Titanium Grade 36 to Titanium Grade 1 weld on Implantable Cardioverter Defibrillator (ICD)

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Abstract *— Finding cost reduction on medical devices production, a new Feedthrough array design will be implemented in an Implantable Cardioverter Defibrillator, incorporating glassed Feedthrough of Titanium Grade 36 in a ferrule with glass insulator. This design will be used in place of the brazed Feedthrough of Niobium Type 2 in a ferrule with sapphire as insulator utilized in legacy devices. The Titanium Grade 36 Feedthrough will be welded per Resistance Spot Welding to Interconnect Ribbons of Titanium Grade 1. Being the first time that will be used of Titanium Grade 36 as material on Feedthrough, this new weld will be analyzed and characterized to meet the device requirement and obtain the economic impact of the material change with a benefit of $18-20M NPV. The Design for Reliable Manufacturing method demonstrate that a robust characterization design can be development in order to meet the specification as implement the new FT array knowing all effected factors.*

Key Terms *— Feedthrough, Niobium Type 2, Resistance Spot Welding, Titanium Grade 1, Titanium Grade 36.*

INTRODUCTION

The Medical Devices make that the people live longer, are most active and that can maintain a normal life, therefore the device must satisfy several requirements. One of the first thing into consideration to design and produce a new medical device is their materials and its compatibility among them, the range of mechanical properties and the biocompatibility.

The Niobium (Nb) is a metal physiologically inert with an extremely high melting point, high thermal and electric conductivity and corrosion-resistant properties [1]. With the growing of the magnetic resonance imaging (MRI) examination, being Niobium compatible with it and that is easily fabricated, Niobium overcome the drawbacks of recently available metals for medical purposes, therefore the Niobium cost has increased.

Currently on Implantable Cardioverter Defibrillator Connector use Interconnect Ribbons (ICR) of Titanium Grade 1 and it are welded to Niobium Feedthrough (FT) Type 2 of .015inch diameter to make the electrical connection between Connector to device, to enable the product therapies. The Titanium (Ti) Grade 36 can be a replacement for Niobium-zirconium alloy more economic, where it is an alloy with nominal composition of 45% Niobium and 55% Titanium. Advantages of using Ti Grade 36 (Ti45Nb) as FT pin material for the glassed FT are based in the biocompatibility and on good match of Coefficient of Thermal Expansion (CTE) with the glass insulator and better mechanical performance compared to that for Niobium Feedthrough.

Depends of the configurations and limitations of the material to weld exits different types of Resistance Spot welding (RSW). In this case, will be used the Parallel Gap Welding (PGW), where both electrodes are placing against the same material surface on just one part, since that to make the weld the space is limited and the heat generated must be minimum. Thus, as the physical properties of Titanium Grade (Gr.) 36 are substantially different from that of Niobium wire, the differences in material properties as the welding process factors, were taken into consideration for the Ti Grade 36 to Ti Grade 1 weld process development, using as method the Design for Reliable Manufacturing (DRM).

RESEARCH OBJECTIVES

The main objective of this project is the analysis and characterization of the Titanium Grade 36 FT to Titanium Grade 1 ICR weld, to archive a cost reduction on materials in the same time that meet with Implantable Cardioverter Defibrillator device requirement.

RESEARCH CONTRIBUTIONS

This project supports the cost down effort in materials to produce medical devices. The objective is to develop a new lower cost arrays Feedthrough that will replace the current in all Implantable Cardioverter Defibrillator (ICD) that currently utilize Brazed Feedthroughs. To development this new array involves major changes but the most important is the changes of FT's material (Ti Grade 36), that it joined to Ti Grade 1 must meet with requirements of welding for devices. The joint between FTs and ICRs create the electric path connection between the Connector/Leads and the Device, to deliver the therapy to the patients. The analysis and characterization of Ti Grade 36 to Ti Grade 1 weld will contribute to meet the welding requirement for the device, have new information of this type of weld as promote the change of the material in other devices to continue with the cost down effort of the Company.

RESEARCH BACKGROUND

This project was initially conducted as lower cost alternative to current Feedthrough design, particularly for devices requiring more than 6 FT pins. The first phase was developing the Feedthrough of Ti Grade 36 in a glass insulator in a Medical Device Company located in Minnesota, United States of America. Due to the successful results with the creation of the new glassed Feedthrough of Titanium Grade 36, the project then continue with the second phase, the welding between Ti Grade 36 to Ti Grade 1. The welding development was initiated in the Medical Device Company branch in Switzerland to continue in the Puerto Rico branch.

