Flow Measurement Center (FMC) – Airflow Measurement and Infrared Through Hole Inspection

INTRODUCTION

Gas turbine engines have been used for decades for propulsion, power generation and other industrial applications. The thermal efficiency and power output of these engines increases with increased turbine rotor inlet temperature, up to the hydrocarbon fuel stoichiometric limit of about 4,200 degrees Fahrenheit. With the melting temperature of the nickel based super alloys used to fabricate components for gas turbines at about 2,000 degrees Fahrenheit, it should be evident that cooling a gas turbine component is critical to their sustained operation. In the case of a gas turbine blade, combinations of thermal barrier coatings and sophisticated cooling techniques have been developed to maintain the blade's temperature at a safe operating point.

As with other components in a gas turbine engine, a turbine blade is formed as a hollow airfoil that is cooled both internally and externally. The coolant used for this purpose is extracted from the compressor, resulting in a reduction in the thermal efficiency for the engine. As such, the amount of coolant extracted is minimized by design and its mass becomes a major design characteristic for the turbine blade. Internal cooling is accomplished by injecting the coolant inside the blade where heat is extracted from the inner airfoil surface. In addition, jet impingement, turbulator and pin fin cooling are used to further extract heat from the inner airfoil. External cooling, known in the industry as film cooling, injects coolant onto the outer airfoil surface at desired locations along the airfoil. If a minimum amount of coolant is not present, the blade's lifespan will be shorter than its intended design.

AIRFLOW MEASUREMENTS

Most production flow measurements are performed using "cold" air to simulate the coolant in the engine. Accurate airflow measurements are critical to verifying the maximum and minimum mass rate of airflow conforms to its design. Meyer Tool has been developing and building accurate and automated airflow measurement systems since 1979. In 2001 the Flow Measurement Center (FMC) was task with the business of airflow measurement. FMC now offers other businesses the opportunity to purchase our production proven and state of the art airflow measurement systems. FMC is located in Cincinnati, Ohio, but also have a Service Center in Poland. Currently Meyer Tool has 77 such systems throughout the world at its corporate and satellite facilities. The FMC laboratory is capable measuring the mass rate of airflow from 0.0001 to 1.5 mass pounds per second (Lbm/sec) with uncertainities (k=2) in the range of less than ±0.4 percent of flow rate directly traceable to flow standards maintained by the National Standards and Technology (NIST).

Other gas turbine components, such as vane ring nozzles and fuel nozzles, need the flow area measured of features. FMC's airflow measurement systems can just as easily be used to measure the effective flow area of these components.

FMC offers three types of airflow test systems. All of systems provide a lean flow measurement solution for finding out the mass rate of air flowing through produced part features. In addition:

 These systems create value by reducing the cost of ownership without sacrificing performance.

 They promote continuous improvement using built-in statistical process controls and enterprise wide access to test data.

 They deliver a standard work environment in a small footprint and user-friendly turnkey system.

The series 3700 is a suitcase test system measuring just 32 by 20 by 15 inches (0,82 by 0,51 by 0,38 meters). Small in size this system has a maximum flow rate of 0.1 Lbm/sec (0,045 Kg/sec), perfect for manufacturing cells or any place space is a premium.

The series 4700 is a cart design that has a footprint of 49 by 26 inches (1,2 by 0,7 meters) and a maximum flow rate of 1.0 Lbm/sec (0,45 Kg/sec), ideal for both manufacturing and laboratory environments.

The series 5700 is a patent pending modular design that has a footprint of 46 by 22 inches (1,2 by 0,6 meters) and a maximum flow rate of 1.0 Lbm/sec (0,45 Kg/sec), a cost effective solution for applications that need to change in the future.

Accuracy in any of these systems is assured by using a combination of sonic nozzles, state of the art instrumentation, and time proven proprietary software. Fast and easy test procedures are provided by using Win32AF™ software that has been refined over nearly 30 years of in-house use in producing gas turbine engine parts, such as blades and nozzles. We do not just build airflow test systems, unlike our competitors; our parent company uses them every day to test thousands of parts they produce. If our systems do not work, it affects our bottom line, just as it would yours. This means we make sure our test systems are the leanest in the world.

