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MODERN TEST FACILITIES FOR GAS TURBINE ENGINES: REQUIREMENTS AND CHALLENGES

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Abstract

Modern test facilities allow R&TD teams to test Gas Turbine components with a wide range of air and fuel parameters. To determine the suitability of the Test Facilities for operation with required fuel and air streams various physical parameters need to be considered: pressure, temperature, dew point, mass flows, fuel composition, and others. In addition, the availability and reliability of the Test Facilities assets are the important issues that management and operators have to deal with on a daily basis. This paper describes the current approach the NRC Gas Turbine Laboratory's National Facilities team is undertaking to provide reliable support for R&TD activities. Special focus is given to the challenges of facilities maintenance in the multi-client environment and the reliability of operations. Suggestions on the type of maintenance, such as Condition Based Maintenance (CBM) and Reliability Centered Maintenance (RCM), and tools for tracking the component life and performance are made.

1 Introduction

Throughout its history, the Division of Mechanical Engineering (DME) and the Institute for Aerospace Research (IAR) of the National Research Council of Canada (NRC) have been the key players in the emergence of the gas turbine industry in Canada. In the early post Second World War II years, the Government of Canada created the National Aeronautical Establishment (NAE) as an entity of the NRC. Originally housed within the NRC's Division of Mechanical Engineering, which had a leading role in the gas turbine research and development at that time, the NAE became a separate division of the NRC in 1959. In 1990, the NAE was renamed the Institute for Aerospace Research. In the same year, the Division of Mechanical Engineering was dissolved and some of its laboratories were integrated into the IAR. In the following years, the aerodynamics research group was further consolidated in 1995 when the newly established Aerodynamics Laboratory (AL) Group merged with Turbomachinery and Combustion Groups of the former DME. These groups successfully collaborated with industrial partners like Pratt & Whitney Canada (P&WC), Rolls Royce Canada (RRC), Westinghouse Canada (WC), and General Electric (GE) and performed a multitude of tests linked to research and development of the gas turbine engines and their components. The Gas Turbine Laboratory (GTL), one of the presently existing five laboratories in IAR, was created in 2005 as a result of the certain re-organizations within NRC-IAR. Currently the GTL comprises of the Propulsion Group (original Engine Lab), the Gas Turbine Aerodynamics & Combustion Group (original Gas Dynamics Lab), and new Mechanical Components Group. The GTAC National Facilities, which will be discussed in this paper, is presently part of the GTL-Gas Turbine Aerodynamics and Combustion (GTAC) Group having the goal to provide reliable technical services to GTL personnel and its clients involved in the gas turbine R&D work. For more then half a century, the National Facilities has offered the major support in the design, development, and certification of the gas turbine engines and its components, and has provided skilled personnel needed to develop and maintain these facilities and to interpret the R&D data generated using these facilities.

2 The History of GTAC National Facilities

The design and construction of the National Facilities at the present Montreal Road, Ottawa location can be traced back to 1939. Since then it has continued to expand to the present time. It was clear to the NRC gas turbine research team at that time, that due to the complexity of gas turbine research it would be necessary to conduct most of the testing on gas turbines and their components at full scale facilities. Thus, the National Facilities' heavy machinery and buildings to house it were designed and built to a full scale (i.e. pressures, temperature, fuel/air mass flow parameters mach the original gas turbine engine specifications). These full scale parameters are described in the next chapter. In 1949 the NRC embarked on an extensive development and expansion of its facilities, including the construction of special purpose buildings and procurement and installation of the exhauster (2MW Brown Boveri), the compressor/exhauster (5MW Brown Boveri), Centrifugal Blowers of different sizes, and various auxiliary equipment to work with the compressor/exhauster units including the wooden Cooling Water Tower. To support internal aerodynamics research on gas turbine components the two tunnels, subsonic and supersonic, were constructed at the same time supplemented by four in-parallel Fuller pumps driven by a 260kW (350HP) electrical motor, two big spherical air holding pressure vessels, and an air dryer system. The construction and commissioning of the first building and its facilities was completed in 1953-1954.

