CONTROL #2

This document has no restrictions inside Dresser-Rand, some restrictions outside Dresser-Rand.

1. OBJECTIVE

This procedure defines the high level process for Functional (factory no-load) and Performance Testing contemplated for the Prototype HydroAir PTO governed by Dresser-Rand Award Number DE-EE0006609. It is not intended to define explicit details for each required system test segment. Its purpose is to summarize the scope of testing and briefly explain each test segment. A comprehensive HydroAir PTO Test Program is being developed that will complement this procedure.

2. SCOPE

This document summarizes the range of test procedures to be followed during the HydroAir turbine factory trials from uncoupled spin testing through fully loaded coupling testing once deployed. Detailed individual test plans will be developed for each of the test segments summarized in this procedure. Each of the individual plans will include detailed requirements for equipment under test, acceptance criteria, required instrumentation, setup and operational parameters, data forms, etc. Individual test segments are written coincident with the detailed product design phase and are not available at the point of initial release of this procedure.

3. APPLICABLE DOCUMENTS

3.1 Internal Documents

List of individual test programs

MTD011-01	Factory No-Load Spin Test
MTD011-02	Factory Spin-down Test
MTD011-03	Factory Shut-Off Valve (SOV) Test
MTD011-04	On Buoy Test at Shipyard
MTD011-05	On Buoy Test at Sea

3.2 External Documents

Dresser-Rand Award Number: DE-EE6609 - Attachment 1 – Statement of Project Objective (SOPO)
Siemens PMG, VFD and control system Instruction Manuals
Siemens PMG and VFD Factory Acceptance Test (FAT) Results

4. PROCEDURE

4.1 General

During HydroAir Power Take Off (PTO) testing persons present should be limited to those directly associated with the test, and must have the appropriate Personal Protective Equipment (PPE).

Dresser-Rand personnel

- Safety Footwear
- Overalls
- Eye Protection
- Ear Protection

Customers Representatives

- Safety Footwear
- Eye Protection
- Ear Protection

4.2 Test Preparation

4.2.1 Safety survey to be carried out and certificate signed by test facility supervision

a) Is the turbine assembly suitable for test?
b) Are rotating parts protected by guarding / shields or cordoned off?
c) Emergency stop fitted and checked?
d) Are electrical connections and wiring suitably fitted and isolated?
e) Is the system correctly earthed?

4.2.2 A high level inspection must be undertaken of the machine to ensure no loose items are on the machine

4.2.3 Electrical alarms & trips panel settings checked against test program, recorded and signed off by electrical engineer.

4.2.4 Test instrumentation, instrumentation requirements are defined in the test program. All Dresser-Rand instrumentation utilized at the test must have a current calibration label and certification. All contract instrumentation utilized at the test must also have appropriate certification held by Dresser-Rand.

4.4 Factory No-Load Spin Test

Summary Objective: This first phase of the test procedure is intended to confirm the basic rotational ability of the turbine and generator drive assembly. It will provide confirmation that the components have been assembled correctly allowing the drive to function up to the over-speed limit. In this test, the generator is externally powered and it will be used as an electric motor to spin the rotor shaft.

This test is performed purely by motoring the generator to rotate the turbine and drive train. During all the below tests, frequent checks must be made to ensure that no internal rubbing is occurring and bearing temperatures and vibration levels recorded. If an issue is suspected, the test must be stopped and the problem investigated.

Details of the Factory No-Load Spin Test outlined below will be defined in Test Program MTD011-01

4.4.1 Start-up – Barring speed test:

HydroAir turbine to be run at barring speed (10 rpm) for 10 minutes. During this time frequent checks will be made to assure that no internal rubbing is audible.

4.4.2 Low Speed Test:

Turbine to be run at low speed (50 rpm) for 10 minutes. During this time frequent checks will be made to assure that no internal rubbing is audible.

4.4.3 Nominal Speed Test:

Nominal running speed test at 650 rpm. Duration: 45 minutes. Incremental speed increase at 150, 300, 450 rpm stages for 5 minutes each then 650 rpm for 30 minutes During the test run drive to the generator must be disconnected and the generator brake activated a number of times and time to stop recorded.

