WOODWARD

Application Note 83404

Original Instructions

Development of Gas Fuel Control Systems for Dry Low NOx (DLN) Aero-Derivative Gas Turbines

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Introduction

Gas fuel control systems have been developed for gas turbine engines to minimize NOx emissions without the need for steam or water injection. These systems will control the fuel mass flow rate to multiple independent manifolds as directed by an electronic engine control system. To achieve the fuel scheduling accuracy required by turbine manufacturers, it is necessary to implement automatic compensation for fuel density and velocity variations resulting from normal changes in inlet pressure, discharge pressure, and inlet temperatures due to time and application factors. These fuel control systems fulfill the stringent system performance requirements with state-of-the-art pressure and temperature transducers, high-accuracy metering valves combined with electronic hardware, and control algorithms.

The oxides of nitrogen come in different forms. Of these only nitric oxide, NO, and nitrogen dioxide, NO_2, are the significant artificially made oxides; they are commonly referred to as NOx. Nitric oxide, NO, is formed during the combustion of all fossil fuels, a result of oxidation of nitrogen present in air or fuel. The rate of NO formation is predominantly dependent on the combustion temperatures, and is more significant at high temperatures. Formation is also dependent on the oxygen concentration present during combustion and the time available (residence time) for the combustion process. In the atmosphere, NO rapidly oxidizes to NO_2, a process greatly accelerated by sunlight and by the presence of organic materials in the air. It is known that NOx has adverse health effects on human beings due to its affinity for hemoglobin, an oxygen-carrying agent to the body tissue which it deprives of oxygen. NOx is also known for its contribution to acid rain and reduction of atmospheric visibility (smog).

Gas turbine engines inherently operate at very high combustion temperatures and therefore are a source of NOx emissions. The traditional method of controlling NOx emission from gas turbines has been to inject either de-ionized water or steam to control the combustion flame temperature. As an added benefit, this method can also be utilized to increase the engine power output by increasing the mass flow of air through the turbine. The basic limitation of this approach is the cost of supplying de-ionized water, when water is used, or ability to provide steam, as in the case of steam injection. As a consequence, it is not always feasible or cost-effective in all applications to provide steam or water for emission control.

The desire to reduce engine emissions without water or steam injection has resulted in the development of multi-zone combustor designs which are intended to minimize both NOx and carbon monoxide, CO, emissions at the same time. In order to minimize NOx and CO simultaneously, the combustion temperature has to be maintained within a very narrow band. To maintain a desired combustion temperature band it is necessary to have a uniform distribution of fuel with the combustion air. This requires a precise knowledge of the air and fuel distribution. The precise air/fuel ratio control can be accomplished in multi-zone combustion with multi-point fuel injection.

The task of the fuel control system is to distribute the fuel to various specified stages of the combustor, with very high fuel metering accuracy, while maintaining stable turbine performance. This requirement has led to the development of a multi-path gas fuel distribution system with capability to independently control the fuel flow in each path to within (± 2%) of each flow point. This precise flow scheduling accuracy has not been possible with prior gas turbine fuel control system technology.

Fuel Flow Accuracy Control Method

The mass flow rate of a compressible fluid through a valve is a function of the valve effective metering area, fluid composition, and fluid operating conditions such as the fluid inlet temperature, inlet and discharge pressures. The valve effective metering area is determined by the valve discharge coefficient (Cd) which varies as a function of many other parameters. In traditional turbine applications, when a certain fuel flow rate is demanded, fuel is metered based on prior knowledge of the valve calibration (flow vs. position) and approximate values of the fluid inlet and discharge pressures. In this scheme, high fuel metering accuracy cannot be realized because of the variations in fluid conditions, valve calibration and discharge coefficients, all of which can cause variation in the fuel flow.

Since the basic requirement for dry low emission control is the ability to meter the fuel to achieve a precise air/fuel ratio, as required by the turbine operating condition, the ideal fuel metering system must be able to provide the fuel flow rate as demanded by the electronic control system with virtually zero error. Given a desired flow rate, the electronic control system must command a valve position, taking into account the fluid conditions and other valve variables, so that the demanded flow is achieved. In order to do so it is necessary to have precise knowledge of all of the valve parameters. At any time the electronic control system must have knowledge of the valve metering area, valve discharge coefficient, and fluid temperature and pressures. Figure 1 illustrates the fuel flow accuracy control concept described above for a representative single-path fuel metering system.

