MODELING A VIRTUAL PROTOTYPE OF STATOR CORE LAMINATION ASSEMBLY DEVICE

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Abstract - New applications for robots in manufacturing are constantly being created as the level of robot technology is increasing. In energy industry, the use of robots is limited due to heavy and large parts. One of the key applications in energy industry where robots can be deployed is the process of stacking stator core laminations for generators and large motors. To eliminate the need of huge investment of time and money to build an actual prototype for such a process, a virtual prototype needs to be modeled. Modeling of a virtual prototype through robotic simulation is a powerful tool and its ability to analyze how a robotic work cell will behave before investing time and money on automation equipment makes a strong case for a smoother transition from concept to reality. This paper describes a modeling process of a virtual prototype of an automated device for stacking stator core laminations for generator leading to development of a virtual prototype. The virtual prototype model developed through robot simulation technology demonstrates the stacking of stator core laminations at variable heights finally achieving the required high stacking heights.

Keywords - Automation, Lamination Stacking, robotics, Robotic Simulation, Virtual Prototype

I. INTRODUCTION

Virtual prototyping involves modeling a system, simulating and visualizing its behavior under real-world operating conditions, and refining its design through an iterative process. It does not produce a physical object for testing and evaluation but, carries out these tasks within a computer. It allows engineering teams to build and test virtual prototypes and realistically simulate them on their computers, both visually and mathematically. The full-motion behavior of complex mechanical systems can be analyzed before building an actual hardware prototype. Users can quickly explore multiple design variations, testing and refining until system performance is optimized. This helps to reduce the time and cost of new product/process development, while significantly improving the quality of overall system designs. Another benefit of creating and using a simulated virtual prototype is that, once a prototype is modeled, users can visualize and walk through multiple scenarios and foresee its consequences to make better decisions on how to manage abnormal or risky situations. Most of the manual methods of assembly of the stator core laminations in an energy industry are performed by arranging the laminations in circular manner on a stationary circular table. The laminations of a stator core are arranged in annular layers and are stacked to high heights of four to six meters. The manual method is not only consumes huge cycle time but also causes stressful and monotonous working conditions for operators. If the same is performed by automatic means by using a robot, the process will be faster and cause less stress on operators. The difficult task in such a process is stacking the laminations at variable and high height.

This is achieved through developing a model of a virtual prototype which is presented.

II. VIRTUAL PROTOTYPE MODELLING PROCESS

Figure-1 depicts the modeling process of a virtual prototype that was followed for the stator core lamination assembly of a turbo-generator. The Virtual prototype modeling process begins with system design that consists of need and functional analysis. This is followed by hardware and software architecture design. In order to develop a meaningful algorithm, the integration of hardware and component layout are next important steps. A functional algorithm is then developed based on which a simulation program is written to obtain a functional model of virtual prototype.

III. SYSTEM DESIGN

Need Analysis
The present method of assembly of the laminations is performed manually by arranging the laminations in annular layers on a stationary circular table or a rotating circular table (Figure-2). The laminations of
A generator stator core are arranged in annular layers to form packets. These packets of annular layers of laminations are axially spaced, one from the other, by a special lamination having ventilation spacers for directing a cooling flow radially thorough the stator. The assembly is aided by mandrels in the holes of laminations to align the laminations relative to each other. To stack the laminations at higher heights, a vertically moving platform is provided for operator. The considerations for virtual prototype for stacking stator core laminations were:

1. Robot Model:
   a. Robot reach: The robot was required to pick the laminations from a stacking table and place it on a circular table in a circular and half-overlapping manner. Hence a long reach robot was selected such that it can reach the farthest position on the assembly table.
   b. Robot payload: The robot with expected payload considering factor of safety was selected.

2. Robot Gripper: The choice of gripper was using vacuum cups, electromagnets or permanent magnets. As some the lamination sheets were perforated, pneumatically operated magnetic gripper was selected.

3. Assembly table: An assembly table with large diameter was selected based on the lamination and turbo generator size.

4. Vertical Column: As the number of layers increased, it was required that the robot travel on a vertical column so that it can place laminations at higher heights. Suitable vertical column with motorized mechanism driven by robot was selected.

5. Pick-up tables: As the robot needed to travel up and down and as the robot was not able to reach the lower pick-up table at higher heights, two tables, one at lower level and one at higher level were selected.

A. Functional Analysis
The function of a virtual prototype was to stack the laminations of a generator stator core in the form of annular layers using an automated device that can incrementally travel up to a high height. Further, the functional requirements of the virtual prototype were:

1. It should be automated equipment like an articulated robot that has a long reach, required payload and other characteristics to pick and place laminations from one point to another without any errors.

2. The automated equipment should be able to travel vertically in infinitely variable incremental steps to stack the laminations from bottom of an assembly table to top of an assembly table on which laminations are stacked.