This new Titanium to Titanium weld process has several new challenges and limitations, since the process is strongly dependent on the part materials and the part geometry. The new glassed Feedthrough of Titanium Grade 36 have .015 inch of diameter, while the Interconnect Ribbon design consist of an extended Tie Bar of .008-inch-thick Titanium Grade 1 and a .010-inch-thick Niobium welded to the underside. Taking into consideration current processes for Ti to Nb weld and existing equipment it is desired to utilize the Parallel Gap Welding to perform Resistance Spot Weld as a joining method for the Titanium Grade 36 to Titanium Grade 1.

Resistance Spot Welding equipment is used to make a metallurgic joint by the heat effect produced as a function of the magnitude of the weld current (level and time) across the two electrodes, the electrical resistance of the parts, the contact resistance between the parts and the weld force applied. The PGW configuration uses two shaped copper alloy electrodes with a gap between them that touch the top part (refer to Figure 1). The work-pieces are held together by the force exerted by the electrodes on the top part and a support tool on the bottom. The process is activated by a foot pedal that moves the electrodes into position on top of the part with a specified force and activates the welding recipe. This forces a large current through the small spot that heats up the parts to form the metallurgic weld.

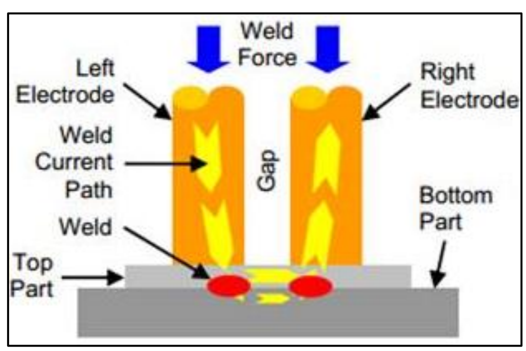

Figure 1
Schematic of PGW

The Ti Grade 1 and Ti Grade 36 have wide range of mutual solubility (refer to Figure 2). No metallurgical limitations for welding as such are expected, but given the high electrical resistivity of Ti Grade 36 as show the Table 1 below and the large diameter of the FT Pin Wire (.015 inch), the use of the existing PGW process window for Nb FT Pin Wires to Ti ICRs would result in low weld current levels to pass through the interface between the FT Pin and the ICR which may result in weak and inconsistent welds. In addition, relatively high thermal conductivity of interposer (Titanium grade 1) dissipates the weld heat in bottom parts quickly; heat also dissipates into the FT wire and electrodes potentially contributing to the weld inconsistency. Both materials: Ti Gr. 1 overlay and Ti Gr.36 wire, both have highly resistive oxide film on the surface. Therefore, a higher heat input may be required (higher voltage and / or longer weld time) for this Ti FT Pin Wires to Ti ICR configuration in order to meet the product requirements. This can increase the risk of getting wire reduction, ICR damage or Connector damage conditions. Thus, as also related literature references were not found, the process interaction for the given material combination and configuration for PGW needs to be understood.

Table 1
Physical Properties of Materials

Physical Property	Ti Gr.36	Nb	Ti Gr.1
Melting Point, ºC	1900	2468	1670
CTE, µm/m. ºC	9.03	7.1	8.35
Thermal Conductivity, W/m.K	10	52.3	16
Electrical Resistivity, Ohm. Cm	$9.00x10^{-5}$	$1.51x10^{-5}$	$4.20x10^{-5}$
Modulus of Elasticity, GPa.	62.05	103	103
Crystal Structure	bcc	bcc	hcp/bcc

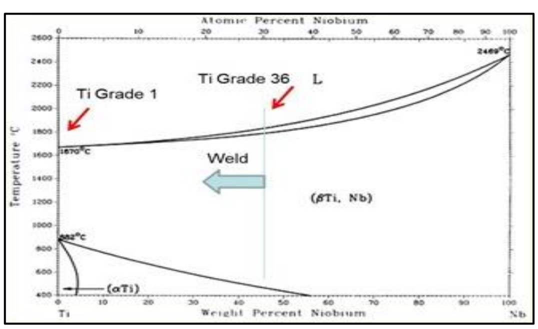

Figure 2
Phase Diagram Ti-Nb

RESEARCH METHODOLOGY

The methodology which will be followed is the Design for Six Sigma and Design for Reliable Manufacturing (DFSS/DRM) (refer to Figure 3). DFSS/DRM is a culture of continuous learning and critical thought to facilitate the manufacturing process and to ensure the possible reliability and quality through customer-focused design, while reduce the costs. DRM is focused in the set of best in class engineering practices, method and tools to drive continuous improvements to product performance, reliability and manufacturability, which stands for: Voice of Customer (VOC), Concept of Engineering, Requirement Flow-Down, Use Condition, Robust Design, Design for Manufacture and Assembly (DFMA), Design for Reliability (DFR), Capability, Control.

