Optimizing an Airplane Generator in the Manufacturing Stage

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Abstract *- Developing an airplane generator is an engineering challenge that takes planning, designing, brainstorming and, manufacturing of the final design. After all the planning is done, the manufacturing process sequence is developed. Developing the sequence depends on the processes to be validated, some processes need to be approved by Review Board (RB) to continue with next processes. Manufacturing such a complex unit also needs highly trained personnel because the automatization of these units would be almost impossible because of the precision work that a generator needs to operate to attain the desire efficiency.*

Key words – *Inspection, Lamination, Quality, Resin.*

INTRODUCTION

Airplane generators produce the airplanes energy to sustain all in flight utilities such as: lights, air conditioner, landing gear power, flight instruments, flight control and Airplanes computer. Manufacturing these Airplanes Generators requires expensive machinery and equipment that could only be operated by experienced operators; this is translated in hours of training. When the planning phase and training of the operators finish, the manufacturing process can begin. To begin this manufacturing, the most important component must be manufactured: the core. The core is where all the components are assembled such as: magnet wires, hair pins, wedges, insulations, separators, and lead wires. Assembling this core with all the components takes various manufacturing processes. These series of processes are winding, insertion, forming, connection, soldering, cleaning, and inspection.

Once the unit is assembled with all the components and passed through all the mention manufacturing process, the unit can then be sent to final stages of the manufacturing processes. These final stages are resin application, excess of resin cleaning, coating, and lastly final inspection.

Problem Statement

An airplane generator is a very sensitive piece of equipment that provides electricity to the airplane. The manufacturing of the generator must be well engineered and designed because of the extreme environment that these parts are submitted to. During the process of manufacturing some of these generators suffers from a series of failures that makes these generators a non-conformance material.

The purpose of the research is to optimize the generator during the manufacturing process. The entire process should be check and analyzed to discover where it can improve and where it should be revised the design. With this research of optimization, the expected enhancement of the manufacturing of the generator will greatly improve the failures during the build process, time spent fixing the units that failed, and providing a finished product in short time. By revising the latest generator design and combining with the newest technology, the outcome from the research can be in the long run a cost-effective solution for the generator.

Research Background

Beginning with a brief explanation, an electrical system is an integral and essential component of all but the most simplistic of aircraft designs. The electrical system capacity and complexity varies tremendously between a light, piston-powered, single-engine general aviation aircraft and a modern, multi-engine commercial jet aircraft. However, the electrical system for aircraft at both ends of the complexity spectrum share many of the same basic components.

All aircraft electrical systems have components with the ability to generate electricity. Depending upon the aircraft, generators or alternators are used to produce

electricity. The generator output is also used to charge the aircraft battery(s). Batteries are usually either of the lead-acid or NICAD (nickel–cadmium) types, but lithium batteries are becoming more and more common. They are used for both aircraft startup and as an emergency source of power in the event of a generation or distribution system failure.

Understanding the difference between a basic and an advanced aircraft, the difference will be depending on the type of engine. For example, basic aircraft that has a piston engine is equipped with a Magneto ignition system, which is self-powering one. In most cases, the system will be DC (direct current) powered using a single distribution bus, a single battery and a single engine driven generator or alternator.

On the other hand, an advanced aircraft has a more sophisticated electrical system, these systems are usually multiple voltage systems using a combination of AC (alternate current) and DC buses to power various aircraft components. Primary power generation is normally AC with one or more Transformer Rectifier Unit (TRU) providing conversion to DC voltage to power the DC busses. Secondary AC generation from an APU (auxiliary power unit) is usually provided for use on the ground when engines are not running and for airborne use in the event of component failure. Tertiary generation in the form of a hydraulic motor or a RAT (ram air turbine) may also be incorporated into the system to provide redundancy in the event of multiple failures.

Research Objective

Implementing a newly developed process requires the researcher to consider that new technology is more efficient than the existing one, the manufacturing process can be achieved in less time, and with fewer operators touching the unit. Creating a new design with new process help develop or adapt new technology methodology to existing or obsolete manufacturing processes.

