NSI Performance Improvement through the use of Automation

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Abstract

Chemring Energetic Devices has transferred the manufacture of the NASA standard initiator (NSI) from its Torrance, CA facility to its Downers Grove, IL facility and performed re-qualification of the manufacturing process. As part of the transfer effort, the use of automation has been introduced into the process to eliminate operations historically performed by hand which has led to reduced cryogenic function time variability, increased manufacturing throughput, and safer handling of the energetics.

Introduction

The NASA Standard Initiator (NSI) along with Chemring's commercial equivalent (PC-23) is a two (2) pin electrically activated, hot-wire, electro-explosive device which provides a source of pyrotechnic energy used to initiate a variety of space mechanisms for use on both satellite and launch vehicle applications. Mechanisms include pyrotechnic valves, separation nuts/ bolts, cable/ bolt cutters, pin pullers and many others. The reliable initiation of these one-time use mechanisms is often mission critical leading, to stringent test requirements being levied upon the manufacture and acceptance of the NSI.

Electrically activated initiators are conceptually simple devices but possess manufacturing sensitivities that can have significant effects on the final performance. A typical electric initiator is depicted in Figure 1 and consists of a glass to metal sealed header (with receptacle), a bridgewire welded across the header pins, energetic ignition mix (ZPP typical) consolidated onto the bridgewire, and a welded closure output. When an electrical stimulus is applied to the header pins (5 amps, 20 ms typical) the current heats the thin bridgewire which in turn heats the consolidated ignition mix. Once the ignition mix reaches its auto-ignition temperature the energetics undergo a self-sustaining reaction which produces heat, gas, and hot particles. These thermal outputs are used to ignite secondary energetics in an energetic train/cartridge or can be used perform work in a device without any additional booster.

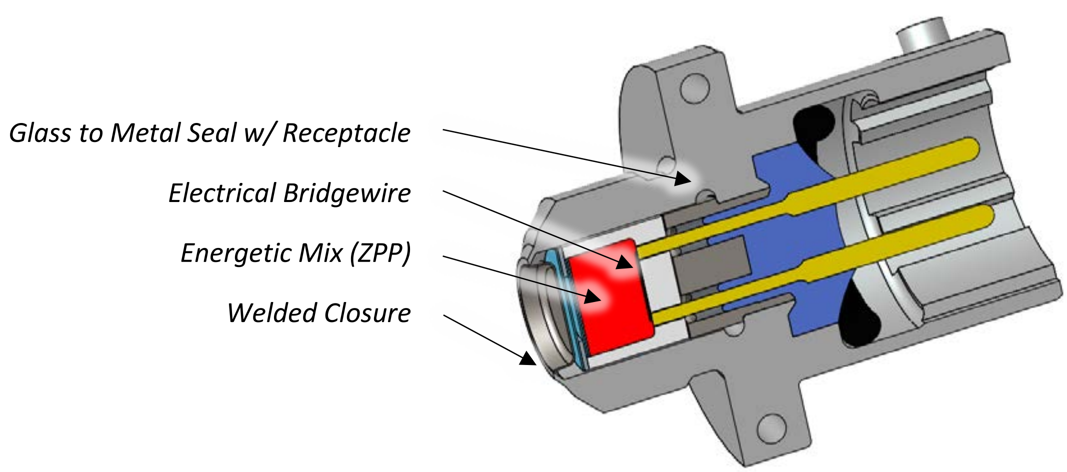

Figure 1. Cross Section of NASA Standard Initiator (NSI)

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Chemring Energetic Devices (CED) is currently NASA's only qualified manufacturer of the NSI. The all-fire/ no-fire stimulus, function time (application of power to first pressure), and peak pressure are all critical performance requirements of an electrical initiator and the NSI requires stringent control of these performance characteristics. All can be sensitive to the manufacturing process with the cryogenic (22 K) firing time, unique to the NSI, being particularly susceptible.