SERIES 3700

The model 5000-33-3702 is a suitcase sized complete airflow test system. It has a built in bank of sonic nozzles and test fixture. It uses the same automatic control electronics and software as the series 4700. Downtime due to calibration or maintenance is slight by using SATSExpress™, our overnight exchange service, available in most parts of the world. Although small, this system is capable of testing most gas turbine parts. However, note that the upper flow rate limit for this model is 0.10 Lbm/sec (0,045 Kg/sec).

SERIES 4700

The series 479x is a fourth generation airflow test system designed to reduce the cost of ownership, increase flexibility and improve accuracy. Improvements to the software (the same software used by the series 5700), modular plug-in instrumentation, platform free computer system, and use of the latest available technology are major improvements. On the top left hand side of the cart is a lid that provides access to a single sonic nozzle for the semi-automatic model 5000-33-4791. This model will automatically adjust the flow rate to the named reference condition or allow the operator the manual adjustment of the flow using an electronic control. However, this model does need the operator to install the necessary sonic nozzle. The primary flow-determining element in all of our airflow test system designs is a sonic nozzle. The model 5000-33-4792 appears the same as the model 4791, except for a bank of sonic nozzles installed inside the cart. The computer automatically controls selecting the necessary nozzle or nozzles. This allows testing a broad range of parts, without needing the operator to manually change the sonic nozzle. The standard upper flow rate limit for the model 4792 is 0.2 Lbm/sec (0,09 Kg/sec); however if needed, we offer several models that have a higher upper range.

The series 4700 uses a rack mounted instrumentation panel found behind the front left hand door. This Secondary Element Panel (SEP) contains all the needed instrumentation necessary for using sonic nozzles for flow measurements. Modular plug-ins is used for each instrument providing a reduced cost of ownership and increased system performance. This panel is used in all 4700 models and can be used to upgrade Customer's existing airflow test systems. Computer connectivity is provided by a single Ethernet port.

SERIES 5700

The series 5700 is a fifth generation airflow test system designed to reduce the cost of ownership, increase flexibility and improve accuracy. It is designed around a compact 19-inch rack-mount enclosure suitable for shop or laboratory use. The standard 5700 provides for mass airflow rates up to 0.2 Lbm/sec (0,09 Kg/sec). All primary and secondary flow elements are housed in plug-in modules. *(A primary flow element is a device that is in contact with the flowing fluid, in this case air, and produces some form of interaction. The secondary flow element is an element that translates the interaction between the fluid and primary element into a flow rate.)* This modular design significantly reduces the cost of ownership, increases system flexibility and improves measurement performance. For example, calibration is accomplished by simply removing the out of calibration modules and replacing them with calibrated modules. Down-time is reduced to a couple of minutes, instead of hours. It also permits the addition of modules on an as needed basis, thus reducing initial system cost. Three standard enclosures are available: 8, 11, and 14 modular Unit (U). The 8U enclosure provides room for up to 3 plug-in Primary Element Modules (PEMs). The 11U enclosure provides room for up to 6 plug-in PEMs. The 14U enclosure provides room for up to 8 PEMs. A 3U Secondary Element Panel (SEP) houses all of the instrumentation needed to accurately measure the mass rate of airflow utilizing sonic nozzles. The SEP consists of a group of plug-in pressure and temperature modules. A built-in embedded computer provides all of the needed data acquisition, controls selection of PEMs and computation of the mass rate of airflow. The SEP computer is designed in a distributed computing architecture, where it performs all of the data acquisition tasks and communicates the processed data as demanded by the main computer system via an Ethernet link. Three 5700 Win32AF™ airflow applications are installed on the main computer allowing the owner to perform airflow testing, maintenance, quality, and engineering tasks. Airflow tests can be performed manually by the operator or automatically by the main computer. The system is designed around an intra-network concept for corporate distribution of all airflow parameters and test data. The Win32AF™ applications use a rational database for storage of all airflow data. Use of this database adds flexibility never available in previous generations. For example, additional test algorithms and integrity checks can be added by simply scripting the algorithm as a new database record. There is no need for software modifications. When the database is running on a remote computer system, the airflow data can be made accessible to all stakeholders. The 11U system is so small it will fit under a standard desk, yet it delivers more power and accuracy then most competitors' larger console systems. The floor space needed for an airflow test system is now dictated by the size of the workbench and tooling. It allows operator ergonomics to be easily incorporated into the work site. The 5700 is available with multiple test ports and higher airflow rate options.