Investigation Contribution

The contribution that this research can provide to the company is in terms of economy, plus innovation. As the manufacturing process advances, the product that is being manufactured can be made in less time, with less workforce and with customer satisfaction by making a product that is guaranteed to perform exceeding the expectations. Also, the efficiency of this new process can substantially increase in comparison with older ones, meaning, less reworks and less material waste.

LITERATURE REVIEW

Companies, Pharmaceuticals, and manufacturers are constantly trying to improve procedures, waste cost avoidance and, at the same time, increase profits. All these criteria to be met is a direct effort in creating new manufacturing principles such as Lean Manufacturing. Lean Manufacturing as the time goes by, has a meaning that covers a big part how companies operate. The five principles of lean manufacturing are value, value streams, flow, pull, and perfection. They guide organizations on how to create the most amount of value for their customers while maximizing efficiency at the same time. Applying lean concepts helps manufacturers to continually improve their offering and the way in which they deliver it. It's helpful at every stage of the production process, from research and development to packaging and delivery. This approach can be used to improve a specific product or an entire assembly line. It's flexible enough to be applied on a small or large scale which means it can benefit a wide range of organizations. The meaning of each of these principles are:

- Value - The first principle begins by identifying value to the customer. It involves isolating exactly what the customer finds valuable about your product or service from their perspective. This is the driving force behind why they will buy from you so it's crucial to get it right. If you don't deliver enough value to customers, then they simply won't purchase, and your sales will suffer.
- Value stream - The value stream refers to the complete product or service lifecycle, from inception to disposal and every stage in between. It encompasses the entire supply chain, source materials, production processes, features, and transport that bring about the product. Mapping the value stream is most commonly the stage where waste is identified, and improvement areas are suggested.

- Flow - Flow refers to the consistent creation and movement of the value stream. It's one of the most abstract of all these principles but is worth taking time to understand. When the value stream flow is blocked or stops moving forward, waste is created. This may be in the form of lost time, additional movement, or extra storage costs. Delays lead to customer value disruptions and result in reduced efficiency, both of which defy the principles of lean.
- Pull - The traditional Western approach to manufacturing involves producing things based on forecasts. Sales teams are asked to estimate how much of a product they'll be able to sell ahead of time. Raw materials are ordered, and manufacturing schedules are created based on these predictions so that the future orders can be met. But when sales exceed forecasts, it can be difficult for production to keep up. Conversely, when demand doesn't meet supply, profitability suffers. A pull system avoids this problem entirely. It helps to maintain flow by ensuring that nothing is made in advance of being ordered. This means that every item is manufactured to order based on a quantified demand from customers. It's one of the key manufacturing principles that ensures supply doesn't outstrip demand. This approach reduces waste and an essential element of lean operations.
- Perfection - To seek perfection is one of the lean manufacturing principles that sometimes surprises people. Lean companies are not satisfied once they've completed the previous four stages and implemented a pull system. They are always looking for other ways to improve and creating steps that facilitate further innovation. As companies continue to improve, more waste is removed, and greater value is created. This results in a continual upward spiral of efficiency, profitability, and customer satisfaction [1].

PROJECT METHODOLOGY

Investigating a sophisticated piece of engineering such as an Airplane generator takes a series of different approaches. What usually happens with new develop technology or engineering designs, is that is far from perfect. It usually needs a few iterations to make them a reliable design.

The research that will be conducted involves working in an experimental design that needs data from all the process that the unit will be submitted to. Because this is a new unit, during manufacturing the possibility of some fails or design flaws could appear.

The lean methodology used was Value Stream Mapping. This methodology was used because is the best methodology for a new product development. The first step is the inventory, in this case, a low volume high mix because it is not made in batch but unit by unit. The design has seven processes in the first stage. These series of processes are winding, insertion, forming, connection, soldering, cleaning, and inspection. The second stage of the manufacturing process are resin application, excess of resin cleaning, coating, and final inspection. Seven employees will conduct each process in this first stage and 4 operators will performed the second stage. Two shifts will be used to complete the two stages. The product is hand crafted and not by batch. The time required to complete each airplane generator is fourteen hours. The plant can work 24-hours period.

