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Developing a Virtual Prototype for Stacking Laminations in Stator Core of Turbo Generator using Robot Simulation Software

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Abstract—*Robotic simulation is used in modeling a virtual prototype. A virtual prototype is modeled to eliminate the status of high investment of time and money to create an actual prototype. It is a powerful tool which makes the user to easily transform the virtual to a real model. The virtual prototype developed by Robot simulation Software describes the stacking of stator core laminations at different number of parts picking, for example; single part pickup, double part pickup and multiple part pickup. At present, the assembly of stator core for a turbo generator is done manually by picking and placing the stampings in a circular manner forming many layers. This manual assembly process not only takes a long time but also causes fatigue on workers due to monotonous and repetitive work that reduces the productivity. It is proposed to develop and establish a robotic technology process that will pick up the laminations from pick-up (de-stacking) table and assemble it in a circular manner on a circular assembly table which thereby increases the annual production of stator core and also eliminates fatigue on workers. Based on the parts picking, it gives a clear idea about how the cycle time varies from single part to multiple part pickup and finally allows the user to choose the better one.*

Keywords: *Robotic simulation, Virtual Prototype, Turbo generator, Lamination.*

1. INTRODUCTION

The turbo generator is invented by Blathy Otto an electrical engineer of Hungary which was developed by Michael Faraday, a British scientist by using a theory of “Electro Magnetic Induction”. Gas turbines drive the smallest class of turbo-generators. The motive force for these turbines is the burning of gaseous fuels. Because they can be started and stopped easily, they are used for a variety of intermittent applications including emergency power [1, 2]. Steam turbines drive much bigger turbo generators. The steam is generated by a variety of methods including burning coal, nuclear power and geothermal energy. These types of turbo generators supply the bulk of the electrical power. The third class of Turbo-generators is powered by water turbines. Water turbines are very efficient devices for extracting energy for moving water. They are used in virtually all hydro-electric power plants worldwide. Components of a Turbo-generator include a Rotor which consists of rotor shaft, rotor winding and rotor retaining rings and a Stator which consists of stator core, stator frame, stator winding and end covers [3].

Now-a-days stacking stator core laminations of a turbo-generator involve manual process. In order to avoid risks involved in manual process, Robotic Technology has developed. As this article is centered on developing virtual prototype for stacking, it is mainly focused on that.

2. STATOR

The generator stator is a tight construction supporting and enclosing stator winding, core and hydrogen cooling medium. Hydrogen is contained within frame and circulated by fans mounted at either end of rotor. The generator is driven by direct coupled steam turbine at the speed of 3000 rpm. The generator is designed for continuous rated output [1, 2]. Temperature detector and other device installed or connected within the machine, permit the windings core and hydrogen temperature, pressure and purity in machine. Typical stator is shown in the Fig. 1.

Fig. 1: Stator [3]

2.1 Stator Core

It consists of thin laminations. Each lamination made of number of individual segments. Segments are stamped out with accurately finished die from the sheets of cold rolled high quality silicon steel. Core is stacked with lamination segments. Segments are assembled in an interleaved manner from layer to layer for uniform permeability. Stampings are held in a position by core bars having dove tailed section. Insulating paper pressboards are also put between the layer of stamping to provide additional insulation and to localize short circuit. [2, 5] Stampings are hydraulically compressed during the stacking procedure at different stages. Between two packets one layer of ventilating segments is provided. Steel spacers are spot welded on stamping. These spacers from ventilating ducts where cold hydrogen from gas coolers enter the core radially inwards there by taking away the heat generated due to eddy current losses. The pressed core is held in pressed condition by means of two massive non-magnetic steel castings of press ring. The press ring is bolted to the ends of core bars. The pressure of the pressure ring is transmitted to stator core stamping through press fringes of non-magnetic steel and duralumin placed adjacent to press ring. To avoid heating of press ring due to end leakage flow, two rings made of copper sheet are used on flux shield. The ring screens the flux by short-circuiting. To monitor the formation of hot spots resistance transducer are placed along the bottom of slots. The core loss test is done after completion of core assembly.

