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Final Report

Center Electrode Life Test of an Iridium Alloy
&
Weld Matrix Database

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1. Introduction

Woodward integrates leading-edge technologies into fuel, combustion, fluid, actuation, and electronic control systems for the aerospace and energy markets. [1] Woodward has 10 offices in the United States of America, and 22 other offices around the world. Woodward, Greenville is located in South Carolina, and manufactures fuel delivery, ignition, and controls components and assemblies to support both land and air turbines. A few of the products manufactured there are: injectors, nozzles, swirlers, and igniters.

Igniters in an industrial gas turbine (IGT) are not always sparking like they would in an automobile. Where there is a spark during every cycle in most gasoline engines, the igniters are used to start the process of a self propagating flame, and then turned off.

The process of ignition is envisaged as occurring in the following manner. Passage of the spark creates a small, roughly spherical, volume of air (henceforth referred to as the spark kernel) whose temperature is sufficiently high to initiate rapid evaporation of the fuel drops contained within the volume. Reaction rates and mixing times are assumed infinitely fast, so any fuel vapor created within the spark kernel is instantly transformed into combustion products at the stoichiometric flame temperature. If the rate of heat release by combustion exceeds the rate of heat loss by thermal conduction at the surface of the inflamed volume, then the spark kernel grows in size to fill the entire combustion volume. [2]

2. Alloy Evaluation

2.1 Objective

The conditions inside an industrial gas turbine engine vary depending on a variety of factors, such as type/quality of fuel used, required emissions, materials used inside the engine, injectors, as well as environmental factors. As a result of these varying conditions, the igniter is not always dry. That is, sometimes there is fuel or even water on the igniters. Through previous research, Woodward ascertained that an igniter that sparks under wet conditions experiences more erosion than one that sparks under dry conditions. Past tests have been made to determine the volume and mass loss of a wet spark versus a dry spark. Past testing consisted of dripping fuel at a timed interval, onto a sparking igniter. No spark test was ever conducted on an igniter whose tip was fully submerged in fuel.

Due to the increase in erosion under wet conditions, current products experience a significant decrease in life as a result of the varying operating conditions. Current life requirement is 800 starts at 60 sparks per start, which equates to five years of use. In order to enhance the life of the igniter, Woodward is exploring new materials for the center electrode, and has obtained samples of an Iridium (Ir) alloy that is proposed to have a longer life than the Inconel 600 material that is currently used. The alloy sample has a diameter of 0.100”

The purpose of this project was to perform a dry and a fully submerged spark test on a production igniter with a center electrode made out of an Ir alloy. A fully submerged spark test was also conducted on a stock (baseline) igniter. The acquired data will help to determine a possible new material for the center electrode.

2.2 Igniter

The stock igniter has a center electrode made of Inconel 600 with a diameter of 0.125". A vertical mill was used to remove a portion of the center electrode. Then, a 0.95" diameter drill was used to drill into what was remaining of the center electrode. Next, a taper was applied to the Ir alloy rod, and the rod was press fitted into the 0.95" hole. The thought behind this was after the first few sparks, the gap between the Ir alloy rod and the Inconel 600 center electrode would arc and weld together. The material for the outer electrode is also Inconel 600. Figures 1 and 2 show a plug that was used for the test.



Figure 1. Igniter Housing.



Figure 2. Igniter Tip with Ir Alloy Electrode.

2.3 Dry Spark Test

2.3.1 Test Set up

In order to obtain an accurate depiction of the life cycle of the Ir alloy, we needed to have an accurate count of the number of times the igniter sparked. Therefore, the igniter was threaded into a stainless steel cylinder. A small hole was drilled in the side wall of the cylinder, and a fiber optic cable was inserted into the hole. The fiber optic cable was connected to a counter that kept count of the number of sparks or flashes that occurred in the cylinder. The counter box was powered by an external power supply. In order to help keep the igniter cool and to blow away any possible debris/deposits, the other end of the cylinder supplied compressed air. A breather was installed on the side wall of the cylinder to help relieve pressure. The sparks were controlled by an exciter box that contained all the necessary components to produce sparks at a set interval and intensity. Figure 3 shows the setup for the dry spark test.