4.4.4 Over Speed Test:

HydroAir turbine to be run at over-speed (1100 rpm) for 10 minutes. During the test run drive to the generator must be disconnected and the generator brake activated a number of times and time to stop recorded.

4.5 Factory Spin-down Test

Summary Objective: This spin down test is required to assess the actual losses compared to the calculated figures derived though the design process. This will then provide a verified baseline loss value for the turbine. In this test, the generator is externally powered and it will be used as an electric motor to spin the rotor shaft at full speed. The power is then cut off and the turbine is allowed to spin down. The viscous losses of the turbine are calculated, as it slows down and comes to rest ultimately.

Details of the Factory Spin-Down Test outlined below will be defined in Test Program MTD011-02

4.5.1 Mechanical Loss Test:

The mechanical losses (windage losses + bearing losses) should be measured before the turbine performance test. Motor the generator bare-shafted, measure the power over the speed range, and then repeat it with the turbine connected. The difference in power/torque would represent the mechanical losses in the turbine only. The generator mechanical losses will be obtained from Siemens Industry Inc. (generator supplier).

4.6 Factory Shut-Off Valve (SOV) Test

Summary Objective: This test will prove the mechanical functionality of the SOV. It will provide confirmation that the components actuating the spider-frame webs of the SOV have been assembled correctly and that the fail safe feature of the system performs as expected.

Details of the Factory Shut-Off (SOV) Test outlined below will be defined in Test Program MTD011-03

4.6.1 The shut-off valve must be actuated a number of times to ensure it operates correctly. Compressor or shop floor air supply shall be used to actuate the shut-off valve.

4.6.2 With the shut off valve in the open position isolate the compressor electrical power (to simulate a power failure) and ensure the valve will operate at least twice (i.e. open and close) using only the stored air in the receiver tank. In addition, checks needs to be done to determine how many operations are possible before the air is exhausted.

4.7 On Buoy Test at Shipyard

Summary Objective: This test is intended to confirm the correct assembly and functionality of the turbine when finally assembled as a complete system onto the buoy. It allows testing to be done in a controlled environment prior to the sea tests.

Details of the On Buoy Test at Shipyard outlined below will be defined in Test Program MTD011-04

During all the below tests, frequent checks must be made to ensure that no internal rubbing is occurring. If so, the test must be stopped and the problem investigated. Only when a solution is found must the test resume from the point when it was stopped.

4.7.1 Safety survey to be carried out and certificate signed by test facility supervision

4.7.1.1 Is the turbine assembly suitable for test?
4.7.1.2 Are rotating parts protected by guarding / shields or cordoned off?
4.7.1.3 Emergency stop fitted and checked?
4.7.1.4 Are electrical connections and wiring suitably fitted and isolated?
4.7.1.5 Is the system correctly earthed?

4.7.2 The shut-off valve must be actuated a number of times to ensure it operates correctly.

4.7.3 With the shut off valve in the open position isolate the compressor electrical power (to simulate a power failure) and ensure the valve will operate at least twice (i.e. open and re-close) using only the stored air in the receiver tank. In addition, checks needs to be done to determine how many operations are possible before the air is exhausted.

4.7.4 Start-up Test:

While the SOV is closed, motor the generator at barring speed (10 rpm) for at least 10 minutes. During this time frequent checks will be made to assure that no internal rubbing is audible.

4.7.5 Low Speed Test:

While the SOV is closed, turbine to be run at low speed (50 rpm) for 10 minutes. During this time frequent checks will be made to assure that no internal rubbing is audible.

4.7.6 Nominal Speed Test:

While the SOV is closed, turbine to be run at 650 rpm. Duration: 30 minutes. During the test run drive to the generator must be disconnected and the generator brake activated a number of times and time to stop recorded.

4.7.7 Over Speed Test:

While the SOV is closed, turbine to be run at over-speed (1100rpm) for 10 minutes. During the test run drive to the generator must be disconnected and the generator mechanical brake activated a number of times and time to stop recorded.

