2010 Gas Turbine Industrial Fellowship

Gas Turbine Igniter Design and Ion Sensor Development

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Introduction:

As a Gas Turbine Industrial Fellow, I was fortunate enough to spend a 12 week period working with the Turbine Systems Division of the Woodward Governor Company, located in Greenville, South Carolina. Woodward is one of the world's leading suppliers when it comes to gas turbine controls, fuel delivery, and ignition systems. At the Greenville, SC facility Woodward designs and manufactures igniters and fuel nozzles for the power generation market. I reported to my Industrial Mentor, Mr. Michael Hackenberg.

During my term at Woodward I contributed to a number of different programs within the company. These included the development of a new igniter design, investigation of potential field failures, testing of fixed geometry liquid fuel atomizers, redesign of variable geometry gas fuel injectors, prototype testing of igniters, and even got a chance to work with some early technology development. My work at Woodward was extremely diverse and some of that work was proprietary and cannot be included in this report. Proprietary work included the testing of liquid fuel atomizers for a customer as well as testing a prototype igniter for another customer.

This report seeks to describe one of the major non-confidential tasks that I performed while working for Woodward. It is not representative of all of the work done during this employment term but is representative of the type of work and the quality of work that was performed while in Greenville.

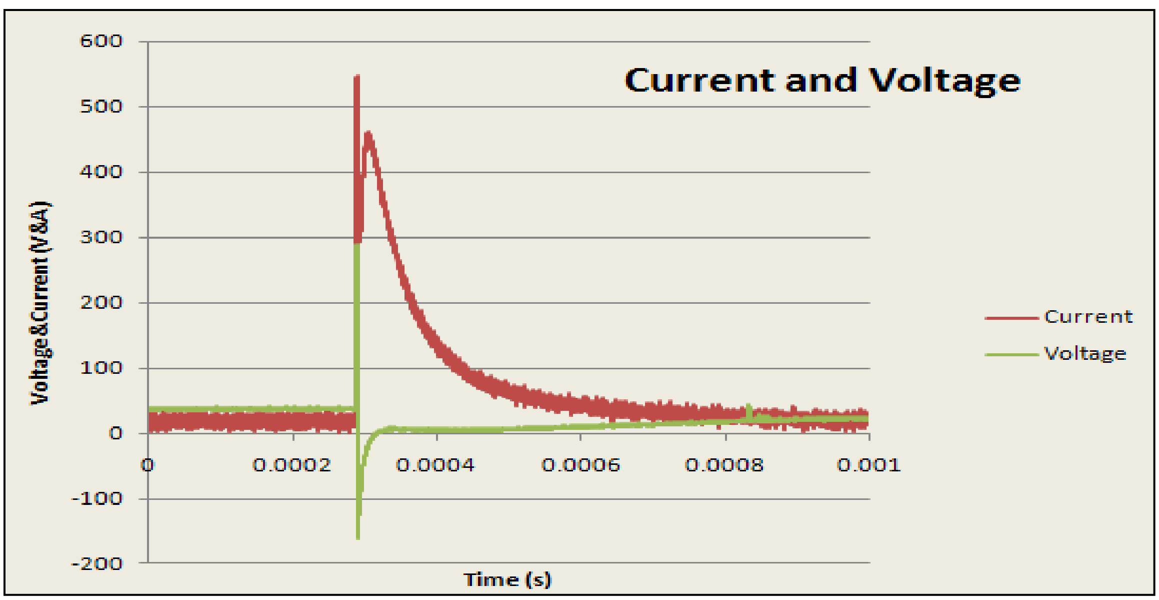
Sample Project 1: Fielded Igniter Set

Spark Energy Investigation

The first project that I devoted my time to at Woodward was an issue concerning some fielded igniters. A customer turbine, utilizing a Woodward ignition system, experienced a failed start at the power generation site. The issue of a failed start in a power generation gas turbine is not only an inconvenience but is also very costly, resulting in operating time lost and a loss in profit due to the downtime. As a result of the failed start the engine was brought down for maintenance, and the ignition system was inspected. Since these igniters were prototype, first generation components that had been installed in the field Woodward seized this opportunity to launch a performance validation of the component. This particular igniter set represented the first of this design to be analyzed after extended field use. Six igniters were retrieved from the field to be analyzed by Woodward.