Process Automation

Historically, the NSI had been produced out of CED's recently closed Hi-Shear facility located in Torrance, CA. The manufacturing process involved performing critical operations by hand with consistency limited by the manufacturing technician. These critical operations include blending of the energetic material batches, welding the bridgewire, applying wet energetic mix (slurry) onto the bridgewire, and loading and consolidating powder zirconium potassium perchlorate (ZPP) into the output charge cup. Performing these critical tasks by hand has limited manufacturing throughput and product consistency, resulting in cryogenic firing performance with variability that put the acceptance of an NSI lot at risk.

With the transfer of NSI manufacturing to CED's Downers Grove, IL facility, the use of automation has been introduced into the manufacture of the NSI leading to less variability in cryogenic firing performance and increased manufacturing bandwidth. To date, three critical aspects of the manufacturing process have been automated at CED; bridgewire welding, application of slurry to the bridgewire, and mix and blend of the energetics (ZPP). A photograph of CED's automated bridgewire welder is provided in Figure 2.

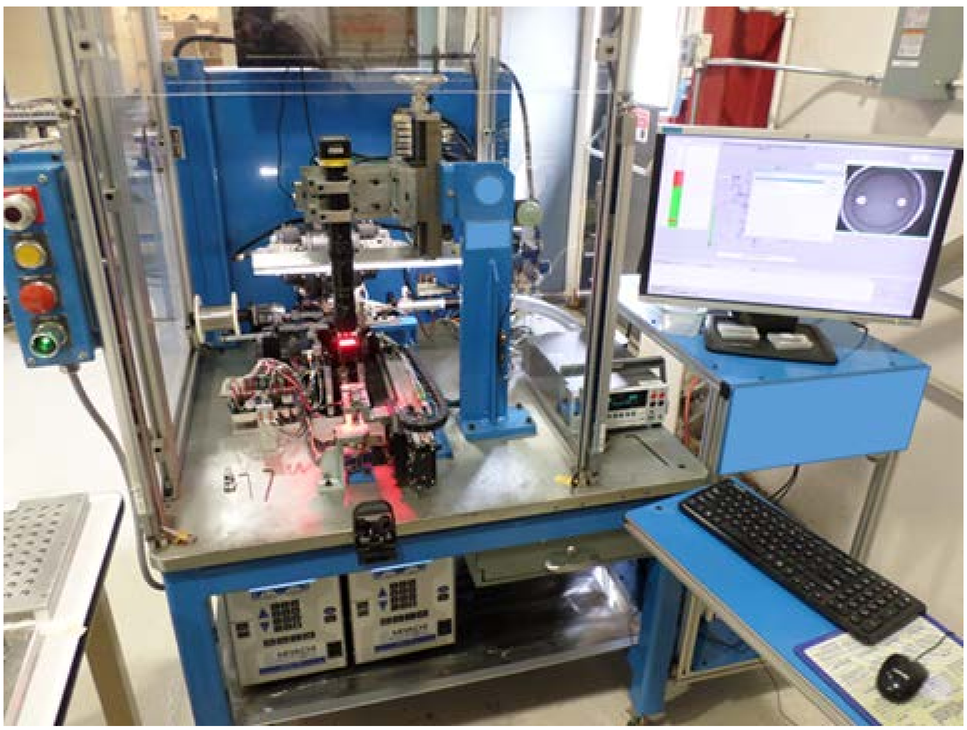

Figure 2. Automated Bridgewire Welder

The automated bridgewire welder reduces operator involvement in the process of loading the prepared glass to metal seal headers into the machine and starting the process. The automatic welder spools the <0.005-in (0.13-mm) diameter bridgewire onto the header pins then positions the weld electrodes using a vision system. Once positioned, the weld force is controlled with feedback control and once welded, the system severs/discards the remaining wire pigtails. Using the automated bridgewire welder has shown to consistently produce welds meeting the 0.95 – 1.15 ohms bridgewire resistance requirements with an average of 1.08 ohms and a standard deviation of 0.018 ohm across four lots as shown in Figure 3. In contrast, the previous hand welding operation involved a technician cutting the wire to length and positioning the wire for welding and securing in place by hand using a hold-down fixture. The extra touch time introduces the potential to damage the thin bridgewire (nicks, dings, etc.) which can affect bridge resistance and create hot spots that can cause no-fire failures when 1A/1W is applied for 5 minutes. Additionally, this process can result in unit to unit variability in the configuration of the welded bridgewire, not present in automated process, which can influence how energetics interface with the bridgewire and ultimately affect cryogenic function times (see Figure 5).

