SIMULATIVE ANALYSIS OF TUBE HYDROFORMING PROCESS

B.Sreenivasulu[1], G. Prasanthi[2], T. Naresh Kumar[3]

[1]*Asst.Professor, MECH, MITS Madanapalle, A.P, India,* **sreenivasulub@mits.ac.in**
[2]*Professor, Department of Mechanical Engineering, JNTUA College of Engineering, Anantapur, India*
[3]*P.G.Student, MECH, MITS Madanapalle, A.P, India,* **nareshpiler@gmail.com**

Abstract

The tube hydro forming process (THF) is an unconventional metal forming process, where in tube is deformed internally and thus it is forced to expand and conform to the shape of the surrounding die. The performance of this process depends on various parameters like internal pressure, axial loading etc. For FEA simulation, it requires proper combination of material selection, part design and boundary conditions. The estimated process parameters are optimized using FEA simulations.

In this work, free bulge shaped tube die was modeled by using Auto CAD. Subsequently, the processes were simulated using DEFORM-3D and it has been verified with experimental work under proper boundary and loading condition. Process parameters study also been conducted. It has been found that the estimated process parameters, developed branch height and the wall thickness distribution along different planes are in good coincidence with experimental results.

***Keywords**: Tube hydroforming, Free bulge forming, DE-FORM Software, EN-31, Axial feeding, internal fluid pressure, FEA Simulation, loading path.*

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1. INTRODUCTION

Tube hydroforming is a one of the most commonly used unconventional metal forming process in Automotive and aerospace industry to produce hallow shapes with complex geometries by using axial force and internal pressure. Tube Hydroforming is also called by many other names Such as bulge forming of tubes, hydraulic pressure and liquid bulge forming depending on the time and country in which it was used. In recent years more researches has done on Tube hydroforming by using FEA software such as LS-DYNA, ABAQUS, PAM-STAMP, AUTO-FORM, DE-FORM. These are used to study and analyze the various processes parameters axial force and internal pressure, friction effect, thickness distribution. Most failure modes in THF can be classified as wrinkling, buckling, bursting. These types of failures are caused by either excessive internal pressure or excessive axial end feed during the forming process. The principle of free bulge test is simple; a metal tubular specimen is loaded with internal pressure and expands, undergoing plastic deformation until bursting occurs. During the process the tubes locked on both ends and straighten freely using hydraulic internal pressure. This paper aims to analyze the hydroforming process by using DE-FORM software and compare the simulation results with experimental results The process provides a number of advantages in comparison with conventional manufacturing via stamping and welding such as:

1. Part consolidation resulting in weight reduction of the component,
2. Weight reduction through more efficient section design and tailoring of the wall thickness,
3. Reduced tooling cost, dimensional variations and scrap rate.
4. Improved structural strength and stiffness,
5. Less number of secondary operations.

1.1 Applications of THF

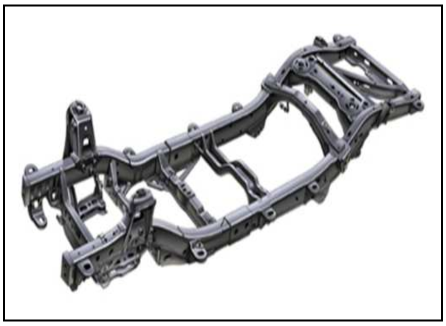

Fig.1. Chevy SSR Hydroformed frame

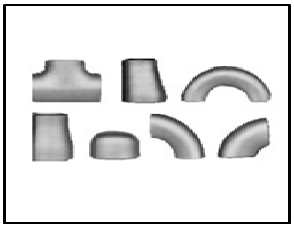

Fig.2. Pipe bindings

2. OBJECTIVES

The present research work mainly deals with the following topics

1. Comparing the hydro forming simulation results with the experimental results.
2. To investigate the load prediction, velocity distribution, damage and effective strain during the hydroforming.
3. To study various process parameters effect on the maximum branch height and wall thickness.
4. To analyze the tube hydroforming process failures.

