WOODWARD

Application Note 83406

Original Instructions

Fuel Metering Systems for Dry Low Emission (DLE) Gas Turbines

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Introduction

The purpose of this paper is to describe the basic concept of the dry low emission (DLE) turbine and the fuel control system options. Initial system concepts being provided by Woodward will be discussed, together with some options for the future.

The allowable emission levels from industrial gas turbines are decreasing across the world as local, state, and federal governments impose stricter regulations on these and other prime movers. In order to meet these new requirements, several of the aeroderivative gas turbine manufactures are developing or have developed dry low emission (DLE) versions of their turbines. The basic principle behind this next generation of turbines is that the air/fuel ratio delivered to the combustor and local flame temperatures of the combustion process must be precisely controlled in order to obtain optimal combustion. The “dry” method of emission control has several advantages to the end-user over methods previous methods such as steam injection, water injection and post process scrubbers. Among these advantages are improved cycle (fuel) efficiency, reduced capital expenditure, and reduced operating costs.

Dry Low Emissions

When a given amount of gas, such as methane, is combined with the theoretical air necessary to obtain the complete combustion of all the carbon and hydrogen present in the fuel, the following basic reaction occurs:

$$CH_4 + 2O_2 + 2(3.67)N_2 \rightarrow CO_2 + 2H_2O + 7.52N_2$$

In this example, the only products of combustion are the harmless compounds of carbon dioxide, water and nitrogen. Under actual operating conditions with pipeline gas, improper air/fuel ratios, and incomplete combustion, additional combustion byproducts such as NO, NO_2, and CO are produced. To minimize both carbon monoxide and NOx production at the same time, localized combustion temperatures have to be controlled within a very narrow band. This requires the uniform distribution of fuel within the combustion air and the precise air/fuel ratio. This is accomplished by accurate metering of the air and fuel as well as the use of multi-point fuel injection and multi-zone combustion.

Fuel Metering

The DLE turbines require precise metering of both the air and the fuel. The tolerance on metered mass fuel flow for some of these turbines is as low as ±2% of point over a 100-to-1 flow range. In the Woodward DLE fuel metering systems provided today, these accuracies are obtained through the use of precision valves, transducers to sense system variables and fast and flexible digital electronic control systems. An important factor in achieving the levels of performance required is the ability to test the valves under actual flow conditions. The large capacity, high accuracy (±0.25% of point), flow calibration facility in Colorado is used for this calibration.

The Woodward fuel metering valve is a rotary sleeve-and-shoe type throttling valve that has a self-cleaning shear-type metering design. This shearing/metering concept minimizes the valve's sensitivity to gas-born debris, particulate contamination, and gas condensates. The profiled metering port is sized for the given flow conditions to take advantage of the maximum valve stroke and to maximize the accuracy of the metered flow as a function of position.

In order to accurately control the mass flow rate of fuel delivered to the turbine, P1, P2, and T1 are measured using high accuracy transducers. In addition, the fuel's supercompressibility, specific gravity, and ratio of specific heats are compensated for in the control system. In order to meet the dynamic requirements of the gas turbine, this complete series of measurements and calculations is performed every 10 ms and the resultant position is sent to the position control module in the NetCon® control and out to the actuator final driver. The position control module and final driver close the position loop using valve position feedback from the resolver which is directly coupled to the rotary fuel metering sleeve.

The fuel system must maintain its accuracy when all possible errors in the system are considered. These errors include P1, P2, and T measurements, position feedback error, and errors in the signal processing. In addition the accuracy of the system must be maintained across a wide band of operating pressures, gas and ambient temperatures, and other environmental conditions. It is apparent, given all the possible sources of error, that each part of the fuel metering system must be as accurate as possible to ensure the metered fuels accuracy and thus the DLE turbine's ability to meet the required emission levels.

Alternative Systems

The fuel metering system could be greatly simplified through the use of a closed loop control biased directly on a mass flow meter output. This would eliminate the need for the P1, P2, and T measurements, as well as the extremely accurate position control. With the use of a fast and highly accurate mass flow meter for closed loop mass flow measurement the fuel metering valve could become a simple throttling valve similar to the proportional actuator/valve assemblies common on today's non-DLE turbines.