In the late 70's and early 80's the National Facilities were further expanded to include the new Altitude Test Facility to support P&WC engine test programs. This facility was upgraded in 2007-2008 and presently it has fully integrated, PLC controlled altitude test cell including air delivery system, upgraded air dryer unit, and dynamometer system. The third compressor/exhauster (7.5MW Ingersoll-Dresser-Rand) was commissioned and added to the National Facilities assets in the mid 80's. This unit was installed in a separate building and was fully overhauled in 2002 with upgraded PLC controls. The old cooling tower was replaced around 1987 with a new 5 ton three-cell Cooling Water Tower equipped with two 60HP pumps.

In 1996, The Aerodynamics Laboratory and its academic and industrial partners identified a requirement for the development of additional experimental infrastructure at the NRC to support increased R&D work of the Canada's gas turbine engine industry. This effort led to the design and construction of the Gas Turbine Environmental Research Centre (GTERC), which resulted in the additional air moving capabilities been added to the existing infrastructure of the National Facilities.

The first part of the GTERC complex, the Inlet Air Treatment System (IATS) and Altitude Test Facilities (ATF) housed in the newly constructed building, together with the 7.5MW Ingersoll-Rand compressor/exhauster control modification, was commissioned in 2004. The IATS system consists of the following PLC controlled elements: 1.86MW Atlas-Copco centrifugal compressor (C1), turbo-expander unit (C2E), two air dehumidifier units, two air heat-exchangers, two 5 ton chillers, auxiliary oil pumps, and a PLC controlled air-distribution system.

The second part of the GTERC was commissioned (in part) in 2006-2007. These new facilities, designated as the High Pressure Distribution System (HPAD) facilities, consist of one 4-stage intercooled centrifugal compressor (6MW Cooper Turbocompressor), two 4-stage intercooled centrifugal compressors (1.8MW Atlas-Copco) outfitted with after-cooler, a 50 ton 2-cell Cooling Water Tower, and a PLC controlled air-distribution system. The HPAD system is currently supporting gas turbine combustion test and research programs in GTL. The GTERC facilities earned the International ISO 9001:2000 Quality Standard registrations and recently ISO: 2008 Quality Standard registration. The GTAC National Facility team use these facilities to support industry in developing both aircraft and ground-based gas turbine engines in compliance with increasingly stringent environmental, operational, and safety requirements. The Figure 1 shows the current layout of GTAC National Facilities buildings and structures.

Figure 1: The aerial view of GTAC National Facilities.

3 The Description of GTAC National Facilities

3.1 The Major Assets

The overall GTAC air moving and air treatment facilities are comprised of four main systems: the Inlet Air Treatment System (IATS), a High Pressure Air Distribution (HPAD) system, an Air Compressor-Exhauster Services (ACES) system, and the Cooling Water Towers Distribution (CTWD) system.

The National Facilities' main compressor/exhauster units are organized in three bays. Bay 1 houses a 2MW Brown Boveri exhauster and 5MW Brown Boveri compressor/exhauster, Bay 2 contains an 7.5MW Ingersoll-Rand compressor/exhauster, and Bay 3 houses new 6MW Cooper Turbocompressor compressor and two 1.8MW Atlas-Copco compressors.

Table 1: Specifications for Air Moving Equipment in GTAC National Facilities.

Equipment	**Output Power MW (HP)**	**Inlet flow kg/s (lb/s)**	**Max. Pres. kPa (psia)**	**Compression Ratio**
Ingersoll-Rand Compressor/Exhauster	7.5 (10000)	27.3 (60)	802 kPa (116.4 psia)/ 12.4 kPa (1.8 psia)	8:1
Brown Boveri Compressor/Exhauster	5.0 (6800)	14.0 (31) 4.5 (10)	689 kPa (100.0 psia)/ 41 kPa (6 psia)	7:1 2.5:1
Brown Boveri Exhausters	2 x 1.0 (2 x 1350)	4.5 (10)	20.7 kPa (3.0 psia)	5:1
M5A Compressor #1 (EECC)	0.9 (1250)	2.3 (5.0)	2170 kPa (315 psia)	22:1
M5A Compressor #2 (EECC)	0.9 (1250)	2.3 (5.0)	2170 kPa (315 psia)	22:1
Atlas Copco Compressor #1	1.8 (2500)	3.2 (7)	2170 kPa (315 psia)	22:1
Atlas Copco Compressor #2	1.8 (2500)	3.2 (7)	2170 kPa (315 psia)	22:1
Cooper Turbocompressor	6.0 (8000)	12.5 (27.5)	2170 kPa (315 psia)	22:1

