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# Design of End of Arm Tool, Guide Plate and Support Plate for Robotic Spot Welding Application

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## ABSTRACT

***Ventilation lamination sheets are required for cooling the stator core of the steam turbine generator and are manufactured by welding ventilation spacer bars on a lamination sheets using resistance welding (spot welding) process. The existing process in the industry to weld spacer bars on a lamination sheet is performed manually. It takes approximately 60 minutes to weld ventilation spacer bars onto one lamination sheet manually. Automating this process can reduce this time to as low as 15 minutes thereby increasing the production rate by at least 400%. Also, for mass production, the running cost of an automated process is much lower than a manual process. The automated process employs a robot to move the lamination sheet through a precise path which corresponds to the location of the weld-spots. As the lamination sheet needs to be suspended off the robot's flange for the entire duration of the process, it becomes necessary to provide a rigid support to the lamination sheet. Also, the spacer bars need to be held in their defined position before they are welded. The lamination sheet is very thin and undergoes considerable deflection under its own weight. While supporting the lamination sheet, the welding operation must not be hindered in any way. This paper aims to design guide and support which sandwiches the lamination sheet between them. The guide plate is used to hold the spacer bars in their defined positions accurately and the support plate is used to support the weight of the lamination sheet with the spacer bars and the guide plate with minimum deflection. Both of the plates are required not to obstruct the movement of the robot and the welding operation in any way.***

**Keywords:** Automated spot welding, guide plate, support plate, spacer bars, turbo generator

## 1. INTRODUCTION

Ventilation laminations are required for cooling the stator core of the steam turbine generator and are manufactured by welding ventilation spacers on a lamination sheets using resistance welding (spot welding) process. **Robotic spot welding is the solution for high volume production** for high volume manufacturers who need to perform thousands of spot welds per shift and where welding cycle time is critical. Welding was, for a long time, a task performed only by humans, being a craft that combines skill with art and science. Automating welding is therefore a very difficult and demanding objective; because of the required adaptive behavior of the automatic system [1]. The robotic spot welding can be done by two methods:

*1)* With Robot mounted spot welding gun
*2)* With fixed spot welding machine while robot will move the lamination sheet.

Robot mounted spot welding gun means a control apparatus for carrying out a spot welding operation using a robot comprises a spot welding gun having a spot welding tip, an electric drive mechanism for driving the tip, and a control unit for controlling the electric drive mechanism, in which the operation of the spot welding gun is synchronously controlled with that of the robot.[2] This requires large capacity robots, having payloads of 150 to 200 Kg., are required as the spot welding gun transformers are heavy. Because of the robotic spot welding gun and large capacity robot this process is very costly.

Other controlled system relates to a spot welding process that uses a fixed spot welding machine (pedestal spot welding machine) and a robot with a material handling end effectors for automatic spot welding of ventilation spacer bars on different variants of lamination sheets of a turbo generator. In this system, the spot welding machine will be stationary and robot will hold and move the assembly consisting of lamination sheet along with the plates and ventilations spacer bars by an end of arm tool attached to the wrist of the robot [3] .The automated process employs a robot to move the lamination sheet through a precise path which corresponds to the location of the weld-spots. As the lamination sheet needs to be suspended off the robot's flange for the entire duration of the process, it becomes necessary to provide a rigid support to the lamination sheet. Also, the space bars need to be held in their defined position before they are welded. The lamination sheet is very thin and undergoes considerable deflection under its own weight. While supporting the lamination sheet, the welding operation must not be hindered in any way. The End of arm tool should be designed in such a way that it is fitted with robot flange which in turn holds the lamination sheet along with bars sandwiched between the pair of templates and will move the complete assembly through a pre-programmed path for precise welding. Guide and support plates are required to enable the mounting of lamination sheet onto the robot for automatic spot welding operation. Also, the spacer bars to be welded are held in desired position by the guide plate. The weight of the assembly of the guide plate and the lamination sheet along with spacer bars has to be supported by the support plate. These requirements are to be met within a few constraints that have to be identified.