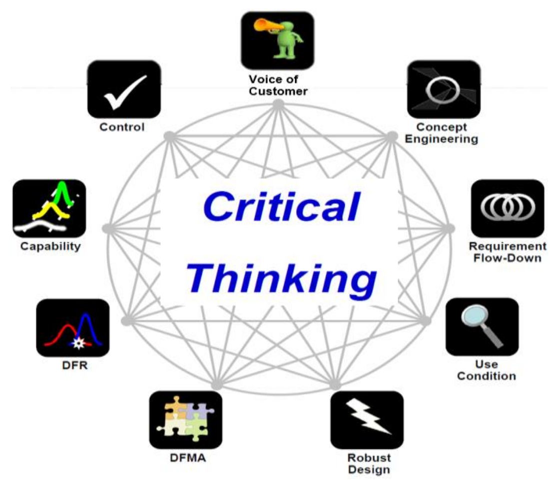

Figure 3
DRM Practices

VOICE OF CUSTOMER – Identifying and segmenting customers/markets, collecting and analyzing data (both reactive and proactive) to understand their needs, and developing a list of prioritized customer needs. Helps to focus in the development efforts on what matters most to customer, and this helps accelerate time to market and earns customer preferences.

CONCEPT ENGINEERING – A structured process/approach to develop multiple concepts and select the best concept to meet the customer needs.

Helps to think broadly about solutions concepts and develop optimal solutions.

REQUIREMENT FLOW-DOWN - Taking the list of prioritized customer needs, developing product requirements (design targets) to fulfill those needs and then flowing down those requirements (design targets) all the way from system to subsystem to components to parts and process levels. It helps prioritize design efforts by making critical requirements visible.

USE CONDITION - Understanding environments and operating conditions under which the product is expected to perform, helps teams create robust designs.

ROBUST DESIGN - Making the product performance least susceptible and minimally sensitive to variables or factors that could potentially cause performance degradation. Helps teams develop reliable products by reducing the impact of factors outside their control.

DFMA - A systematic process to simplify product design through component and process steps reduction. It promotes use of standardized methods, components, and materials.

DFR - A design methodology used to assure that the designed product will perform the desired function, without failure, for a stated period of time under stated use conditions.

CAPABILITY - Understanding, improving, and compiling process, parts, components capability to predict/estimate product capability in meeting customer needs. Helps to predict the performance of the system, and fix subsystem and component issues early even before the system is built.

CONTROL - Implementing techniques and methods to monitor and maintain desired capability over time.

The VOC, Concept of Engineering, Requirement Flow-Down and Use Condition concepts were established as describe in the Research Background section, since the customer wants a cost reduction effort, was researched that the new material combination of Ti Gr. 36 to Ti Gr. 1 is potential replacement of the current Nb Feedthrough, taking in consideration the existing process and equipment. Therefore, this development will be focused in the Robust Design until cover Control method.

The intent of Robust Design is developing a robust product/process regardless of variations in usage and environment. To understand the variations in the process is important not only know the main factors, also the Noise Factors that impact the process. Therefore, will be used different tools as statistical analysis and measurement system analysis to have new information of this type of weld, contribute to meet the welding requirement as promote the change of the material in other devices to continue with the cost down effort of the Company.

As part of Robust Design, one of the first tool used will be the Parameter Diagram (P-Diagram) to analyze Inputs, Outputs, Noise Factors and Control Factors that can affect performance of desired Response, as minimize the Error States [2].