3. The pick points for laminations should be such that the robot can reach the pick-up point when positioned at different heights.

4. The automated process should be faster than the current operation.

5. The layout of virtual prototype should have the minimum footprint.

Considering the above requirements, an assembly process involving an articulated six-axis robot travelling on vertical column was considered as an ideal choice.

IV. ARCHITECTURE DESIGN

A. Hardware
The considerations for virtual prototype for stacking stator core laminations were:

1. Robot Model:

   a. Robot reach: The robot was required to pick the laminations from a stacking table and place it on a circular table in a circular and half-overlapping manner. Hence a long reach robot was selected such that it can reach the farthest position on the assembly table.

   b. Robot payload: The robot with expected payload considering factor of safety was selected.

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5. Pick-up tables: As the robot needed to travel up and down and as the robot was not able to reach the lower pick-up table at higher heights, two tables, one at lower level and one at higher level were selected.

B. Software
Simulation software for modeling the virtual prototype was selected from the same manufacturer as the manufacturer of robot to achieve the full functionality. The simulation software was used to create the virtual robot and also model of other hardware such circular assembly table, pick up tables and vertical column. The virtual robot was then programmed using the internal built-in teach pendant and run in test mode to verify the process.

V. INTEGRATION AND LAYOUT OF HARDWARE

A. Integration of Hardware
The integration of hardware of virtual prototype model for stacking the stator core laminations consisted of a robot mounted on a horizontal base plate that traveled vertically on a vertical slide column, a gripper mounted at the end of the robot wrist, a robot controller, a circular assembly table,
lower lamination pickup table and upper lamination pickup table. The movement of the vertical slide was driven by electrical servo motor that was linked to robot and caused up and down movement of the horizontal base plate on which the robot was mounted.

B. Layout of Hardware
All the hardware was placed in desired location making sure that the robot reached all the desired points in programmed path without any collision.

VI. ALGORITHM DEVELOPMENT

A. Process
The robot picks the laminations from the lower pickup table or upper pickup table by an electromagnetic gripper and disposes the picked-up lamination on the circular assembly table at a pre-defined programmed position to form an annular layer. After completing one annular layer, the robot moves up on a vertical slide column by a pre-defined programmed distance, picks and places the laminations for second and subsequent layers of the laminations. Further, special laminations having ventilation spacers are picked from a separate table (not shown) and disposed on the stacked lamination on the circular assembly table at pre-defined layer and position. Depending on the relative position of the robot and the pickup tables, a program instructs the robot to pick up laminations either from lower pickup table or upper pickup table. As a result, when the robot reaches a certain height on a vertical slide, it picks up the laminations from the upper pickup table and stacks the laminations on the upper annular layers of the generator stator core.

B. Simulation and Verification
Following points were considered while developing the simulation program:
1. The robot is integral part of horizontal plate which travels on vertical slide and its motion is controlled through an integral axis of the robot.
2. The end of arm tool i.e. gripper of the robot is attached to the robot wrist in correct position and orientation.
3. Positioning the lower pick-up table and higher pick-up tables is within robot’s work envelope such that the robot is able to pick the laminations from any of the tables from a programmed position on vertical slide.

The algorithm consisted of following steps:
1. For the first layer of stack, the robot picks up first lamination from the lower pick up table and places it on circular assembly table at a programmed position to complete first layer.
2. The cycle repeats for the 2nd and subsequent layers.
3. As the height of stack rises, the robot is programmed to move at a higher position on the vertical slide.
4. When the robot is not able to reach the lower pick-up table, it picks the laminations from higher pick-up table and repeats the steps 1 to 3 till the entire stack is completed.

Figure-3 shows part of the simulation program developed based on the algorithm.

VI. VIRTUAL PROTOTYPE MODEL
Final output of simulation program is shown in Figure-4 to Figure-9. Outputs of simulation program at different points of operation are shown in Figures 4-8. Due to the requirement of very large number of steps, the simulation program was done completely for the first layer only. For other layers only nearest and farthest lamination position was programmed at every 1 meter height.

Figure-9 shows the final virtual prototype model of the stacked lamination for the turbo generator.
In today’s manufacturing environment, virtual prototyping is used for a wide variety of applications such as throughput analysis and system validation eliminating the need for actual prototype saving time and money. A systematic process was developed to model a virtual prototype for stacking of stator core laminations. This demonstrated a key technology in modeling a virtual prototype through robot simulation that led to a faster design development with less investment. The virtual prototype model for stacking of laminations demonstrated that the stator core laminations can be stacked at variable heights by using an articulated six-axis root travelling on a vertical slide. It also demonstrated the automated process was 45% faster than the current manual process, thus saving the cycle time, leading to higher productivity and eliminating stressful monotonous working conditions for operators.

Further, it also demonstrated that the virtual prototype model can be implemented for different ratings and sizes of turbo-generators and large motors due to its flexibility.

REFERENCES