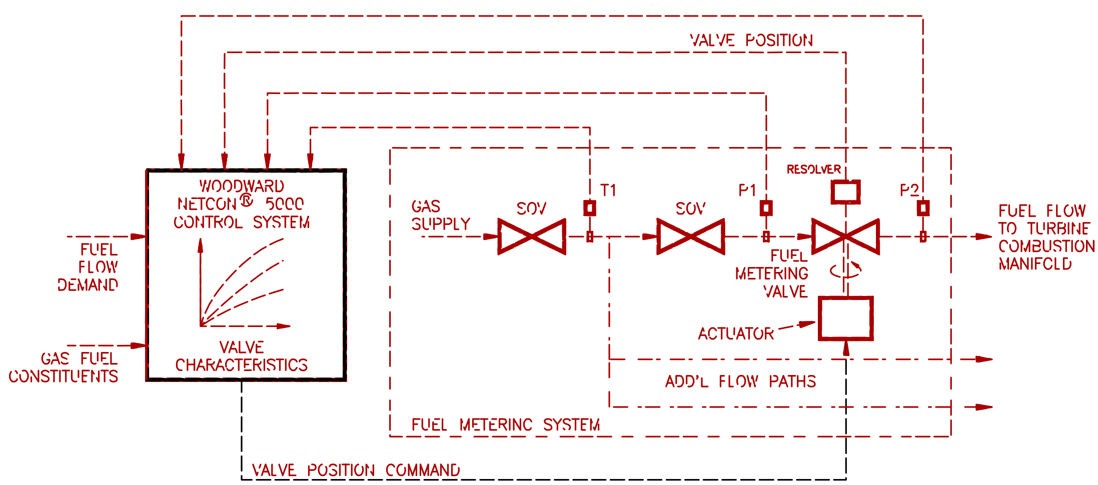

Figure 1. Fuel Metering Control Scheme

Valve Design and Characterization

The Woodward gas fuel metering valve is a rotary sleeve and shoe type throttling valve which has a self-cleaning shear-type metering design. This concept minimizes the sensitivity to gas-born debris or particulate contamination. This design also facilitates tight dimensional control of the profiled metering port. These features allow the valve metering area to be determined to great accuracy for any valve position and also minimizes the variation in the metering area due to contamination. These advantages are usually not achievable with typical butterfly or poppet metering valves.

The fuel metering valve is positioned by high performance electric or electrohydraulic actuators which are capable of moving the valve from the fully-open to fully-closed position within 100 milliseconds or less. The valve is designed with a resolver position transducer attached directly to the valve rotor shaft. This transducer provides valve position data to the electronic control system for position control and fuel metering purposes. The resolver is capable of achieving position measuring accuracy of within 0.2% of the total valve rotational stroke range.

Each metering valve is characterized to determine valve discharge coefficient as a function of valve position and fluid operating conditions (temperature and pressures). This information is stored in the form of look-up tables in the electronic system memory and can be rapidly retrieved as required during fuel metering.

Temperature and Pressure Transducers

A highly accurate RTD transducer is utilized to continuously measure the gas inlet temperature. This RTD temperature sensor possesses a highly linear and stable resistance versus temperature relationship. Valve inlet and discharge pressures are also measured continuously using a digital transducer system. This system combines a state-of-the-art silicon pressure sensor with digital signal processing technologies and temperature compensation scheme to provide a digital pressure output that is accurate over a large range of operating temperatures. Utilizing characterized pressure vs. temperature data stored in the on-board microprocessor, this pressure transducer is able to provide accuracy within ±0.02% of full scale.

Electronic Control System

The electronic control system is designed specifically for turbine control. It includes a dual-microprocessor capable of transmitting or receiving data from the fuel metering system within 5 milliseconds. Within 10 milliseconds it is able to take temperature, pressure, valve position data and, using the stored look-up tables, compute a control signal to the valve which drives the valve to a position that provides the fuel flow rate required to control emissions.