3.2 The GTAC National Facilities Systems

The IATS system is comprised of the following components housed in or atop new stand alone building:

- Turblex 1.8MW (2500HP) single stage centrifugal compressor (C1),
- Two tube-in-shell air heat-exchangers,
- Mafi-Trench compressor with turbo-expander (designated as C2E),
- Two Munters dehumidification units c/w two, Mcquay and Carrier types, chillers,
- The intermediate pressure air distribution stainless steel piping network

A 4-stage intercooled, Ingersoll Rand centrifugal compressor/exhauster serves the IATS system. This unit is driven by a 7.5MW (10,000HP) GE electric motor. All machinery is PLC controlled with Allen Bradley systems which allow for both automatic and manual mode control with data acquisition and trending made possible by INSQL server historian. The diagram of IATS system is presented in Figure 2.

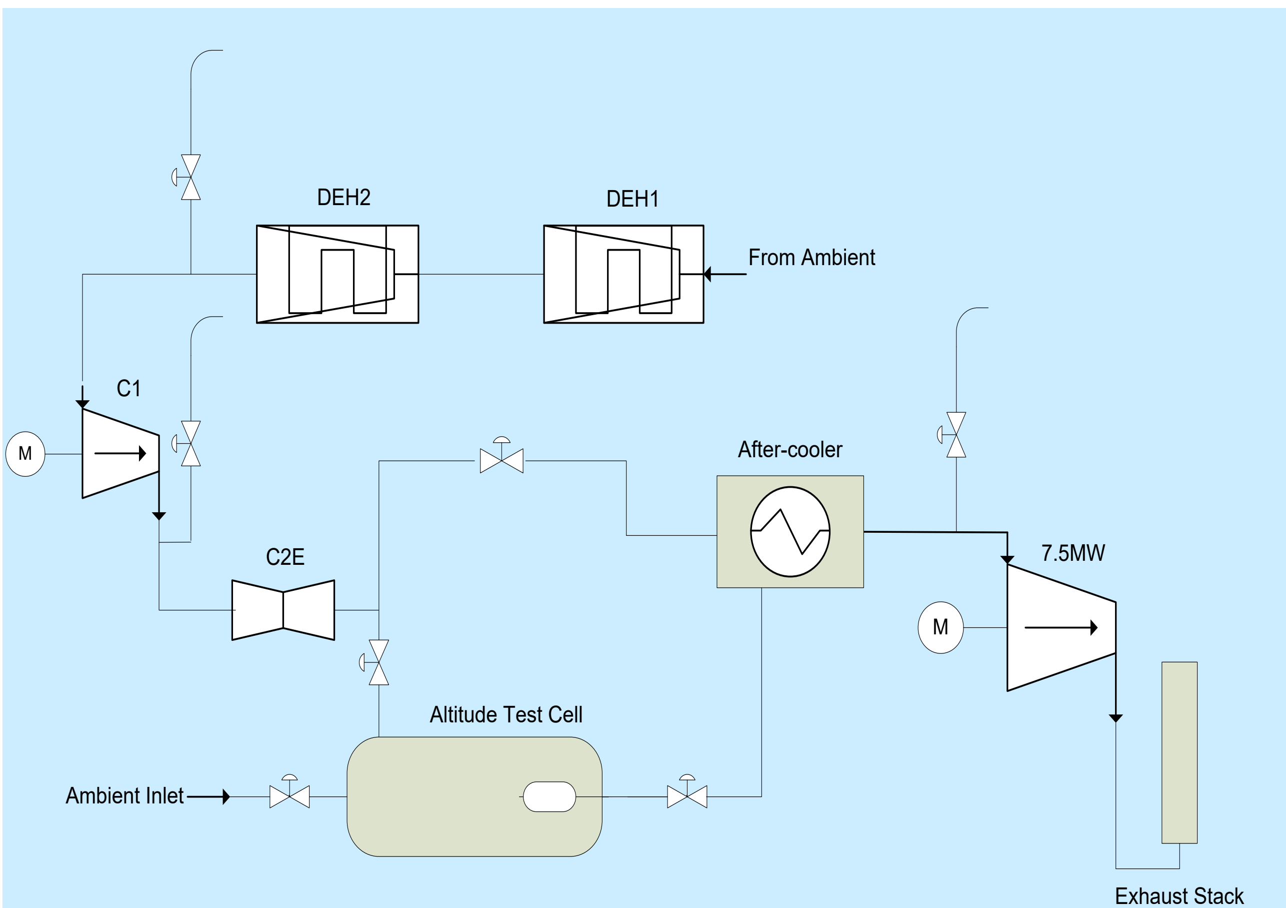

Figure 2: Diagram of IATS system.

The HPAD system comprises of the following components:

- A 4-stage, centrifugal, inter- and after-cooled, fully automated, Atlas-Copco compressor equipped with 1.8MW (2,500HP) Siemens electrical motor drive (CMP1),
- A 4-stage, centrifugal, inter- and after-cooled, fully automated, Atlas-Copco compressor equipped with 1.8MW (2,500HP) Siemens electrical motor drive (CMP2),
- A 3-stage, centrifugal, inter-cooled, semi-automated, Cooper Turbocompressor compressor equipped with 6MW (8,000HP) ABB electrical motor drive (CMP3),
- Two, 9.1kg/s (20pps) each, 650^0C ($1200\ ^0$F) Stahl natural gas fired process air heaters on the roof of the Combustion Test Facility housed in the new stand alone building,
- The 2-stage reciprocating type 0.68kg/s (1.5pps), 3.8MPa (550 psig) IMW Natural Gas Compressor;
- The high pressure air distribution stainless steel piping network,
- All machinery and control valves are PLC controlled with Allen Bradley hardware and Wonderware based Human-Machine Interface (HMI) systems which allow for both automatic and manual mode control.