The following steps are involved during the DEFORM Simulation:

1. Solid modeling
2. Material model
3. Contacts
4. Boundary condition
5. Loading

3. SPECIFICATIONS AND THEORETICAL CALUCLATIONS

The principle of tube hydroforming is the tube is first filled with a liquid emulsion of a water-soluble material after which the die is closed. The tube is then forced to adopt the inner contour of the die by application of an internal pressure and two axial forces.

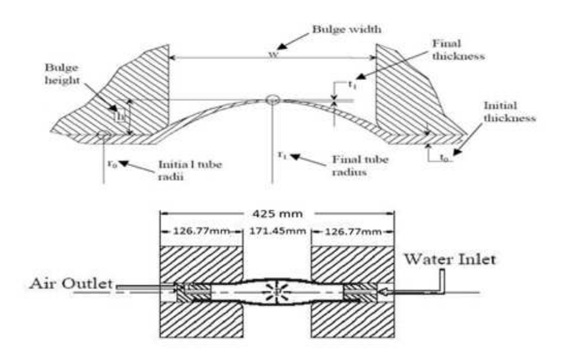

Fig.3 Detailing Specifications of the Tube and die

3.1 Failures in Tube Hydroforming

The risk of bursting is a result of too high internal pressure and is initiated by a local neck in the tube wall, whereby the onset of this local necking significantly depends on the initial tube wall thickness. To prevent this risk it must be ensured that the tube wall briefly comes into contact with the wall of the tool at the latest before the onset of necking.

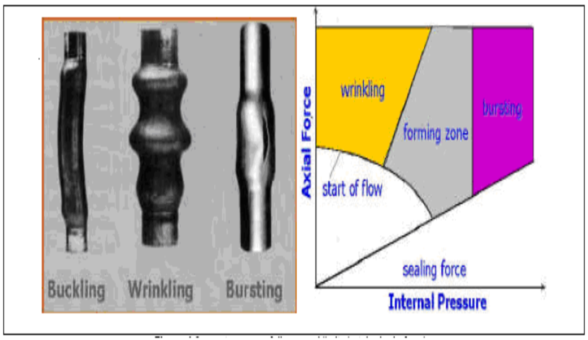

Fig. 4 Failures and Limits in Tube Hydroforming

The risk of buckling is posed at the start of the process by too high axial loads on the initial tube, and it is also present for the entire starting phase. So the risk of buckling can be avoided by compensation the unsupported tube length with increasing in the section modulus of the tube cross section through the simultaneous expansion of the tube wall.

Wrinkles are, as exhibited during free forming at the intake regions of the expansion zone, if the pure-shear path is selected. These wrinkles cause no problem and are straightened out during calibration.

3.2 Geometrical Specifications of the Tube

Table 1: Dimensions of the tube

Length L (mm)	Internal diameter tube Di (mm)	Outer diameter tube D0 (mm)	Thickness t0 (mm)
250mm	54.15	57.15	1.5

Table 2: Chemical Composition of EN-31

EN-31	C	Mn	Si	S	Ni	Mo	P	Cr
Wt. %	1.08	0.53	0.25	0.015	0.33	0.06	0.022	1.46

Table 3: Mechanical characteristics EN-31

Density(Kg/m3)	8900
Yield strength (MPa)	110
Modulus of elasticity (MPa)	215000
Tensile strength (MPa)	241.59

