Design and Analysis of A-Frame for Roller Hemming Cell

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Abstract—off late the automotive industry faces many competitive challenges including weight and cost reduction to meet the needs for high fuel efficiency. Therefore, the use of light metals such as aluminum alloys has been increased to produce the body structure of light-weight vehicles. However, since the form-ability of aluminum alloy is not as good as that of steel, it needs a special attention to body manufacturer during their forming process. Roller hemming technology has been introduced as a new production technique which has several advantages in terms of cost and time saving for trial and error. Hemming is the final forming process in stamping; which determines the aesthetics of automobile.

An effort is made to improve the process & optimize the existing A-frame. A-Frame has multiple benefits like reducing cost, reducing space, reducing weight, improving performance and easy loading. From the design point of view like bending stress, bolt diameter, thickness of the rectangular plate, strength of the base plate are bearing same load even after optimizing A-Frame. This paper presents the optimization and analysis of the A-Frame with the help of CATIA modeling and Nastran software.

Keywords- Hemming; A-Frame; FEM; Robotics; Roller cell.

I. INTRODUCTION

A. Robotic Roller Hemming Cell

In An automotive BIW part used for ingress & egress of passengers & other purpose is called closure. The closures are typical compared to its other counterpart sub-assemblies because of being fastened to the main body instead of rigidly welded. Many researches of automotive companies have focused on reducing weight of vehicles in order to meet the needs for high fuel efficiency. Therefore, light metals such as aluminum alloys have been applied on automotive body structures. Recently, roller hemming process has been introduced for hemming of aluminum automotive closing parts such as doors, roofs and hoods. During roller hemming; the flange of outer panels is bent and folded along the edge of inner panel by a roller attached robot. Since the stress caused by roller hemming can affect the quality of hemming flanges, the research has focused on the stress analysis by simulation and experiment. Residential stress has been measured in the hemmed flanges and compared to the values of finite elemental analysis. Fig. 1 shows the path of the roller hemming.

![Path of Roller Hemming](image1)

Fig. 1: Path of Roller Hemming

![Illustration, Parts of the Roller Hemming Cell with 2 Turntables](image2)

Fig. 2: Illustration, Parts of the Roller Hemming Cell with 2 Turntables
Three production modes of the Robot Hemming cell are:

A) **Production mode in which all the three doors need to be hemmed in a single Cycle:** Here all the 3 doors i.e. Front door RH, Front door LH, Center Flap will be hemmed in single cycle in any sequence. Suppose the operator 1 loads the Front door RH first, simultaneously the Operator 2 loads the Center Flap and both presses the Start PB, all the clamps will close, guide clamps open and TT1 and TT2 rotates and the front door RH and Center Flap comes in front of the robot. Whichever Turntable comes to the reference position first, the Robot will get the Start Program Command for that particular bed. Once it gets the Start command the robot moves from the home position and starts the hemming for that door. Meanwhile the operator 1 will load the other part of the door (Front Door LH in this case) and keep it ready for rotation. The robot completes the hemming for the front door RH and goes back to home position, all the clamps for the front door RH close and turntable 1 rotates, the robot after reaching home position again checks for Start program command if any, now the Front Door LH is ready for hemming hence once robot gets the Start command for the Front Door LH then it starts the hemming for the Front Door LH, meanwhile the TT1 with Front door RH loaded comes in front of the robot. The robot after completing the hemming for the Front Door LH moves back to home position and starts the hemming cycle for Front door RH. After completing the hemming for Front Door LH one cycle of Hemming is completed in which 1 hemmed part of Front door RH, Front door LH and Center Flap is produced and the operation continues. Here in Single cycle we will get one Hemmed Part of Each door (Front Door RH, Front Door LH & Center Flap) in any order.

B) **Production mode in which only Front door RH and Front Door LH needs to be hemmed:** In this case the operator should take care to unload the Center Flap component and load only the front door RH and Front door LH. Center Flap bed should always be empty.

C) **Production mode in which only Center Flap and Front Door LH needs to be hemmed:** In this case the operator should take care to unload the Front door RH component and load only the Center Flap and Front door LH. Front door RH bed should always be empty.

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I. **HISTORY OF A-FRAME**

A-Frame is a main part of roller hemming process. It is made of mild steel. A-Frame is a fixture mounted on the turntable. It’s had been designed in such way that the Front/Rear hemming bed is placed on either side of the A-Frame. FRL unit for both hemming beds and Rear/Front Bed junction boxes are mounted on the A-Frame. The earlier design of the Frame in roller hemming cell is as shown in Figure 2. Frame is divided in two parts Frame A and Frame B. This Frame is joined by welding process. In the First design, the frame is inclined at an angle 45 deg. The mass of the frame is 1448.052 kg and density of the material is 7860 kg/m³ which is more.