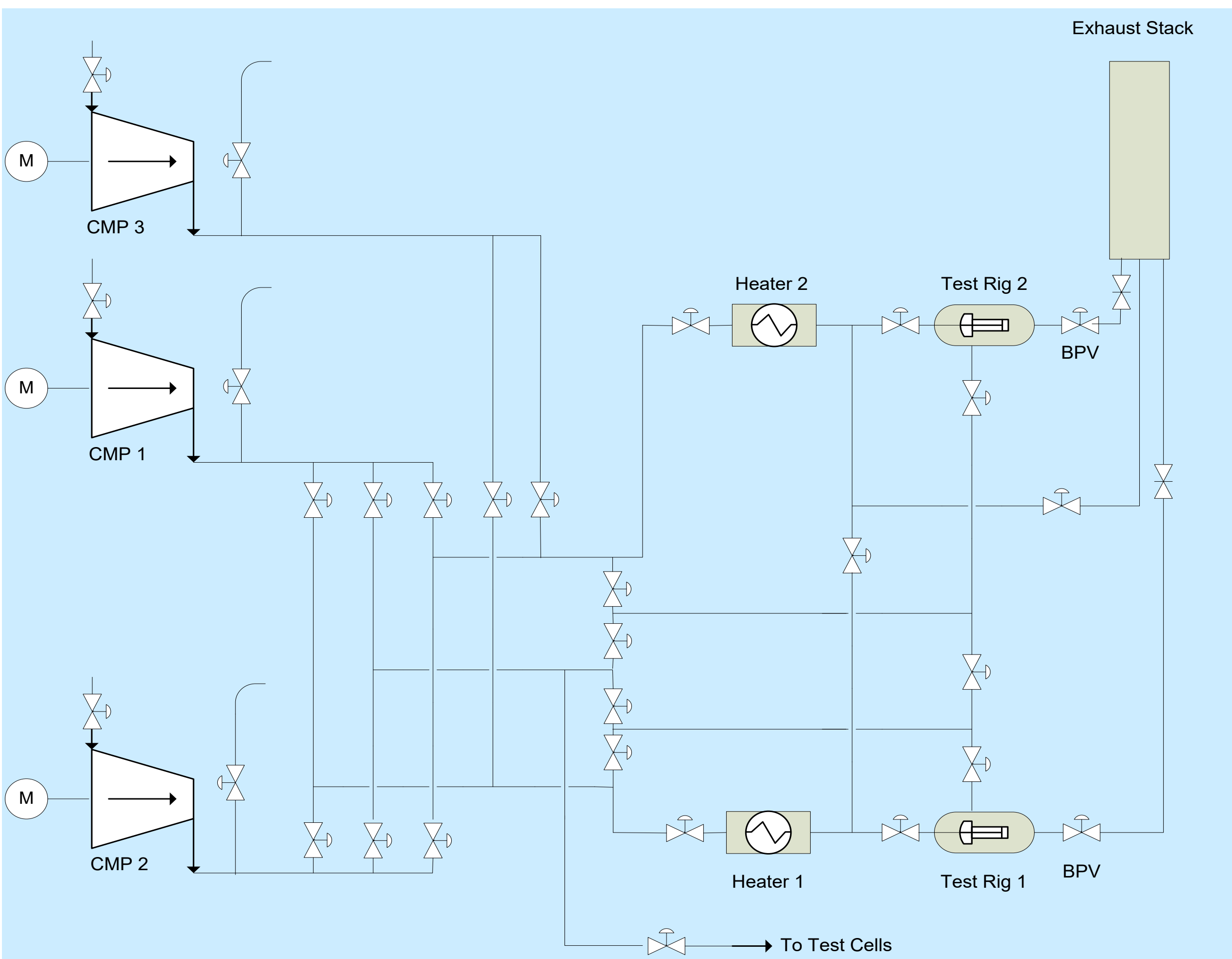

Figure 3: Diagram of HPAD system.

The ACES system consists of the following components:

- A 2-stage Brown Boveri Exhauster driven by two 1MW (1350HP) ABB electrical motor drives,
- A 2-stage Brown Boveri Compressor/Exhauster driven by 5MW (6800HP) retrofitted ABB electrical motor drive,
- The low pressure air distribution piping network,
- These machines are controlled with PLC Allen Bradley equipment and analog relay circuitry, limited mainly to manual mode control.