Commercially Available Mass Flow Meters

There are mass flow meters commercially available today which have the accuracy necessary (a minimum of one fourth of the metered flow accuracy or 0.5% of point) to obtain 2% fuel flow accuracy when run closed loop with a fuel metering valve. Woodward has successfully demonstrated this technique of fuel flow control under steady state conditions at the CEESI test facility in Nunn, Colorado. However, there are several technical problems that must be overcome before this approach can be successfully used for closed loop fuel control on industrial gas turbines.

The main limitation of the mass flow meters currently available is the update rate of the flow meters. All of the mass flow meters available today have a relatively slow update rate of approximately 1 second. By contrast, the Woodward DLE fuel control system has an update rate of 0.01 second. The slow update rate of the mass flow meters make it impractical to dynamically control a gas turbine. Current fuel control systems for aeroderivative gas turbines must be able to control the fuel flow to changes in demand at rates of 5 Hz and upwards. This means that the current turbine control system could have received a change in demand and changed the fuel flow five times before the flow meter ever updated. The update rate of the flow meter is generally a function of the minimum average time necessary to obtain the published accuracy and is independent of the output signal used (4–20 mA, 0–10 Vdc or pulse). However, it should be noted, that the 4–20 mA signal generated by most flow meters has a resolution of only 10 bit or less of full scale and thus will add considerable error to the actual flow accuracy. The raw signals from the flow meters, without any processing, change at a frequency of approximately 80 to 150 Hz and are too noisy, small and inaccurate to control from directly.

Another problem with commercially available mass flow meters is that they are susceptible to any piping or external vibration in addition to any pressure noise in the gas supply and acoustic noise from the turbine. The meters use one or more oscillating elements in a simple bending mode which is easily excited and changed by vibration. Any artificially induced changes in the oscillation of the meter directly effects the accuracy and stability of the meter. There are also concerns over the meter's field interchangeability and long term calibration stability.

Future Mass Flow Meter

Woodward is currently investigating direct mass flow meters which could overcome the problems mentioned in the section above. The flow meters being evaluated operate at high frequencies (2 to 3 kHz) and do not use the simple bending method of excitation. The high frequency operation makes it possible to get enough points, to average, to obtain the required accuracy, and still have the necessary system response. The fact that the flow meters use higher order modes of excitation (simple bending is a first order mode) prevents the flow meters from being excited by external vibration at the frequencies in the normal turbine operating range. Woodward has tested prototype meters at our Loveland flow facility and has successfully demonstrated these meter's accuracy, stability, and immunity to vibration.

Other Flow Meters

There are other methods of flow measurement which are not direct mass flow that might be considered for closed loop flow control. These flow measurement techniques include turbine meters, swirl meters, positive displacement flow meters, vortex shedding flow meters and other types of volumetric flow meters. Volumetric flow meters have the same limitations as commercially available mass flow meters and as such are generally unacceptable for closed loop control of anything other than very slow changing systems. In addition most volumetric flow meters have a turndown ratio of 20:1 or less. This flow range is often insufficient to cover the complete fuel flow schedule of medium to large aeroderivative and industrial gas turbines. Volumetric flow meters also require up to 50 diameters of straight pipe upstream of the meter to obtain the published accuracy. With flow straighteners this length can be reduced by half.

Since the fuel flow demand to the turbine is in terms of mass flow rate, the volumetric flow rate must compensate for the meters inlet temperature and pressure, gas compressibility, specific gravity, and specific heat. Volumetric flow meters are usually only 1% of point flow meters. This requires the pressure and temperature compensation measurements as well as the gas characteristics and signal processing to be very accurate if the 2% of point accuracy for mass flow is to be maintained. For closed loop control purposes it would be necessary to measure the mass flow rate a minimum of four times more accurately than the desired flow accuracy. This would result in the total tolerance for the volumetric flow measurement, the correction measurements, and the signal processing necessary to convert volumetric flow to mass flow to be 0.5% of point or better.

Conclusion

The dry low emission turbines being developed require precise control of the combustion process. The turbine pre-mixers and combustor must receive the correct mixture of air and fuel, and control the combustion temperature to limit emissions to acceptable levels. The Woodward fuel metering system is able to accurately control the fuel to the turbine to the 2% of point accuracy required for DLE. The fuel system could be simplified if a mass flow meter with acceptable bandwidth, accuracy, and vibration resistance was found. Woodward is working on the development of a mass flow meter to meet this need. Commercially available flow measurement techniques other than mass flow offer little hope of being an effective solution to the fuel metering needs due to bandwidth, accuracy, and compensation limitations

[Written by Jeff Stewart]

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