3.3 Theoretical Calculations

3.3.1 Process Parameter Evaluations

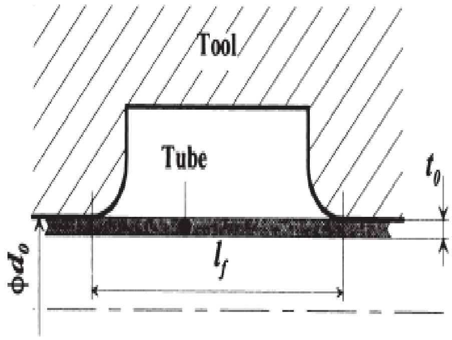

Fig.5 Illustration of free tube length

1. Free tube length

If 20 ≤ d0/t0 ≤ 45 → lf ≤ 2d0

If d0/t0 > 45 → lf <<2d0

If d0/t0 <20 → lf > 2d0

2. Corner radius of the die

$$R_1 = 3t$$

3. Internal Pressure Limits

1. Internal pressure at yielding is calculated by

$$(P_i)_y = \sigma_y \frac{2t_0}{(D_0 - t_0)}$$

2. Maximum internal pressure can be calculated by

$$(P_i)_b = \sigma_u \frac{4t_0}{(D_0 - t_0)}$$

4. Sealing force

$$F_{sealing} = \pi R_0 t_0 \sigma_y$$

5. Friction force

$$F_{friction} = \mu P_i \pi d_0 (l_0 - s)$$

3.3.2 Input Parameters

Internal pressure at yielding

$$(P_i)_y = \sigma_y \frac{2t_0}{(D_0 - t_0)}$$

$$= 2034 \frac{2*1.5}{(57.15-1.5)} = 110 Mpa$$

Internal pressure at bursting

$$(P_i)_b = \sigma_u \frac{4t_0}{(D_0 - t_0)}$$

$$= 2240.39 \frac{4*1.5}{(57.15-1.5)} = 241.59 Mpa$$

4. MODELING AND SIMULATIONS

4.1 Modeling of Tube, Dies and Axial Plungers

The solid models of tubler blank, top die and bottom die, axial plungers with proper dimensions are shown below figures.

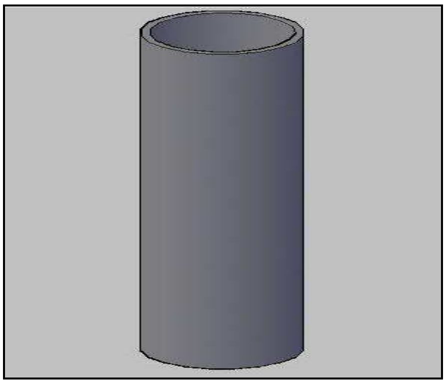

Fig.6 Solid Model Tubular blank

4.1.1 Tube blank details

Length L = 250 mm
Internal diameter Di = 54.15 mm

Outer diameter of tube D0 = 57.15 mm
Thickness of tube t_0 = 1.5 mm

4.1.2 Die, Plunger for free bulge

Two upper and lower dies are modeled by using Auto cad as shown in below. Model of the die is, as shown in the Figure.7

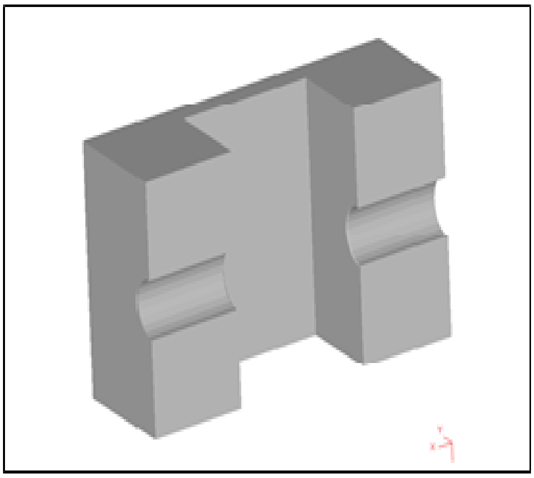

Fig.7 Solid Model of die for free bulge forming

Die length L_d. = 250 mm
(Length perpendicular to tube axis)
Width b = 171.45 mm
(Width parallel to the tube axis)
Corner radius R_1 = 5 mm
Tube cavity diameter d_0 = 57.15 mm
Height of die H= 110 mm