## 2. DESIGN OF END OF ARM TOOL

The End of Arm Tool (EOAT) consists of a flange made of Aluminum alloy. The inner and outer diameter of this flange varies according to the design of the lamination sheet. Holes are drilled to this flange through which the complete setup will be fitted to robot wrist. Two L channels are attached to the flange. Six pneumatic clamps are fitted to the L channels, three on each side. Through these channels the lamination sheet and other supporting plates are lifted. The End of arm tool is fitted with robot flange through holes which in turn hold the lamination sheet along with bars sandwiched between the pair of plates using pneumatic clamps and will move the complete assembly through a pre-programmed path for precise welding. All the clamps are fitted with proximity sensor to verify the sheet presence. The EOAT is fitted with a pressure sensor of range 0-10 bars, to maintain the adequate pressure for clamp operations. The main constraint in designing the end of arm tool is that its weight should be as minimum as possible. The pneumatic clamps work at an operating pressure of 4-6 bars with 180 degrees angle of operation and each of them has a gripping force of around 75 N. The design of End of Arm Tool is shown in fig 1 and 2.

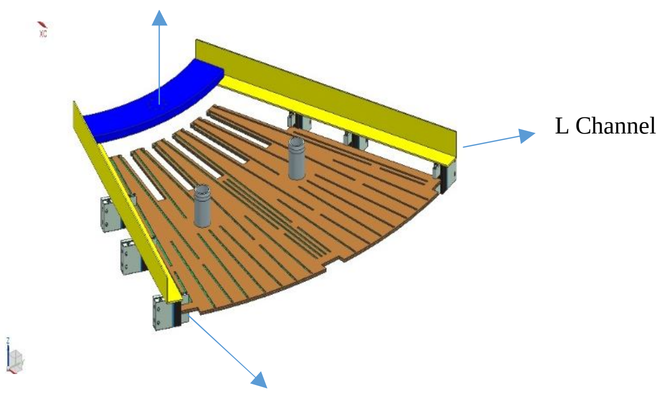


**Figure1** Design of End of Arm Tool

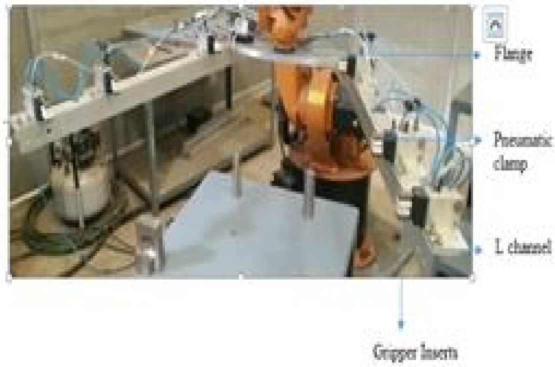


**Figure 2** Actual End of Arm Tool

## 3. CONSTRAINT EVALUATION FOR PLATE DESIGN

### 3.1 Weight Constraint

The maximum allowable payload of the robot is 16 kg. The weight of the lamination sheet with spacer bars is 3.89 kg. The weight of the plates and other components (channels, grippers etc.) must therefore not exceed 12 kg under any circumstance. In order for the assembly to remain within the maximum allowable payload limit under dynamic conditions (when the robot is moving or the welding is performed), it must weigh sufficiently below 12kg under static conditions. The weight of the channels and grippers cannot be altered as they are standard designs being used to serve their respective purpose. The plates must, therefore, be designed for the minimum possible weight permitted by the other constraints.

### 3.2 Size Constraint

The grippers must not obstruct the path of the robot or the electrodes of the spot welding machine as the operation is performed. Therefore the grippers must hold the plate beyond the outermost spacer bar. The plates have to be made wide enough to enable the gripper to hold them firmly in place. The length of the gripper jaw is about 25 mm. Therefore, at the narrowest gripping point, there must be at least 20 mm free width available for the gripper jaw. This implies that the span of the plate must extend at least 20 mm beyond the outermost spacer bar at the narrowest gripping location. It was observed that by increasing the angular span of the plate by $1^0$, the distance between the edge of the plate and the outermost spacer bar is a minimum of 23 mm. Therefore, an angular span of $42^0$ of the plate would satisfy the size constraint. (Fig 3)