II. **MODELING**

CATIA, which stands for Computer Aided Three-dimensional Interactive Application, is the most powerful and widely used CAD (computer aided design) software of its kind in the world. CATIA was created by Dassault Systems of France which is one of the World’s leading solutions for Product Design and Innovation. For this work, CATIA V5 R19, CAD / CAM Software are used to develop the Robotic Roller Hemming cell.

**Part Design**
The Part design is the tool in which it’s used for making the 3D models & Parts using the sketch. This sketch is always parametric based feature, this part design consist of Sketch-based features, Dress up features, Surface-based features, Transfer features, Boolean operations & Advanced Dress-up Features. During the part design stage of A-Frame with help of Catia software, it was discovered that there was some limitation.

1. The plate cross section and upper plate length has to be kept constant in current scenario. Keeping this limitation in mind, when optimizing the angle for the upper plate will be constrained hence the down plate length will changed. A-Frame length will change and space of the frame will be reduced.

2. When the thickness of one plate is changed, remaining all plate thickness will get changed for A-Frame of roller hemming cell.

From CATIA software, the mass inertia of the A-Frame is evaluated and the mass of the A-Frame was found to be 827.46 kg, reducing by 140 kg within the given constraints.

III. **STRUCTURAL ANALYSIS**

**Linear static analysis**

A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to

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iJARS/ Vol. II/ Issue 2/Feb, 2013/331

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vary slowly with respect to time. The types of loading that can be applied in a static analysis include: NASTRAN is primarily a solver for finite element analysis.

It does not have functionality that allows for graphically building a model or meshing. All input and output to the program is in the form of text files. However, multiple software vendors market pre- and post-processors designed to simplify building a finite element model and analyzing the results. These software tools include functionality to import and simplify CAD geometry, mesh with finite elements, and apply loads and restraints. The tools allow the user to submit an analysis to NASTRAN, and import the results and show them graphically. In addition to pre- and post-processing capabilities, several Nastran vendors have integrated more advanced nonlinear capabilities into their Nastran products.

Boundary condition and material details of A-Frame

Material: M.S density 7.8 g/cc. Material grade st52-3

Static Load is applied and the load is distributed uniformly

Bottom of the base plate is fixed.

Yield Strength of MS is 37 kgf or 362 MPa

Shear Strength of MS is 18.5 kgf or 181MPa

Load on A-Frame:
From the figure 8, the Von Mises Stress is found to be 27.51 Mpa and from figure 9 the Maximum displacement is 0.106 mm.

IV. RESULT AND DISCUSSION

Chosen area of research clearly shows that the existing drawbacks are overcome after design optimization of A-Frame.

- It has high weight and high thickness.
- Cost is more
- Space requirement is high.
- Structural inefficiency.
- Turn table life less.

After modeling, according to given constraint weight of A-Frame is reduced to 827 kg as compared with the existing weight, which is 965 kg. The weight of A-Frame is reduced by 138 kg.

According to design calculation:

Existing A-Frame has:

1. Selected thickness of the plate \( t = 6 \) mm
2. Bending stress of the plate = -29.48 N/mm\(^2\)
3. Bolt size is M12
4. Central plate bolt size M10

After considering simply supported overhanging beam for optimized A-Frame it has:

1. Selected thickness of the plate \( t = 4 \) mm
2. Bending stress of the plate = -24.03 N/mm\(^2\)
3. Bolt size is M 8
4. Central plate bolt size is M 6

Comparing the analysis results with theoretical calculation it reveals that

- Bending stress is in valid range i.e. Theoretical 24.03 N/mm\(^2\) and analysis 27.51 N/mm\(^2\)
Thickness of the plate bears the load
- Bolt of the A-Frame is not in shear
- Center plate bolt is also not in shear
- Bending stress is less than allowable stress i.e. 112 N/mm²

From the above calculation it is evident that the optimized A-Frame design is safe.

V. CONCLUSION

The existing A-Frame of the roller hemming cell weights 955.65 kg. After optimization its weight is 827 kg. With the help of Catia software V5R19, after increasing angle of the A-Frame to 60°, the cost is reduced because of less space, less weight, less material requirement, more efficiency, longer turn table life and easy operation for the operator. After theoretical calculation, it is clear that even after increasing the angle and reducing weight of the A-Frame it is bearing the load of existing A-Frame. The thickness of the plate bears the load and the bolt does not shear. From the analysis, A-Frame is found to be safe. Stress on the frame is 27.51 N/mm² and theoretical stress is 24.03 N/mm².

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