Fig. 2: Stator core [3]

The main features of core are, it provides mechanical support and ensures perfect link between core and rotor and thereby carries electric and magnetic flux efficiently. This paper mainly demonstrates the stacking of laminations in an annular manner on a stationary circular table. Stator core is the part which is made by assembling laminations. This discusses about the existing process in the industry, approach for the development of virtual prototype for the stacking of laminations. It also gives the detailed description of the programming technique used for building a virtual prototype. Internal view of the core is shown in the Fig. 2.

2.2 Lamination sheet

The lamination sheet is made up of silicon steel, having thickness 0.65mm. The silicon steel which is also called as electrical steel, silicon electrical steel or lamination steel is a specially steel tailored to produce certain magnetic properties, such as small hysteresis area and high permeability. The material is usually manufactured in the form of cold rolled strips less than 2mm thick. These strips are called laminations when stacked together to form a stator core. Typical view of lamination sheets are shown in the Fig. 3.

Fig. 3: Lamination sheets [3]

3. EXISTING PROCESS IN THE INDUSTRY

During normal manual process, lamination sheets are placed in a circular manner one by one by an operator. There are many disadvantages included in this process, so simulation software is used to develop a virtual robot to initially perform the operation. The main feature in this is that, the robot can be programmed and manipulated according to the process. It can also modify after programming if there are any requirements needed.

3.1 Manual assembly

In manual process, lamination sheets are placed in a circular manner one by one by an operator on a stationary circular table as shown in the below figure.

Fig. 4: Manual assembly process [4]

4. AIMED PROCESS

The assembly of stator core for a turbo generator is done manually by picking and placing the stampings in a circular manner forming many layers. This manual assembly process not only takes a long time but also causes fatigue on workers due to monotonous and repetitive work that reduces the productivity. It is proposed to develop and establish a robotic technology process that will pick up the laminations from pick-up (de-stacking) table and assemble it in a circular manner on a circular assembly table which thereby increases the annual production of stator core and also eliminates fatigue on workers.

4.1 Robotic Technology

Robotic Technology is used to enhance the process of stacking laminations in stator core of a Turbo-generator. This project is mainly focused on the simulation of the Robotic process which reduces the risk of repetitive manipulating of the actual process which is already designed. It reduces the stress involved in making a real and physical Robot. The manufacturer can modify the program done in the software up to his requirements and make a desired design finally after all the modifications which saves time and cost also [6].

4.2 Software Tool Used

Robot System Intelligent Teaching Tool, FANUC, ROBOGUIDE (E) _v06 is used to develop virtual prototype of stacking laminations of stator core in a turbo-generator. 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 [6, 7].

4.3 Approach to the problem

A virtual prototype can be developed using robot simulation software. To reach the objective, that is to reduce the time and cost, the approach is to compare the cycle time for different parts picking, single part pickup, double part pickup and multiple part pickup as:

4.3.1 Single part pickup

A single stamping is picked up by the gripper from a stationary table where the lamination stacks are placed and placed on another stationary circular table where the laminations are finally stacked together in an annular manner. The gripping tool used in this pickup is a magnetic gripper which holds the single lamination sheet. It is designed in such a way that the lamination gets tightly fixed to that using the magnetic parts attached to the tool according to the shape and size of the lamination sheet. This process is taking a time of 45.85 seconds for picking and placing each part. Main view of the robot envelope and typical program for picking laminations in single part pickup is shown in the Fig. 5 and Fig. 6 respectively.