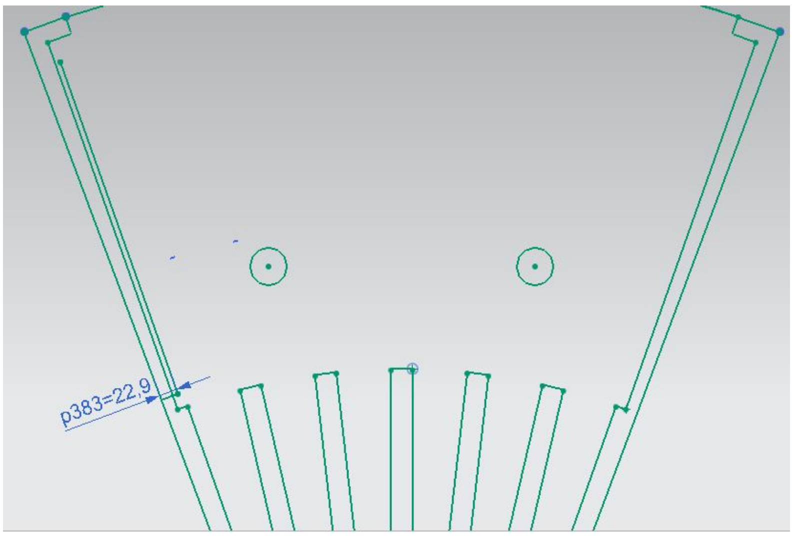


**Figure 3:** Width of the narrowest mounting position of the Gripper

### 3.3 Compatibility Constraint

The guide plate needs to have slots cut into it according to the size and position of the spacer bars. There are three types of spacers are being used depending on the generator rating [3].
1) Square cross section bar (side length: 5mm)
2) I- Section (5 mm width and 10mm thickness)
3) I-Section (8 mm width and 10mm thickness)
These bars come in different lengths based on the generator rating. Based on the length and size of the bars the slots in the guide plate need to be cut. The support plate also requires removal of material from the position of the weld spot.

### 3.4. Strength Constraint

The support plates must not yield under any circumstance and the plastic deformation must also be within a suitable limit. The support plate has to be analyzed for these constraints and designed within them.

### 3.5. Material Selection

The material to be used for the both the plates needs to fulfil very specific requirements. The material used plays a significant role in optimizing the strength and weight constraints and the convenience and overall cost of machining the plates.
The material must not be affected by spot welding (should not hinder the welding process or get fused itself).
The material should have good machinability.
The material should have a high Young's Modulus.
It should be low weight.
It should be inexpensive.
It should be non-corrosive.
Based on these properties, the material chosen was Aluminum 5086. (Fig 4)

| | |
|---|---|
| Category | : METAL |
| Sub-Category | : Aluminum Alloy |
| Material Type | : IsotropicMaterial |
| Version | : 4.0 |
| Mass Density (RHO) | : 2.66e-006kg/mm^3 |
| ======== Mechanical | |
| Young's Modulus (E) | : 72000000mN/mm^2(kPa) |
| Poisson's Ratio (NU) | : 0.33 |
| Type of Nonlinearity (TYPE) | : 1 |
| Yield Function Criterion (YF) | : 1 |
| Hardening Rule (HR) | : 1 |
| ======== Strength | |
| Yield Strength | : 217000mN/mm^2(kPa) |
| Ultimate Tensile Strength | : 290000mN/mm^2(kPa) |

**Figure 4:** Standard Properties of Aluminum 5086[4]

## 4. DESIGN APPROACH

The subjective constraints and objective constraints are defined as:

### 4.1. Objective Constraints

Defined as the constraint for which the absolute value of it is inconsequential so long as the constraint is satisfied i.e. the constraint value must be within the limiting value but the margin between them is not of any significance. The size and compatibility constraints can be classified into this category. The size of the plate must be big enough to accommodate the grippers but making the plate any bigger will serve no purpose. The slots in the guide plate must successfully arrest the spacer bars.

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### 4.2. Subjective Constraints

Defined as the constraint for which its absolute value must be within the limiting value and as further away from it as possible. The weight of the plates must not be so high as to exceed the permissible payload and should be as low as the other constraints permit. Similarly, the stress on the support plate must not exceed the yield point and should be as low as possible.