The primary function of a gas turbine igniter is to deliver a spark energy sufficient to light a combustible mixture. The design requirement for these particular igniters was to deliver a spark energy of 1.5 Joules per spark. In order to test these igniters they were each individually tested while being monitored with an oscilloscope. The oscilloscope was used to record voltage across the igniter gap as well as current through the igniter tip, each as a function of time, throughout the duration of the spark event. 10 spark events were averaged to ensure accurate readings. The raw data can be seen below:

Sample spark signal recorded by the oscilloscope

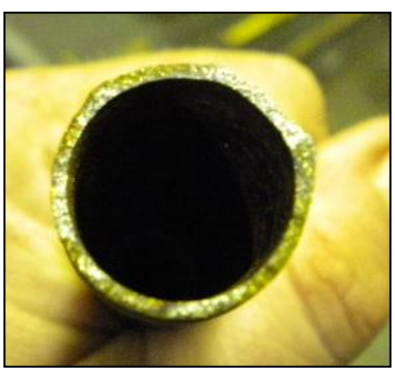


The spark event begins when the voltage is seen to spike and ends when the voltage readings return to their ground level. However, it is interesting and non-intuitive that the voltage would have a negative value. It is even stranger that the voltage does not seem to be negated, but rather shifted downward. This results in a negative signal for the first portion of the spark event and a positive signal towards the end of the spark. This apparent shift of the voltage signal is attributed to a shift in the baseline, or ground, voltage. Due to the extremely high voltage that the system is exposed to, and assuming some inherent capacitance of the system, it is hypothesized that the reference voltage is shifted. After its initial shift the reference voltage slowly drifts towards its original value, as the system discharges and recovers from the shock.

In order to compensate for this drifting baseline a method of determining the ground drift was devised. After modeling a logarithmically decaying reference voltage it was possible to subtract the measured signal from its variable ground signal. Then the voltage and current signals could be multiplied and integrated over time to determine the total energy released during the average spark event. All of the 6 igniters were found to release adequate spark energy to ignite a combustible mixture.

Torsional Strength:

Another issue concerning the igniters that needed to be addressed was their torsional strength. The igniter design was tested without failure to 30 ft-lb of torque prior to installation in the field. This was considered adequate strength for the application. However, evidence has shown the possibility of fracture due to over torquing in the field. The two halves of a broken igniter are shown below:



After performing a calculation at the location of the fracture (a raised shoulder) the igniter was seen to have a minimum yield strength of 25 ft-lbs of torque. This assumes Maximum Shear Stress Model, worst case material properties, and maximum stress concentration factor for the geometry. While this calculation shows a yield strength of 5 ft-lbs less than the tested yield strength it is still reasonable. The calculation assumes worst case scenario in multiple ways. This extreme worst case would be highly unlikely to occur simultaneously in a single part.

In order to overcome the low yield strength it was suggested that the minimum radius on the shoulder be increased. The new yield torque was calculated for a variety of different minimum radii. The final results are shown below:

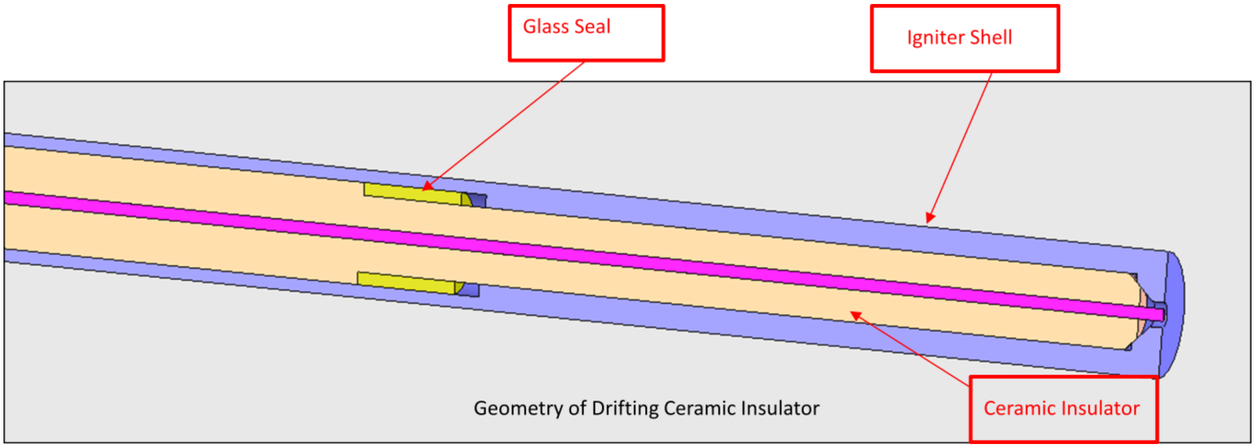
R (in)	K	Yield Torque (ft-lb)
0.005	3	25
0.01	2.4	31
0.05	1.5	50
0.1	1.25	59

Strength variation as a function of minimum radius

It is important to note here that if the minimum radius increases above .0015" the location of the minimum yield torque will simply move to the location of a nearby butt weld. It was therefore recommended that the minimum radius be changed to between 10-15 thousandths resulting in a yield strength increase of about 7 ft-lbs (28% increase).