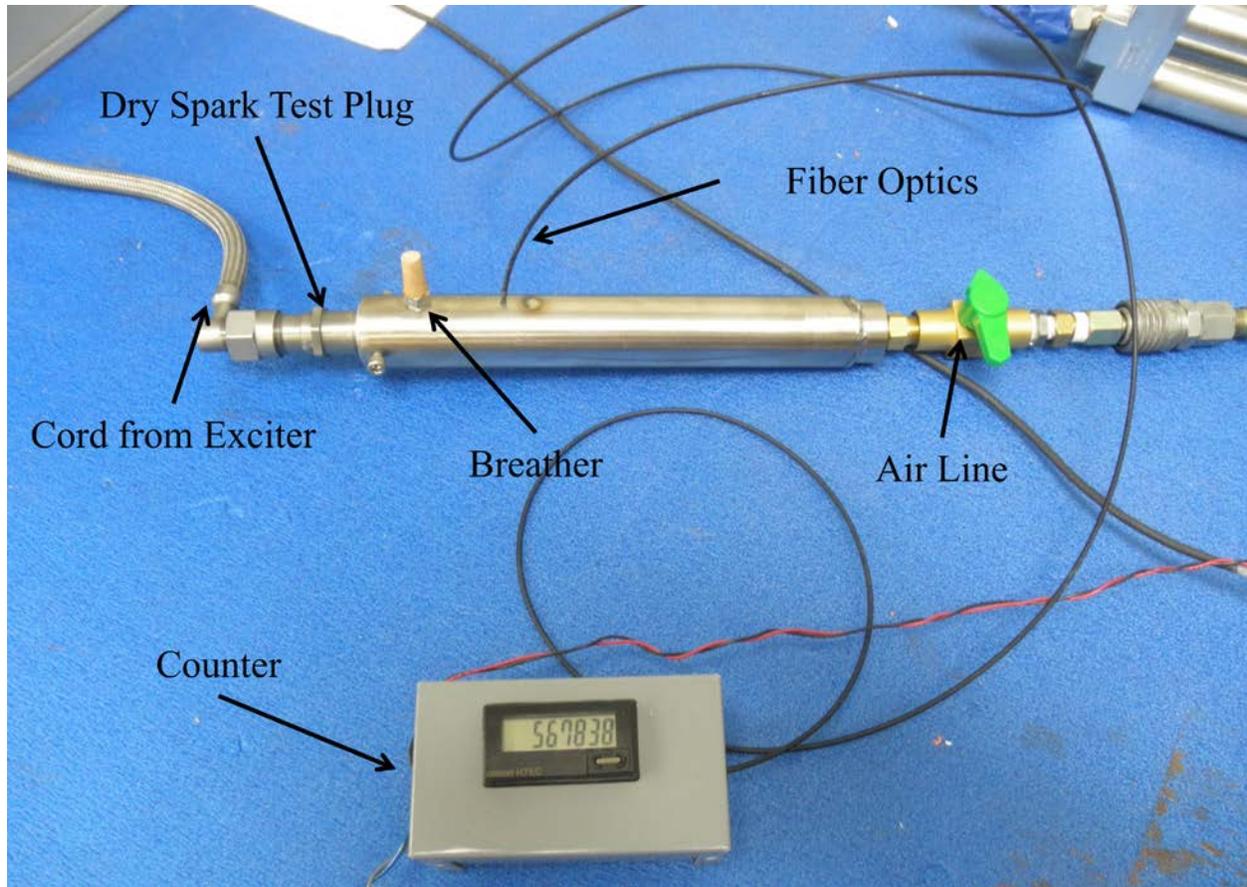


Figure 3. Dry Test Setup.

2.3.2 Test Procedure

Throughout the test, many different parameters were measured, specifically: igniter mass, center electrode height and diameter, outer electrode height and diameter, as well as the distance between electrodes. Initially the test was stopped every four hours to take measurements. After the first full day of sparking, they dry spark test was allowed to run day and night. Measurements were then taken at the start and end of the day.

