Stack and Bond Automation for Rotor and Stator Cores Manufacturing Application

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Abstract – *The manufacturing process for the core of the electric motors or electric generators starts with the stacking process of core. The main objective in this project is to reduce the manufacturing time and improve the ergonomics on the manufacturing process. This project will be deployed following the DMAIC methodology that consists in five steps (Define, Measure, Analyze, Improve and Control). This systematic process of continuous improvement will provide a specific order for implementing the project, which also cover all aspects of the process. Multiple tools were used such as Pareto analysis, process flow and other selected based on the methodology, which to analyze the Stack and Bond process and how it can e improved using an automated system. This project will reduce the manufacturing cost of the product, making the stacked cores more attractive to the future projects. In addition it reduces some the ergonomics issues caused by performing repetitive movements during long periods of time.*

Key Terms – *DMAIC Methodology, Lamination Core, Lamination Notch, Stator Fins.*

INTRODUCTION

Lamination of the stator, rotor or exciter core is accomplished by stacking the core with a series of segments or punching of steel each of which is insulated with a layer of adhesive enamel on both sides. The adhesive enamel is comprised of an epoxy resin and a sufficient amount of a glass fiber spacer filler to substantially provide uniform separation and insulation between the individual segments. [1]

The stack and bond process takes a long time (from 30min to 3hrs) depending the amount and the size of laminations, and the mechanical requirements on the core (Parallelism, concentricity, circularity). In addition the stacking process requires that the bur that all the lamination have (the bur in the lamination is caused by the stroking process that produces the laminations). Actually the stack and bond process is completely manual, what cause some ergonomic and efficiency issues.

The main ergonomic issue of this process is the repetitive movement that the employee needs to do in order to stack the whole core (Some cores have more than 400 laminations). Some Cores weight about 130lbs without the fixtures; including the fixture the assembly may weight about 200lbs.

The automation of this process is very challenging because the robot or the machine must identify the bur and the notch that the lamination has. The operators identify the bur by touching the lamination with their fingers. The notch is locate in an specific location of the lamination. There is some robots that can see the lamination and identify where is the notch, and in that way identify the bur side.

RESEARCH DESCRIPTION

The project consist in the reduction of the production cost, and manufacturing time by automating the stack and bond process. This improvement will help the company to meet its scope of work, and will be more competitive against low cost production center. It also will reduce the price of the bonded and stacked cores making them more attractive versus the other technique of core manufacturing process.

Research Objective

The objective of this project is automate the stack and bond process, in order to reduce the manufacturing time, and improve the ergonomics of the process eliminating the fatigue caused by the repetitive movement.

Research Contributions

The contributions of this project are: manufacturing time reduction (25 to 30%) production time more repetitive, operator fatigue elimination due repetitive movement, operator related non conformance elimination (Quality improvement).

Literature Revision

There is basically three methods for manufacture the stator, rotor exciter cores for motor or generators from steel laminations. Those methods are welding, stitching or bonding the lamination together. The laminations are stacked together on a n aligning fixture, then the laminations are bonded, pinned, welded or stitched together [2]. The reason of this is keep the laminations together during the upcoming process as machining and winding. The core manufacturing method to be improved is the bonded one. This method consist in the application on the application of a relative thin layer of bonding material to the laminations, then stack the laminations together taking in consideration the side of the bur left on the lamination by its manufacturing process [3]. The lamination bur could be identified by a notch (asymmetrical hole done in specific lamination fins).

During the manufacturing process, the operator weights the stack of lamination to be bonded together. Then the operator identifies the side of the lamination with the bur. The following step is the application of the bonding to the opposite side if the bur. Finally stack the lamination on the stacking fixture with the bur side up. This process could take from 30 minutes to 3 hours. This process cause fatigue to the operators, reducing their performance during the day. In addition the combination of some cores and the fixture could weight more than 150lbs; this could result in an injury on the operator.

This project will use the Six Sigma tool called DMAIC (Define, Measure, Analysis, Improve and Control). The DMAIC Methodology consists in the following five steps [4]:

1. Define: Clearly articulate the problem statement, the goal. In this step the potential resources are also identified. This step is very important because it lead the rest of the steps in the project.
2. Measure: In this step the actual performance of the system is analyzed. The different data gathering tools are used to establish the start point of the project or current state. In this step accurate metrics are used to establish the project baseline.
3. Analysis: It consists in the analysis of the data, in order to align it to the project goals. In occasions some modifications need to be made to the goals, based on the process metrics and the data analysis results.
4. Improve: Implement the process or business improvements, also the improvement results are measured on this phase.
5. Control: Validate the process improvement, analyzing the process performance and implementing control systems to avoid process variation. The control phase ensures the success of the implemented system, and it sustainability.