The diameters of the two axial Plungers are same and models of axial plunger shown in figure.8

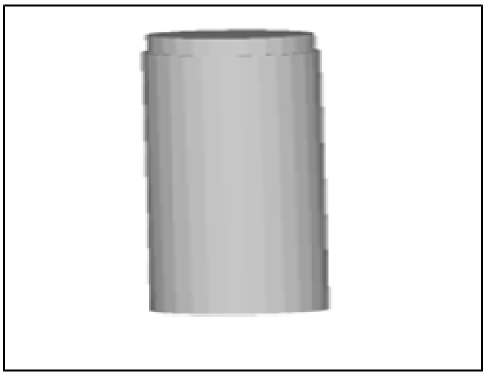

Fig.8 Solid model of axial plunger

4.2 Fem Simulation Procedure

During simulation of Tube hydro firming process using computer, we need to create computer models of the deformation system and the metal forming process. Through the last few years it has been discovered that it is expensive and time consuming to use trial and error for the investigation of tube hydroforming process and conventional metal forming process. The application of numerical simulation of the hydroforming process was help to engineers efficiently improve the process development avoiding the cost and limitations of real world parts.

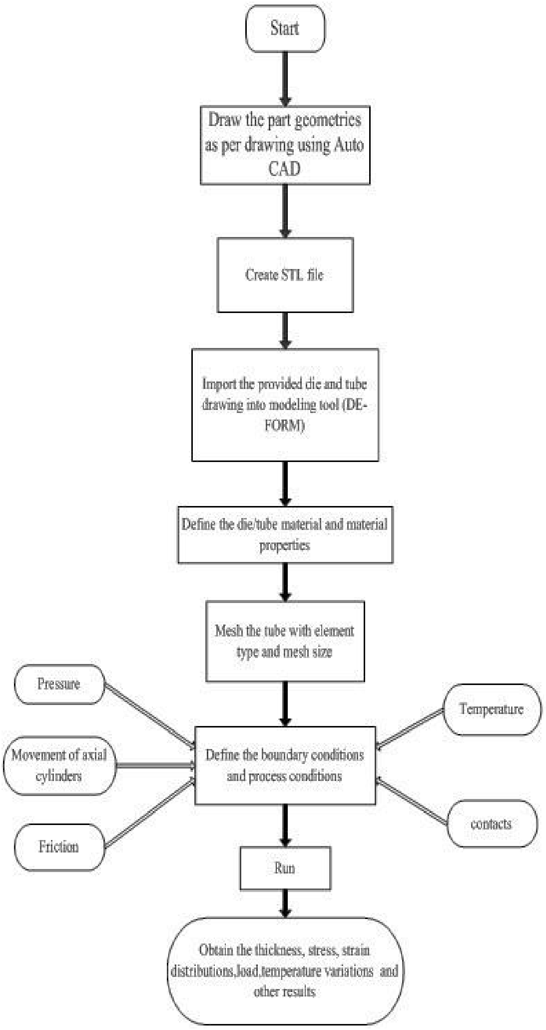

Fig.9 Flow Chart for the Simulation

DEFORM is a Finite Element Method (FEM) based process simulation system designed to analyze various forming and heat treatment processes used by metal forming. By simulating manufacturing processes on a computer, this advanced tool allows engineers and designers to reduce the need for costly shop floor trials and redesign of tooling and processes.

1. Improve tool and die design to reduce production and material costs.
2. Shorten lead time in bringing new products to the market.

For dies, rigid analysis was selected and the tube is having have Isotropic behavior and after mesh verification the simulation and experimental results were compared. Material used for this analysis is EN -31. Mechanical and physical properties and tube dimensions are shown in Tables. The following steps are involved during FEM based DEFORM simulation process.