4.7.8 Maintenance Procedure Test:

The HydroAir PTO should be disassembled and reassembled again based on the maintenance procedure and any potential issue should be investigated.

4.7.9 Instrumentations – Check if signals are collected by the instrumentations equipment.

4.8 On Buoy Test at Sea

Summary Objective: The sea testing is the final stage of the test program and will confirm the functioning of the complete HydroAir PTO in sea conditions. It will provide the final validation that the overall system is performing and functioning as designed.

Details of the On Buoy Test at Sea outlined below will be defined in Test Program MTD011-05

When the HydroAir PTO is commissioned, the following tests should be performed for the duration of the sea trails. The sea trails should be commenced on a relatively calm day where the power of the turbine is not expected to exceed 100kW. In other words, the significant wave height (Hs) on site should not exceed 1.35m.

4.8.1 The shut-off valve must be actuated a number of times to ensure it operates correctly.

4.8.2 SOV Effectiveness

While the holding brake is off, close the SOV and measure the torque on the rotor and the flow rate inside the turbine. Ideally there should be no flow rate and hence torque on the turbine.

4.8.3 Holding Brake Test:

While the SOV is closed, actuate the mechanical holding brake. Then open the SOV and ensure the mechanical holding brake is fully functional, i.e. the rotor is not rotating.

4.8.4 Running Test:

The turbine shall start operating to prove its mechanical operation, and that of the auxiliary equipment as a complete unit. A series of safety trip tests, as listed in the test program, will be carried out at the commencement of the running test. During the run the operating values of the pressures, flow rates, temperatures, and vibration must be within the range specified in the test program. The instrumentation listed in the test program will be monitored with readings being recorded at 30 minute intervals for the duration of the test.

4.8.5 Generator Loading Test - 50 %, 100%, 150 %:

This test enables us to monitor the temperature through the stator windings to determine the overall temperature rise through the variation in load tests. This will enable us to have confidence that the generator will not see a condition where it will go into thermal overheat.

4.8.6 Electricity Grid Loss Test / Power Drop-off Test:

Power drop-off test provides validation of the electrical circuit`s ability to reject power to the breaking resistor and validate system shut down procedure.. This is achieved by starting with 50% input load to generator and incrementing the loads by 25 % to a maximum value of 150%. This test is imperative when using a Permanent Magnet Generator (PMG) as stored energy can cause the PMG to go into a 'run-away' condition which will in turn damage the PMG.

In this test, the switch gear (circuit breaker) shall be manually disconnected. This simulates electricity loss from grid. Following actions shall occur (shut-down routine):

1. SOV: solenoids should revert back to default position, enabling the closing of SOV
2. Parallel electrical path connecting PMG to resistor should be closed by the contactors and turbine-power shall be dumped to the resistor bank.
3. Holding brake shall be engaged after a time delay of 10 sec and lock the rotor shaft in place

Once the electricity grid becomes live, i.e., switchgear is closed, following actions should occur

1. The holding brake shall be disengaged
2. The SOV valves will be opened
3. Parallel path for resistor bank shall be opened via the contactors
4. Turbine shall start spinning and VFD shall be powered on, ready for power-take-off to be implemented

4.8.7 Loss of Auxiliary Power Testing:

In case of loss of auxiliary power, following components could lose power

1. PMG pump cooling
2. Resistor bank Fan cooling

3. Sensors and instrumentation (pressure, flowrate, RTD, solenoids etc.)

Following this loss of power, a similar shutdown routine, as described in 4.6.4 shall be implemented. This ensures safety of components. Also, an alarm shall be logged for auxiliary power failure, to help service personnel diagnose the problem.

4.8.8 Data Logging Failure Test:

Data logging failure can occur, if there is breakage of the cable connecting the I/O panel to the data logger device. It should not cause the system performance to be affected; however, it will cause loss of data and hence needs to be addressed. Controller will have an alarm in case data logging fails.

