ACCURATE PRESSURE MEASUREMENT FOR STEAM TURBINE PERFORMANCE TESTING

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ABSTRACT

Accurate pressure measurement is vital to the understanding of steam turbine efficiency, reliability, and service condition. This paper describes a safety purge system that isolates and protects inexpensive PC based pressure sensors from steam pressure media while providing high accuracy, serviceability, and automation. Programmable pneumatic configurations sequentially isolate the pressure sensors from the measurement source, purge the scanner lines, and purge the test article pressure input lines of any accumulated condensate with no affect on the properties of the turbine during a test.

CURRENT METHODS

Typically, steam turbine measurement applications use individual all-media pressure sensors designed for harsh and corrosive applications. With the all-media approach, differential readings are achieved with either, two sensors measuring and mathematically comparing pressures, or by using large, expensive all media differential sensors. Using two sensors for one differential measurement may result in a reduced accuracy, as well as doubling the instrumentation costs when compared to a single differential sensor. All media sensors, which may weight up to 29 lbs (1.3 kg) are designed for a permanent installation. They must be removed and sent to a calibration lab for calibration, which for a system measuring 128 inputs, could require up to 40 hours to complete. Sensors calibrated in a laboratory environment may experience significant zero and span shift errors when subjected to the high ambient temperatures near steam turbines. Measurements that are good at the beginning of a test may deteriorate as the test progresses due to head pressures formed as trapped air leaves the pressure media and forms air pockets in the system tubing. The permanent installation prevents measurement validations during a test.

A SAFETY PURGE MEASUREMENT SYSTEM

A new method using intelligent electronic pressure scanners, incorporating relatively inexpensive piezoresistive sensors, has been developed to measure pressures in steam turbines. These sensors normally could not be used to measure liquid or high temperature steam media pressures. However, this system has a safety purge feature that isolates the sensors from the harsh media without affecting the accuracy of the pressure measurement. Two separate purge paths are used in the safety purge system, one within the scanner equipment rack, and one at the input lines from the turbine. The first purge path, referred to as “cabinet purge”, uses a valve in the pressure scanner to purge input lines to atmosphere. The second purge path, referred to as “turbine purge”, uses a remote purge valve located near the system measurement connection to the steam turbine to purge those lines to a drain.

PNEUMATIC PRESSURE SCANNERS WITH SAFETY PURGE

The safety purge system modules contain 16 thermally compensated individual differential pressure sensors. The sensors are coupled to a pneumatically piloted valve allowing ‘in situ” pressure calibrations, isolation, and line purge. Standard modules connect the reference side of the sensors to a common reference, typically local atmospheric pressure. True differential measurements may be manufactured by adding pneumatic valves to the reference side of the sensors. Full scale accuracy of 0.05% is achieved by pressure-temperature characterization of each sensor with 9 pressure points at 10 temperatures from 0°C to 69°C. The calibration temperatures used are module operating temperatures as the sensors are isolated from the high temperature steam.

These modules also have line reference capabilities. In high-line, low differential testing, pressures higher than the normal sensor value are introduced to both sides of the sensor diaphragm. Accuracy is maximized when the differential measurement is distributed over the full range of the pressure sensor. When equal high pressures are introduced to both sides of the sensor diaphragm, the differential reading is not zero. The sensor housing does not have a balanced construction and due to its greater surface area, the reference side of the sensing diaphragm experiences greater forces than the positive measurement side. After re-calibrating the zero point at this elevated pressure only slight span errors exist when applying known differential pressures. Supporting results of this can be found in the Reference 3. A typical pressure sensor is shown in figure 1.