2.4 Wet Spark Test

2.4.1 Test Set Up

The wet spark test apparatus used for this testing differed from previous wet spark test setups. Instead of dripping fuel onto the igniter at a controlled rate, the igniter tip was fully submerged in fuel. A special container made with an expandable bellows was fabricated to hold the fuel and also to keep the igniter upright. The expandable bellows allowed the sealed container to adjust to the rises in temperature and pressure of the sparks. In the extremely unlikely that a spark would actually cause an ignition of the fuel, the bellows needed to be shielded in argon gas. To contain the argon gas, as well as protect people and equipment from harm, the bellows and igniter were placed in an explosion rated steel enclosure. A breather was outfitted to the steel enclosure to depressurize the internal volume. Figure 4 shows the inside of the steel enclosure while Figure 5 is an outside view of the enclosure.

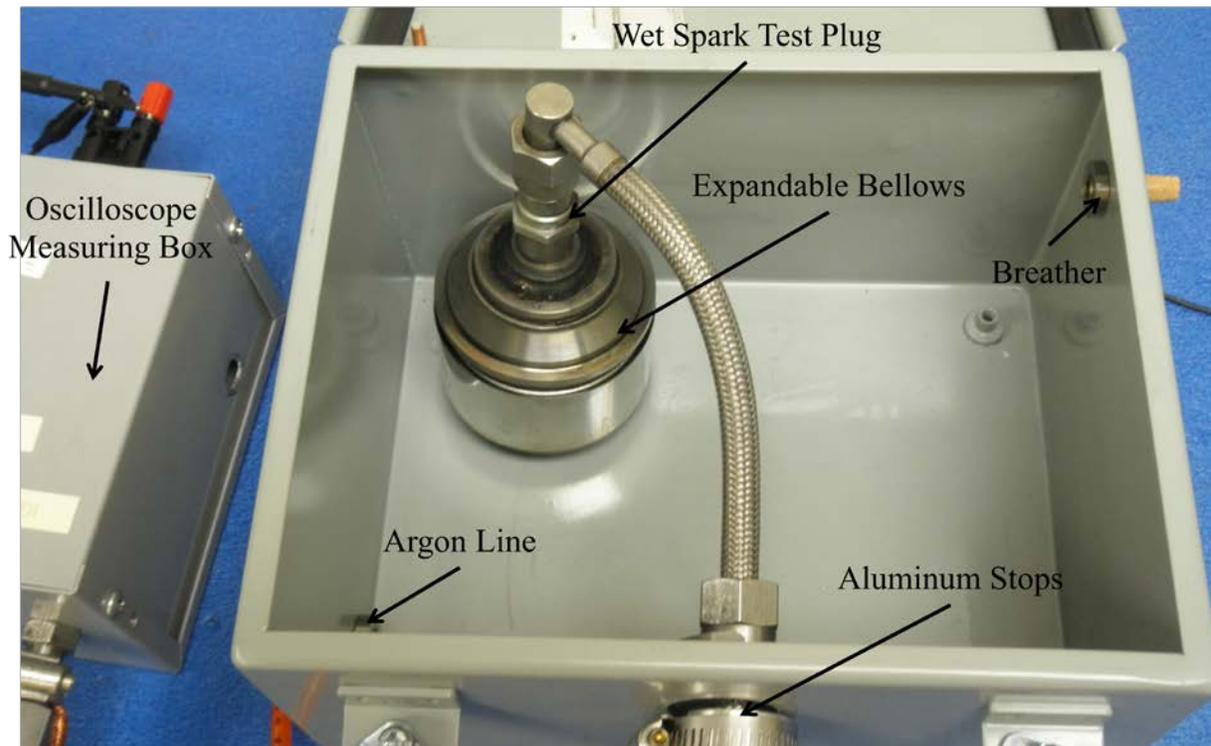


Figure 4. Wet Spark Setup, Inside View.

