The objective of the entire program was to assure optimum reliability of the entire equipment system including the turbomachinery train and its auxiliaries. In order to meet the program objective, all systems had to be proven as thoroughly as possible prior to plant startup. The order in which the program was followed is very important. The team used the building block approach by first proving the auxiliary lube system, the steam turbine control system, the seal system and then proceeding with machinery testing. Proceeding in this manner assured the proper operation of each component and system before proceeding on to the next phase.

AUXILIARY SYSTEM CHECKS

Auxiliary system checks must be performed in a very detailed manner to assure that all components are proven prior to startup of the specific system. Described below are the details which were followed concerning the commissioning of the auxiliary systems associated with the propylene refrigeration compressor train.

OIL SYSTEM FUNCTIONAL TESTS

The lubrication and control oil system for the charge gas train is shown in Figure 8 and the system schematic in Figure 9. For purposes of completeness and documentation, every field commissioning test was performed with the aid of a procedure. The specific procedure was written prior to the test date and reviewed by all associated parties; equipment vendors, site contractor, plant operations, maintenance and engineering staffs. The procedure was written in a detailed, yet concise format that lent itself to documentation and record keeping that could be referred to at a later date. This procedure therefore achieved the following program objectives:

- It detailed work to be done.
- It allowed for complete documentation of the work.
- It served as a training guide and confidence builder for site operations, maintenance, and engineering personnel.

The format of each procedure included the following major items:

- Pretest completion check
- Scope
- Instrumentation required
- Required data

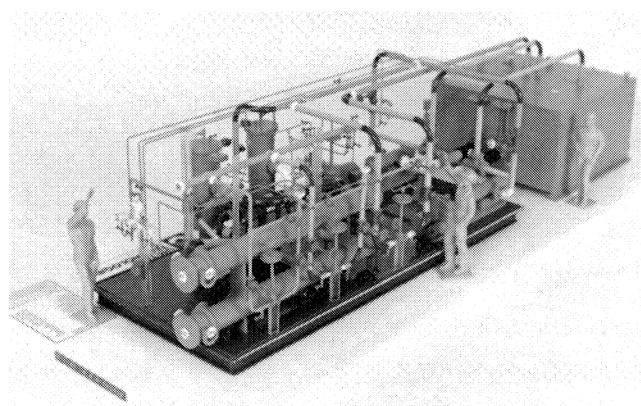


Figure 8. Scaled Model for Charge Gas Lube/Control Oil System.

A sample of an actual procedure is shown in Figure 10. This "check list" format proved effective in providing a quick reference for test descriptions, requirements and results. An outline of lube/seal system functional test procedure is shown in the APPENDIX. Prior to commencing the oil system functional test, a meeting was held with all involved site personnel. The team tried to include the highest level of operating, maintenance, and engineering personnel that would be associated with that unit. During this meeting, the procedure was reviewed with all parties and specific tasks were delegated. The test objectives were to confirm the correct operation of the equipment and provide an effective training session to demonstrate the function of the equipment and show that these tasks could be performed safely without causing system upsets.

Prior to initiating the test, the entire oil system, console interconnecting pipe, and unit piping was "walked" to confirm that all flushing screens were removed, all instrumentation was calibrated

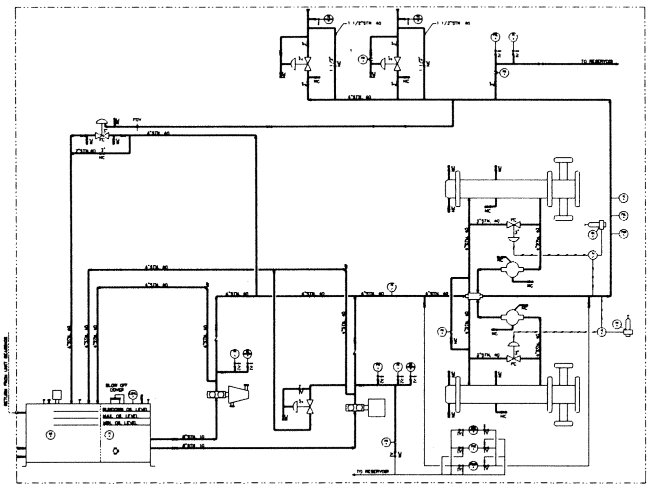


Figure 9. Charge Gas Lube/Control Oil System Schematics.