## 5. DESIGN

The approach is to design the plates for the subjective constraints and then verify them with the objective constraints. The optimum design is obtained for the lowest values of the subjective constraint which satisfy the objective constraints. At the same time, the subjective constraints must not violate each other. Therefore, the design process starts with a conservative design which satisfies the objective constraints and then modifications are made to minimize the subjective constraints to achieve the optimum design. (Fig 5)

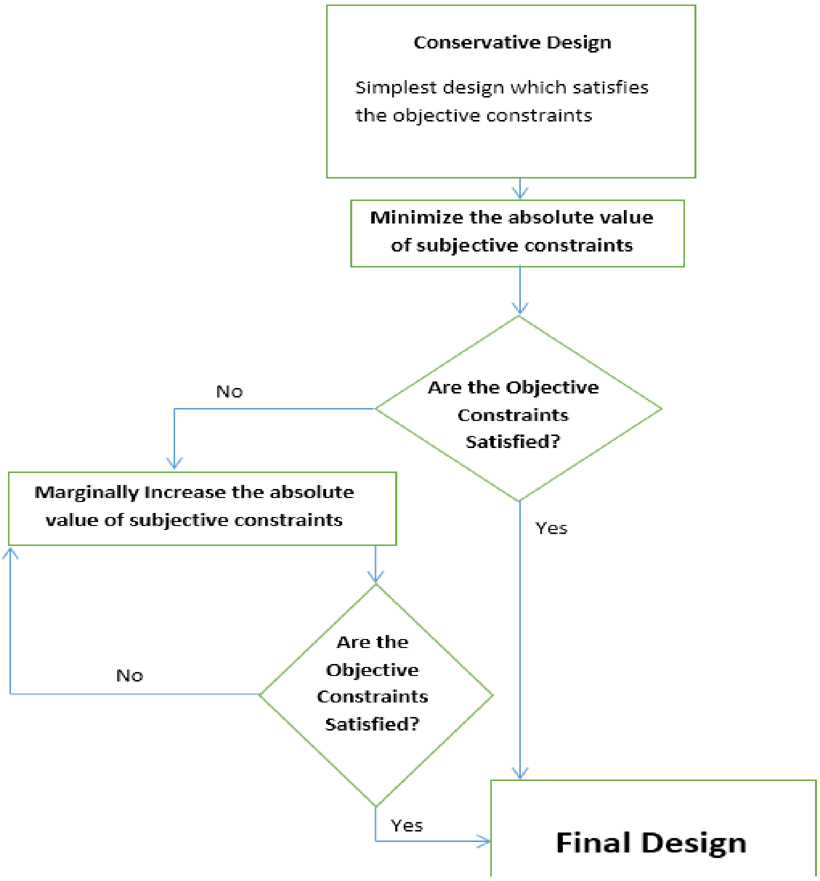


**Figure 5** Flow Chart for design optimization

### 5.1. Conservative Design

The plates are designed as per the size and compatibility constraints. These designs inherently satisfy the strength constraint but may exceed the weight constraint. The dimensions of the blank plates are decided as per the size constraint and material is removed as per the compatibility constraints. Initially, the same conservative design was selected for both plates (Fig 6) but it was found that the width of similar slots required for the support plate will be greater as it needs to allow the electrode to much material was being removed from high stress points. But, the entire length of slots was not required in the support plate for allowing welding. The slots were required only at the location of weld spots. Consequently, slots in the support plates were replaced by holes at location of weld spots. The holes provided much greater clearance for the electrode as they could be made much larger without violating the strength constraint. Also, holes could be generated by drilling which is much faster and less expensive. As a result, the conservative design for the support plate consists of holes of 20 mm diameter at the location of weld spots.