Methodology

This project will be implemented following the DMAIC steps, but the project will be documented through the system simulation phase.

The first step in the DMAIC methodology is Define. The project was defined using the process SIPOC, to define the process requirements, then using brainstorming to define the system requirements. As result the system was defined as follow:

- Stack and bond process key characteristics:
    - Lamination stacked using a fixture that guarantees the drawings requirements.
    - The glue need to be applied only in one side of the lamination (always the opposite side of the bur).
    - All the laminations must e stacked with the bur side up, in order to guarantee the flat side down.
    - All the cores characteristics need to be measure after stack process.
- Automated system characteristics:
    - The system should consist in two independent synchronized robots.
    - The first robot on the system should pick the lamination from a randomly package stack.
        - The robot must determine if more than one lamination was picked.
        - The system must be able to return the undesired lamination to the stack, or place in a separate location the laminations sticked together.
    - The visual system must verify if the lamination need to be flipped.
        - A magnetic conveyor with a flipping mechanism flips the lamination as necessary.
        - The flipping mechanism must flip the lamination based on the feedback from the visual system.
    - After the lamination pass through the bonding application machine, the second robot must pick the lamination, and clock it in the fixture as necessary.
        - The second robot must stack the lamination with a variation below the 0.002".
        - The second root must determine if the stack of lamination meet the drawing requirements.
    - The system must unload automatically the stacked core.

In the Figure 1 is the flow chart of the expected process steps of the automated system.

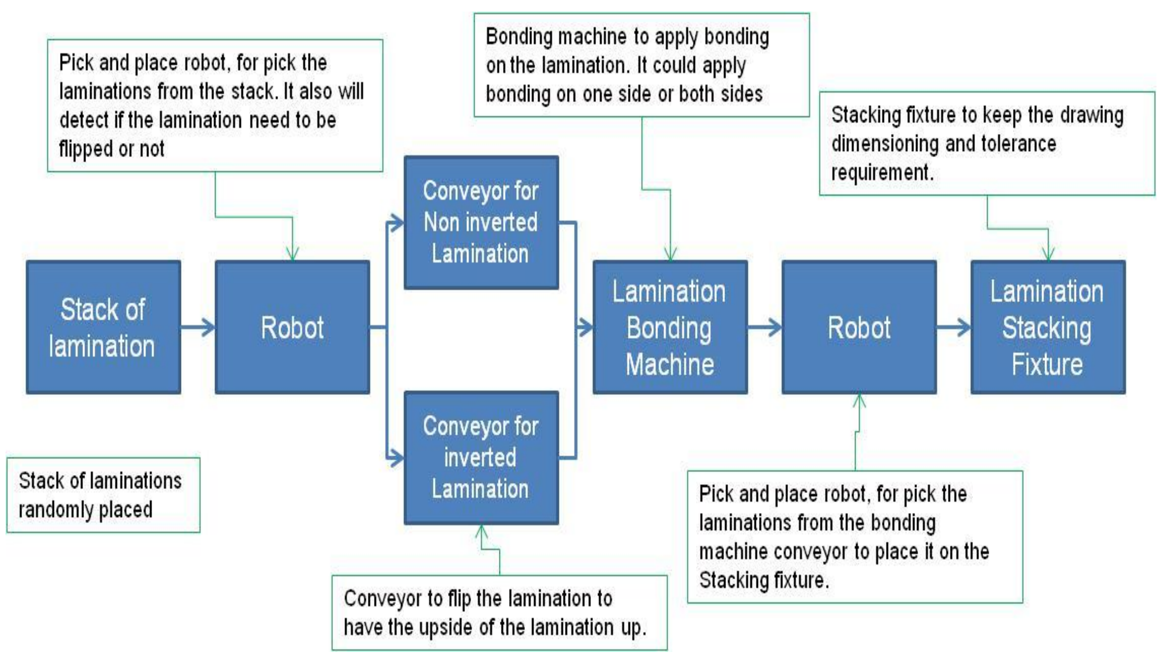

Figure 1
Automated System Characteristics

The second step is Measure. The historical data was collected, as the process time variation, shop defects, product demand. In addition an survey were provided to the operators to determine which products cause the highest amount of fatigue, and correlate it with the process variation. In addition impact first the products with the highest process variation and the highest demand.