The objective of this work is to analyze the forming process in detail, and compare the finite element simulation results with the corresponding experiment results. Since complete FEM formulation using DEFOERM software for THF is well established, the mathematical calculations are not discussed here.

5. RESULTS & DISCUSSION

The various simulated process parameters values are compared with experimental values below.

5.1 Branch height

The final branch height (H) for free bulge forming from the simulation results is compared with the hydro formed experimental sample's branch height. Table: 5 show the results of the final branch height development. The maximum deviation in the branch height obtained from simulation is within ±5.9 % of the experimental value. The variation in the simulation result may be due to various factors such as

(i) Accuracy of finite element modeling,
(ii) Frequently changing boundary and friction conditions during the forming process and
(iii) Error in measurement of the wall thickness.

Table.5 Branch height comparison—experiment and simulation results

	Free-bulge
Maximum Internal pressure (MPa)	186
Maximum Feed (mm)	5.37
Branch height (mm) (Experimental)	9.81
Branch height (mm) (Simulation)	9.23

5.2 Effects of Variation of Internal Pressure to the Branch Height

Simulations of free bulge forming are conducted to study the effects of variation of internal pressure on the final branch height (H) development. The boundary conditions and material properties used are same as those used for previous simulations with a tube length of 250 mm and die corner radius of 5 mm. The plots in Fig.10 shows the relationship between branch heights, with the increase of pressure the branch height also increased. The graph shows the comparison between the simulated and experimental branch heights. And it is observed that the branch height in simulation is very much closer to the experimental bulge heights. So it is concluded that the simulated result value are reliable.

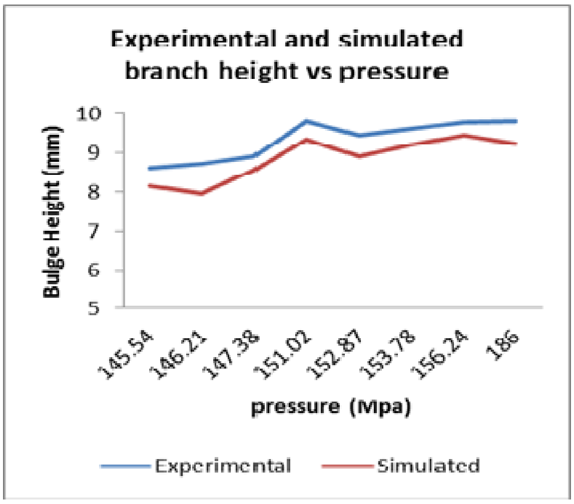

Fig.10 Experimental and simulated branch height vs. pressure

The free bulge tubes are modeled with 22485 tetrahedral mapped meshed elements for the deformable blank portion (i.e. tube). Contact boundary conditions of dies and plungers are also specified. The loading paths/boundary conditions used for the simulations were matched with the loading paths as used length of the tube, i.e. from the center or forzy-plane point of maximum branch height to towards tube end. Due to the presence of plungers the wall thickness at the tube end has decreased in comparison to the straight portion of the tube. Thus in the wall thickness plots the thickness at the tube end was ignored.

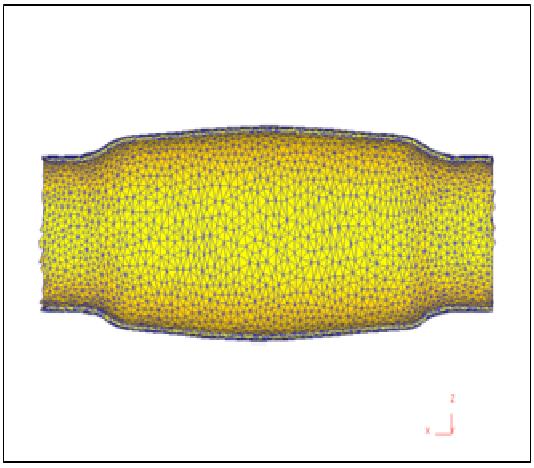

Fig.11 Simulation of free forming

5.3 Load on Axial Punches

The deformation load during free bulging of hydro forming simulation is shown in Fig.12 There are two different portions in the deformation loading path. Firstly, deformation load increases rapidly as shown in figure until initial flow of the central part of the tube. After this, the load decreases to a lower rate until the end of free forming.