PROPYLENE LUBE/SEAL SYSTEM FUNCTIONAL TEST

ITEM	DESCRIPTION	SPECIFIED VALUE	ACTUAL VALUE	MODIFICATIONS
	RESERVOIR CHECK			
1.	Record reservoir temp. rise in four (4) hours with heater on. Read on T.I. 481L	Record actual AT		
2.	Check reservior level switch LSL 083L setting, Read on Annun. LAH 083L LAL 083L	High level 14" from top low level. 45" from top	High_____ Low_____	
	AUXILIARY PUMP UNIT CHECK			
3.	Energize aux. lube pump check:			
	3A. Pump vibration	.2 in/sec		
	3B. Motor vibration	.2 in/sec		
	3C. Cavitation	none		
	3D. Pump/motor brg. temp.	165 deg. F.		
	RELIEF VALVE FUNCTION			
4.	Block in aux. pump using pump discharge valve-set relief valve PSV 320L. Valve chatter is not acceptable	3130 Kpa		
5.	Confirm the "Aux.pump running" Annun. PAH 147L is actuated by switch PSH 147L. By shutting off pump and restarting while reading pressure on PI 900L	690Kpa Rising		
	SYSTEM PRESSURE ADJUSTMENT			
6.	Allow system to heat up to 49 deg. C downstream of coolers TI 511L and TI 511L and adjust the following times (if required) to attain specified values:			
	6A. Back press. regulator PCV 092L. Read value on PI. 897L	2262 Kpa		
	6B. Lube oil supply valve PCV-091L. Read value on P.I. 816L	124-138 Kpa		
	6C. Control oil valve PCV-090L. Read value on P.I. 817L	883 Kpa		
	6D. L.P. case seal oil differential valve PDCV-118L. Supply N press of 5 PSIG at gas reference side of PDT 298 and read differential press on PDI 152L	241 Kpa		

Figure 10. Propylene Lube/Seal System Functional Test Check List.

and in place, and all connections were made up. Once the system was judged complete, the test consisted of performing major component functional checks to confirm proper component operation. Care was taken to note any abnormalities which had to be corrected before further system operation. It should be noted that this entire test was performed without the equipment in operation, but completely connected to the unit. Therefore, slightly higher pressures and oil flows were experienced during equipment operation. After the major component functions were proven, system functional checks were run (automatic pump transfer, two pump operation, etc.).

During the propylene unit functional test, it was discovered that the bypass control valve was unstable. It was noted that the pressure drop from the inlet of the oil supply header (compressor end) to the steam turbine end was sufficiently large such that the supply pressure to the compressor had to be increased to approximately 25 psi to allow the minimum required 15 psi at the turbine bearings. Since the unit had not been shop tested with the actual turbine lube oil supply header, the bearings required more oil flow in the field than they did in the shop test. As a result, the bypass control valve was operating closer to its valve seat (at a lower Cv value than it had in the shop test). The options available were to completely revise the unit supply piping, or to change the valve trim. The team chose to modify the valve trim, since it was the most cost effective solution.

As a temporary fix, an orifice plate was installed upstream of the valve to increase the valve coefficient and to move the valve plug farther away from it's seat. A smaller valve trim was ordered and added at the first turn around. This is a good example of the benefits of such a test. If this test had not been performed, this problem would have developed during startup and caused a delay. Performing the tests in this manner documented the problem and allowed sufficient time for an acceptable short term solution.

The functional procedure was retained by the unit operators for future reference during turnarounds or for use during online functional tests. Another benefit of such a procedure is that it provide baseline data for predictive maintenance problem analysis. As an example, if pressure switch settings were to drift, reference can be made to the original startup base case. Following the completion of the oil system test, a meeting was held with all interested parties to document the action required to modify the system prior to startup. Instrumentation changes, etc., were documented and issued to the appropriate parties. Sign off was required upon completion of each modification.

During all of these operations, the vendor equipment specialists were involved and were required to sign off only after they were satisfied with the completed work.

It cannot be overemphasized how important it is to have plant personnel present during these tests. The majority of critical equipment unscheduled shutdowns are caused by auxiliary system malfunctions. Auxiliary systems have many components that deteriorate with time and local atmospheric conditions. A prime example is control valve stroking. A properly designed auxiliary system will operate day after day at the same operating point. The control valves will be rendered essentially a fixed orifice. Consequently, when the need arises for rapid control valve stem movement, excessive valve stem friction could inhibit this requirement which could result in a shutdown. Therefore, it is essential that systems be functionally checked from time to time. The functional test as outlined in this section affords the operating unit the opportunity to prove to all associated personnel that the system functions correctly and can be tested accurately and precisely while the unit is in operation. It shows the operators that the main turbine driven pump can be tripped with the auxiliary pump coming on before the unit will trip, shows that two pump operation is possible and, demonstrate how control valves can be stroked. All of these items are essential for the continued satisfactory operation of the equipment.