The Value stream mapping process allows you to create a detailed visualization of all steps in your work process. It is a representation of the flow of goods from the supplier to the customer throughout your organization. A value stream map displays all the important steps of your work process necessary to deliver value from start to finish. It allows you to visualize every task that your team works on and provides single glance status reports about each assignment's progress. It is essential to clarify that value in Lean is everything that the customer would pay for. However, when it comes to mapping a value stream, some steps may not bring direct value to your customer but help ensure that you will deliver the final product/service. A clear example of such steps is the quality inspections that are irreplaceable in every production process. Of course, your customer is not paying you to do these checks, but if you deliver a final product that doesn't meet their quality standard or expectations, they will be less willing to buy from you ever again. Value stream mapping became a popular practice with Lean's rise in the second half of the 20th century. It was one of the foundations that made the

Toyota Production System a manufacturing sensation, although, by that time, the term VSM was not present. However, it is a common misconception that Toyota invented the practice associated with visually mapping a workflow. There are records of diagrams showing the flow of materials and information in a 1918 book called "Installing Efficiency Methods" by Charles E. Knoeppel. By the 1990s, the value stream mapping process became part of the lives of many western managers. Its popularity started to outgrow manufacturing and eventually spread into knowledge work industries such as software development, IT operations, marketing, and many others [2].

Recollecting the data takes time because of the emerging problems or issues that can be presented in each of the manufacturing process. During this time the proposed research should shed light in creating methods or devices that helps in the manufacturing phase. Because of all the new data and the creation of the new manufacturing aids, the approximate time of completion will be 3 four-month period.

Months	Milestone	Data collection
July-October	Number of processes	Machining time
November-March	Fixture creation	Temperature readings
April-July	Project completion	Time of completion of unit

Figure 1

Timeline Table

Value stream mapping

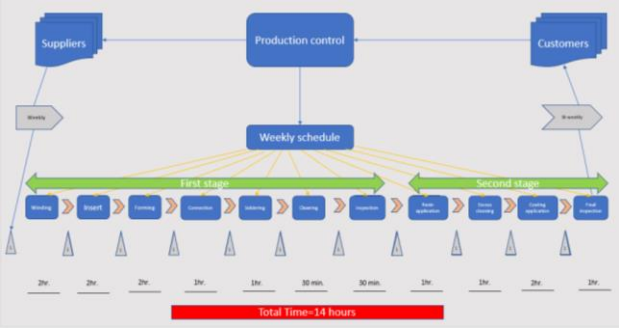

Figure 2

Value stream mapping of the two stages

RESULTS AND DISCUSSION

Processes and Arrangements

Designing processes from scratch takes time and a lot of brainstorming. To call a process an effective one, the team designing, organizing, evaluating, and validating such processes must be in accordance with every staff member.

The first step to this manufacturing journey would be the manufacturing phase of the core. A stator core for a generator may contain over 600 punching's. These punching's are clamped axially to cause them to act as a solid mechanical body. Two basic methods are used to achieve the axial clamping force. In one, "through bolts" are passed through holes punched in the core yoke. In the other, the axial key bars behind the core to which the punching's are assembled are used to apply the force. Pressure is spread over the surface of the end punching's using plates, or ring flanges. "Fingers" (or "outside space blocks") are used to extend the clamping pressure to the ends of the teeth. Friction between punching's causes them to transmit peripheral bending stresses. Bonding of punching's may be used in places to help assure the mechanical integrity of the core. The laminated construction is used to limit eddy-current losses due to the alternating flux that the core carries. To accommodate stray flux impinging on the ends of the core, the ends of the teeth are commonly slit to reduce eddy currents that are produced in the end punching's. It is common to cool the stator core with gas (air or hydrogen), and radial ducts are generally provided in the core for this purpose. Water cooling is used by some manufacturers [3].