For the wet spark test, a fiber optic cable/spark counter was not used for several reasons: First, the cable should be mounted somewhat close and pointing to the center electrode as there was no good way of doing this while still being able to seal around the cable. Secondly, the cable could potentially lose its sensitivity to sense the flash of the spark as the fuel clouded up. Lastly, there was a concern that the fuel would corrode the fiber optic cable. Instead, an oscilloscope was used. The oscilloscope was displaying a voltage output from a 10:1 current transformer, Pearson Model 110 Current Monitor. A trigger was set to 80V on the upward slope of the function. Any time the voltage passed that trigger, the program recorded that event as a spark.

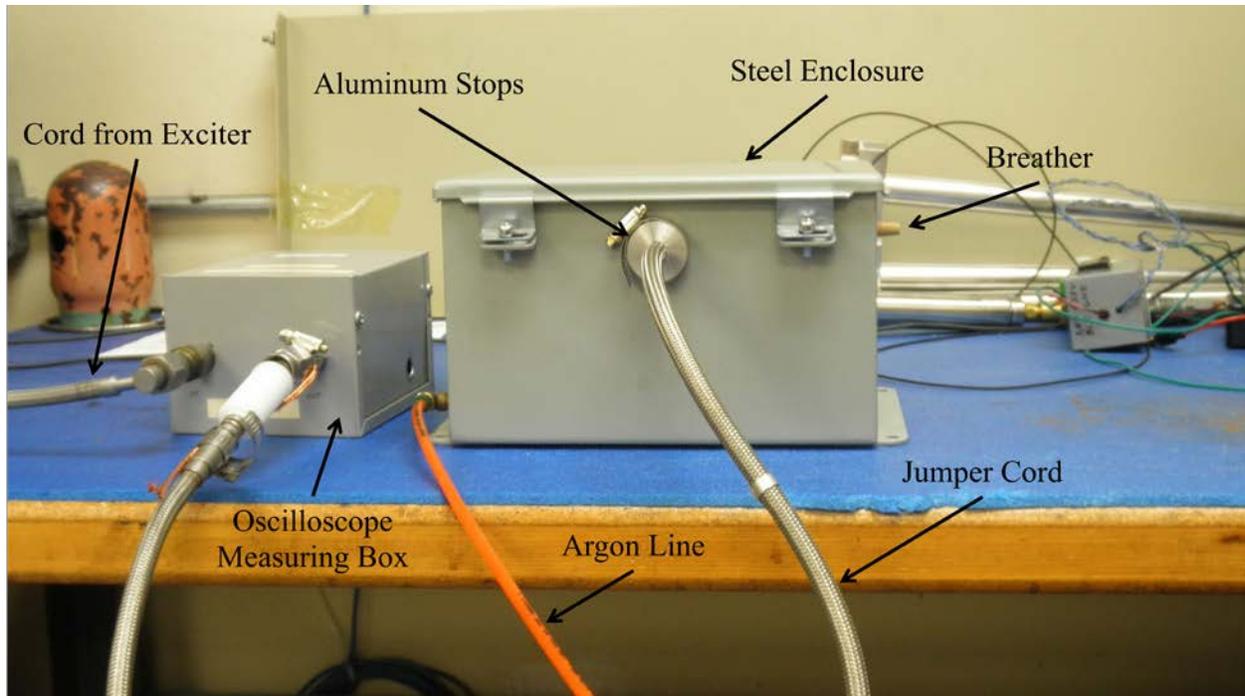


Figure 5. Wet Spark Setup, Outside View.

2.4.2 Test Procedure

The procedure for the wet test was similar to the dry test in that the same parameters were measured. The measurements for the wet tests had a few additional steps than the dry test. For the wet test, the tip had to be cleaned of all deposits. Every time the igniter sparked, a very small amount of fuel was burned. The burned fuel could then deposit on the igniter. The deposits had to be removed in order to obtain an accurate weight and height measurement. Also all of the excess fuel had to be removed from the igniter. One main difference was that the wet test was not allowed to run overnight, due to the possibility of fire/explosion. The test was checked on periodically during the day to ensure that sparking was still occurring. After every measurement, additional fuel was added to replace some of the fuel that was consumed.