SOFTWARE WIN32AF™

All models use software developed by FMC that run in a Microsoft® Win32 environment such as Professional 7. It provides the user with the familiar Windows environment to not only test parts, but also perform backend roles like creating and editing test procedures, bringing back test data, and performing calibration and maintenance procedures. The simple to use graphical test procedure involves selecting the needed test procedure, loading the part under test into a fixture, entering the part audit information (e.g., serial number), and adjusting the reference test condition. Once the reference test condition has been set, the computer performs the necessary pressure and temperature measurements, calculates and reports the test result. Running in the automatic flow adjust mode, the operator would load the part, enter the serial number and the computer would then automatically complete the rest of the test cycle.

The new generation six application moves all airflow data from the current flat file structure to an Oracle® database. The use of a rational database removes restrictions and added capabilities never before available with flat files. Simplifies the user interface that reduces test cycle time. The main test window has been simplified and a group of new windows added to provide never before functionality that increases testing throughput.

Built-in integrity checks can be used to ensure a test setup is performing within named performance limits. These checks include a system shutoff valve, system leak and flow restriction check. In addition, an airflow master test can be used. Any combination of these checks can be named in the test procedure. The airflow master test is programmable for the beginning, end, and at mentioned intervals. The integrity checks and master must test within the named control limits before an operator can continue to test production parts.

QUALITY CONFORMITY

All systems are designed, built and tested to comply with the international standards for Laboratory Equipment Safety, EN61010-1 and Laboratory Equipment Electromagnetic Compatibility, EN61326-1. The quality system of Meyer Tool, Inc. is certified to be conforming to the needs of ISO9001:2000 and AS9001:01.

NETWORK AND PROCESS CONTROLS

All systems are network capable for enterprise distribution of software and test data. Real time statistical process control chart is performed by the computer during the test procedure to give the operator immediate process control responses.

Maintenance

All of our airflow systems come with a 2 years parts and labor warranty. The system is covered by an uptime guarantee of 95% for a minimum of 20 consecutive months during the warranty period. Uptime shall mean any time (24 hrs/day, 7 days/wk) that the system is not down. We recommend calibration of the secondary element panel once a year and every five years for the sonic nozzle. We can provide these calibrations for a nominal charge.

Tooling

The series 3700 has a built in plenum acceptable for testing small parts such as aircraft turbine blades. For other parts we offer a wide range of universal plenums. These plenums serve as base for custom "mold plates" that are produced to provide an airtight seal between the plenum and part under test. For testing small to medium size gas turbine parts we offer a fixture that has three build in plenums for testing multiple passages in a single setup. The manual version of this fixture, 1001-817B, needs the operator to change the plenum valve sequence by hand. We also offer a model that automatically changes plenums under computer control. Several other standard or custom fixtures are available; ask for details.

Static Hole Pressure

For parts needing static hole pressure checks, option /P4 adds a pressure transducer and software changes necessary to perform this operation.

Flow Standards

FMC maintains a set of primary flow standards that have been directly calibrated by NIST. Uncertainties (k=2) in the coefficient of discharge for these primary flow standards are generally better than ±0.1 percent, or the best obtainable from NIST. We also maintain several sets of working flow standards that have been tested using the primary set. Uncertainties in the coefficient of discharge for these working standards are between ±0.20% and ±0.37%.