While the end quality of the hand bridgewire weld (resistance, all-fire/ no-fire performance) is similar to that of the automated process, the automated process significantly increases the first pass yield reducing the need to rework or scrap in-process hardware.

In conjunction with bridgewire welding, the interface between the bridgewire and the energetics as well as the amount of energetic material applied to the bridgewire have significant effects on the cryogenic function time. Historically the application of wetted energetics ("slurry") directly to the bridgewire has been performed by hand and been difficult to precisely control. The Downers Grove manufacturing line has implemented an automated application process which controls the rate and duration of slurry application, tightly controlling the amount and condition of the slurry applied to the bridgewire. The process has averaged 5.2 mg with 0.6 mg standard deviation across four lots as shown in Figure 3.

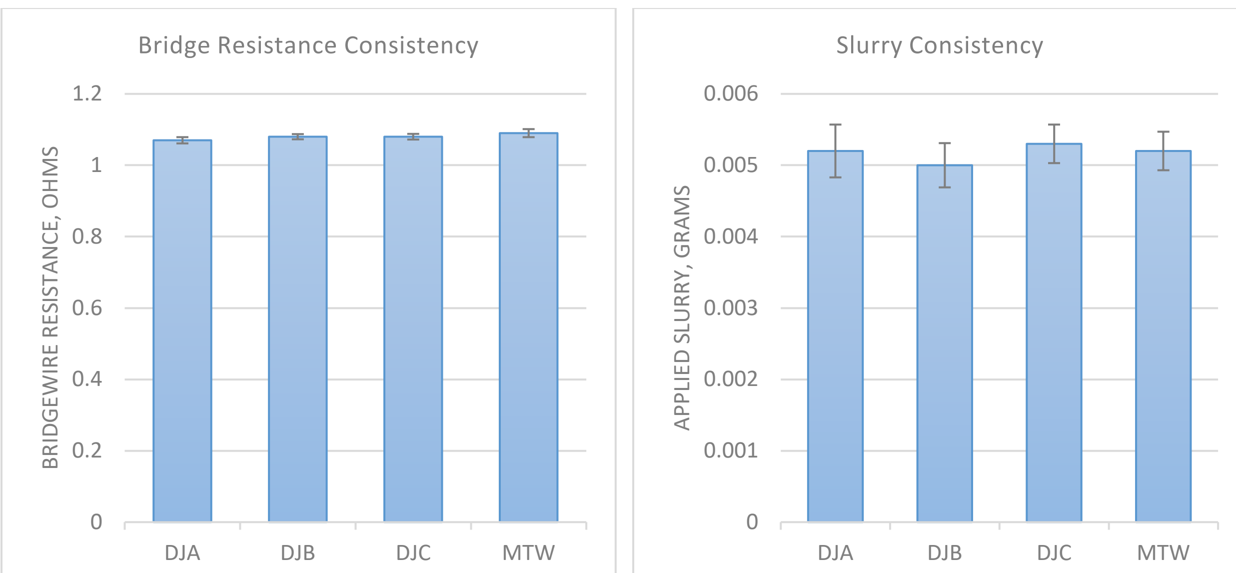

Figure 3. Automated Process Consistency (Mean w/ Standard Deviation Error Bars)

Bridgewire welding and application of slurry to the bridgewire are critical operations controlling the all-fire/ no-fire current, output pressure performance of the initiator between –162°C and +149°C as well as the function time performance at cryogenic temperatures as low as 22 K. The automated processes have demonstrated significant improvement in the function time variability at the cryogenic conditions.