2.5 Results

2.5.1 Dry Spark Test

When the test started, the instructions stated to end the test when the igniter fails to spark. After analyzing the igniter at 567,838 sparks, it was decided to end the test. The igniter had greatly exceeded its required sparking life. Figures 6 and 7 are different views of the igniter tip at the end of the spark test. The majority of the material removed came from the outer electrode, which is comprised of Inconel 600. The center electrode had rounded edges. Instead of being a cylinder, it was more of a hemisphere on top of a cylinder.



Figure 6. Dry Spark Tip, End of Test.



Figure 7. Alternate View of Dry Spark Tip, End of Test.

2.5.2 Wet Spark Test

As with the dry spark test, this test was supposed to end when the igniter failed to spark. Nobody expected the test to last longer than 100,000 sparks. Therefore, the test was ended at the end of the day, when the count was at 126,028 sparks. The erosion characteristics were much different than that of the dry spark test. The center electrode was rounded, as in the dry test, but the electrode had eroded down to the insulation. There was much less erosion on the outer electrode when compared to the dry test. There was also a large crack in the insulation. It appears that the sparks would travel through the crack to the outer electrode, as there is a noticeable amount of material missing from the outer electrode at that location. Possible reasons for the crack include but are not limited to: high temperature and pressure within the test apparatus, damage from manufacturing, cracks in the microstructure that propagated during the test, etc. The results from the wet spark test can be seen in Figures 8 and 9.



Figure 8. Wet Spark Tip, End of Test.

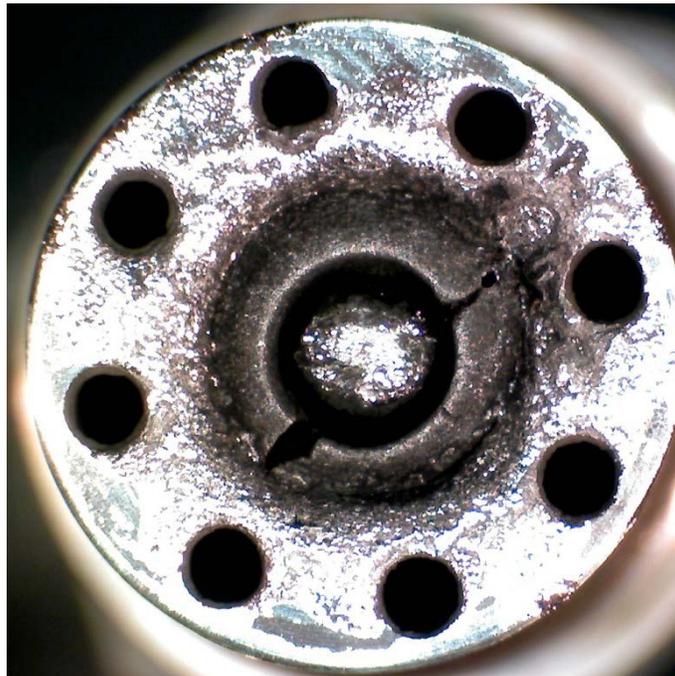


Figure 9. Alternate View of Wet Spark Tip, End of Test.

2.5.3 Baseline Wet Test

The wet test was supposed to be ended after the igniter failed to spark. The baseline wet test actually failed to spark twice, once at 99,250 and again at 107,948. When restarted, the igniter continued to spark. This led us to believe that there may be some fatigue in the driver. Another

indication of this was that the current was falling throughout the test. After 142,254 sparks, the test was ended. The erosion pattern was similar to the alloy wet test, with a few differences. The center electrode was not rounded at the tip like in the other tests, but was flat on top. Also, the center electrode was eroded to a point below the insulation. The erosion on the outer electrode was similar to the other wet test. Figures 10 and 11 show the igniter tip at the end of the test.



Figure 10. Baseline Wet Spark Tip, End of Test.