Once the core is manufactured and cleaned, the next phase can begin. This phase is where the unit takes the form of a stator or a rotor with almost all the components assembled (magnet wire or hair pins, wedges, insulations, lead wires, sensors etc.). The next process would the winding, the electric motor winding definition is, windings in electric motors are wires that are placed within coils, generally enclosed around a coated flexible iron magnetic core to shape magnetic poles while strengthened with the current. Electric machines are available in two fundamental magnet field pole configurations namely salient pole as well as a non-salient pole. In the salient pole configuration machine,

the magnetic field pole can be generated produced with a winding wound approximately under the pole face. In the non-salient pole configuration, the winding can be dispersed within slots of pole face. A shaded pole motor includes a winding which is placed around the pole part that holds up the magnetic field phase. Some kinds of motors include conductors with thicker metal like sheets of metal otherwise bars generally copper, otherwise aluminum. Generally, these are power-driven with electromagnetic induction. There are two types of windings:

- **Stator Winding-** The slot on stator core of the three-phase motor winding carries stator winding. This winding can be supplied with 3-phase AC supply. The motor winding in three-phase which is connected in star or delta form based on the type of starting method used. The motor like squirrel cage can be frequently on track by the star to delta stator & thus the stator of the motor can be connected in delta. The slip ring 3-phase induction motor is in progress by including resistances, thus the slip ring induction motor's stator winding can be associated in star otherwise delta form. Whenever the stator winding is energized by 3-phase ac supply, then it generates a rotating magnetic field (RMF).
- **Rotor Winding**- In a motor, the rotating part is known as the rotor. The rotor includes the rotor winding as well as rotor core. The rotor winding is energized by the DC supply. The rotor can be classified into two types namely the phase wound and the squirrel cage.
- **Winding Calculation-** The motor winding wire calculation can be done using an ohmmeter. Connect the positive terminal of the multimeter which is in red color to the positive terminal of the windings of the motor. Similarly, connect the negative terminal which is in black color to the negative terminal of the windings of the motor. The reading of the winding machine can be displayed on the multimeter screen that is resistance in ohms.

From the above information finally, we can conclude that windings are made with copper wires which are wound around a core to make or obtain electromagnetic energy. The wire utilized within the windings should be protected. But in some cases, we can see the windings like bare copper, but it's simply coated with enamel. The most used material for winding is copper.

The next process is called Insertion. The Insertion process is when all the windings from the magnet wires or hair pins are inserted into the core, taking in consideration if the unit is a single phase or three phase one. The main difference between single-phase and three-phase is that single phase induction motors are not self-starting while the three phase induction motors are self-started. Choosing between a single-phase or three-phase motor is a question of your necessity, economy, and practicality. While you benefit from these two power supplies, always consider your practical need. Single-phase is the most common system and is mainly used in homes, while a three-phase system is common in industrial or commercial buildings, where heavy loads of power are required. Single-phase systems use alternating current (AC) electric power in which the voltage and current flow changes in magnitude and direction in a cyclical fashion, typically 50 to 60 times per second. In electrical engineering, single-phase electric power refers to distribution using a system in which all the voltages of the supply vary in unison. In simple terms, single-phase electricity can be viewed very much like a single-person canoe. The paddle enters the water to deliver power and then leaves the water before the second paddle re-enters the water to deliver more power, resulting in a variation of power. In simple terms, three-phase electricity can be viewed as three single-phase electricity supplies that supply their peak power 120° apart. As an analogy, consider a canoe with three canoeists, paddling the canoe in rotation. Unlike with a single canoeist, there is always a power output and never a zero output, which makes this power supply more suitable for industrial motors and equipment [4]. It is very important to determine whether the unit is a single phased or a three passed one, as soon this is determined, the unit can be configured to a single phased or a three phased by requiring one coil of winding or a three coil windings option. The process of insertion is a difficult one and it is usually done by hand, this process takes hours and can only be performed by highly trained and skillful people. As a side note, this process is being studied to be converted into an automated one, but it is a challenging one to achieve.

Once the process of insertion is complete, the process of forming can begin. Wire forming is a method for applying force to change the contour of wire by bending, swaging, piercing, chamfering, shearing, or other techniques. The various techniques for wire forming can produce any type of shape, form, or configuration. The process starts with coiled wire that is straightened before being formed. Wire forming is performed using several different processes each designed to achieve a different shape, pattern, or configuration. Manufacturing a coil assembly for a stator formed with slots includes a coil wire combination forming step of forming a band-like coil wire combination by overlapping a plurality of coil wires while forming them with in-slot portions to be accommodated in the slots and turn portions each connecting each adjacent two of the in-slot portions, and a shaping step of shaping the band-like coil wire combination into a cylindrical shape by helically winding the band-like coil wire combination. The coil wire combination forming step is carried out by performing an interlaced part forming step of forming an interlaced part by overlapping the coil wires with each adjacent two of the coil wires intersecting with each other and a non-interlace part forming step of forming an interlaced part by overlapping the coil wires with each adjacent two of the coil wires not intersecting with each other.