A comparison illustrating the effects of process automation is presented in Figure 4. A single blended lot of ZPP (lot 13-44352) was manufactured using four methods; hand welded with a hand slurry application using the documented Torrance method, hand welded with a hand slurry application using a Downers Grove developed method, hand welded with automated slurry application, and both automated welding and slurry application. These groups were then tested at both 77 K and 22 K.

The data demonstrates higher average function times and wider variability when loaded with the heritage hand operations. By implementing either an improved hand or automated slurry application process to the heritage hand welding process, the average function times and the variability were shown to decrease, which indicates the inherent variability of the hand process. These batches still produced flyers which resulted in standard deviations similar to the hand process, which were attributable to inconsistency in the hand welding operation. By adding the automated bridgewire weld process to the automated slurry application process, the flyers were eliminated and both average and standard deviation cryogenic function times was significantly improved.

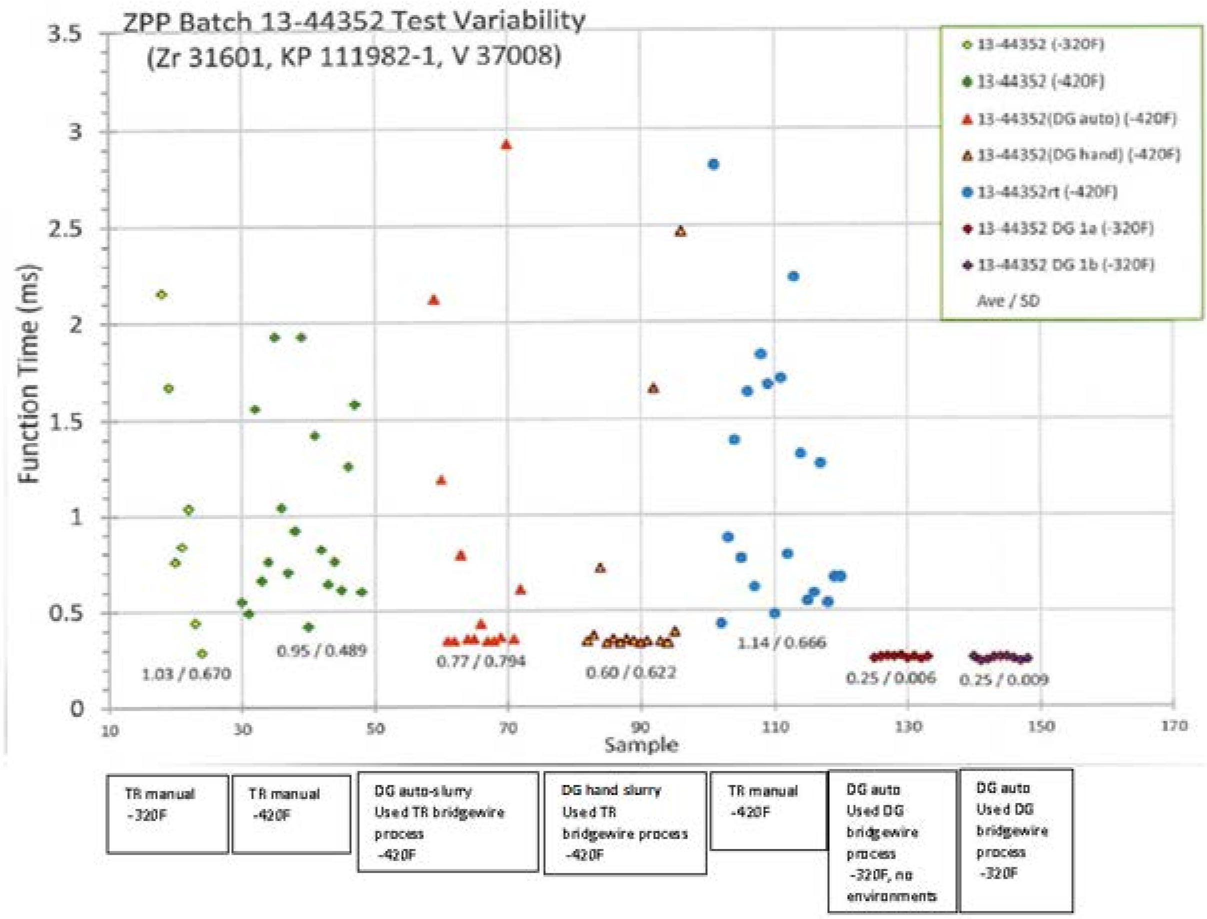

Figure 4. Effect of Process Automation on ZPP L/N 13-44352

The ZPP lot (13-4432) depicted in Figure 4 was deemed not suitable for loading into production NSIs during batch acceptance testing due to function time variability which is required to have an average of less than 1 ms and a 3-sigma limit less than 3 ms. Historically when a blended ZPP lot failed to meet batch acceptance testing, the ZPP lot was scrapped and a new lot blended. The results presented in Figure 4, indicate the root cause of the cryogenic function time failure was not the raw material but the process. The test units built with the same ZPP lot, but with the automated processes produced acceptable results, indicating the lot to be suitable for production.

Cryogenic function times of NSI test lots spanning 2013 through 2017, manufactured at both CED's Torrance facility (using hand operations) and CED's Downers Grove facility (with automated bridgewire welding and slurry application) is presented in Figure 5.

Data shows that lots loaded at CED's Downers Grove facility (DG) had function times (0.43 ms and 0.44 ms mean with 0.19 and 0.23 ms standard deviation) which were faster and tighter than the most consistent lot ever fabricated at CED's Torrance Facility (0.59 ms mean with 0.25 ms standard deviation manufactured in 2013) and had significantly tighter performance when compared to routine production lots loaded in 2016 and 2017.