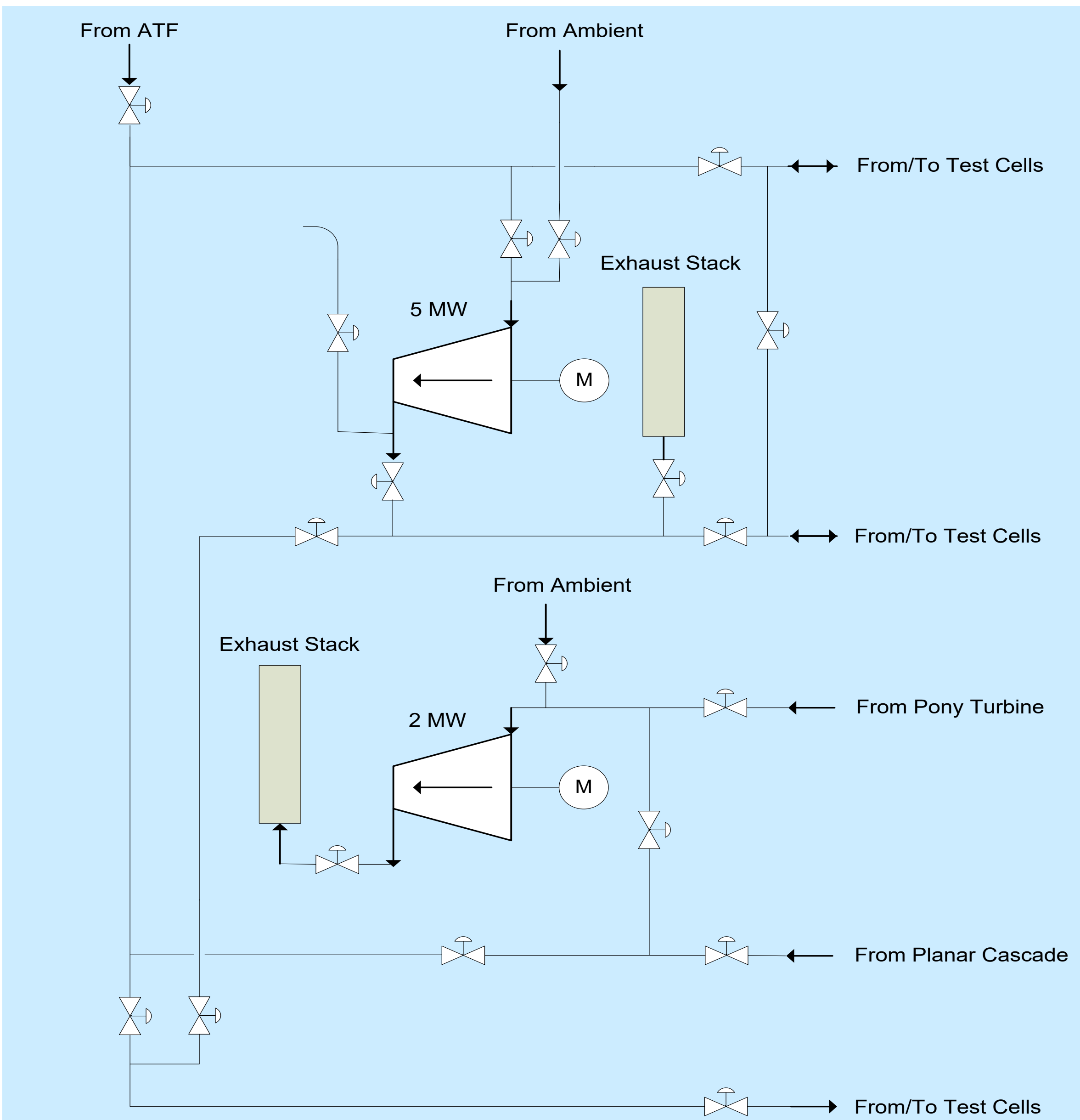

Figure 4: Diagram of ACES system.

The new 2-cell Cooling Water Tower (CTW) together with water cooling distribution network form another major facility required for IATS, HPAD, and ACES systems operations. It is comprised of 380 ton (100,000gal) sump; two 150kW (200HP) VFD controlled cooling fans and three pump-motor units. These units are: an 30.3m³/min (8000 gal/min), 335kW (450HP) pump provides cooling water for IATS system, another 22.7m³/min (6000 gal/min), 335kW (450HP) pump provides cooling water for HPAD system, and the third 7.6m³/min (2000 gal/min), 112kW (150HP) pump, is providing back-up and extra loading capacity. The M-47 CTW system is fully configurable and PLC controlled.

The old 3-cell Cooling Water Tower together with a distribution pipe network is providing water cooling capacity to the ACES system. It has a 3.8 ton (10,000 gal) sump, two 45kW (60HP) pumps and three 30kW (40HP) fan units. This system is analog in design and manually controlled.

The GTAC National Facilities operates low and high pressure distribution natural gas networks, including metering stations, filter stations, pressure regulation stations, and pressure relief systems completed with purge capability. The Facilities also owns and operates the fuel farm in GTL compound. The pump house, equipped with five fuel supply pumps and two transfer pumps is a hub of the fuel distribution system. The seven 48,000 liter underground storage tanks, one for Diesel fuel, and six for Jet fuel, provide the large storage capability for GTL operation. The Liquefied Petroleum Gas (LPG) fuel storage facility and above- and under-ground fuel transfer system to different test facilities of the GTAC Complex are also parts of this system.

The Facilities is a major user of the Hydro resources on the NRC Montreal Road Campus. The total combined power requirement of its equipment is close to 30MW. To support the operation two 13.2kV Transformers in the Main Electrical Yard are feeding two 4.16kV and two 2.4kV substations. The whole Hydro Power infrastructure is very complex and requires continuing support from internal and external entities. To mitigate the parallel operation and starts of the very large synchronous and induction type electrical motors used on Facilities compressors, a new capacitor bank system was installed on one of the 4.16 kV sub-stations. Another way to deal with in-rush current and harmonics was to introduce the “soft start” hardware in switchgear of the units. Due to the nature of the test schedules the equipment has to be started and stopped every day, and in some cases, several times a day. Currently the Facilities team is working closely with the NRC Engineering team to resolve the issue of aging components and reliability of the Hydro network.