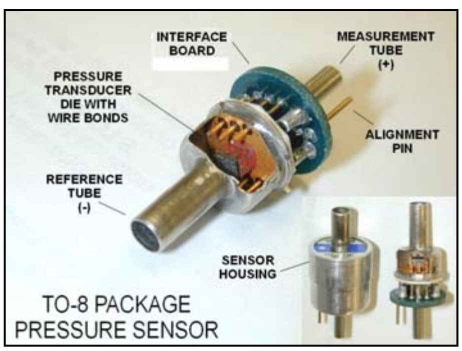

Figure 1 – Sensor

SYSTEM INSTALLATION AND OPERATION

In all cases, steam from the test article will migrate through the measurement lines to the scanning module even though there is no flow. Condensate forms and collects inside of the tube due to ambient temperature differences. If water enters the measurement system, head pressure errors will result. If water reaches the sensor level, sensor die and wire bond corrosion will occur, resulting in sensor failures. To prevent problems, the system must be installed as shown in Figure 2. The safety purge cabinet should be located 4 to 6 feet (1.2 to 1.8 meters) above the measurement points. The measurement system should be mounted 6 feet (1.8 meters) or more above the safety purge system. A customer supplied purge air source capable of providing purge pressures 20% greater than the maximum test pressure is required. The purge pressure may be dry air, or Nitrogen. If air is used, it must conform to the ISA-S7.3 Instrument Air Quality Standard. The purge pressure will move any condensate that might form in the pressure input lines back to the turbine. Purge pressure levels greater than this can paint the inner walls of the tubing with a fine layer of micro droplets which can reform into large drops. Purge flow meters may be installed in each line to monitor purge flow and adjust final purge pressures to the steam turbine. The system uses clear Teflon tubing from the safety purge cabinet to the measurement cabinet. Periodic visual checks of this tubing must be performed to insure that condensate has not formed in the measurement lines.

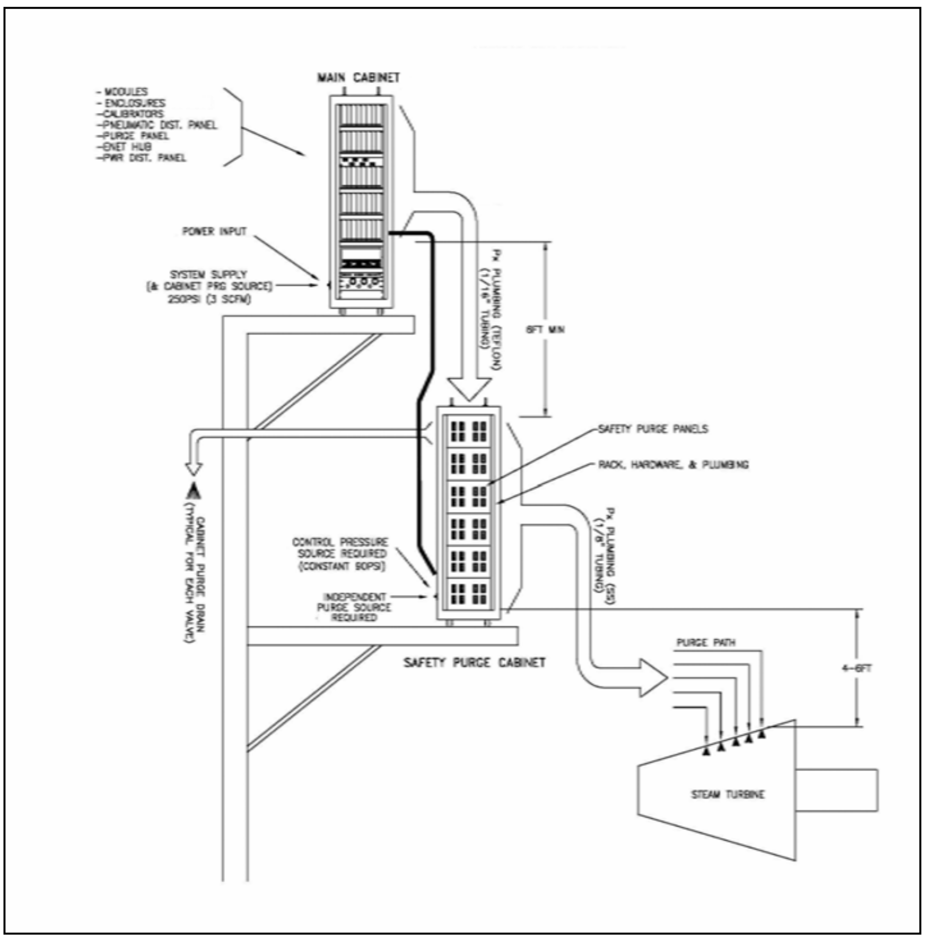

Figure 2 – Recommended System Installation

PURGE FLOW REQUIREMENTS

Purge flow requirements may vary with the test requirements. Purge flow will be determined by the number of pressure points, the maximum pressure to be measured, the capacity of the purge pressure source, and the test article backpressure.

SYSTEM VALVE CONFIGURATIONS

The system operates in the following configurations:

De-energized Mode	All purge air is removed. The input lines to the sensors are disconnected in the pressure module valves. This mode should only be used when the steam turbine is not operating.
Dormant Mode:	Measurement lines are closed and the system is put in a safe mode. This mode is used to conserve the purge pressure source while the turbine is being allowed to stabilize prior to data collection.
Purge Mode:	All lines are purged. Purge pressure is used to prevent moisture from making contact with the sensors. If electrical power is lost, the system will default to this mode.
Measurement Mode:	Measurement lines are connected to the pressure scanners. This mode is used for short periods of time when data is to be collected. If control pressures are lost, the system will default to this mode.