GOVERNOR SYSTEM CHECKOUT

The turbines for this application employ analog electronic governor systems and position control backup. If the main electronic control unit fails, the position of the valve rack will remain in the last position of record prior to the equipment failure. The turbine would then be on manual control while the system was repaired online. Plant operations chose not to automate (sequence) startup, based on the relative unfamiliarity with electronic governor systems. An outline of the electronic governor checkout procedure that was used is shown in the APPENDIX to demonstrate some of the test requirements. Since this was the first exposure that many of the plant personnel had to electronic governors, all details were explained fully prior to the start of the functional tests. The startup team reviewed the procedure with the governor vendor prior to finalization to assure that all details stated were accurate and complete. Governor prechecks and loop checks were performed and signed off prior to the test.

The agenda was written to incorporate all anticipated functions of the system. Transfer was simulated from the main governor to the position control. It was important to include all operating personnel, especially with the governor transfer and the trip and throttle valve exercise. One of the biggest sources of significant machinery damage through the years has been the inability of the trip valve to close on command after it has operated for some time in the field. This is due primarily to build up on the stem of the valve and valve mechanism which does not allow the valve to close or close completely. Systems usually incorporate a trip value exerciser (limited or full movement type) to assure that valve movement is present. More often than not, this exerciser is rarely used. The main reason is that operators are not confident that this mechanism will operate without causing machine shutdown. The functional test is the perfect opportunity to demonstrate the proper operation of this mechanism and instill confidence in operators that the mechanism will work.

The governor system tests demonstrated the inability to transfer under certain conditions from main governor to position control and transfer back from position control to main governor. A slight circuit modification was required by the manufacturer. Since the test was scheduled sufficiently in advance of the proposed startup date, time was available to secure the modified equipment, test and install it. Remember, the objective of all critical equipment is to operate continuously between turnarounds. Thus, the improper functioning of any component will exist for at least two years in most cases, and could cause significant downtime, damage or safety hazards at that plant. Therefore, system functional tests really pay out.

At this point then, all major auxiliary systems had been completely functionally tested, modified where necessary and confirmed to operate satisfactorily prior to start up. What now remained was the checkout of the particular equipment and their associated process systems.

STEAM TURBINE SOLO RUNS

A test procedure was prepared. The procedure outline is shown in APPENDIX. The turbine was confirmed ready for solo run, the lube oil and control system had been functionally tested, steam lines had been blown and all instruments and controls including the governor and trip were calibrated and found to be in proper working order. All vibration probe channels were calibrated. The test objective was to run the driver for four hours, or until all bearing temperatures stabilized to demonstrate the stable operation of the governor system and the proper operation of the safety (trip) system. The shop test report was used as the baseline for all measured parameters. The turbine was started per the manufacturers startup procedure.

Another benefit of this test was to confirm the proper turbine startup procedure, and modify it if necessary. It should be noted that two different objectives are at work here. The vendor wants to assure that the turbine is started in a proper fashion, while the operating unit usually wants to start the unit as quickly as possible. Something has to give. The operation of the turbine on the solo run affords the opportunity to check the prescribed start up procedure and modify where possible. Sometimes, it is too long, sometimes it is too short. The vendor recommended startup procedure (turbine speed vs time) was copied (Figure 11 for a typical chart) and was put on the local control panel for all operators to follow during this initial run. In the case of this particular turbine, the procedure was slightly modified to shorten the startup time.

Also after operation for four hours, the turbine was brought down and started up again to observe the change in vibrational characteristics with a hot start. The graph was modified to include both cold and hot start conditions. This is time saving and practical in many applications, particularly with turbines having long bearing spans. We then proceeded to operate at minimum continuous speed and confirmed that the governor system operated satisfactorily and then immediately proceeded with caution to trip the turbine three times. We then operated the unit at the maximum continuous speed and confirmed that the trip and throttle valve tripped on low control oil pressure.