Things to Consider

The most important thing to consider when selecting a system is how it is going to be used. Almost all airflow testing is performed by setting a pressure ratio across the part under test and measuring the mass rate of airflow. First and foremost have an idea of the range of flow rates you will need to measure and the range of the part inlet pressure you will need to set. For example, some parts require low inlet pressure. This means you will need a low range pressure transducer. If you will only be testing a few different parts, a single nozzle system may make the most cost effective solution. If you will be checking a group of different parts in a production environment, a multiple nozzle system may make the most cost effective solution. Sometime OEMs use different measures of airflow rates (flow parameter or effect flow area) and need to be converted in order to be comparable with the actual mass rate of airflow used here. If you do not know the answers to these questions, we will be glad to work with you to determine the most cost effect system that will meet your special needs.

BENEFITS

The major benefit of owning one of our systems, compared with our competitor is that you get a lean solution that reduces wasted labor and adds value to all stakeholders, whether it is the operator, engineer, calibrator or administrator. We have over 30 years of shop proven experience in building, testing and using lean flow measurement systems. Our systems have tested millions of parts, been used by thousands of different people worldwide and for a dozen different OEM Customers. When you buy from strictly a manufacture of airflow test systems, separated from its stakeholders, you do not get the experience and feedback from all of those stakeholders that daily use the system or test data. That is why our systems are so lean and accurate. It comes with the real demand of meeting our customer's schedules and test needs for over thirty years. You simply will not find a better lean airflow test system on the market today.

INFRARED THROUGH HOLE INSPECTION MACHINE

THE NEED

Modern film cooling designs consist of groups of cooling features sometimes numbering in the hundreds. In production the plurality of cooling features is divided into groups of cooling features. The airflow for each of these groups is measured individually. However, it is possible that one or more cooling feature in the group can be defective (the amount of airflow not conforming to design) yet the group airflow measurement is conforming to design. One method used verify each individual cooling feature is a manual method in which an inspector is provided with a drawing of the desired hole pattern and a pin. The inspector first confirms that a feature exists at each location identified by the pattern; and then, the inspector inserts the pin through each of the features to determine whether the feature is properly machined as a through-hole. As can be appreciated, such an inspection process is highly repetitive, tedious and stressful for the inspector and, in addition, is expensive and inefficient for the manufacturer of the turbine component. FMC has researched, developed and built an Infrared Through Hole Inspection Machine to address this problem. Since 2008 FMC has built and been using 6 such machines at its corporate and satellite facilities that have been used to inspect millions of cooling features every six months.

THE SOLUTION

The Solaris® through-hole inspection system uses a revolutionary, proprietary, patented, and patent pending technology to measure the film cooling effect of film cooling holes fabricated in gas turbine components, such as a blade or nozzle. A computer controlled robotic arm positions a camera in view of a group of holes and then captures a “raw” image. This image is used to produce the “analyzed” image where white signifies the hole and black the skin. This image is used to identify properly formed, undersized and blocked holes.

FILM COOLING EFFECT MEASUREMENT

One should recognize from the introduction that if the film cooling effect is too small, a result of either a reduction in the mass of coolant flowing through the cooling feature or defective cooling feature geometry, the gas turbine blade's lifespan is decreased. Furthermore, if the film cooling effect is severely out of location, the blade's life span will be decreased. As in the case of an aircraft engine, this decreased lifespan could result in the loss of life. Therefore, the size, shape, and location of the cooling effect are critical design characteristics for the turbine blade. One should readily recognize from this discussion that the design intent of cooling features is the film cooling effect, and not the incidental characteristics such as its geometry, location and mass flow rate. To this end FMC has been researching the combination of Solaris and airflow measurement to measure the film cooling effect. Using this patent pending process the film cooling effect for an individual hole is easily measured without the need for its isolation from the remaining plurality of holes. This greatly reduces the need for masking groups of holes and significantly reduces the cost of inspection.