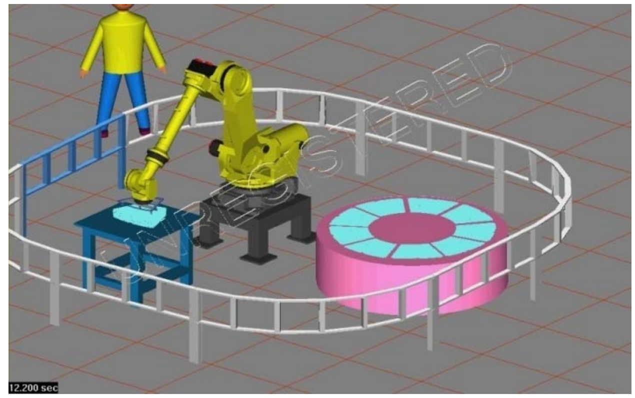

Fig. 5: Layout of single part pickup

```
!FANUC Robotics America ;
!ROBOGUIDE Generated This TPP ;
!Run SimPRO.cf to setup frame and ;
UTOOL_NUM[GP1]=1 ;
UFRAME_NUM[GP1]=0 ;
LBL[1] ;
J P[1] 100% CNT100 ;
! Pickup ('Part1[9]') From ('Fixt ;
!WAIT 0.00 (sec) ;
L P[2] 2000mm/sec CNT100 ;
! Drop ('Part1[9]') On ('Fixture2 ;
!WAIT 0.00 (sec) ;
L P[3] 2000mm/sec CNT100 ;
! Pickup ('Part1[8]') From ('Fixt ;
!WAIT 0.00 (sec) ;
L P[4] 2000mm/sec CNT100 ;
! Drop ('Part1[8]') On ('Fixture2 ;
!WAIT 0.00 (sec) ;
L P[5] 2000mm/sec CNT100 ;
! Pickup ('Part1[7]') From ('Fixt ;
!WAIT 0.00 (sec) ;
L P[6] 2000mm/sec CNT100 ;
! Drop ('Part1[7]') On ('Fixture2 ;
!WAIT 0.00 (sec) ;
L P[7] 2000mm/sec CNT100 ;
! Pickup ('Part1[6]') From ('Fixt ;
!WAIT 0.00 (sec) ;
L P[8] 2000mm/sec CNT100 ;
! Drop ('Part1[6]') On ('Fixture2 ;
!WAIT 0.00 (sec) ;
L P[9] 2000mm/sec CNT100 ;
! Pickup ('Part1[5]') From ('Fixt ;
!WAIT 0.00 (sec) ;
L P[10] 2000mm/sec CNT100 ;
! Drop ('Part1[5]') On ('Fixture2 ;
!WAIT 0.00 (sec) ;
L P[11] 2000mm/sec CNT100 ;
! Pickup ('Part1[4]') From ('Fixt ;
!WAIT 0.00 (sec) ;
L P[12] 2000mm/sec CNT100 ;
! Drop ('Part1[4]') On ('Fixture2 ;
!WAIT 0.00 (sec) ;
L P[13] 2000mm/sec CNT100 ;
! Pickup ('Part1[3]') From ('Fixt ;
!WAIT 0.00 (sec) ;
L P[14] 2000mm/sec CNT100 ;
! Drop ('Part1[3]') On ('Fixture2 ;
!WAIT 0.00 (sec) ;
L P[15] 2000mm/sec CNT100 ;
! Pickup ('Part1[2]') From ('Fixt ;
!WAIT 0.00 (sec) ;
L P[16] 2000mm/sec CNT100 ;
! Drop ('Part1[2]') On ('Fixture2 ;
!WAIT 0.00 (sec) ;
L P[17] 2000mm/sec CNT100 ;
! Pickup ('Part1[1]') From ('Fixt ;
!WAIT 0.00 (sec) ;
L P[18] 2000mm/sec CNT100 ;
! Drop ('Part1[1]') On ('Fixture2 ;
!WAIT 0.00 (sec) ;
JMP LBL[1] ;
```

Fig. 6: Program for single part pickup

4.3.2 Double part pickup

Two parts are picked at a time by the robot from the stationary table and placed on the circular table one after the other on the respective position taught using command. In the same manner the program is repeated until the stacks are placed. The gripping tool used here is a mechanical clamp which holds two laminations at a time. This process is taking a time of 33.10 seconds for picking and placing two parts. Main view of the robot envelope and typical program for picking laminations in double part pickup is shown in the Fig. 7 and Fig. 8 respectively.