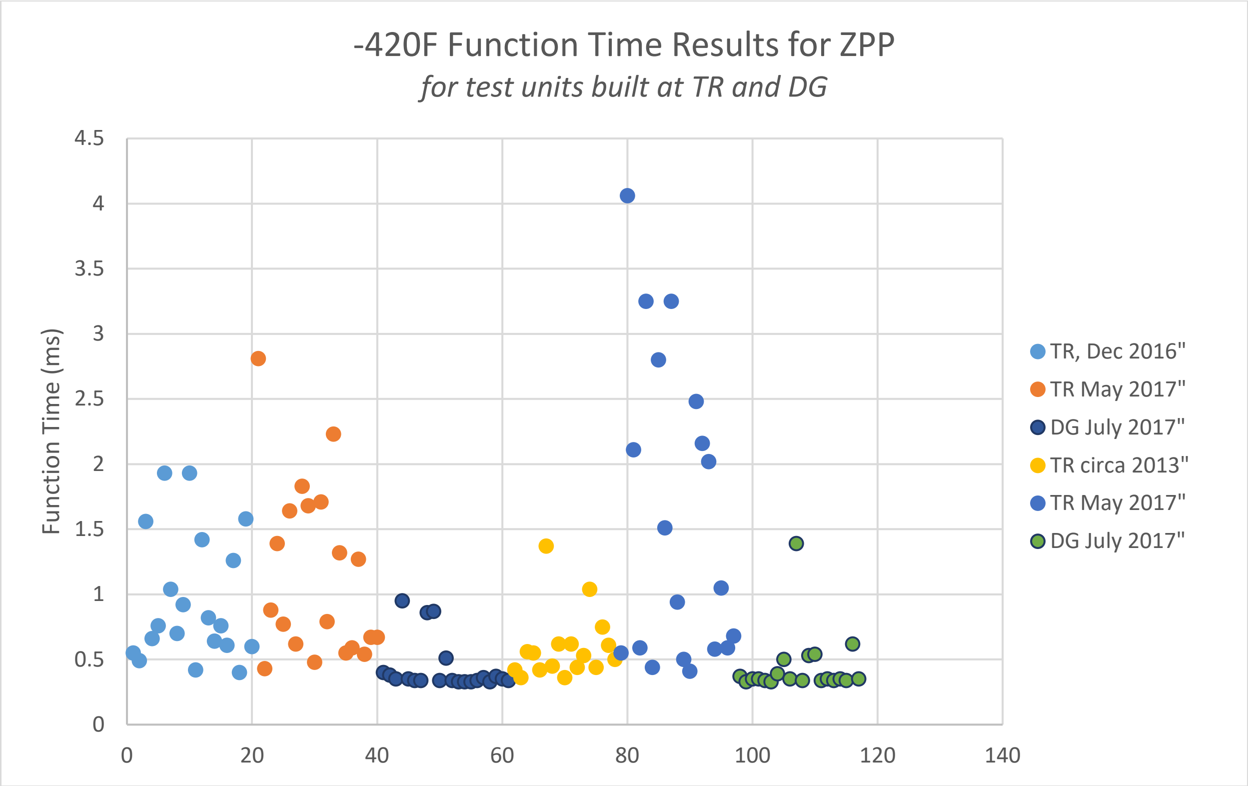

Figure 5. Cryogenic Function Time Comparison

In addition to improved cryogenic firing performance, the implementation of automation has allowed CED to increase manufacturing throughput. The automated bridgewire welder allows CED to bridge 100 initiator headers in roughly an hour and a half which previously took two days when this operation was performed by hand. Automated slurry application has increase capacity from approximately 200 pieces per day to 200 pieces in 30 minutes of application time. This increased capability allows CED to reduce lead time of the NSI and other initiators.

Automation has also helped CED to manufacture initiators in a safer manner than previously possible at its Torrance facility. The advantage of ZPP as an initiating material, its high sensitivity and rapid self-sustaining reaction, also makes it dangerous to blend as a raw material. The blending of the ZPP raw materials (fine granular zirconium and potassium perchlorate) had historically been done by hand at a remote facility by specific, highly trained technicians. The hand blending operation previously put the technician in close proximity to the volatile raw ingredients and exposes them to a lethal amount of energetics. Chemring is committed to improving safety and has developed automated energetic blending capability, depicted in Figure 6. It ensures no personnel are present in proximity to the raw materials during blending. Once a blend is completed the equipment dispenses and seals the ZPP into 7-gram velostat pucks for safe handling. ZPP batches blended using the automated energetic blend