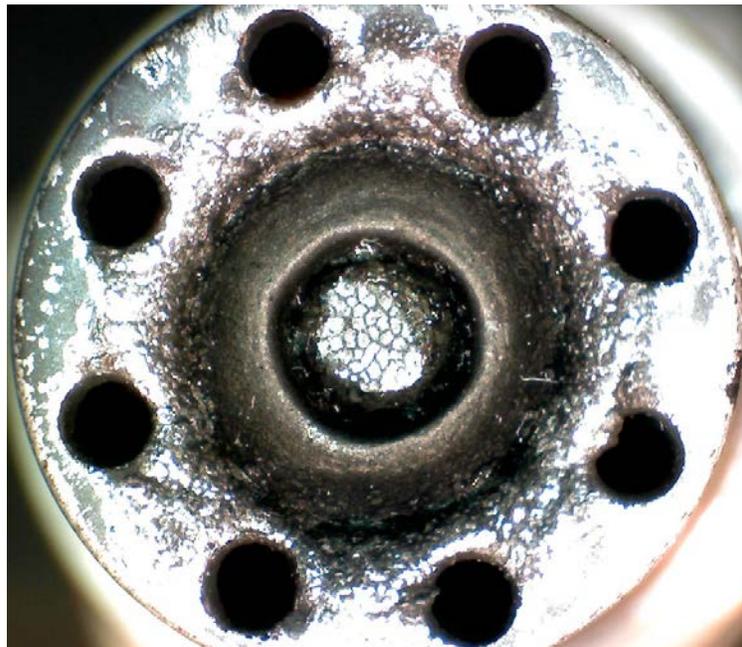


Figure 11. Alternate View of Baseline Wet Spark Tip, End of Test.

The data that was collected during the tests were compiled into an Excel spreadsheet. The volume loss was calculated for each test, assuming various geometries for the material lost. Then, using the densities of the various materials, a mass loss was calculated. All data is for the center electrode only. Figure 12 shows the change in volume, in cubic centimeters, per spark. The baseline wet test is an order of magnitude greater than the alloy wet test. Figure 13 displays the change in mass, in grams, per spark. At the end of the test, the wet alloy actually loses more mass per spark than the baseline, due to the higher density of the alloy. A graph of each test and the total volume loss, in cubic centimeters, at 140,000 sparks can be seen in Figure 14.

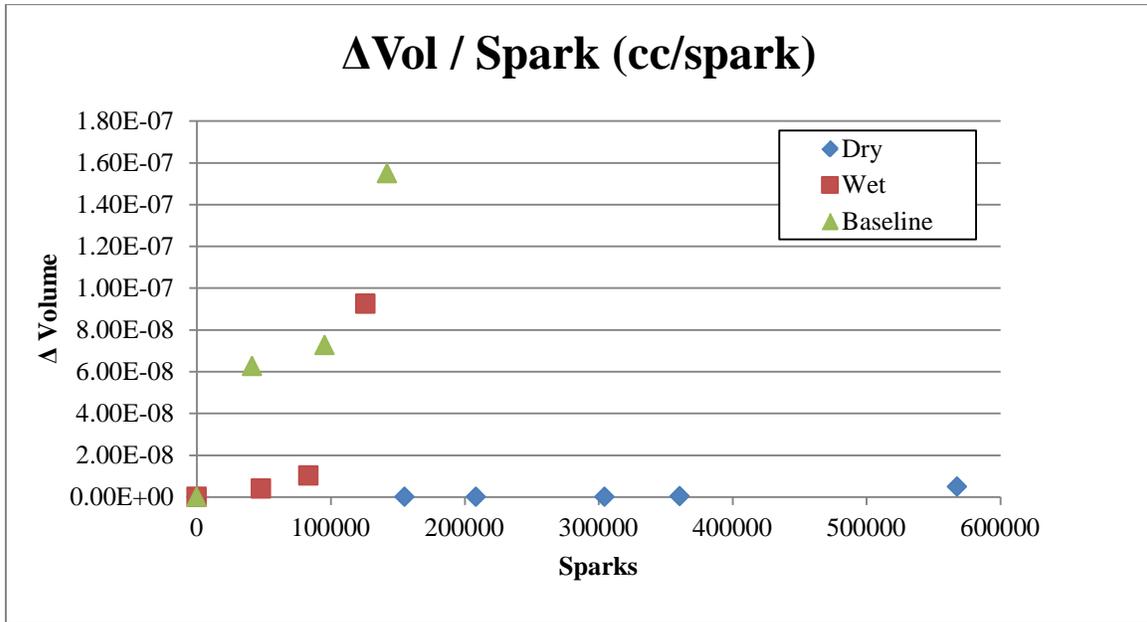


Figure 12. Change in Volume per Spark.

