Development and Evaluation of Prototype Heat Shrink Masking Machine

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Abstract *— This design project consists in developing a prototype equipment to reduce the heat variability produced by the current heat shrink installation process. A heat Shrink tubing is a shrinkable plastic tubing commonly used to insulate, protect and joint. The methodology followed in this design project was the six sigma development methodology DMADV which means: Define, Measure, Analyze, Design, and Verify. The implementation of this prototype equipment will provide temperature and time process controls that do not dependent on the operator's perception and will allow reduction of the heat variability of the current process.*

Key Terms *— Heat Shrink Masking, Lead, Temperature, Time.*

INTRODUCTION

As of part of the Continues Improvement initiative it was identified an opportunity at the Heat Shrink Masking installation process. During the manufacturing process of the lead; heat shrink tubing's are used to hold in place, protect and mask. This project was focused in the masking function of the heat shrink tubing. The masking is performed to avoid the primer or adhesive over the required area. Current process uses a heat gun to install the Heat Shrinks; the operator manually rotate the lead in the hot air flow produced by the heat gun until by visual verification identified that the heat shrink is in thigh contact with the lead. The heat gun has a temperature variability of ±50°F thus producing excessive heat in the lead body that causes extreme thermal adhesion between the heat shrink and the lead making very difficult for the removal of the heat shrink without causing damage to the lead. In addition the air flow moves the heat shrink position, thus requiring a rework to place a new heat shrink. Due to the process depends on the perception of the operator in some occasions the heat shrink is not in thigh contact with the lead resulting in rework to place a new heat shrink or to remove the primer or adhesive.

PROJECT OBJECTIVES

The objective of this design project was to develop a new equipment to reduce the heat variability produce by the actual heat shrink masking process and improve the process to make it less operator dependent. The new equipment must provide temperature and time controls in order to establish manufacturing process parameters to reduce the rework and the scrap related with the Heat Shrink Masking installation.

PROJECT CONTRIBUTION

This continues improvement initiative will allow for the optimization of the Heat Shrink Masking process by controlling the process parameters with semi-automatic equipment.

PROJECT BACKGROUND

The development of this design project was performed in a Medical Devices Manufacturing Company located at the north of Puerto Rico. In a scrap reduction exercise, it was identified the Heat Shrink Masking installation process as a major scrap offender. During the line walkthrough it was noticed that the removal of the heat shrinks was very difficult causing damaged to the body lead. A manufacturing investigation was performed and was found that the heat gun used to place the heat shrink masking have a temperature variation of ± 50°F. Due to this finding a request was performed to the Process Development Department for a new machine that provides better process parameters controls.

LITERATURE REVIEW

The heat shrink tubing is shrinkable plastic tubing used in different applications to insulate, protect, join and provide visual coding. Heat shrinks are manufactured from thermoplastic material such as fluoropolymer, viton, silicon rubber, polyolefin, PVC, polyvinylidene fluoride, fluorinated ethylene propylene, neoprene, polyester and nylon. Are usually used for electrical insulation, protect wires from abrasion, provide color coding, masking process, reinforcement, tube marking, bundle together, etc. It comes in a variety of sizes, colors and materials making it suitable to use in the construction, electric, automotive, electronics and medical manufacturing industries.

Figure 1
Heat Shrink Tubing

Some of the common alternatives to shrink the heat shrink tubing are an oven, hot air gun, source of hot gas flow, soldering iron not in contact with the tube and the heat of an open flame. The problem with some of the alternatives above is that uncontrolled heat can cause uneven shrinkage, insulation failure and physical damage like melt, scorch or cause fire [1] [2].

Key facts needed for the project:

- The heat shrink masking is made from polyester tubing which when subject to heat shrinks radially and axially.
- Shrinkage is a function of temperature: the higher the temperature, the higher the shrinkage.
- Shrinking temperature ranges from approximately 185°F to 374°F, with a typical shrinking temperature of 302°F recommended for most applications [3].
- The lead body material melting points start at 295°F. [4]

PROJECT METHODOLOGY

The methodology followed in this design project was the six sigma development methodology DMADV which means: Define, Measure, Analyze, Design, and Verify [5] [6].