4.8.9 System Reboot Test:

The goal for system reboot test, is to check , when there is a loss of grid power, and the grid power comes back, (after a time delay), the PTO system is able to start autonomously. The testing sequence would be similar to section 4.6.4

4.8.10 Controls Algorithm Test:

The rotor shaft should be run at a nominal rpm of 650 and incremented/decremented by 50 rpm while the power-out readings are recorded.

4.8.10.1 If DC bus voltage drops below 690 V, power should be taken out from inverter side (PMG) till the DC bus reaches 690 V. This occurs as long as rpm > 350. If rpm drops below 350, the electrical efficiency of PMG falls and hence power take-off is stopped and rpm is allowed to build up.

4.8.10.2 The Voltage may not go above 690 V instead, current can increase from 480 A to 770 Amps. 770 A is the limit that LCM (Line connection module) can allow to pass to the transformer without damage. If current exceeds this limit, excess current gets dumped to the brake resistor.

4.8.11 Drop-out Test:

While the turbine is operating, exercise the emergency drop out procedure. This means the Dynamic Brake would operate to dump the power and slow the shaft down to stationary position and the holding brake should activate to hold the shaft in place. During this procedure, the SOV should have also been automatically activated to stop the air to go through the turbine. When current through the line module increases the rated capacity of S120, it will dissipate the excess current to the brake resistor. This should stop, once the current level comes to acceptable value. While current is being dumped in resistor, if the temperature of resistors increases above a threshold value, the SOV should be activated and stop the turbine from spinning. The time should be recorded to assess how quick DBR and mechanical brake works and test the effectiveness of how strong the mechanical break is.

4.8.12 Sensor Failure Testing:

Disconnect sensor power wires so as to create sensor failure and see if relevant alarm shows up, and ensure that sensors are designed to be fail-safe (pressure, pitot tube, vibration, temperature)

4.8.13 Turbine Performance Test:

While the turbine is operating, data on the pressure, flow rate, power output, torque and efficiency of the turbine should be recorded. The analysis must be performed to create the damping curve and efficiency plot of the turbine and compare it to the original envisaged performance targets based on the design file.

4.8.14 Autonomous Drop-out Test:

Manually set the upper limit of the drop-out procedure to a lower limit based on the current weather condition. Leave the turbine operating for a period of time until the weather condition limit is met which means the turbine should be dropped-out automatically. In other words, if the manually set limits are met, the DBR, holding brake and the SOV should all be activated automatically.

4.8.15 Short-term Endurance Test – Autonomous Mode:

Leave the turbine to operate on its own for a period of 7 days and assess the power output and performance at the end of the period. All the data on various performance indicators should be recorded regularly during this period.

4.8.16 Long Term Endurance Test – Autonomous Mode:

Leave the turbine to operate on its own for a period of the test (5 months) and assess the power output and performance at the end of the period. All the data on various performance and noise and vibration indicators should be recorded regularly during this period.

4.9 Records

4.9.1 Following the successful completion of the Tests, the accepted test record will be signed and dated by the presiding Dresser-Rand Engineer. The test record will then be incorporated into the turbine test documentation pack.

5. REVISION RECORD

Rev	Description	Date	APP	ECN
A	Initial Release	6/26/2015		
B	Remove Factory No-Load Flow Test (MTD011-03) and Factory Part-Load Flow Test (MTD011-04) as they are not in the scope of current award DE-EE0006609	12/18/2015		

Appendix 1 – Example of the test program input sheet

DRESSER-RAND	TURBINE TEST PROGRAM No: *MTD011*
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TO :- **PROJECT MANAGER**

ISSUE	1		
DATE			
Factory Acceptance Test Date			

D-R O/No:	
Customer:	
Customer O/No:	
Number Off:	
Issued by:	
Approved by:	

FACTORY ACCEPTANCE TEST PROGRAMME

GENERAL

Turbine Type	HydroAir Radial Turbine	
Max Speed	1000	rpm
Power	500	kW
Max Pressure Differential	10000	Pa
Design Temperature	20	°C
Nomina Speed (or Range)	300-700	rpm
Driven Unit	Permanent Magnet Generator	

Appendix 2 - Punch List

Item requiring attention	Responsibility	Action Date