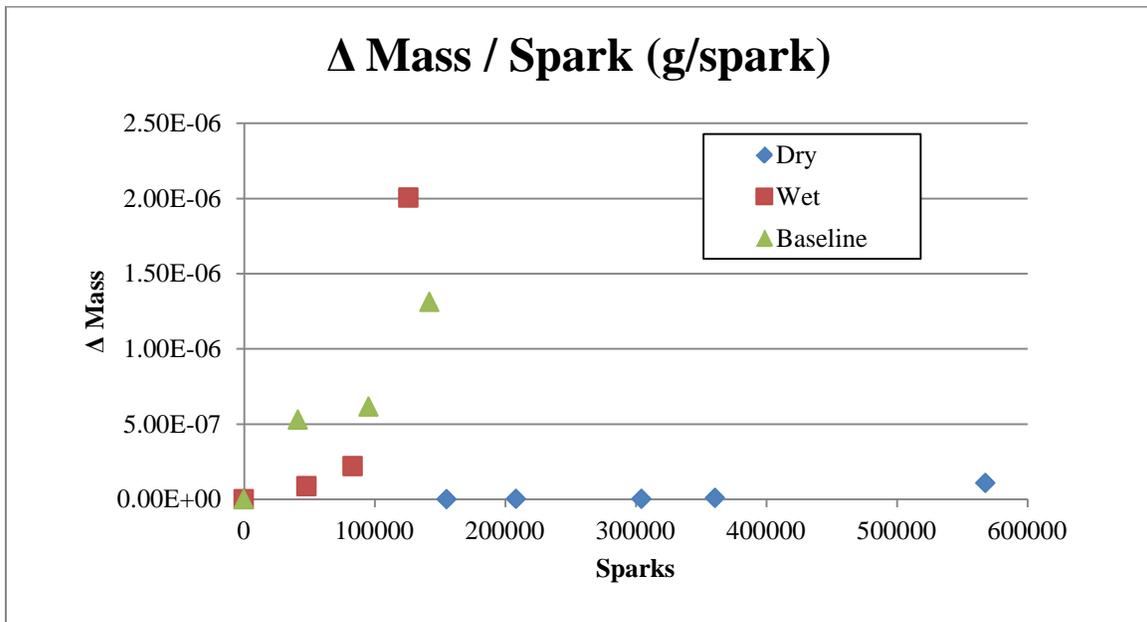


Figure 13. Change in Mass per Spark.