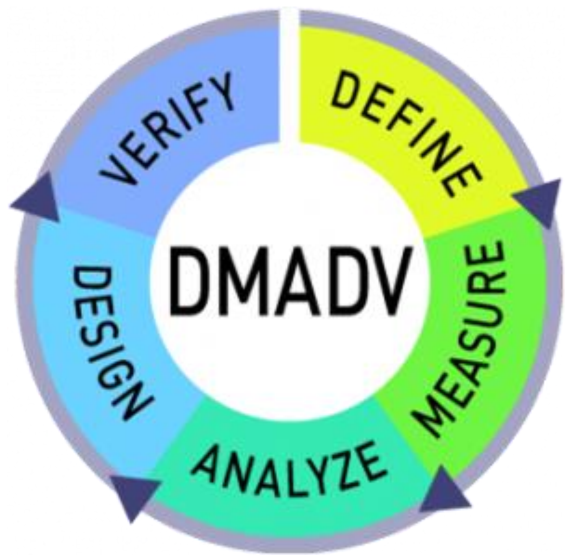

Figure 2
Six Sigma DMADV Model

Define

The purpose of the project is to develop new equipment that can heat the heat shrink masking evenly until is in tight contact with the lead body. The equipment should control the temperature and time to eliminate the variation induced by the operators. The temperature applied could not cause damage to the lead body.

Measure

The critical to quality (CTQ) tree diagram tool was used in order to translate the customer requirements into the key performance indicators. A multidisciplinary team was place together to generate the critical to quality tree diagram. During the exercise the team defines the customer needs, brainstorms the drivers necessary to deliver the requirement and determined the critical to quality measures to determine the key performance indicator. See figure 3 for the CTQ tree diagram.

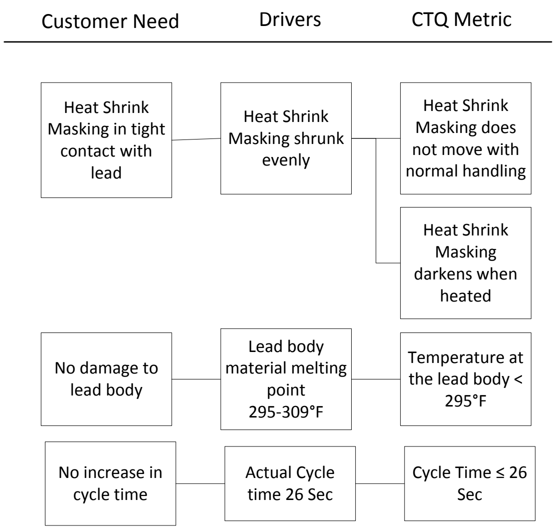

Figure 3
CTQ Tree

Analyze

In this phase the team develops design alternatives, conceptual designs and evaluates the best option to meet the requirements at the lowest cost. During the brainstorming exercise various alternatives were evaluated; such as heat shrink oven conveyor, heat block, torches, stove, etc. A prioritization matrix was used to select the heat source technology to be used.

Conceptual Design - At the process development department a conceptual design was generated based on the alternative selected in the prioritization matrix. The conceptual heat shrink masking machine has a heat block controlled by a temperature controller and timer. The equipment will be manually loaded by the operator. The operator will use the heat shrink positioning guide to locate the heat shrink in the required position. Then the operator will activate the machine with a hand tie switch that will trigger the heat block to move up at a controlled temperature and time. The heat block will have a U form that will heat the heat shrink without contact. Once the cycle is completed the heat block will move down and the operator will be able to unload the lead. See figure 4.

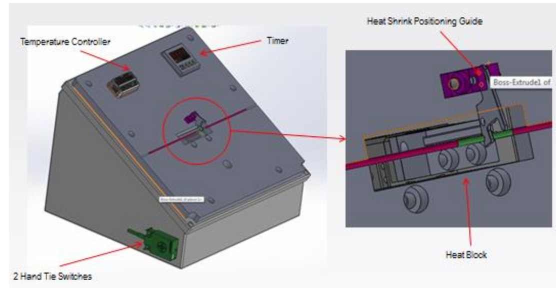

Figure 4
Conceptual Design

Prototype Design Review - A prototype Heat Shrink Masking machine was built base on the conceptual design. The prototype was tested in the process development department laboratory and various opportunities were identified as follows:

- Change the travel of the heat block from vertical to horizontal to avoid the temperature exposure of the lead during the loading.
- Add a small programmable logic controller (PLC) to eliminate the timer and facilitate the integration of future features.
- Change the overall form of the machine to lower the loading area to improve the ergonomic aspect.
- Move the electronic components to an enclosure to facilitate the maintenance and service.
- Move the positioning guide below the heat shrink to make the operation easier.
- Add mandrel guide to facilitate the positon of an additional heat shrink masking.