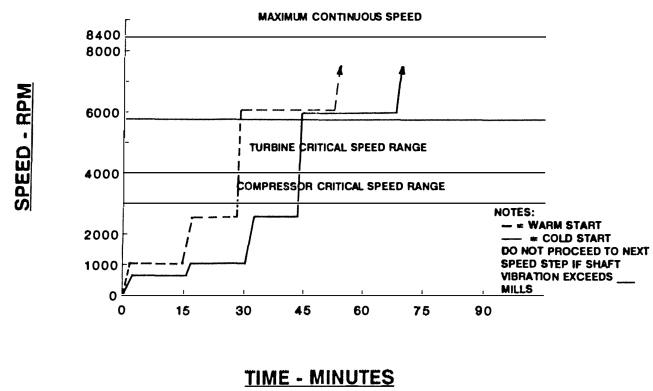


Figure 11. Suggested Steam Turbine Startup Map.

Having previously demonstrated that the manual exerciser limited travel would not trip the turbine while the unit was stationary, the team now confirmed to the operators that this could be done with the turbine operating.

Note that the procedure is written in such a way that the opportunity is presented to check and confirm satisfactory operation of each major component: the exerciser, the main and auxiliary lube oil pumps, etcetera, to show the operator that the unit will not trip. Also, we tripped the unit using each unit trip device to demonstrate their proper operation. It must be remembered that all units are comprised of many systems and sub-systems. As an example, a simple lube oil trip system incorporates the switch sensing point, the switch itself, the hard wiring from the switch to the solenoid valve on the turbine that in turn must dump oil to activate the trip and throttle valve. Therefore, the entire system must be checked and proven, not just the root switch. During the run all systems were checked as much as physically possible. Proper extraction turbine regulator operation, etcetera, was confirmed.

The data required to be obtained were detailed in the procedure. The intent was to follow the shop test agenda as closely as possible and establish a field baseline which would now replace the test baseline which was followed. Refer to APPENDIX for specific mechanical data requirements. The data then was compared with the shop operating data and it was confirmed that the turbine had operated properly. This confirmed that all activities performed during commissioning had been satisfactory, and the turbine was now a highly reliable piece of equipment ready to be fully commissioned into process service.

Following the test, a meeting was held to discuss any modifications that were required. Baseline data were reduced and filed with the reliability group. A report was published by the reliability group which was circulated to that particular unit and now served as the baseline information which would be utilized during the startup.

COMPRESSOR STRING RUNS

After all auxiliary systems were checked out and steam turbine solo run and safety checks were completed, it was time to couple the steam turbine and compressor casings per the arrangements established in the planning section. The team ensured that the required amount of steam quantity was available. The extraction condensing turbines were run in a straight condensing mode. At design stage, the turbine condensing casing was sized for 80 percent of rated required power in a straight condensing operation which gave us sufficient capability to run this test.

The goal of the test was to run the string until system temperature stabilized and to confirm the system response in terms of rotordynamics, temperatures, hot alignment, and all associated auxiliary systems functions. This goal was tempered wherever they noted the limitation of testing in the planning section. This was the first time they ran the string together, since the compressors and turbine were separately shop tested due to the geographical location of the compressor and turbine vendor facilities. The team decided to control the test locally at the compressor deck. They were able to monitor the vibrations and temperatures right at the local panel including all annunciations of the auxiliary system. The operators having gone through the turbine solo run had the confidence and knowledge of the procedure. The manufacture service representatives were also present in the startup team.

An air run test procedure was prepared which closely followed the steam turbine procedure outline as noted in the APPENDIX. In addition, a graph was prepared of the procedure (time vs string speed). The procedure was posted on the local panel in graphical manner with critical speeds (compressor and turbine) clearly shown as determined by the shop testing (Figure 12). The Bodé and Nyquist polar plots and all other data obtained during shop testing were available for reference. At slow roll speed of 500 rpm the team checked for any indications of distress (internal rubs, etc.) in the system. The speeds were increased in increments within the recommended time span, while the system was continuously monitored. After going through the first critical speeds and reaching minimum continuous speed, operation of the governor control was confirmed. From this point, the speed was increased through governor control system to reach maximum continuous speed. They closely watched the vibration monitors on the local panel and temperature gauges on the piping. At the same time, they kept radio contact with the main control room. There was a small amount of uncertainty in running the refrigeration units, due to