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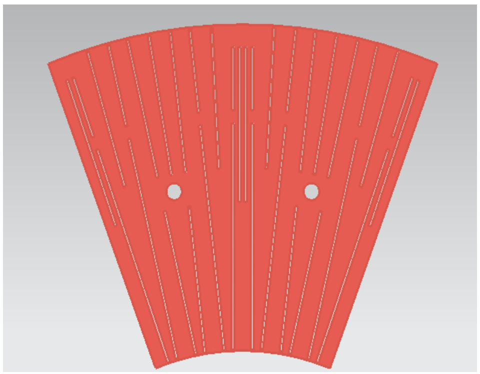

**Figure 6**: Conservative design of the Plate satisfying Objective Constraints

**5.2. Optimum Design**

The size constraint will not be violated as long as the material is not removed from the outer edges. Therefore, all the material that needs to be removed must be removed from the interior of the plates with sufficient clearance from the outer edges.

**5.2.1. Guide plate:**

The guide plate is not bound by strength constraints. It is required only to accommodate the compatibility constraint while removing material for weight reduction. For spacer bars to remain in place there should be sufficient material towards the ends of the slots and material from the middle portion of the slot can be removed. The length of the slot that is to be preserved was chosen to be 40mm on each end for the smallest slot in the region being trimmed out. Accordingly, three regions were cut out from the plate. The thickness of the guide plate also needs to be evaluated. The thickness is to be minimum for minimum weight. The plate has to be thick enough so that all different types of bars can be arrested in the slots without being displaced from their positions during the movement and welding process. Hence, the thickness was chosen to be 4 mm. (Fig 7,8)

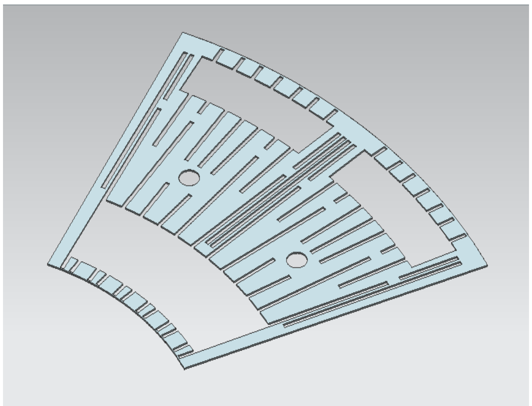

**Figure 7:** Optimized design of the Guide plate [4]

**Figure 8**: Actual Image of Guide Plate after manufacturing

### 5.2.2. Support plate:

The optimum design for the support plate is more complicated as stress-strain analysis needs to be performed for evaluating the strength constraint. The size constraint is satisfied in the same way as it is for the guide plate by removing material from the interior. However, the compatibility constraint for the support plate allows material removal from the curved edges.

To satisfy the compatibility constraint for the support plate, there is a need to ensure that none of the holes are covered up. Therefore, the material around the holes can be removed without affecting the compatibility constraint.

To satisfy the strength constraint, a threshold value of stress is chosen depending on the stress distribution [5]. Material from the plate with stress less than this threshold value is then removed so as to obtain a light and strong design. (Fig9)

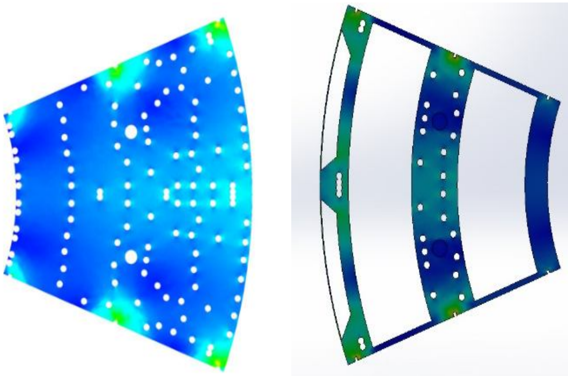

**Figure 9: Plot** of the Static Nodal Stress (von Mises stress) for the conservative (top) and optimized (bottom) design of the support plate.

The thickness for the support plate is determined as a trade-off between strength and weight. As a result, the thickness is chosen to be 3 mm.