The GTAC National Facilities serves multiple test cells. The two new test cells in the Combustion Test Facility, and two combustion test cells and low/high pressure spray test facility located in another building are supported by the HPAD system. One altitude test cell associated with the IATS system is in a separate building. Another research altitude test cell located in older part of the complex is supported by the ACES system. The five engine test cells in Propulsion Facility are associated with the ACES and HPAD systems. The separate test cells such as the ones in a Wind Tunnel and Aerodynamic Laboratory building are supported by GTAC National Facilities by using different low pressure compressed air piping network.

A typical test cell will contain air and fuel handling manifolds, test rig c/w test instrumentation, cooling water system, various fire & explosion detection devices, and protection and fire-suppression systems. The gas monitoring sensors are connected to Armstrong monitoring panels throughout the Facilities. The control and monitoring systems also include multiple Master Control Centers, dedicated MIMIC panels for the ACES system, and PLC cabinets with video and audio surveillance capabilities dedicated to IATS and HPAD systems.

4 Maintenance Programs in National Facilities

The Facilities currently employs Condition-Based Maintenance combined with Predictive Maintenance programs in its operation. The planned maintenance is conducted using the Plan Expert (Plannex) maintenance software, where all major assets are registered and maintenance schedules (work orders) are prepared on a weekly, monthly, and yearly basis. The usage data in the form of number of starts/stops on the individual facilities components is not presently the main drive for the maintenance scheduling and preventative maintenance work order generation. The machinery run hours is used as a secondary factor into the Plannex maintenance scheduling and decision making process. The Predictive Maintenance data does impact formal maintenance scheduling and work order generation.

The Quality Management System (QMS) introduced in the Facilities drives the collection of unscheduled outages and system trips for the IATS system - performance limits are set and monitored and constantly updated. The HPAD and ACES system's facilities components do not receive the same level of scrutiny at a present time but there is work in progress to change this. The assets inventory and parts management is Excel-based and monitored on regular basis.

A vibration analysis capability is in place with IRD hand held units and machine mounted accelerometer pads. Spectral data is collected and monitored against alarm limits as part of the GTAC National Facilities Predictive Maintenance program. Outside OEM contractors are used to calibrate vibration monitoring systems installed on the different components of the Facilities.

The IATS system is currently equipped with INSQL system which has a data logging and performance trending capabilities. The analyses are done periodically to use this data in scheduling of some maintenance tasks for the components of the IATS system. This is the pilot project and the same approach is going to be introduced for the HPAD and ACES systems.

The ultrasonic monitoring system is in place primarily for leak detection and as a back up for the bearings health monitoring currently monitored by the IRD unit. There is currently a work in progress to introduce ultrasonic inspection program for compressed air pipe network throughout the Facilities.

5 Introduction of Reliability Program for National Facilities

The Gas Turbine Laboratory goal is to improve the availability of its Gas Turbine Aerodynamics & Combustion (GTAC) National Facilities and is currently developing a phased work-plan to undertake a risk based assessment of key systems and sub-systems to target critical assets and their specific operating requirements.

Given the GTAC National Facilities mission to support the Canadian gas turbine technology base through the provision of unique test and evaluation facilities and expertise through maintaining its asset values and client expectations, the National Facility team is seeking further understanding of the inherent operation risks with the emphasis on the High Pressure Air Distribution (HPAD) system operation and maintenance options to increase its availability. As a plan forward, the currently used Conditioned-Based Maintenance approach in the Facilities is going to be enhanced by introducing elements of Reliability Centered Maintenance program. A reliability centered assessment (RCA) has been proposed as a first step to achieve the stated goal. This pro-active approach shall demonstrate diligence and resiliency of Facilities assets in the event of any incident that may materialize during operations, limiting impacts to the Facilities to a manageable level.