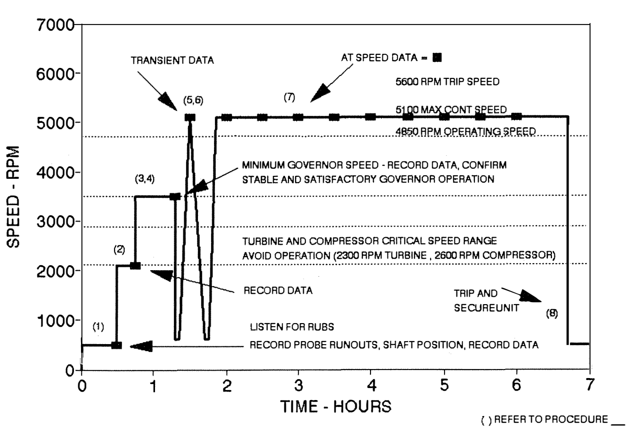


Figure 12. Typical Compressor Field Air Run Program Chart.

temperature concerns. As expected, temperature on the ethylene compressor rapidly increased and the unit was tripped within 15 minutes after reaching maximum continuous speed. The unit was tripped well before the temperature limits as a precaution. Even with the short duration of the test, they were able to confirm the vibration levels, critical speeds and the complete system response.

The startup team did not find any significant difference in system response from what was expected based on shop test data. All vibration levels were within 0.5-0.75 mils including total runouts. The vibration criteria for shop test acceptance for these units were 1.25 mils, including electrical and mechanical runout. They allowed 0.5 maximum total runout based on equipment vendor acceptance criteria, however, they were able to limit total runout to 0.25 mils in most cases.

CONCLUSION AND SUMMARY

Each of the four compressor trains described was fully tested. Each major auxiliary system, driver and compressor was tested according to a specific procedure as outlined herein. Modifications were made where required and documented. All commissioning test data were recorded and filed. Commissioning test values were compared to shop test results to confirm satisfactory operation. Throughout the testing program, site personnel were used to operate equipment and perform required tasks.

The effort expended in planning, preparing and executing this large scale program paid off tremendously in a trouble free ethylene unit startup and continuous reliable operation. It really looks like we "Did It Right The First Time."

APPENDIX

Functional Lube/Seal System Test
Procedure Outline

Objective: To confirm proper functional operation of the entire system prior to equipment startup.

Procedure Format: Detail each test requirement. Specifically note required functions/setpoints of each component. Record actual functions/set points and all modifications made.

Note: All testing to be performed without the unit in operation.

I. Preparation
   A. Confirm proper oil type and reservoir level.
   B. Confirm system flush is approved and all flushing screens are removed.
   C. Confirm all system utilities are operational (air, water, steam, electrical).
   D. Any required temporary nitrogen supplies should be connected.
   E. All instrumentation must be calibrated and control valves properly set.
   F. Entire system must be properly vented.

II. Test Procedure
   A. Oil Reservoir
      1. Confirm proper heater operation.
      2. Check reservoir level switch and any other components (TIs, vent blowers, etc.).
   B. Main pump unit
      1. Acceptable pump and driver vibration
      2. Absence of cavitation
      3. Pump and driver acceptable bearing temperature
      4. Driver governor and safety checks (uncoupled) if driver is a steam turbine
   C. Auxiliary lube pump unit—same procedure as item B above
   D. Relief valve set point and nonchatter check

E. Operate main pump unit and confirm all pressures, differential pressures, temperatures and flows are as specified on the system schematic and/or bill of material.
F. Confirm proper accumulator precharge (if applicable).
G. Confirm proper setpoint annunciation and/or action of all pressure, differential. pressure and temperature switches.
H. Switch transfer valves from bank "A" to bank "B" and confirm pressure fluctuation does not actuate any switches.
I. Trip main pump and confirm auxiliary pump starts without actuation of any trip valves or valve instability. NOTE: Pressure spike should be a minimum of 30 percent above any trip settings
J. Repeat Step I above, but slowly reduce main pump speed (if steam turbine) and confirm proper operation.
K. Simulate maximum control oil transient flow requirement (if applicable) and confirm auxiliary pump does not start.
L. Start auxiliary pump, with main pump operating and confirm control valve and/or relief valve stability.

Note: Some systems are designed to not lift relief valves during two pump operation

III. CORRECTIVE ACTION

A. Failure to meet any requirement in Section II requires corrective action and retest
B. Specifically note corrective action
C. Sign off procedure as acceptable to operate

Electrohydraulic Governor Functional Test
Procedure Outline

Objective: To confirm proper system functional operation prior to equipment startup.

Procedure Format: Detail each test requirement. Specifically note required functions/setpoints. Record actual functions/setpoints and all modifications made.

Note: All testing to be performed without the unit in operation.