The lamination sheet is designed to have two holes. These holes can be used to accurately align the plates with the lamination sheet before mounting the assembly on to the grippers. For this purpose, two aluminium discs of appropriate thickness and diameter, same as the hole in the lamination sheet, with very little tolerance are used. These discs are fixed on the support plate. The lamination sheet and guide plate can now be aligned by simply aligning the holes with the aluminium discs. (Fig,10,11)

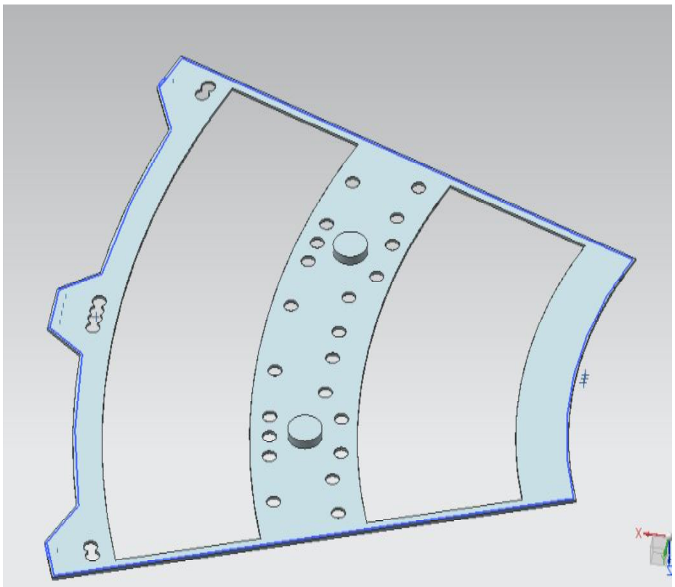

**Figure 10**: Optimized design of the Support plate [4]

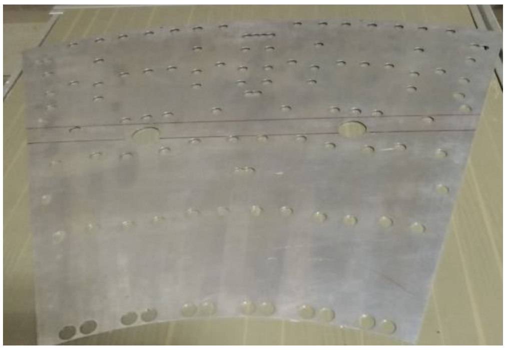

**Figure 11:** Actual Image of the Support plate

## 6. MODIFICATION DUE TO MANUFACTURING CONSTRAINT

While generating the tool path for the plate, it was observed that slot (3) was on the outer edge of the plate. This meant machining the outer edges as well or manually editing the part program to prevent unwanted machining. The clamping of the plate blank to the CNC mill is to be done along the outer edges. Therefore, the tool cannot be permitted to move along those edges. Also, as the outer dimensions of the plate blank are chosen to be same as those of the plate itself, the outer edges are not required to be machined.

To prevent this anomaly, a very thin extruded strip of 1 mm is introduced along the outer curved edge so that slot (3) effectively falls in the interior of the plate thus facilitating the process of generating the tool path. This extra material remaining after machining can be easily removed by filing. (Fig 12)

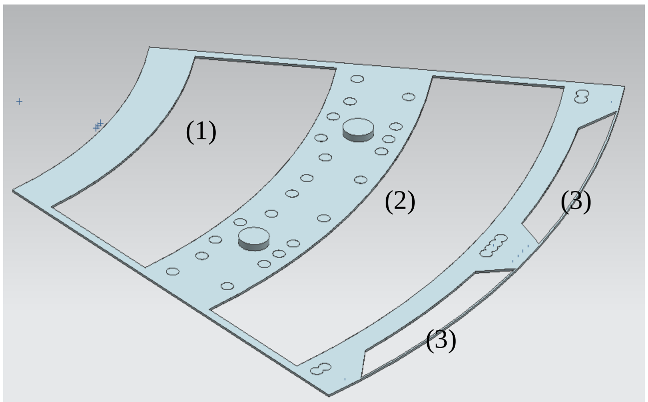


**Figure 12:** Final Design of Support plate

## 7. CONCLUSION

The primary objective of this paper is to develop a functional design for a pair of plates. These plates are meant to firmly hold the lamination sheet and the spacer bars while spot welding is performed with the help of a robot. It has been ensured that at no point, during the course of the robot's motion, the load is to exceed the maximum payload by minimising the weight of the plates. At the

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