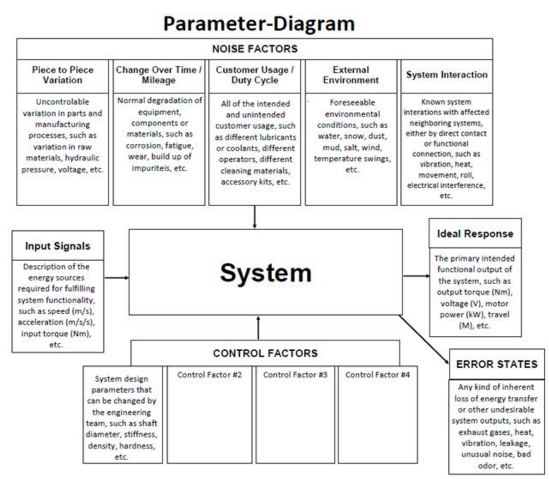

Figure 4
P-Diagram Concept

Then of know all factors and know the First Principle equations for the Resistance Spot Weld Process, following the methodology of DRM will be utilized different tools as:

RANGE FINDING – Random test used to find preliminary parameters with good results.

DESIGN OF EXPERIMENT (DOE) – Used to determine the relationship between factors, as obtain the Transfer Function and develop the process window.

MEASUREMENT SYSTEM ANALYSIS (MSA) - Used to qualify a measurement system by quantifying its accuracy, precision, and stability to reduce the error in the decision or data collection [3].

PREDICTIVE ENGINEERING – Used to demonstrate the forecast, capability and control of the process. In this case, will be used Monte Carlo simulation.

RESEARCH RESULTS

In order to know the PGW process and the new FT arrays design of Ti Grade 36 to Ti Grade 1 welding configuration a P-Diagram was created. Since this new FT array is a replacement for the current Nb to Ti Grade 1 weld and the equipment used will be the same, the preliminary Factors of Input, Control as Error states are known (refer to Figure 5).

Process Inputs:
Scan the device
Place support tool to device
Place the device on fixture
Adjust position to weld
Press pedal

Error States:
Blown Weld
No weld
Cold Weld
ICR Deformation
Weld Contamination
Connector Cosmetic Defects
Electrode sticking
Excess of wire reduction
Discoloration
Pull Strength <X lbs
Weld Break (Pull test)
Weld cracks

Control Factors (X's)
Argon flow
Electrode Force
Squeeze time
First Pulse:
UpSlope1
Duration1
DownSlope1
Peak Power
Cool time
Second Pulse:
UpSlope2
Duration2
DownSlope2
Voltage
Hold time
Electrode position
Electrode gap
Electrode Holder Pressure
Polarity
Electrode Configuration
Electrode wear
Material

Figure 5
Input Factors, Control Factors and Error States

As a desired Response of the process, the weld joint must be more strong of their weaker material, therefore was analyzed the strength of each material using 15 samples of raw material. As method was used a Pull Strength Test, obtaining that the Ti Grade 36 FT wire has 7.4lb as results of the 50% of the strength average while the Ti Grade 1 ICR has 6.6lb, therefore as requirement for new welding joint, it must have a strength ≥ 6.6lb. To continue with the use of the Pull Strength test as method for measure the weld strength capability, it was validated per MSA to reduce variation and noise in the welding development.

To understand the interaction with Control Factor and the Error State, is important know the basic principles for the Resistance Spot Weld Process, thus the following First Principle equations are established:

- Constant Current Pulse:

$$Heat = Current^2 x(Resistance_{BulkMaterial} + Resistance_{Contact})xTime \quad (1)$$

- Constant Voltage Pulse:

$$Heat = \frac{Voltage^2}{Resistance_{BulkMaterial} + Resistance_{Contact}} xTime \quad (2)$$

- Voltage (V):

$$V = Current(I)xResistance(R) \quad (3)$$

- Resistance of Wire:

$$Resistance_{BulkMaterial} = Resistivity(\rho)x\frac{Lenght}{Area} \quad (4)$$

The Design of Experiments (DOE) developed utilized the Heat Input equations to optimize the Current / Voltage and Time process input parameters in order to ensure a high level of capability to meet the product requirements. The hypothesis for this new Ti Grade 36 to Ti Grade 1 PGW applications is that a higher level of heat input is required when compared to the existing Nb to Ti Grade 1 weld recipe. Based on the main material properties for electrical resistivity with Niobium at 151 nΩ-m (at 0ºC) and Ti Grade 1 at 420 nΩ-m (at 20ºC), the Ti Grade 36 alloy has a higher electrical resistivity which will require a higher heat input during the PGW process to achieve the required weld strength and weld integrity.