Sample Project 2: Ceramic Drift in Glass Seals

In igniter design it is standard that a ceramic insulator be used to serve as the dielectric separating the center electrode of the igniter from its shell. One method of securing this center electrode is to preload it into the igniter shell, securing it with a glass seal. The glass seal softens when heated in an oven and then solidifies during cooling to secure the insulator against the igniter shell. The geometry can be seen below:

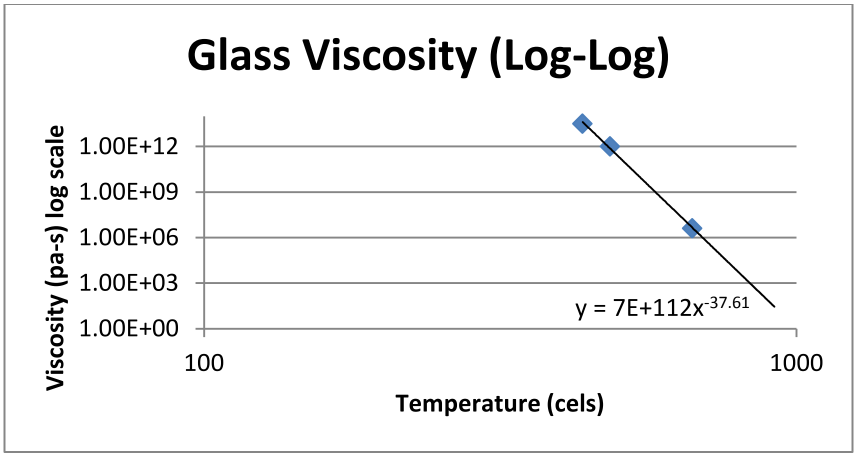


Geometry of Drifting Ceramic Insulator

Once concern with this design is that the ceramic insulator may recess, or drift, away from the surface of the shell. This ‘drift’ of the ceramic insulator away from its seat will result in a loss of the preload that the ceramic was designed to be under. This would not affect the functionality of the part, but it does leave the part more open to damage since an unsupported ceramic is more likely to crack when jostled.

It is hypothesized that the glass seals, responsible for holding the ceramic insulator in place, may soften at elevated temperatures and result in ceramic drift. Once the glass seal is soft the pressure from the combustion chamber provides an axial force significant to cause axial drift of the ceramic and center electrode off of its seat.

Having established this hypothesis it was now necessary to model the ceramic drift mathematically. First, in order to determine a relationship between temperature and glass seal viscosity, manufacturer’s data and material properties of the glass were consulted. From that data the following relationship was obtained:

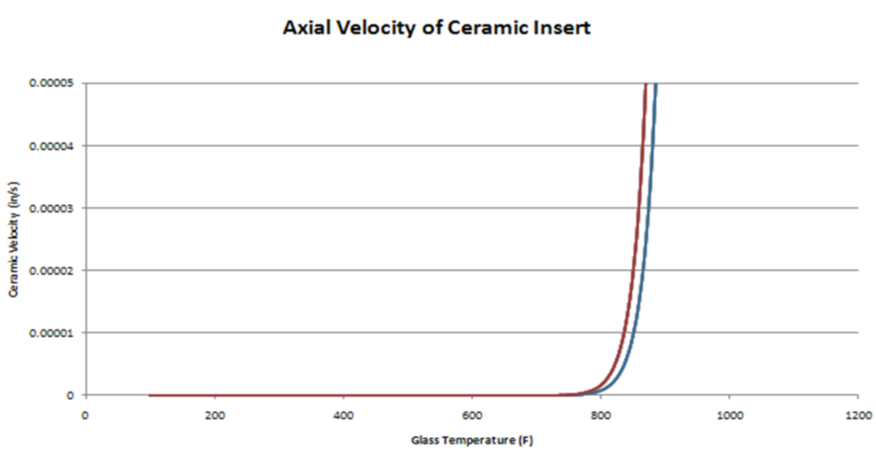


Having established viscosity as a function of temperature it was necessary to model the glass as a fluid. Since the geometry is axisymmetric the fluid problem was approximated as 2D. The problem was also approximated as Plane Couette Flow since we are concerned with the relative velocity of one wall, the ceramic, to the other wall, the shell. We also can assume that the system is at steady state, fully developed, and resulting in a constant velocity at the ceramic-glass interface. Taking the governing equation to be the definition of shear stress:

Governing Equation:

$$\tau_{yx} = \frac{dF_x}{dA_y} = \mu \frac{du}{dy}$$

It was possible to isolate du/dy and then integrate, plugging in boundary conditions to solve for constants. In the end we found the following relationship:



This plot shows that for two different loading schemes, represented by red and blue lines, the glass becomes soft enough at a temperature of 800 F to experience an appreciable amount of ceramic drift. This is a reasonable temperature for the igniter tip to see.

Woodward is currently investigating this topic and seeking for ways to improve its current sealing method. The intention is to go beyond the design requirements, despite the fact that this behavior would not affect function of the component.

Conclusions:

In summary I would say that my experience at Woodward has been extremely beneficial. The Gas Turbine Industrial Fellowship program serves as an excellent link between academia and the industry. I learned a lot of practical knowledge about the gas turbine industry and about manufacturing/design processes in general. My ability to perform in my own thesis work was enhanced by the fellowship and I like to think that my academic experience has allowed me to contribute to the Woodward team. In summary I value very highly the experience, connections, and knowledge developed during my fellowship.