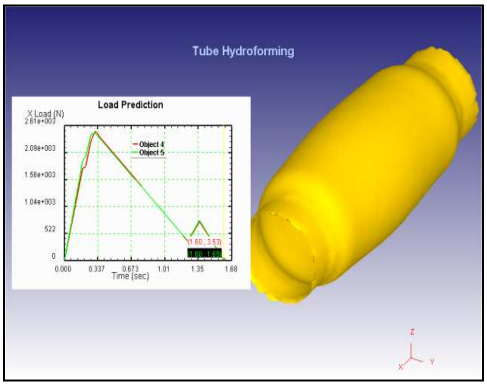

Fig.12 Load prediction in x load

5.4 Velocity Distribution

Velocity distribution is shown in Fig.13 for free bulge hydro tube forming. It is lower at the ends of the tube blank and is higher at the center of the tube. This is because the axial load is more effective at the ends of the tube. But in the case of free bulge, this velocity has distributed up to the center of the tube because more material is moving to the deformation zone. At the ends of the tube, nodal velocity for free bulge is 0.503 mm/s.

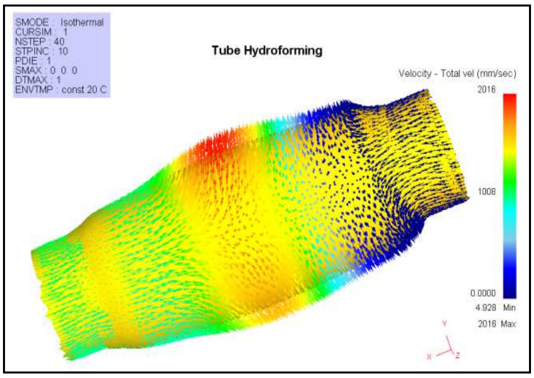

Fig.13 Velocity distribution of free bulges forming THF

The axial feed between two axial plungers i.e., objet4 and object5 are shown in Fig.14.The axial feed is mutually applied with the corresponding time. The velocity is increases with the time increment up to 1mm/sec and then maintains constantly show in fig.14

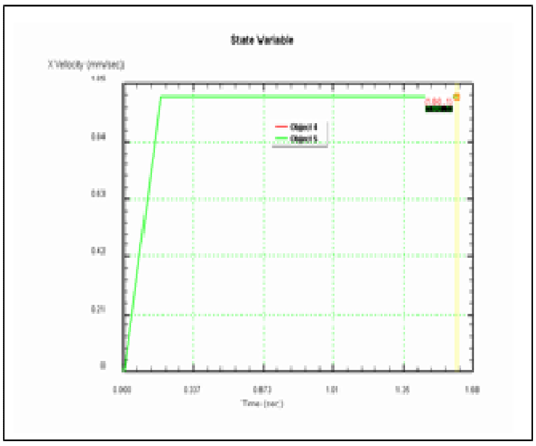

Fig. 14 Time vs. velocity distribution in x direction

5.5 Effective Strain

The distribution of Effective plastic strain is shown in Fig.15 the distribution in the center of the tube is biggest value of effective strain but no failure occurs due to predominant compressive strain. In the fig shows red colour zone part of the tube, effective strain is smaller than that in the center, but tensile strain is predominant, so this is the region where failure occurs. Another important aspect is the radius region bellow the plane part in the tube. It has a similar behavior of biaxial stretching.