A Response Surface DOE with 5 factors (Power, Duration1, Electrode Force, Current, and Duration2) while the other factors were maintained constant, was performed to determine the behavior of the weld using constant Power for Pulse 1 and constant Current for Pulse 2. Constant current was selected for this study based on the Equipment Supplier's recommendation for flat materials. The results of the DOE confirmed that constant Current for Pulse 2 did not work properly for this PGW configuration using Ti Grade 36 to Ti Grade 1 since the welds created a superficial expulsion and the pull test failure modes is in the weld instead of the ICR or the Wire. Therefore, the following Characterization Studies were focused on using constant Voltage. The results from this DOE demonstrated the significance of the First Pulse on this PGW weld configuration. This Pulse significantly reduces the contact resistance of the interface between the parts (refer to Figure 6) in order to avoid several welding conditions including splatter or excessive expulsion [4]. The Pulse 1 weld period provides sufficient heat to displace the plating or oxides, seat the electrodes against the base metals and force the parts into intimate contact. However, to obtain a good welding in this PGW configuration, Pulse 1 must be balanced with the Upslope of Pulse 2 Pulse to avoid a rapid increase in heat input and damage the parts. Afterwards, the Pulse 2 weld period will complete the weld to achieve the strength required.

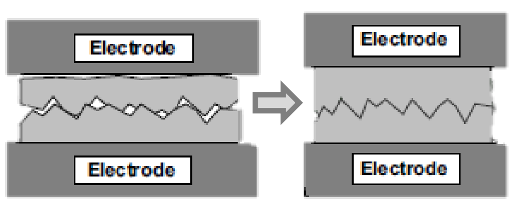

Figure 6
Contact Resistance between Two Parts

After decision was made to proceed with double pulse, number of preliminary experiments was performed for the process parameters Range Finding and was added the Argon gas as cover gas during the welding process in order to protect the weld from oxidation and contaminants with a flow of 35±5 SCFH. As results of the Range Finding study were fixed the Upslope for Pulse 1 and Pulse 2 at 1ms and 10ms respectively and the Squeeze time at 180ms. While the Downslope as the Cool time and Hold time factors are not required for type of welding material therefore were fixed to 0ms, 1ms and 50ms per equipment recommendation or default.

The weld results showed that Power and Duration1 levels need to maintain a balance to avoid welding failures. The Power level can decrease if the Duration1 is increased. The Power level was set between 0.40 kW to 0.50 kW and Duration1 level was set between 2ms and 3ms based on the results. As part of the Range Finding the welding visual criteria was established as the expulsion (Melt Pool width) that must be have a width ≥ .020 inch as control. Therefore, the Voltage, Electrode Force and the Duration 2 range were chosen based on having a Melt Pool width ≥ .020 (refer to Table 2). Thus, to continue with the development, the visual criteria as the measurement of the Melt Pool Width were validated per MSA to avoid or minimized any error, since these depend more directly of the human factor.

Table 2
Preliminary Process Window

Power:	0.40 to 0.50 kW	**Duration2**:	31 to 40 ms
Duration1:	2 to 3 ms	**Electrode Force:**	4.0 to 5.0 lbf
Voltage:	1.30 to 1.50 V		

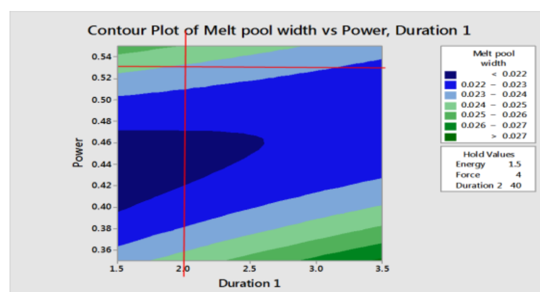

Figure 7
Contour Plots – DOE Results

Having a Preliminary Process Window as a result of the Range Finding was performed a second Response Surface DOE with 5 factors (Power, Duration1, Electrode Force, Voltage, and Duration2) to establish a process window. Within the range of parameters selected, the study revealed the levels at which the weld integrity met the product requirements and where the pull test failure mode occurred on the weld. The results were than filtered for samples with Melt Pool Widths ≥ .020 inch. The data was used to crate Contour Plots (refer to Figure

7) against this target width to start selecting levels for each process input parameter.

Another Range Finding Study was executed based on the Contour Plots obtained from second DOE. The Preliminary Process Window was selected using the best visual criteria results and ensuring a Melt Pool Width ≥ .020 inch. The Pulse 1 parameters were selected at Power level of 0.50 kW and Duration1 of 2ms. The Electrode Force was selected between 4 lbf and 5 lbf based on the Melt Pool Width results. The results showed that an Electrode Force of 4 lbf would allow a higher range for the Pulse 2 Voltage and Duration2 compared with the 5 lbf level. In addition, the resultant weld has better stability and a better wire reduction condition at 4 lbf when compared to the samples ran at 5 lbf.