In addition a preliminary test to verify the temperature variation that the lead body receives was performed. Using a thermocouple attached to the lead body; thirty (30) temperature measurements were collected. The heat block temperature was set to 350°F and the cycle time to 12 seconds. Also for all thirty (30) measurements was verified that the initial lead body temperature was 72°F to avoid adding variability to the study. A process capability was performed using 295°F as the maximum temperature allowed for the lead body. The overall standard deviation was 5.87 and the overall process performance capability (Ppk) was 4.44. See figure 5.

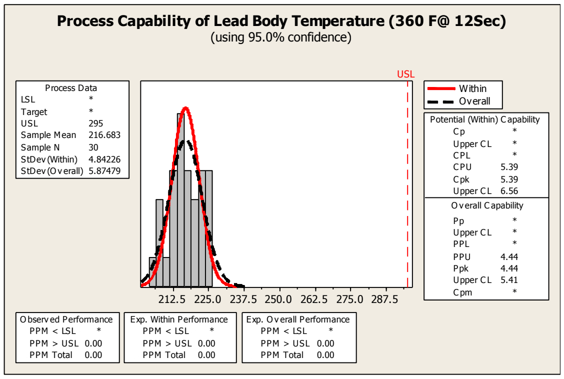

Figure 5
Prototype Process Capability

Design

In this Phase all the required modification found in the analysis phase were performed and incorporated to the new design. A second prototype was build and evaluated by the operators, manufacturing technician, trainers and engineering. Minimal modifications related with the ergonomic and aesthetic aspects were incorporated in the design as per the feedbacks received from the end users.

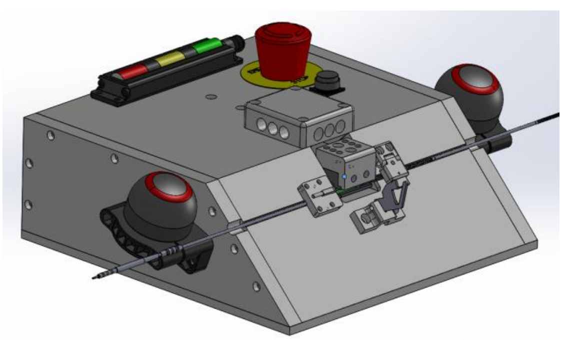

Figure 6
Prototype Heat Shrink Masking Machine

A design of experiment (DOE) was performed and executed in order to understand the relation between factors and to found the optimal parameters for the Heat Shrink Masking process. The first step was to perform a P-Diagram that is the graphical representation of the process inputs, process outputs and the failures modes.

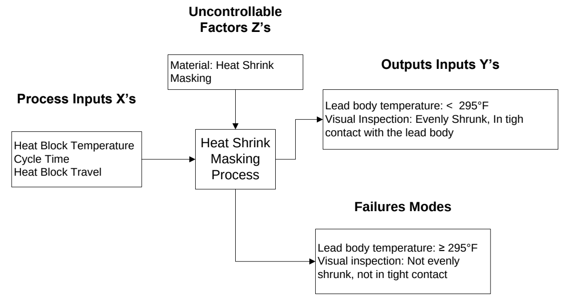

Figure 7
P- Diagram

A full factorial design was used to determine the experiment trial condition for this DOE. Two (2) factors at two extreme ranges of values (2 levels) were considered for the design. These factors and their levels are shown in the table 1 below:

Table 1
DOE Factors

Factors	Description	High	Low
Heat Block Temperature	The temperature Set in the temperature controller of the heater block	360°F	340°F
Cycle Time	The period of time that the Heat Shrink Masking receives heat.	20 Sec	10 sec

The DOE design was conducted in Minitab 16; as part of the design; three (3) replicates and three (3) center points were applied. Based on the full factorial design with two (2) factors [(2^2)] and three (3) replicate and three (3) center points, fifteen (15) randomized runs were required for this DOE.