In a multi-path fuel metering system this electronic control system processes information and controls each fuel flow path independently, i.e., each flow control loop is essentially parallel to the others. At any given time the electronic control system modulates the fuel flow in each path as determined by engine condition and the fuel ratio scheme required by different combustor design.

Multi-Path Fuel Metering Configuration

The fuel metering system is packaged to minimize the effect of volume dynamics. Flow straighteners are utilized in the fuel piping to reduce flow turbulence due to bends and high velocity flow effects. The fuel metering valves are arranged on a common fuel plate which can be located inside the turbine enclosure and in close proximity to the combustor manifolds. Shutoff and vent valves are provided in each flow path to ensure minimal leakage and a safety shutoff feature. All equipment has been designed for operation within Class I, Division I hazardous locations. A three-path fuel metering arrangement is shown in Figure 2. However, for aero-derivative gas turbines the number of flow paths can vary significantly.

Compressible Flow Test Facility

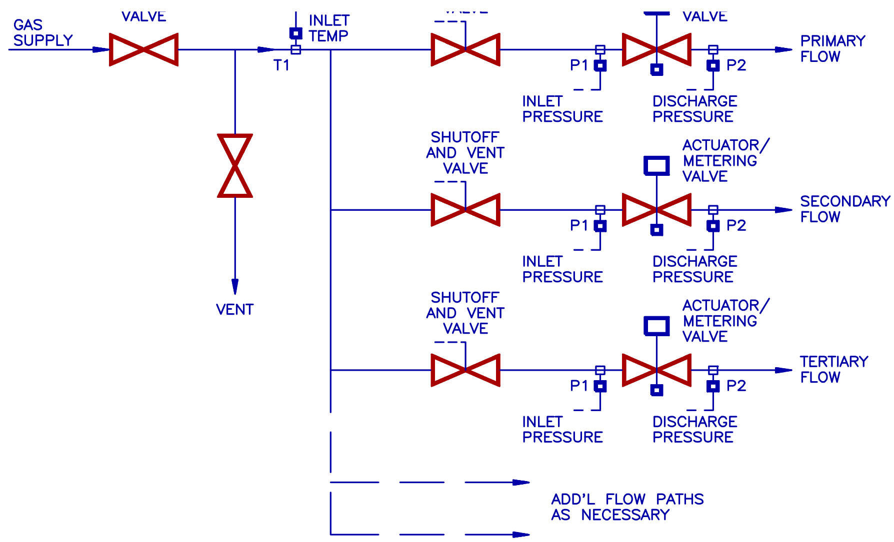

Figure 2. Multi-Path Fuel Metering System

A key consideration in the achievement of the specified low emission goals is accurate quantification of the fuel delivery system performance. As a result, highly accurate measurements are required during development and production testing. Considering these factors, all fuel metering system components are designed, assembled, and tested as a system. For this work, the Woodward compressible fluid test facilities in Loveland, Colorado, are utilized for flow metering accuracy verification. This test facility is capable of better than ±0.5% flow measurement accuracy in flow ranges from 10 to 50 000 pounds (4.5 to 22 680 kg) of air per hour and operates at pressures up to 1100 psia (7584 kPa). Results of tests with air are mapped to equivalent fuel flows using well established algorithms.

Conclusion

The Woodward gas fuel metering strategy utilizes the latest hardware and software technology to achieve the metering accuracy required by dry low emission aero-derivative gas turbine engines. The valve compensation scheme presented above reduces the uncertainty in the different valve parameters that can affect the ability to meter fuel accurately. This fuel metering scheme is made feasible today by the advanced electronic hardware which provides the computational capacity and speed.

The cost benefit of the dry low emission fuel control system compared to water or steam injection systems results from the savings in initial investment of hardware and long-term maintenance, as well as obviating the need for costly de-ionized water.

Although this fuel control system was developed primarily for aero-derivative gas turbine applications, its capability can also be utilized in heavy industrial turbines. The highly responsive electronic and actuation systems that are designed for aero-derivative turbines can be a significant enhancement to the performance of industrial turbines which normally operate with less capable control system hardware.

[Written by Troy Nguyen, and appearing in the January/February 1994 issue of *Diesel & Gas Turbine Worldwide*.]

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