The Third step is Analyze. A Pareto chart were made to determine which parts have the highest process variation, also this variation was segregated by the different family of product type (Stator, Rotor, or exciter), process variation, and product demand. The Figure 2 shows the products family that have the highest manufacturing time. In the Chart can be appreciated that the Rotor Family and Rotor Family C has the highest time consumption. This represent that those product have a mayor amount of opportunities compared with the other products. Based on this data those families of rotors will be the first to be included on the automation program, in order to have a big impact the process and the manufacturing cost.

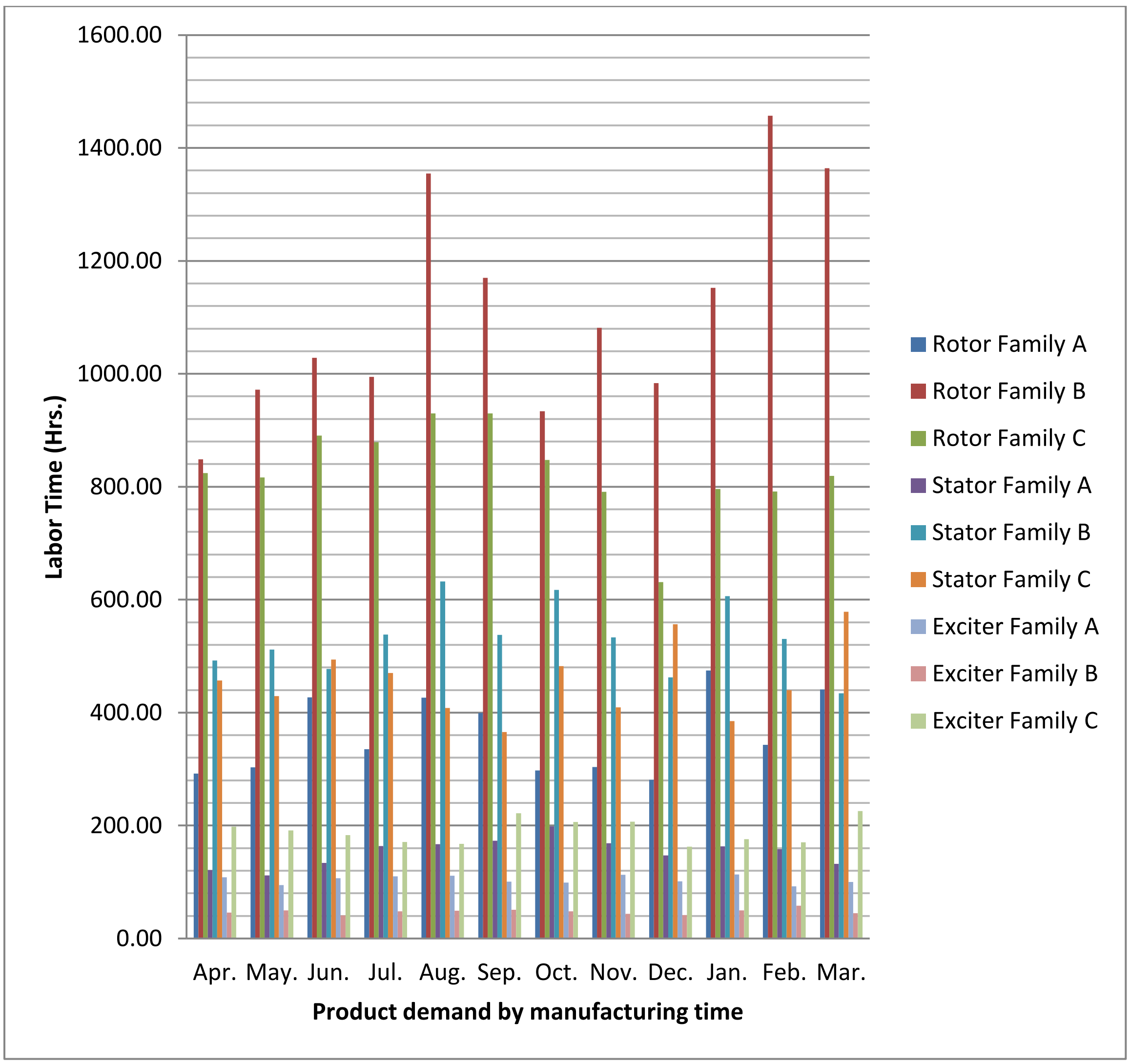

Figure 2
Pareto of the Product Demand by the Manufacturing Time

The fourth Step is Improve. A simulation of process automation was made using two FANUC LR mate 200iC Series robots and a magnetic conveyor with a selective flip mechanism. The Figure 3 represent a comparison for the rotor family B, considering that the assemblies has approximately 325 laminations. The simulation shows a reduction on the Stack and bond process in approximately 60.9%. This reduction is enough to justify the process implementation, and the project cost. Based on this result is possible to use dedicated system on certain product families, grouping them by specific characteristic, reducing the setup time between batch changes.

The fifth step is Control. SPC data collection and analysis will e track during at least 6 months to validate the system performance. In addition a process certification project needs to be held to certify that the variability of the process is under control. During the process certification project, all the critical characteristics of each stacked core will be measured. After complete the certification a stacked core will be measured per batch, reducing the inspection frequency to the minimum possible, but the process need to be monitored in order to detect any process malfunction as quick as possible.