DE-ENERGIZED MODE

This valve configuration is shown in Figure 3. In this mode, all valves in the safety purge cabinet and the measurement cabinet are vented. No purge pressure is applied. The internal valve in the pressure scanner is set to the calibrate mode which connects the input line to the module calibration manifold. This mode must not be used during tests, or whenever the steam turbine is operating.

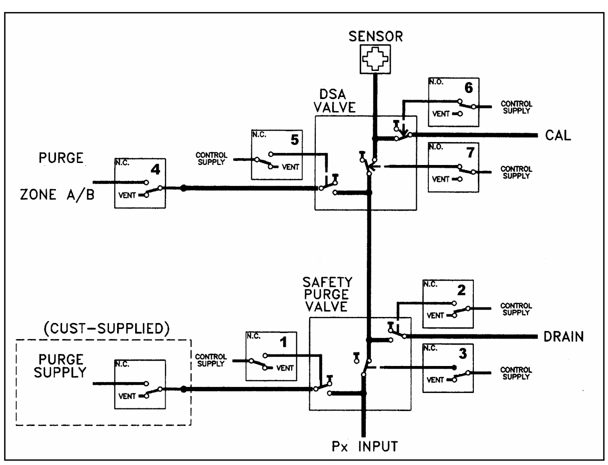

Figure 3 – De-Energized Mode

DORMANT MODE

This valve configuration is shown in Figure 4. In this mode, Valves 2 and 3 are energized, placing the system in the "safe" mode. The pressure inputs are isolated in the safety purge cabinet. The connection from the safety purge cabinet to the measurement cabinet is connected to a drain line. The sensors are isolated from the input lines. The input lines are connected to the pressure scanner calibration manifold.

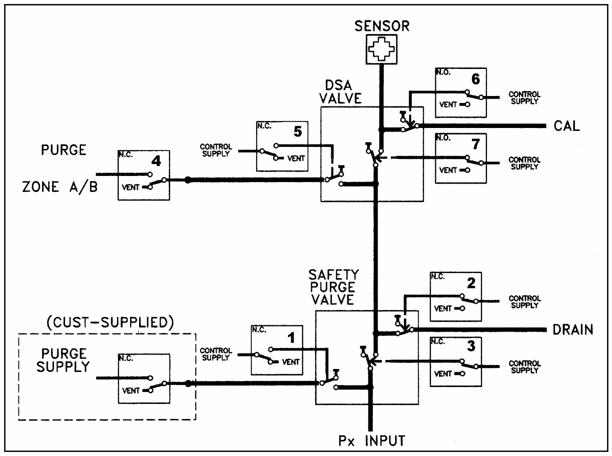

Figure 4 – Dormant Mode

PURGE MODE

This valve configuration is shown in Figure 5. The purge supply to the safety purge cabinet has been energized. Valve 1 has been energized directing purge air to the steam turbine. The measurement cabinet valves 4 and 5 have also been energized, directing purge air to the input lines forcing any condensate out the drain line. The sensors are still isolated. This mode should be used at all times during a test unless pressures are to be measured. The system must be in the purge mode for a minimum of 10 minutes prior to a test.

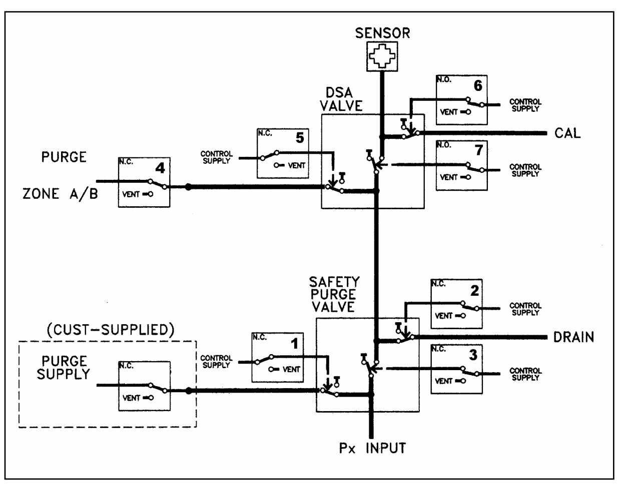

Figure 5 – Purge Mode

MEASUREMENT MODE

This valve configuration is shown in Figure 6. The purge air supply has been de-energized. Valves 1 through 7 are set to vent. The pressure input lines are connected to the sensors. Empirical testing has shown a purge time to measurement time ratio of 2:1 is required for the best accuracy.