Full Factorial Design

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Factors:   2   Base Design:         2, 4
Runs:     15   Replicates:             3
Blocks:    1   Center pts (total):     3
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Figure 8
Summary of Minitab 16 session window

The response variable taken in consideration for this DOE was the lead body temperature. For the attribute variable response a ranking was established in order to facilitate the analysis. See table 2 below:

Table 2
DOE Responses

Response	Ranking
Visual Inspection	1-Tubing appears normal, does not move with normal handling, does not have bubbles or cracking, and darkens where heated. 2-Tubing does not move freely but slides with normal handling, has some bubbles or cracking, or darkens unevenly where heated 3- Tubing does not move freely but slides with normal handling, has many bubbles or cracking, or does not darken where heated

Verify

In this final phase a pilot run was performed with the prototype Heat Shrink Masking machine to confirm the optimal parameters and the worst case scenario. For the worst case scenario the combination of highest temperature and time were set and thirty lead body temperatures were gathered to confirm that the machine do not reach the maximum temperature allow by the lead body of 295°F.

RESULTS AND DISCUSSION

As part of the process characterization the data collected from the DOE exercise was analyzed using Minitab 16. The Pareto Chart and the Main Effect Plot were used to determine the factors that have significant effect in the responses and to understand the effect.

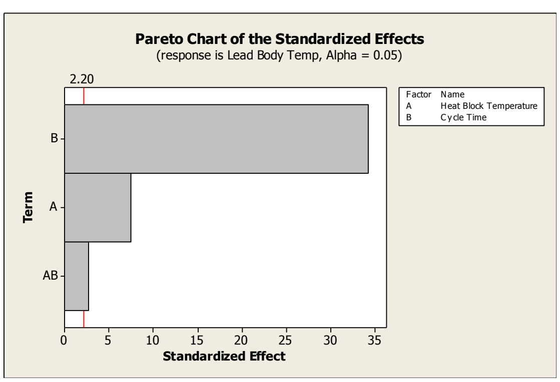

Figure 9
Lead Body Temperature Pareto Chart

For the lead body temperature response the factor with mayor effect is the cycle time as shown in figure 9. As the cycle time moves from the low level to the high level the lead body temperature significantly increases. See figure 10.

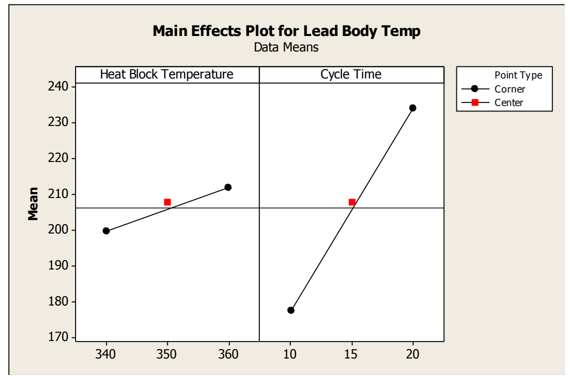

Figure 10
Lead Body Temperature Main Effects Plot

For the visual inspection response the factor with mayor effect is the cycle time as shown in figure 11. As the cycle time moves from the low level to the high level the visual inspection characteristics significantly improve. See figure 12.

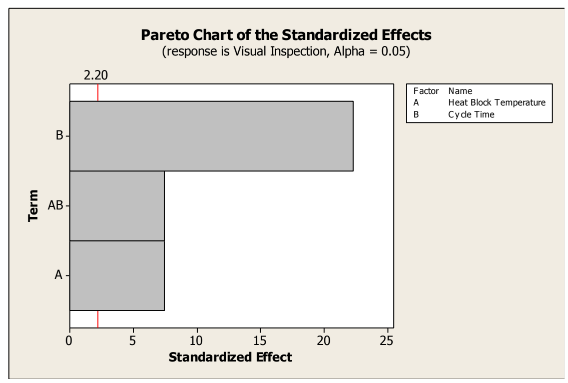

Figure 11
Visual Inspection Pareto Chart

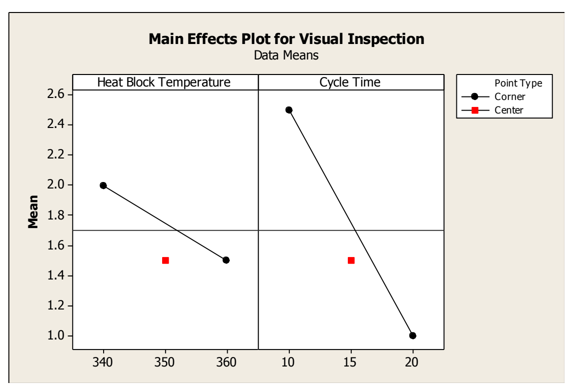

Figure 12
Visual Inspection Main Effects Plot

The Optimization Plot tool was used to determine the optimal parameters for the heat block temperature and cycle time. The optimization plot model explains 98.27% of the variability of the data. As per the tool the optimal values are 346°F and 20 seconds for the heat block temperature and cycle time, respectively. The composite desirability of these optimal parameters to the responses is 0.99. The composite desirability assesses how the combination of input variables satisfy the goals defined, if is close to one, indicates the settings appear to achieve the results for all responses as a whole. See Optimization Plot in figure 13.