The following process of connect is the one that joins the magnet wires with the lead wires. The motor lead wire is the key component to realize the connection between the motor and the power supply. According to the rated voltage of the motor, the rated motor, and the use environment, etc., the conductive area, insulation structure, heat resistance and corrosion resistance of the motor lead wire are made. Some motor lead wires are connected after the windings are dipped, and some manufacturers complete the connection before the windings are immersed and are dipped together with the windings. Different production and processing processes have different requirements for the lead wires. With the winding dipping process together, the requirements for the lead wires are relatively high. The lead wires must be able to withstand the corrosion of the insulating paint at a certain temperature. The lead-out leads from the base and the fixing in the inner cavity of the machine are very important quality control requirements. At the exit of the lead wire, there must be insulation protection to prevent the damage of the lead wire. When the inner cavity of the seat passes, the lead wire should be reliably fixed to prevent vibration caused by the motor running, causing the lead wire to be damaged and causing electrical failure [5]. This can also be fixed with thicker sleeving tubing.

The following process is called soldering, is when the magnet wire is joint with the lead wires that transmit the power not the outlet of the unit. The enameled copper wire can be soldered without scraping of the enamel. Soldering iron cannot be used to scrape of enamel. As the Enamel is very heat resistant. Wire enamels are some kinds of varnishes coated on the surface of copper or alumina wires and cured to form electrical insulation film possessing certain mechanical strength, thermal resistant and chemical resistant properties. These products are mainly used for manufacturing of magnet wires [6].

Soldering uses a heat level that will melt solder, but not copper. While a small amount of copper can alloy into the solder, the amount that does during a soldering job would be minuscule. First you must remove the insulation without damaging the wire. Some has a thin plastic covering and some a painted-on enamel finish. The plastic is easier to remove, and still difficult not to damage, and the enamel is difficult. Then, it must be sanded a bit to the bare metal as solder will not stick to corrosion. This part for small wire is the hardest. The soldering of enameled copper wires to a terminal such as required when making transformers, inductors, electromagnets, motors, solenoids, and other devices are often performed by dip soldering, this process has historically used high lead content alloys [7].

After soldering and all the other process have concluded, the process of cleaning can begin. The process of cleaning involves different stages such as buffing, ultrasonic clean, and hand cleaning.

Let explain each phase, the stage of buffing is to make sure no imperfection is visible on the unit, by buffing a unit's core, excess of oil, impurities (foreign objects) and bumps can be eliminated. Once the unit is buffed, it goes into an ultrasonic cleaning. Ultrasonic cleaning is a process that uses ultrasound (usually from 20–40 kHz) to agitate a fluid. The ultrasound can be used with just water, but use of a solvent appropriate for the

object to be cleaned and the type of soiling present enhances the effect. Cleaning normally lasts between three and six minutes but can also exceed 20 minutes. Ultrasonic cleaning uses cavitation bubbles induced by high frequency pressure (sound) waves to agitate a liquid, the agitation produces high forces on contaminants adhering to substrates like metals, plastics, glass, rubber, and ceramics.

Finally, the last step of the first phase is the hand cleaning procedure. In this step is where usually the unit is inspected and approved to continue the process or turnback to the process be fixed. Hand cleaning involves highly skilled operator because of the delicacy of the process. This process involves the use of Exacto blades to remove the imperfections that buffing and ultrasonic cannot remove. Because the hand cleaning method involves visual inspection the operator must have good vision and criteria to reject or pass the units.

Final Stages of Manufacturing Process

The second stage of the manufacturing process of an Airplane Generator begins with resin application. The resin application is a process better known as impregnation. Impregnation is the process of closing and sealing the voids between wires in a component such as an electric drive motor with an insulating material. Impregnation of the electrical windings of rotors and stators in the electric motor. Resin impregnation of windings and copper wires provides better insulation and prevents vibration. It also increases resistance to stresses and temperature loads and heat exchange during normal operation and reduces the risk of short circuits in the windings. Thus, the impregnation process increases thermal conductivity and contributes to a better environmental balance.