equipment have passed required differential scanning calorimetry /thermogravimetry analysis (DSC/ TGA) and heat of explosion testing (HOE) required to accept a batch as well as meet cryogenic function time requirements required to be suitable for production NSI manufacture.

Along with automating the blend process, CED is currently working to load NSIs using a robotic manipulator. The robotic manipulator will remotely load ZPP into the NSI charge cup, consolidate it to a feedback-controlled pressure, then confirm and log ZPP charge weights on a piece part basis. Qualification of this effort is set to begin in 2020 and once complete, in conjunction with the automated blend equipment will allow CED to blend and load ZPP without personnel coming into contact with the raw materials.

Figure 6. Automated ZPP Blend Machine (left) and Robotic Manipulator (right)

By implementing key automation processes, CED has improved consistency of the already reliable NSI and tightened performance, increased the manufacturing throughput, and markedly improved the safety by minimizing the exposure of employees to potentially hazardous conditions. Upcoming work with the robotic manipulator will further increase these benefits.

More consistent performance, shorter leads times, and reduced scrap will allow Chemring to better service NASA by providing NSIs. In addition to the NSI, CED offers the PC-23 initiator produced on the same manufacturing line as a commercial equivalent. The PC-23 is currently in use on a number of space platforms for many of the prime contractors and those customers are set to realize the benefits implemented on the NSI.