According the results a third Response Surface DOE was performed to establish the optimum process window for Pulse 2 using constant Voltage. With a process window for Pulse 2 with Voltage from 1.4 V to 1.5 V, Duration2 from 30ms to 40ms and the Electrode Force of 4.0lb, all samples met the criteria established for the visual inspection. Some sample were observed with Melt Pulse Widths close to the .020inch recommended control limit therefore the window was shifted upwards (refer to Table 3). Since, if is applied the Voltage Constant Pulse (2), the Voltage and the Time need increase for increase the heat and as result is obtained more Melt Pool Width.

Table 3
Optimized Process Window

Power:	0.50 kW	**Duration2**:	35 to 45ms
Duration1:	2ms	**Electrode Force:**	4.0lbf
Voltage:	1.45 to 1.55 V		

To establish the process windows a Verification Run was performed. Runs at different levels for Voltage and Duration2 of Pulse 2 using constant Voltage. All Samples met the visual criteria and the pull test requirements with Melt Pool Width results between .02012 inch and .03154 inch. The pull test failure mode in all samples occurred in the ICR or the Wire locations. In addition, several samples were welded using the process window for metallography analysis to evaluate the fusion zone. As shown in the Figures 8 (arrow zone) the process window showed fusion between the materials. Therefore, the Optimized process window met all the visual criteria, product requirements and manufacturing verifications established.

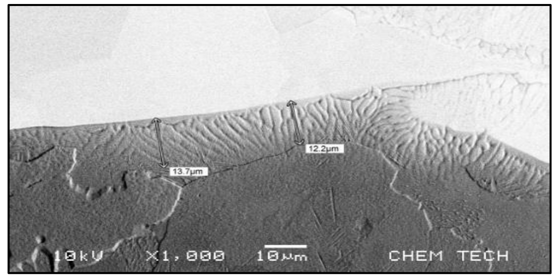

Figure 8
Metallography

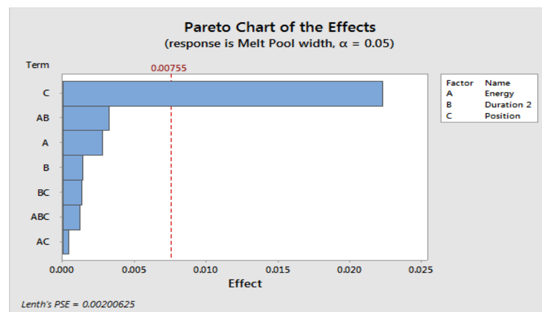

Figure 9
Pareto Chart for Electrode Holder

Also, the Verification Run results showed higher variability than expected for the Melt Pool Width when using the same settings. Due to the high level of variability identified in the Melt Pool Width results were running several tests for identify another noise factors. A Full Factorial DOE was completed to verify the impact of Electrode Holder Clamp (device to hold the electrodes) Force adjustments via a screw. To design the experiment, the left side knob for the screw position was marked to have a visual reference aid to control and replicate the position in order to evaluate the effects on the weld result. Moving the knob counter clockwise means that the screw moves out and the Electrode Holder clamp level gets looser. Moving the knob clockwise means that the screw moves in and the Electrode Holder clamp level gest tighter. The knob on the screw position for the right-side Electrode Holder was kept constant. The Pareto Chart as show the Figure 9 from the DOE results, confirm the knob position (C), studied as the most significant response factor.

Lowering of the Clamp Force via the screw increased the system resistance and resulted in having welds with high expulsion levels to having a weld with minimum expulsion. Reducing the force means that increase the resistance so according the (2) the heat will be reduced and vice versa.

The previous Full Factorial DOE confirmed the impact on the weld result of the force screw adjustment on the Electrode Holder. Thus, a new Range Finding Study was performed using a new Electrode Holder setup in both Electrodes where the force is established using a torque wrench instead of an uncontrolled knob. The two existing M4-0.7 11mm Plain Thumb Screws were replaced with M4-0.7 12mm Socket Cap Screws. Pulse 1 was fixed using constant Power based on the results from third DOE. A Torque Wrench was used to set a constant force of 3.0in-lb in order to minimize the electrical resistance through the Electrode Holder Assemblies. The weld results showed the need for a lower Pulse 2 Voltage and Duration2 parameter ranges due to the reduction in the electrical resistance.