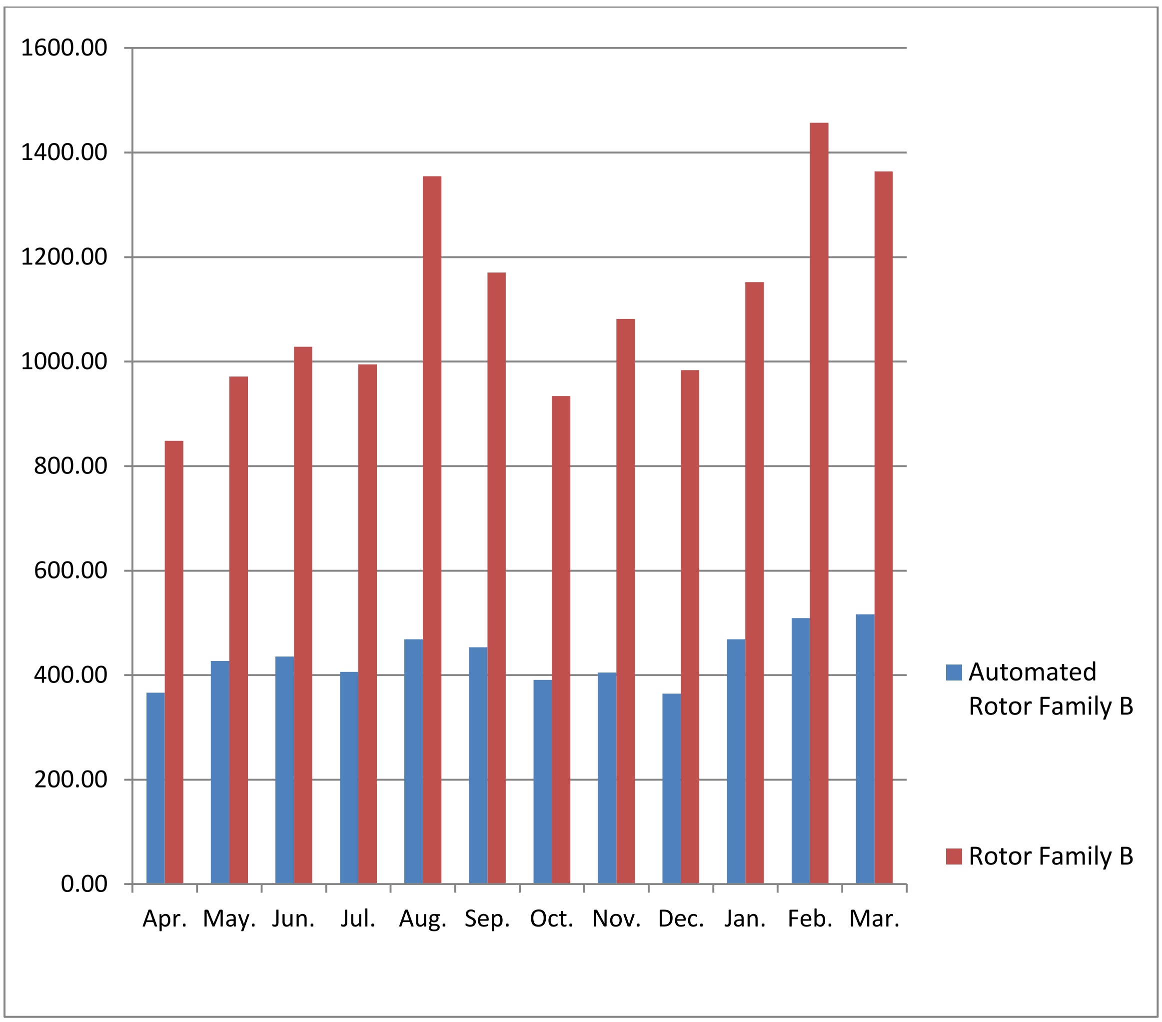

Figure 3
Comparison of the Rotor Family B Actual Process vs. Automated Process

RESULTS AND DISCUSSION

After using the DMAIC methodology for project implementation it can be seen improvement in the process. The automated system flows chart facilitate the process understanding, and allow to identify possible gaps in the process, allowing to mitigate them before it start to affect the process. The brainstorm session help us to add many innovative ideas that may cannot be possible because the lack of technology, but also allow us to consider a next step on the automation process improvement as the improvements on the bonding applicator machine "Roller Coat". During the brain storming session, was consider to use a pigmentation on the glue to identify if it was applied uniformly on the lamination.

The manual process start weighting the stack of laminations to be bonded, then the operator need to identify one y one the notch and the bur side to determine how the lamination will be passed through the bond applicator machine, then the laminations are stacked on the stacking fixture. Finally the top of the fixture is placed to apply pressure to the laminations. The Figure 4 shows the actual process flow for stack a single core.

The automated process start loading order on the system, then the laminations for all the parts in the order are place on the loading area, then the system pick the laminations from there, apply the bond and stack. After the stack is completed the operator removes the complete stacked core to continue with the next process. The Figure 5 shows the process to stack multiple cores in a work order (four to six cores per order).