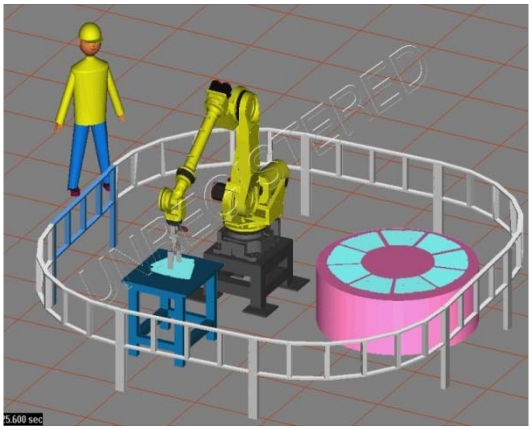

Fig. 7: Double part pickup

```
 1:  !FANUC Robotics America ;
 2:  !ROBOGUIDE Generated This TPP ;
 3:  !Run SimPRO.cf to setup frame and ;
 4:  UTOOL_NUM[GP1]=1 ;
 5:  UFRAME_NUM[GP1]=0 ;
 6:  LBL[1] ;
 7:J P[1] 100% CNT100    ;
 8:L P[2] 2000mm/sec CNT100    ;
 9:  ! Pickup ('Part1[9]') From ('Fixt ;
10:  WAIT   1.00(sec) ;
11:  ! Pickup ('Part1[8]') From ('Fixt ;
12:  WAIT   1.00(sec) ;
13:L P[3] 2000mm/sec CNT100    ;
14:  ! Drop ('Part1[8]') From ('GP: 1  ;
15:  WAIT   1.00(sec) ;
16:L P[4] 2000mm/sec CNT100    ;
17:  ! Drop ('Part1[9]') From ('GP: 1  ;
18:  WAIT   1.00(sec) ;
19:L P[5] 2000mm/sec CNT100    ;
20:  ! Pickup ('Part1[7]') From ('Fixt ;
21:  WAIT   1.00(sec) ;
22:  ! Pickup ('Part1[6]') From ('Fixt ;
23:  WAIT   1.00(sec) ;
24:L P[6] 2000mm/sec CNT100    ;
25:  ! Drop ('Part1[6]') From ('GP: 1  ;
26:  WAIT   1.00(sec) ;
27:L P[7] 2000mm/sec CNT100    ;
28:  ! Drop ('Part1[7]') From ('GP: 1  ;
29:  WAIT   1.00(sec) ;
30:L P[8] 2000mm/sec CNT100    ;
31:  ! Pickup ('Part1[5]') From ('Fixt ;
32:  WAIT   1.00(sec) ;
33:  ! Pickup ('Part1[4]') From ('Fixt ;
34:  WAIT   1.00(sec) ;
35:L P[9] 2000mm/sec CNT100    ;
36:  ! Drop ('Part1[4]') From ('GP: 1  ;
37:  WAIT   1.00(sec) ;
38:L P[10] 2000mm/sec CNT100    ;
39:  ! Drop ('Part1[5]') From ('GP: 1  ;
40:  WAIT   1.00(sec) ;
41:L P[11] 2000mm/sec CNT100    ;
42:  ! Pickup ('Part1[3]') From ('Fixt ;
43:  WAIT   1.00(sec) ;
44:  ! Pickup ('Part1[2]') From ('Fixt ;
45:  WAIT   1.00(sec) ;
46:  ! Pickup ('Part1[1]') From ('Fixt ;
47:  WAIT   1.00(sec) ;
48:L P[12] 2000mm/sec CNT100    ;
49:L P[13] 2000mm/sec CNT100    ;
50:  ! Drop ('Part1[1]') From ('GP: 1  ;
51:  WAIT   1.00(sec) ;
52:L P[14] 2000mm/sec CNT100    ;
53:  ! Drop ('Part1[2]') From ('GP: 1  ;
54:  WAIT   1.00(sec) ;
55:L P[15] 2000mm/sec CNT100    ;
56:  ! Drop ('Part1[3]') From ('GP: 1  ;
57:  WAIT   1.00(sec) ;
58:L P[16] 2000mm/sec CNT100    ;
59:  WAIT   2.00(sec) ;
60:  JMP LBL[1] ;
61:  CALL Prog4    ;
62:  UTOOL_NUM[GP1]=1 ;
63:  UFRAME_NUM[GP1]=0 ;
```