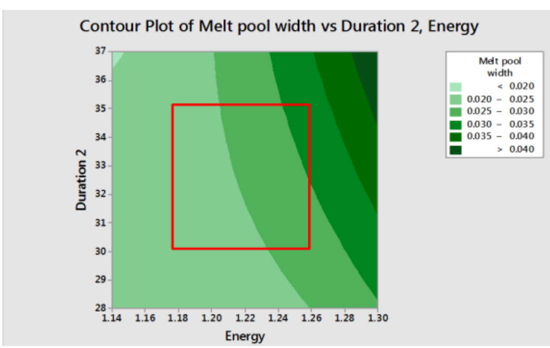

Figure 10
Contour Plot – Optimized DOE

A fourth Response Surface DOE was performed based on the previous Range Finding results to establish an optimum process parameter range for Voltage and Duration2 factors after the change to the Electrode Holder setup. All samples met the visual criteria and the pull test requirements with Melt Pool Width results between .02185 inch and .03661 inch. The pull test failure mode in all samples occurred in the ICR or the Wire locations. Below is the Contour Plot for this DOE showing the red box for the recommended process window.

The Melt Pool width (expulsion measurement) was taken as control for this type of welding since previous studies in Switzerland demonstrated that have a Melt Pool Width less than 0.020inch have the potential of have cold welds. In order to analyze the overall process input variability related to the Melt Pool Width, the Optimized Surface Response DOE was analyzed in Minitab for this process control output. The DOE Analysis resulted for the Melt Pool Width in an R-Square Adjusted of 97.72% and the following Regression Equation.

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0006294	98.67%	97.72%	94.36%

Regression Equation in Uncoded Units

Melt pool width = 1.374 - 1.927 Energy - 0.01470 Duration 2 + 0.6512 Energy*Energy - 0.000014 Duration 2*Duration 2 + 0.01325 Energy*Duration 2

Figure 11
Model Summary and Transfer Function for DOE4

The DOE residuals analysis demonstrated a normally distributed and random behavior, as a Pull Strength capability of 1.78 of Ppk. The Interactions Plot shows that Voltage and Duration2 are inter-related where there is a different response curve at different Duration2 levels and there is an inflection point around 1.175 V which is below the established process window. The plot shows that there is a higher slope when the Duration2 is increased. The plot also suggests that the use of a lower Duration2 level at 30 may guarantee a Melt Pool Width above .023 inch.