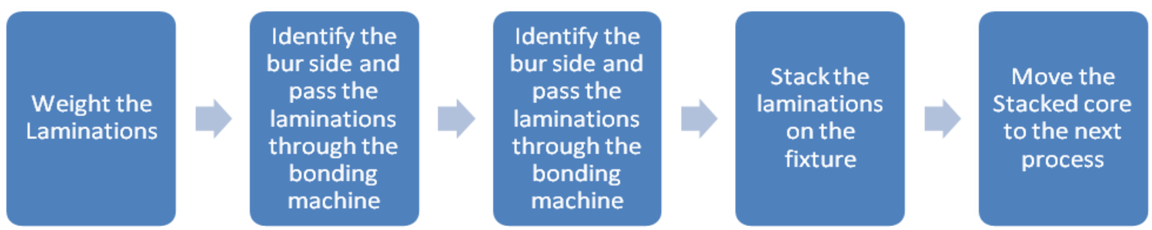

Figure 4
Flow Chart of the Process Performed by the Operators (Actual)

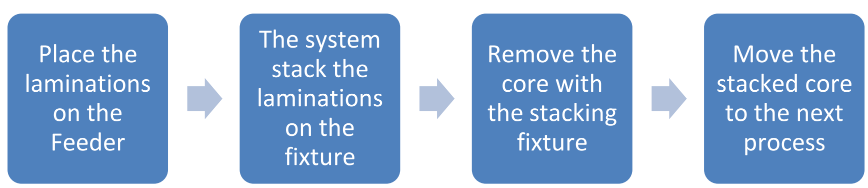

Figure 5
Flow Chart of the Process Performed by the Operators after Automation (Future)

This process improvement reduces between a 35% to a 70% the time required to stack a single core. This do not consider that for each core, the operator need to pick the fixture, and need to weigh the laminations to e stacked to comply with the minimal weight of the core. Considering this the improvement on the manufacturing time could e higher than the expected. The Figure 6 show the time difference between the actual process and the expected manufacturing time by the automated system. The Figure 7 shows the percentage of reduction on each product family.

CONCLUSION

Using the Six sigma tools as the DMAIC process is easier to understand the process and its gaps. This methodology clarifies the process flow, reducing the time for the process definition and shows in a objective way the process needs. As the process is evaluated using the appropriated tools, understanding the process inputs, variations and the output needs, then is more clear to define how the process will e improved. Then using comparison charts the improvement is visually documented, demonstrating in easier way the process improvements.