I. Preparation

A. Confirm all shutdown contacts are in the normal condition.
B. Confirm all power supplies are on.
C. Secure necessary test equipment.
   1. Pressure sources (Nitrogen bottles) for pressure simulation at transmitters
   2. Frequency generators for simulating speed signals

II. Test Procedure

A. Take required action to put system in "run" mode.
B. Open trip and throttle valve only after ensuring the main steam block valve is closed.
C. Simulate turbine start, slow roll and any start sequence "hold" points up to minimum governor operating point.
D. Confirm proper operation of "raise" and "lower" speed buttons.
E. Connect external process signal inputs (one at a time) and confirm proper governor action to input signal variation.
F. Check overspeed override feature.
G. Confirm automatic transfer to and from backup governor ("position control") for each of the following cases:
   1. Loss of main governor power supply
   2. Zero external input signal
   3. Failure of "final driver" (internal governor component).
   4. Zero speed inputs
H. Confirm manual transfer to and from backup governor and "emergency override."
I. Check raise and lower speed controls while in backup governor mode.
J. Confirm governor shutdown (trip) operation under the following conditions:
   1. Overspeed setting
   2. Failure of both main and backup governor controls

III. Corrective Action

A. Failure to meet any requirement in Section II requires corrective action and retest.
B. Specifically note corrective action.
C. Sign off procedure as acceptable to operate.

Steam Turbine Solo Run Functional Test
Procedure Outline

Objective: To confirm acceptable mechanical operation of the steam turbine, governor system and safety (trip) system.

Procedure Format: Detail each test requirement. Specifically, note required test limits (*Note:* shop test data should be used to define acceptable limits.) Recorded actual test values using appropriate instrumentation and note all modifications made.

I. Preparation

A. Confirm all auxiliary system tests are complete (governor, lube system, etc.)
B. Confirm all inlet steam lines have been cleaned and signed off.
C. Confirm all installed instrumentation is calibrated.
D. Secure all required instruments.
   1. Calibrated pressure and temperature gauges
   2. Occiloscope(s)
   3. Vector filters
   4. Amplifier(s)
   5. Spectrum analyzer
   6. Tape recorder or information gathering module
E. "Walk" all steam inlet, extraction and exhaust lines. Confirm all spring hangers are released (unlocked) and safety valves are installed.

II. Test Procedure

A. Confirm all auxiliary systems are operational and at proper conditions ("lined out")
   1. Lube/control oil system
   2. Governor/Trip system
   3. Turning gear (if applicable)
   4. All warming lines drained and operational
   5. Condensing system including condensate pumps (if applicable)
   6. Extraction system (if applicable)
   7. Steam seal system

8. Condition monitoring systems (vibration, temperature, etc.)
9. Steam conditions within allowable vendor limits

B. Slow roll and start unit per vendors instructions. (Refer to cold startup speed vs time chart.)
C. Demonstrate manual trip (panic button) at low speed (500 rpm).
D. Reset trip, accelerate back to desired speed—listen for rubs etc.
E. Gradually increase speed to next speed step. Record the following data for each vendor required speed step up to minimum governor speed.
   1. Overall vibration at each vibration point (record frequency if specified limits are exceeded).
   2. Bearing oil temperature rise at each bearing
   3. Bearing pad temperature (axial and radial) at each point (if applicable)
   4. Turbine speed
   5. Axial shaft displacement
   6. Turbine exhaust temperature

Note: Use shop test data for comparison.

F. After confirming stable operation at minimum governor speed, accelerate carefully to overspeed trip setting and trip the turbine three times. Each trip speed should fall within the vendors' trip speed setpoint allowable range.
G. Return to minimum governor speed and confirm satisfactory manual and automatic speed control. Also confirm automatic transfer from main to backup governor.
H. Connect vibration recording instruments (see Item ID), reduce turbine speed to 500 rpm and record shaft vibration (at each vibration monitoring point) and phase angle, while gradually increasing speed to maximum continuous speed. Repeat step in reverse direction (maximum continuous speed to 500 rpm).

Note: This data will be reduced to Bodé, Nyquist and Cascade plots and should be compared to shop test data.

I. Increase turbine speed to maximum continuous speed and run for four hours or until bearing temperatures stabilize.
J. Finally, trip the turbine using a system trip switch (simulate low oil pressure etc.).

III. CORRECTIVE ACTION

A. Failure to meet any requirement in Section II requires corrective action and retest.
B. Specifically note any corrective action.
C. Sign off equipment as acceptable to operate.

REFERENCE

1. Dunaway, J. L., "Guidelines For Mechanical Field Testing of Compressors," Elliott Service. Bulletin C-35, pp. 2-12 (1979).