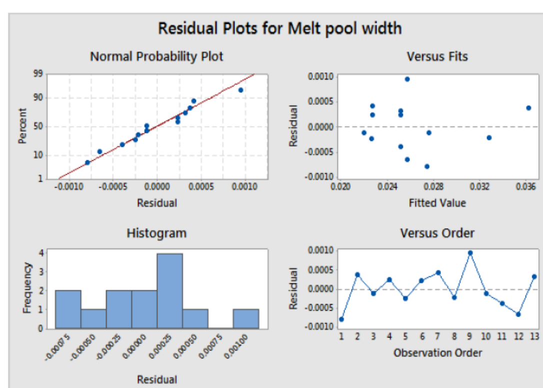

Figure 12
Residual Plots for Melt Pool Width

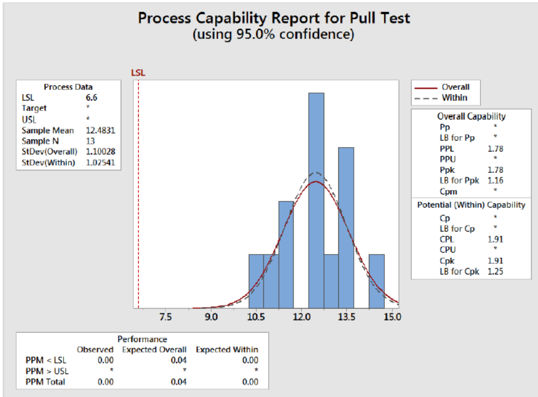

Figure 13

Process Capability for Pull Strength test

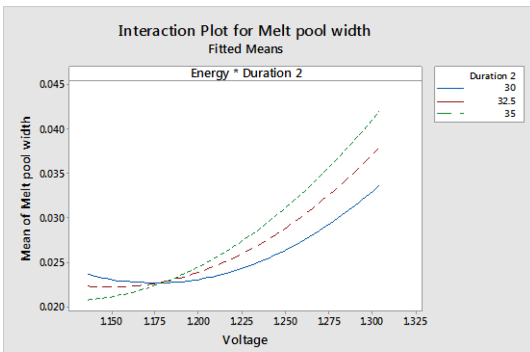

Figure 14

Interaction Plot

A Monte Carlo simulation was executed with the Transfer Function of the Optimized DOE, to understand the process behavior predictively with the regression equations. As shown the Figure 15, the result obtained is a probability of 100% to have results with the melt pool width ≥.020inch and ≤0.030inch (upper limit desired) and a Ppk of 1.55 in the Nominal Parameters.

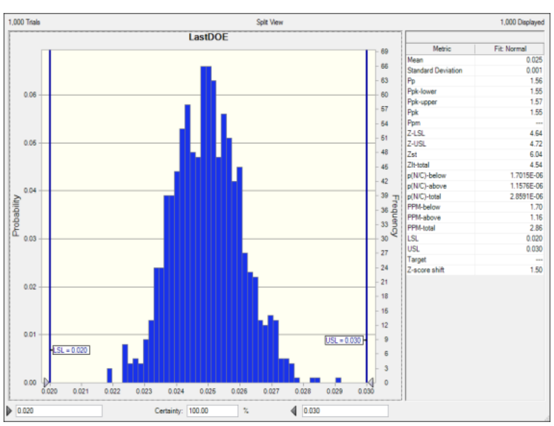

Figure 15

Monte Carlo Simulation for Nominal

As analysis of the results obtained, the Noise factors and Process Output for the P-Diagram were completed as show the Figure 16. Since the Pull Strength is the specification to measure the capability of the weld, running a confirmation run of 15 samples with the Final Optimized Process Window, according the results per a Tolerance Interval, the Monitoring required is only of 3 samples per production shift.

Table 4

Final Optimized Process Window

Power:	0.50 kW	**Duration2**:	30 to 35ms
Duration1:	2ms	**Electrode Force**:	4.0lbf
Voltage:	1.18 to 1.26 V		

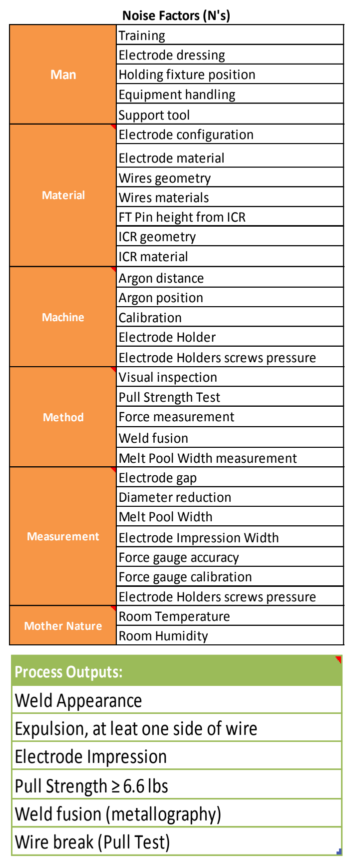

Figure 16

Noise Factors and Process Output

CONCLUSIONS

The characterization for the PGW process for Ti Grade 36 to Ti Grade 1 ICR following the DRM methodology gather the sufficient information to understand the factors and noises of the process as the behavior of the equipment and its parts.

Analyzing the information was achieved a robust process window design, where met the applicable specifications for visual criteria as defined on the studies and the pull strength requirement for the chosen process window with a Constant Voltage (2).

Thus, all previous studies demonstrated that the Melt Pool Width was met, as the other criteria established. Now with the screw factor noise controlled and with the parameter characterized will have 100% fulfillment of the Melt Pool Width in the Nominal parameters. Therefore, the characterization not only could gather the information to demonstrate that the Ti Grade 36 can replace the current brazed Feedthrough of Niobium Type 2 array, if not, also can place the Melt Pool Width as monitoring instead of a 100% visual inspection in the line, fulfillment with the effort of cost reduction.

FUTURE PROJECTS

Continue the development of Ti Grade 36 to Ti Grade 1 welding, where the windows process has a capability of 4 sigma or higher in its limits, both for the Pull Strength as for the Melt Pool Width. Confirm the Process Window with a significant sample size to reduce or eliminate the monitoring. As apply the methodology with a different geometry and shape of the same material for other products, in order to continue with the Company's cost down effort.

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