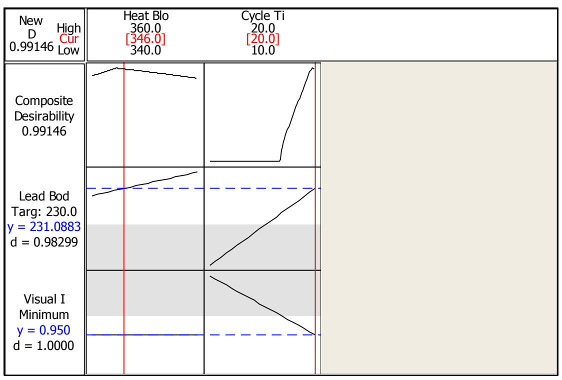

Figure 13
Optimization Plot

A confirmation run was performed; in order to verify the optimal parameters thirty samples were produced and visually inspected. All heat shrink masking inspected do not move with normal handling, does not have bubbles or cracking, and darkens where heated therefore, all pass visual inspection.

Based on the data collected in the DOE worst case parameters were selected. The worst case parameters selected for the heat block temperature was 355°F and for the cycle time was 20 seconds. The worst case parameters obtained a composite desirability of 0.93. In order to confirm that lead body temperature does not reach the maximum lead body temperature allow of 295°F a confirmation run was performed. The lead body temperatures of thirty (30) samples were collected and a tolerance interval was performed. See figure 14 for reference. The calculated tolerance limit of 254°F is less than that the maximum lead body temperature allow of 295°F.

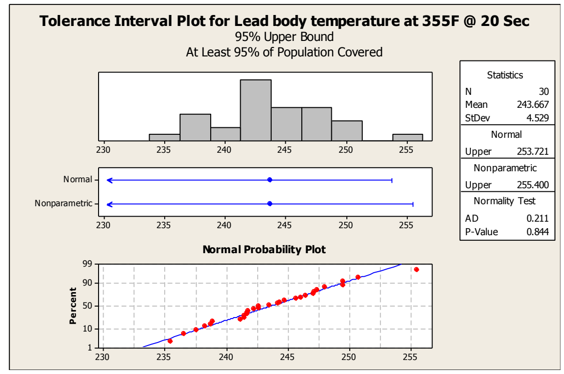

Figure 14
Tolerance Interval Plot

In addition a process capability was performed using 295°F as the maximum temperature allowed for the lead body temperature. The overall standard deviation was 4.52 and the overall capability Ppk was 3.78. See figure 15.

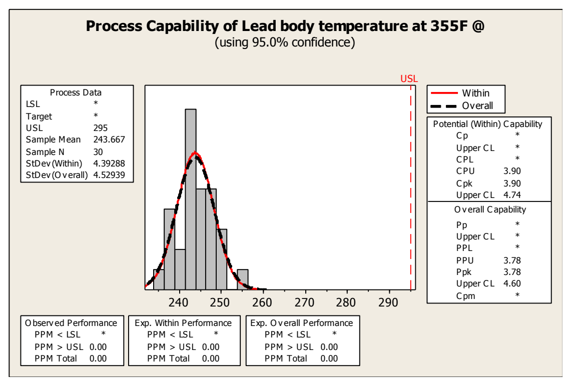

Figure 15
Process Capability

CONCLUSION

The semi-automated Heat Shrink Masking machine provides the required temperature and time controls to the manufacturing process; reducing the heat variability of the current process which will allow to reduce the rework and the scrap related with the heat shrink masking process. Based on the results obtained from the DOE and the Confirmation run is conclude that the Prototype Heat Shrink Masking Machine is ready to start the validation and implementation phase.

FUTURE WORK

The results obtained during this design project demonstrate that the Prototype Heat Shrink Masking Machine is ready to be implemented in the production line. A project plan will be develop and implemented to transition the Heat Shrink Masking Machine to the production line.

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