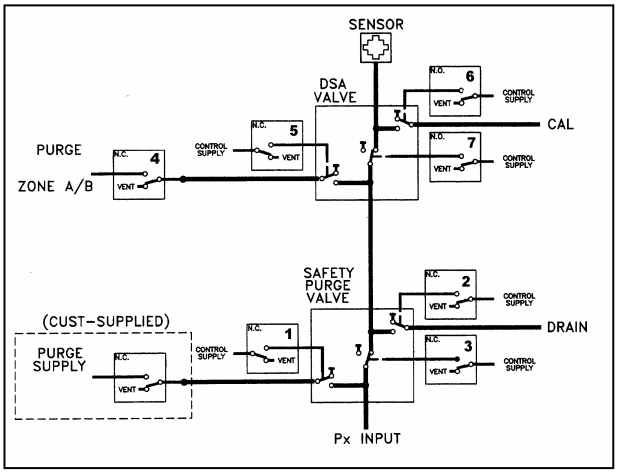

Figure 6 – Measurement Mode

MEASUREMENT SYSTEM

The measurement system may be comprised of one or more pressure scanner enclosures, and a calibrator enclosure. Each pressure scanner enclosures can accept up to 8 pressures scanners for a total of 128 pressure input channels. Each enclosure is a mini-data system, containing a processor, RAM, a hard disk drive, and 16 bit A/Ds. The pressure scanners have a Transducer Electronic Datasheet (TEDS) chip installed which will identify each module to the enclosure. Calibration data for all system pressure scanners are stored on the hard disk drive. At power-up, or when commanded, the enclosure reads the TEDS chip data from each of the scanners and maps the calibration coefficients into RAM. When a data scan is initiated, the enclosure scans the input channels, converts the voltage outputs from each sensor to an A/D count value. The A/D count values are converted to engineering units and written to the hard disk or transmitted to a “Host” computer. This system communicates with a “Host” or Plant Computer via Ethernet TCP/IP.

All data are transmitted in a choice of formats. Pressure data may be converted to one of 23 pre-programmed engineering units. Data may be output in Binary or ASCII formats. All of these setup parameters may be configured by the user. A typical 128 channel pressure measurement system consisting of 8 pressure scanners in an enclosure is shown in Figure 7. Calibrator enclosures are not shown in this view.

Figure 7 - 128 Channel Pressure Measurement System

CALIBRATION AND VALIDATION

A key function of this system is its ability to perform a full system calibration or validate individual sensors "on demand" and "in-situ". The system includes secondary standard pressure calibrators that are controlled by the system software. This feature allows a user to perform a calibration/validation while the system is monitoring the steam turbine. The calibration/validation process requires only a few minutes for each pressure range.

PORTABILITY

The system does not have to be permanently installed at a turbine. System cabinets can be made portable so that the system could be used to test several turbines at a power plant. Turbines could be monitored more frequently thus improving overall plant efficiency.

CONCLUSIONS

Although the system shown in this paper is a fixed installation, portable systems are in use. Portable systems operate in the same manner as a fixed installation. Portable systems allow a user to test steam turbines in remote locations.

- This method of steam turbine pressure measurement has been proven at six installations world wide with more systems on order.
- This system has a lower overall cost per channel when compared to a system using individual all media sensors for each pressure input. Individual all media sensors cost approximately $1000 per channel including signal conditioning, but not the cost of calibrations. This system will cost approximately $500 to $600 per channel including pressure calibrators.
- Calibration is simplified from individual sensors. Each pressure range may be calibrated in situ, simultaneously, and "on demand" as required during a test.

- Increased Turbine Efficiency lowers cost of operation. This system allows more frequent tests to improve efficiency.
- The safety purge cabinet ensures that the pressure measurement system is protected from harsh media.
- Ethernet Communications – a system may be monitored from any PC or plant network connection.

AKNOWLEDGEMENT

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REFERENCES

1. Greener, Derek, *Intelligent Pressure Measurement for TurboMachinery Applications*, 1996, ASME paper
2. Matthews, Charles, *Intelligent Pressure Measurement in Multiple Sensor Arrays*, Proceedings, 41st International Instrumentation Symposium, 1995
3. Chalpin, Blair and Labanei, Raef, *High-Line, Low Differential Pressure Measurement and Calibration During Turbine Testing,* Proceedings, 40th International Instrumentation Symposium, 1994
4. Chalpin, Blair, *Methods and Apparatus for Precise Measurement of Differential Pressures*, 1994, U.S. Patent #08/280,780