Once the resin application or impregnation is complete, the process of excess cleaning can begin. The process of excess cleaning is the process that any unwanted resin that gets harden on the unit must be remove. This process is a delicate and critical one in this stage of the manufacturing process. The unit can be damage beyond repair if the operator is not careful enough, also because it is impregnated if the physical dimension is not achieved the unit must be disposition as scrap or non-conforming material. This process should be considered top two most important of the manufacturing process. A method often used is Acetone cleaning. Acetone has a high evaporation rate, making it safe to use on intricate pieces, it will quickly evaporate from tight spaces without causing pooling or damage from prolonged exposure.

Using Acetone leave the unit without visible residue, but to ensure any dust or particles that could become FO (Foreign Objects), the unit is sent to a bath in Cyclohexane, a solvent with physical properties like alcohol and employed in identical equipment, is effective for removing organic films (oil and grease). It is frequently used as a recrystallization solvent, as many organic compounds exhibit good solubility in hot cyclohexane and poor solubility at low temperatures. Cyclohexane vapor is used in vacuum carburizing furnaces, in heat treating equipment manufacture. Cyclohexane, similarly, to hexane, is a non-polar solvent and does not dissolve water. It is used as a solvent to dissolve substances such as fats, oils, waxes, lacquers, resins, and cellulose ethers.

Up next the process of coating or painting can take place, is the last manufacturing process before final inspection. This process involves the use of a coating that protects the unit from rust and excessive heat. This coating also is scratch resistant, it was designed taking in consideration all the elements that could damage the unit. This coating is specifically design for the alloy used for making the core. This coating must be applied in steps and cured in oven between these steps at different temperatures and time.

This process of curing ensures good coating adherence. Epoxy Phenolic coating is a polyamine cured paint that has excellent resistance against solvents, chemicals, acids, and bases. It can be used as a protective coating for steel structures where chemical resistance and heat resistance up to 180 C is required. When these paints are cured, a high density of crosslinking through thermosetting is produced, so it creates an excellent resistant layer against chemicals. These coatings are frequently used as coatings for tank lining, pipes, electrical motors, etc. [8]. The type of phenolic resin and epoxide component used alters the properties of the epoxy phenolic resin, leading to a wide range of physical properties depending on the formulation. Each formula

may have a particular advantage, such as ease of application, higher resistivity to chemical attack, corrosion, or temperature. The choice of formulation depends on the application. Epoxy phenolic resins are typically colored and so topcoats are sometimes used on top for aesthetic purposes [9].

Finally, the last manufacturing process of an airplane generator to obtain a high quality efficient and well-designed piece of engineering can take place. The final inspection process is more than just visual inspection. The operators are highly trained to identify structural failures, impregnation deficiency, electrical tests failures, coating peeling and physical dimensions. As you can see this process is highly critical because if the unit is not inspected thoroughly, the unit can be mounted and an airplane and can cause a series of malfunctions that can affect the performance of an airplane or worse, a catastrophic failure.

Final inspections take place when production is complete. The overall product is measured against engineering, customer requirements, and standards. Final inspections and device approvals play an integral role in the decision to move items to stock or shipment. An inspection report is run prior to final unit approval to ensure there are no non-conformity items. A final inspection report will validate that all required operations are complete, all nonconformances have been resolved, and required traceability has been recorded [10].

CONCLUSIONS

As expected, investigating an engineering newly developed design takes times to achieve its full potential. This only can be done with a schedule focusing in the main areas that's needs improvement or fine tuning. The first thing that is on schedule and needs first attention is how is going to be organize in terms of processes, the first processes are the most crucial of any generator unit because if any fail is not caught on time the issue would be recurring and could make a faulty unit at the end of manufacturing process.

To ensure that the product is a reliable one and to reduce any scrap or waste, the implementation of inspection after every process will greatly benefit the manufacturing process. Every inspection should be done by a highly certified and experienced operator to ensure optimal product. Once the inspection is done the unit can continue to the next process without the uncertainty that if the unit will fail. All inspections should be documented and accompanied by test sheets and data analysis if applicable.

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