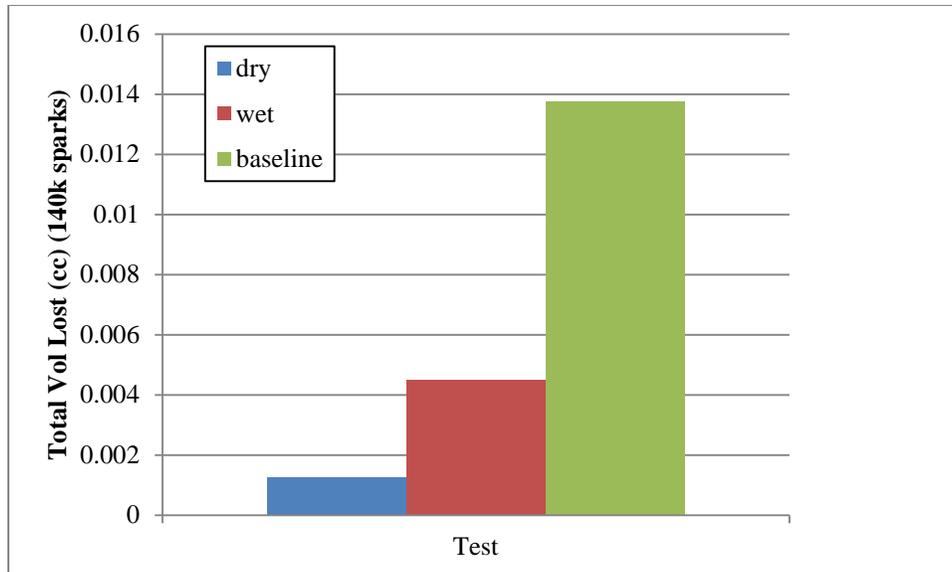


Figure 14. Total Volume Lost at 140,000 Sparks.

3. Weld Matrix Database

Many of the parts at Woodward are welded together using an Electron Beam (EB) welder. All of these parts that are welded must pass inspections based on ASME criteria, the customer's criteria, as well as Woodward's own internal criteria. Many different attempts must be made at completing a weld in order to qualify the weld. Trying to save some money, Woodward uses weld coupons. Weld coupons are blank parts that are similar to production parts, but without all of the features. This saves time, material, and money. A concern was raised as to the amount of money that was being spent on weld coupons, given Woodward's extensive knowledge of welding. The purpose of this project was to develop a database to help quote and better estimate the number of coupons required. This would save time, material, and money. It would primarily be used by manufacturing engineers, weld engineers, as well as product engineers.

The weld database was made for both EB welding and Tungsten Inert Gas (TIG) welding. It was made in Excel, one page for EB welds, and another for TIG welds. The database contained many different parameters, with filters that can help to narrow down the search. The parameters contained within the database are: part 1, material 1, part 2, material 2, top level assembly, type of weld, weld thickness, weld speed, focus, amperes, circle size, frequency, as well as the weld schedule, or program that the EB weld machine reads.

4. Conclusions

A new alloy was to be used for the center electrode in a stock igniter. The hope was that this center electrode would have a longer life than the current part. In order to quantify this, a dry and wet spark test was conducted. The dry spark count exceeded 10x the life requirement at 567,838 sparks. A new test procedure had to be developed for the wet spark test, as no fully submerged wet spark test had been done before. The wet spark test was stopped after 126,028 sparks. The next step was to test the baseline production part with the fully submerged wet test. This test was ended after 142,254 sparks. After analyzing the data, it appears that the new center

electrode made of the alloy performs better than the current center electrode. The current center electrode has almost three times the volume loss as the center electrode made up of the alloy. Previously, it was thought that the wear rate was only dependant on the material of the electrodes. Now, however, it appears that the wear rate is a function of both the material and the geometry of the electrode.

The weld data base is currently being reviewed for accuracy. The database will then be made a read-only file to all but a few, and then released to the intranet for use.

5. Acknowledgments

The time that I spent at Woodward was extremely beneficial. It gave me an insight as to how a company works in the gas turbine industry. I gained a better understanding of how planners, engineers, technicians, and manufacturing work to meet the needs of the customer.

I would like to thank all of the people that I worked with, they were all very professional, knowledgeable, and helpful. They made me feel like I was a Woodward employee and not just another summer intern. I would like to thank Dan Burke and Bruce Harrar for helping me with getting the projects going, fabricating parts, and making sure nothing went wrong. I would like to thank Mike Hackenberg for being my mentor and for having answers to all of my questions. I would also like to thank Ann Kreutziger for inviting me to many different meeting and getting me to learn many different Woodward products. Finally, I would like to thank UTSR and GTIF for providing me with this opportunity to work in the gas turbine industry.

Works Cited

- [1] About Woodward. Web. 06 Aug 2012. <http://www.woodward.com/AboutWoodward.aspx>
- [2] Lefebvre, Arthur H., and Ballal, Dilip R. (2010). *Gas Turbine Combustion Alternative Fuels and Emissions*. Third Edition. CRC Press.