Fig. 8: Program for double part pickup

4.3.3 Multiple parts pickup

A total of nine stampings are to be placed on the circular table and the robot picks all the nine parts at a time and places one after the other on their respective positions. The gripping tool is made in such a way that it holds all the nine parts firmly until the last part is placed. This is a time, energy and cost saving process. This process is taking a time of 19.184 seconds for picking and placing all the nine parts. Main view of the robot envelope and program for picking laminations in multiple part pickup is shown in the Fig. 9 and Fig. 10 respectively.

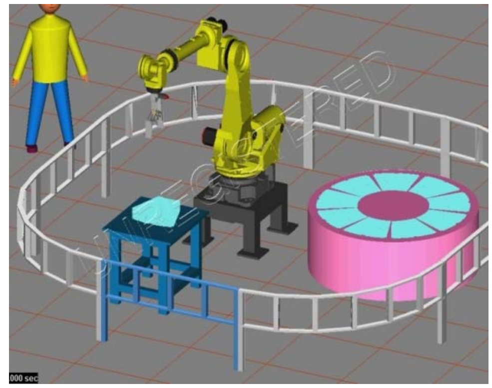

Fig. 9: Multiple part pickup

```
 1:  !FANUC Robotics America ;
 2:  !ROBOGUIDE Generated This TPP ;
 3:  !Run SimPRO.cf to setup frame and ;
 4:  UTOOL_NUM[GP1]=1 ;
 5:  UFRAME_NUM[GP1]=0 ;
 6:  LBL[1] ;
 7:J P[1] 100% CNT100    ;
 8:L P[2] 2000mm/sec FINE    ;
 9:  ! Pickup ('Part1[9]') From ('Fixt ;
10:  !WAIT 0.00 (sec) ;
11:  ! Pickup ('Part1[8]') From ('Fixt ;
12:  !WAIT 0.00 (sec) ;
13:  ! Pickup ('Part1[7]') From ('Fixt ;
14:  !WAIT 0.00 (sec) ;
15:  ! Pickup ('Part1[6]') From ('Fixt ;
16:  !WAIT 0.00 (sec) ;
17:  ! Pickup ('Part1[5]') From ('Fixt ;
18:  !WAIT 0.00 (sec) ;
19:  ! Pickup ('Part1[4]') From ('Fixt ;
20:  !WAIT 0.00 (sec) ;
21:  ! Pickup ('Part1[3]') From ('Fixt ;
22:  !WAIT 0.00 (sec) ;
23:  ! Pickup ('Part1[2]') From ('Fixt ;
24:  !WAIT 0.00 (sec) ;
25:  ! Pickup ('Part1[1]') From ('Fixt ;
26:  !WAIT 0.00 (sec) ;
27:L P[3] 2000mm/sec CNT100    ;
28:L P[4] 2000mm/sec CNT100    ;
29:  ! Drop ('Part1[1]') From ('GP: 1  ;
30:  WAIT   1.00(sec) ;
31:L P[5] 2000mm/sec CNT100    ;
32:  ! Drop ('Part1[2]') From ('GP: 1  ;
33:  WAIT   1.00(sec) ;
34:L P[6] 2000mm/sec CNT100    ;
35:  ! Drop ('Part1[3]') From ('GP: 1  ;
36:  WAIT   1.00(sec) ;
37:L P[7] 2000mm/sec CNT100    ;
38:  ! Drop ('Part1[4]') From ('GP: 1  ;
39:  WAIT   1.00(sec) ;
40:L P[8] 2000mm/sec CNT100    ;
41:  ! Drop ('Part1[5]') From ('GP: 1  ;
42:  WAIT   1.00(sec) ;
43:L P[9] 2000mm/sec CNT100    ;
44:  ! Drop ('Part1[6]') From ('GP: 1  ;
45:  WAIT   1.00(sec) ;
46:L P[10] 2000mm/sec CNT100    ;
47:  ! Drop ('Part1[7]') From ('GP: 1  ;
48:  WAIT   1.00(sec) ;
49:L P[11] 2000mm/sec CNT100    ;
50:  ! Drop ('Part1[8]') From ('GP: 1  ;
51:  WAIT   1.00(sec) ;
52:L P[12] 2000mm/sec CNT100    ;
53:  ! Drop ('Part1[9]') From ('GP: 1  ;
54:  WAIT   1.00(sec) ;
55:J P[13] 100% CNT100    ;
56:  WAIT   1.00(sec) ;
57:  WAIT   2.00(sec) ;
58:  JMP LBL[1] ;
59:  CALL Prog4    ;
60:  UTOOL_NUM[GP1]=1 ;
61:  UFRAME_NUM[GP1]=0 ;
```