The process improvement varies between a 30% to a 60% percent depending on the amount of laminations required y the cores. The larger cores show a higher time reduction, because more repetitive movements are done during the manufacturing process. This also will eliminate the ergonomics issues caused by the stacking process, because it will e reduced as the parts are included on the automated system.

Automation of this project will open the possibility to evaluate other process that consists in repetitive movements, reducing or eliminating similar ergonomic issues. This wills be a high improvement in a manufacturing plant which almost all processes are performed manually.

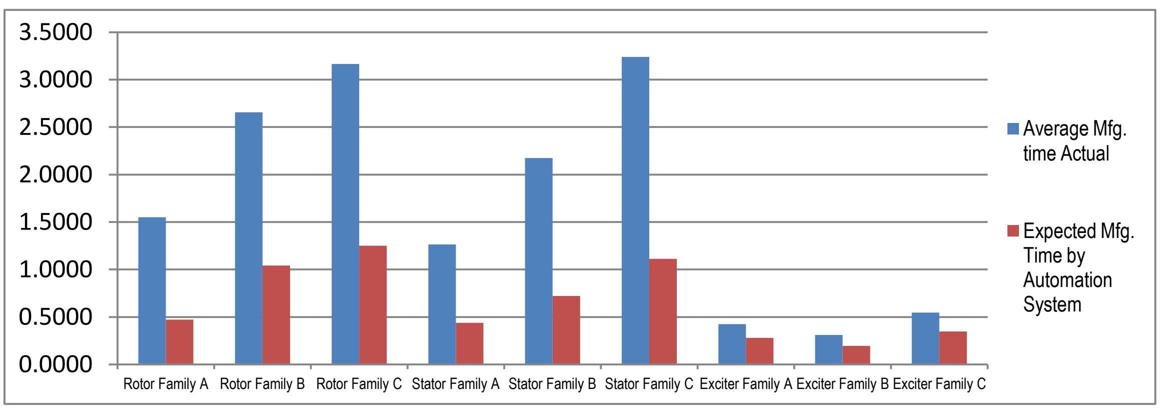

Figure 6
Comparison of Actual Process vs. Automated Process per Product Family

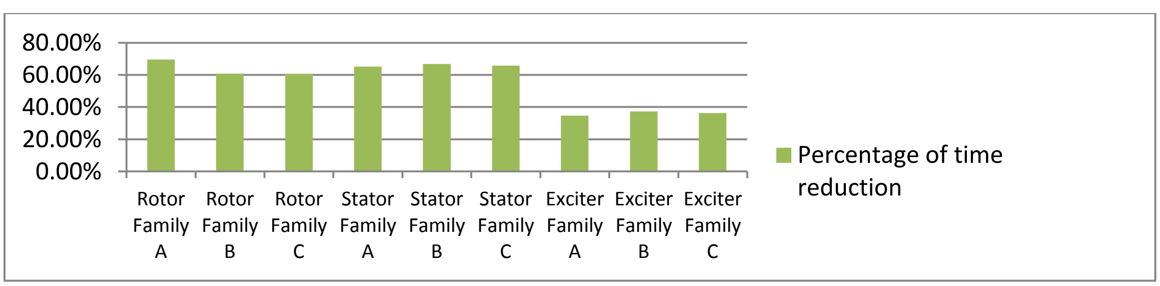

Figure 7
Percentage of Time Reduction per Product Family

REFERENCES

[1] Lynn, Alexander L. Torossian, Kevork A. Bonded laminations forming a stator core. U.S., US4103195 A (310/216.65; 310/45), 25 Jul 1978. Appl. 05/781,439, 25 Mar. 1977.

[2] Jiun-Yu Lai. (1997). A Study of the Fabrication of Thin Lamination Stator Cores by the Uniform Droplet Spray Process. (Master Degree Thesis). Massachusetts Institute of Technology.

[3] Baciu, Nick and Wayne, Fort. Laminated Magnetic Core for use in an Electric Inductive Device. U.S., 3,122,667 (310/45; 310/215; 310/216.137), 25 Feb 1964. Appl. 5 May 1961.

[4] Quality Council of Indiana (2007) CSSBB Primer (Second Edition). Quality Council of Indiana