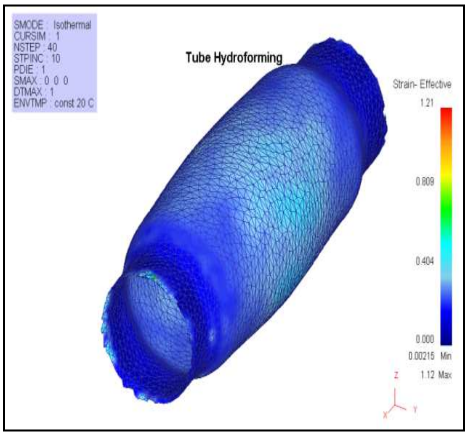

Fig. 15 strain effective with mesh mode

5.6 Stress Effective

Effective stress distribution for free bulge forming is shown in Fig. Due to compressive load, the stresses occur at the ends of tube. At the center of the tube, the tangential stresses are predominant. These tangential stresses occur due to internal pressure. Due to higher tangential stress at the center of the tube (at the protrusion), fracture occurs shows in fig16

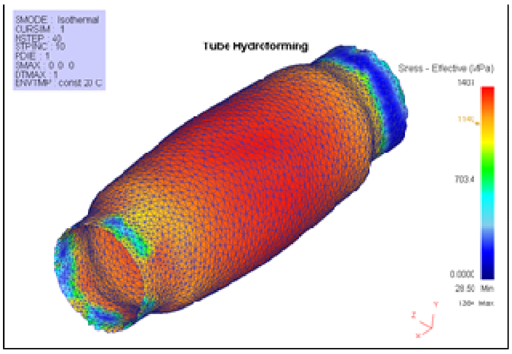

Fig.16 Stress Effective with Mesh

The experimental results of free bulge forming compared with THF simulation results with proper boundary conditions and loading paths. The DEFORM-3D simulation results for branch height obtained and the strain and stress effective distribution during forming, total velocity travel are compared with experimental results. Various simulation results can also be used for different parametric studies using the postprocessor of the simulation solver.

CONCLUSIONS

From various simulations conducted for free bulge shaped tubes, it can be concluded that, in order to form a part with relatively uniform wall thickness throughout the new geometry while simultaneously maximizing the part expansion, it is quite important to select the optimum tube blank length, die radius and suitable contact lubrication conditions.

From the various parameter studies, the wall thickness and the branch height are most sensitive to friction, axial load, and internal pressure. It is found that a maximum velocity takes place in the plunger movement direction, whereas in transverse direction there is comparatively lower velocity.

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BIOGRAPHIES

Mr.Bathina sreenivasulu, Assistant professor in Mechanical Engineering Department, Madanapalle institute of technology and sciences, Angallu, Madanapalle. He has 5 years of teaching experience and 3 years of industrial experience. He completed M.Tech in 2007 at Institute of technology, Banaras Hindu University, Varanasi and pursuing Ph.D. at JNTUA College of engineering, Anantapur Under the guidance of Dr.G.Prasanthi. He had guided 3 M.Tech projects and published 8 papers in various National and International Journals and Conferences.

Dr.G.Prasanthi, Professor in Mechanical Engineering Department, JNTUA College of Engineering, Anantapur. She has 18 years of teaching experience. She has guided 22 M.Tech projects and supervising 9 Ph.D students. She has published about 28 papers in various National and International Journals and Conferences. She has completed an AICTE (R&D) Project “Multi- Attribute Decision Models for the Design and Operation of FMS ". Her areas of interest are CAD/CAM, Manufacturing Systems Engineering and Energy Conservation. She served as Board of Studies chairman for Mechanical Engineering in 2011 at JNTUA CE, Anantapur.

T.Naresh Kumar, Pursuing M.Tech (Machine design) in Madanapalle institute of technology and sciences, Angallu, Madanapalle. He completed B.Tech at Sri Venkateswara College of engineering and technology in Mechanical Engineering. He has received his diploma in Automobile engineering in 2005.