Fig. 10: Program for multiple parts pickup

5. CONCLUDING REMARKS

A virtual prototype using Robot Simulation Software in stacking stator core laminations of a turbo-generator. For picking single part the Robot takes much time compared to the multiple part picking. So, it can be concluded that the time can be saved in the multiple part picking which thereby increases the rate of production.

a) Time taken to complete the picking and placing in single part pickup is 45.85 seconds, double part pickup is 33.10 seconds and in multiple parts pickup is 19.384 seconds is shown in the Table 1, where as in manual process it is more which depends on the operator.

b) The consistency of the Robotic technology is much higher than the manual process which can be clearly understood from the cycle time.

c) The manual handling of lamination sheets by the workers can be avoided and thereby reducing risk.

d) The rate of production can be increased when compared with the manual process.

Table 1: Time for different number of parts pickup

Number of parts pickup	Cycle Time (seconds) 9 stampings – 1 layer
Single part pickup	45.85
Double part pickup	33.10
Multiple part pickup	19.384

5.1 Comparison between cycle time for number of parts pickup

In this comparison the time taken by the single part pickup is much more than the multiple parts pickup which is the key to fulfill the objective. As discussed in the previous chapters the manual process is completely labor dependent process, it completely depends on the skill and the experience of the robot. It also varies from number of parts picking. So the comparison is made between the cycle time for each process of picking. In this report cycle time is defined as the total time taken for the robot to pick and place all the nine objects in a single layer. Analysis between number of parts picking and cycle time are shown in the Fig. 11.

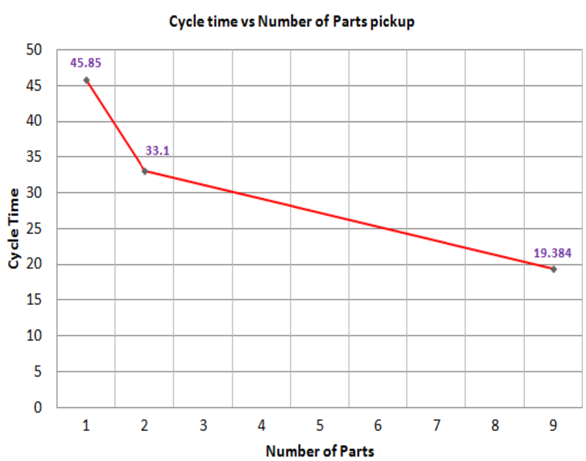

Fig. 11: Graphical analysis

A graph is drawn between the number of parts pickup and cycle time which clearly gives an idea why the Robotic technology plays a major role in the process of stacking stator core laminations. The stacking process using a robot is not cost effective for many small productions. The Robotic Technology can be extended in making other process which is more productive than other manual processes and eliminates human efforts. It will also decrease the repetitiveness in manipulating the physical or real robot.

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