The GTL maintains a very large and high value inventory in GTAC National Facilities that must be maintained and managed to ensure that these assets are reliable in the short term, sustainable in the long term, and adaptable in the future to new technology requirements. The Reliability Centered Maintenance (RCM) is one of the maintenance options which addressing modern performance tracking and planned maintenance including anticipatory upgrades and component replacement. There is also continuous effort to improve the existing design of the Facilities' systems and sub-systems to increase their reliability and reduce the impact of maintenance downtime. This approach can benefit the existing Condition Based Maintenance program which is currently implemented in the National Facilities.

The aim of the new initiative is to achieve the following:

- Establish functionality and performance envelopes for major GTAC National Facilities systems, subsystems and utilities – initial focus on HPAD system,
- Assess critical facility operational risks primarily through failure mode and effect analysis,
- Review current maintenance practices, systems and vendor support,
- Key internal & external stakeholders will be informed and will participate in the RCA,
- Develop operating/maintenance practices to be adhered to for each HPAD sub-system,
- RCA deliverables will be in place by winter 2010 to support GTL management decision on the plan forward.
- Establish a minimum operational and maintenance budget requirements for GTAC National Facilities.

The following initial steps will be taken to reach the objectives of RCM study:

- Identify, assess and treat GTAC National Facilities risks throughout its lifecycle,
- Identify critical Facility systems, subsystems & components and assess maintenance systems & improvements to meet uptime/downtime criteria,
- Optimize maintenance expenditures and improve energy efficiency by introducing new maintenance approach.
- Develop a plan for GTAC National Facilities to sustain the RCM practice throughout the facility lifecycle including the budget requirements.
- Provide tools & techniques for GTAC National Facilities manager and supervisor to accomplish Facilities availability objectives in the face of inherent operational risks.

RCM is usually defined as a process used to determine the maintenance requirements of any physical asset in its operating context. The assets or system functions and their associated performance standards need to be documented thoroughly. Also, the functional failures and their impacts must be formulated and gauged methodically in the operation of the Facilities. These preceding steps form the RCA component of the process when risk-based techniques such as FMEA and BIA are deployed. The RCM also identifies what can be done to predict or prevent failures and offers failure management strategies.
The results of the proposed implementation of RCM components for HPAD system shall allow GTAC National Facilities team to operate its large, high value inventory and maintain infrastructure reliability as demanded by GTL operational requirements, currently targeted at 90% availability or not more than 10% downtime.

6 Conclusions

The Gas Turbine Laboratory is striving to improve the availability and sustainability of its Gas Turbine Aerodynamics & Combustion (GTAC) National Facilities and, is developing a plan to undertake a risk based assessment of key systems and subsystems to target critical assets and their specific operating requirements.

To improve GTAC National Facilities assets reliability requirements and client expectations, the laboratory's management team is seeking further understanding of the inherent Facilities risks with emphasis on the High Pressure Air Distribution (HPAD) system and maintenance options for reducing downtime.

As the GTAC National Facilities approaches its full capacity the frequency of a major component failure is of serious concern. The Facilities undertakes a maintenance plan for its major systems including Condition-Based Maintenance and two-week Preventative Maintenance annual shutdown. The current maintenance system will be upgraded to a Reliability Centered Maintenance Plan that will take advantage of an existing NRC SAP module (financial tool).

7 Nomenclature

BIA Business impact assessment – a risk-based technique for assessing asset outage impacts on facility users and its clients. A form of consequence analysis that further quantifies the impacts identified during FMEA and develops cost, client rapport and possible environmental effects.

FMEA Failure mode and effect analysis is a risk-based technique for identifying possible equipment failure scenarios, their causes and impacts and estimating the importance of each on a case by case basis.

RCA Reliability Centered Assessment - the initial steps of the RCM process where system functions and their associated performance standards are documented, functional failures and their impacts are formulated and assessed.

RCM Reliability Centered Maintenance - a process used to determine the maintenance requirements of any physical asset in its operating context.

System Major Facility buildings block (i.e. HPAD).

Subsystem A unit of equipment at the asset or machine level.

Component A significant part or assembly of the machine or asset.

Downtime Time elapsed from the beginning of a machine unplanned outage to when that machine is put back in service. It is measured as a % of total operating time.

Availability 1 - Downtime

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