

Optimization of Isogrid Rib-Pattern on Mechanical Housing

Vijay Thammisetty¹, Narashima Reddy²

M.Tech. Student, Dept. of Mechanical Engineering, Malla Reddy Engineering College, Maisammaguda, Telangana, India¹

Associate Professor, Dept. of Mechanical Engineering, Malla Reddy Engineering College, Maisammaguda, Telangana, India²

ABSTRACT: Isogrid structures are used in aerospace applications because they reduce weight while maintaining structural efficiency. This paper presents the specific stiffness of isogrid plates with and without skin. Isogrid plates can be regarded as flat plates strengthened by an appropriately designed superimposed grid structure of ribs either flanged or unflanged. The concept in which the most promising factor is triangulation of stiffening members. This rib-pattern took advantage of the simple fact that triangular trusses are very efficient structure. This paper outlines how optimization of Isogrid structures are developed by using MATLAB. This paper also emphasis the relevance of the reduction of time of design on designing software, and also helps to trace out the set of dimensions of isogrid structure, mass significantly the specific stiffness

KEYWORDS: Isogrid structures, optimization, rib-pattern, MATLAB, specific stiffness

I. INTRODUCTION

The design of the isogrid structure allows the part to maintain isotropic properties even though material has been removed for weight reduction. . These structures usually consist of a base structure forming the “skin/without skin” and local reinforcement elements called “stiffeners” to improve the static and dynamic characteristics of the base structure. Isogrid stiffener configuration is a special class of stiffened or grid structures whereby the grid members are arranged in an isosceles triangular patterns. Due to their efficiency, these isogrid members have been widely used in many structural applications especially in spacecraft components. Since then extensive efforts have been exerted to study isogrid structures in an attempt to maximize their stiffnesses, Eigen frequencies, and/or critical buckling loads while imposing stringent constraints on the total structural mass.

MATLAB (Matrix Laboratory) is a multi-paradigm numerical computing environment and fourth-generation programming language. A proprietary programming language developed by Mathworks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, Fortran and Python.

II RELATED WORK

The isogrid rib-grids are analyzed by "smearing out", averaging, or taking mean values of the grid properties so that the grid work is considered as a solid continuous sheet of material with appropriate elastic properties. It is shown that if one assumes a uniaxial state of stress in the bars, the smeared-out elastic constants are identical to those of an isotropic material in plane stress. When ribs and skin are combined, the composite construction is treated as an isotropic layered material, with appropriate elastic constants for each layer, viz., rib-grid and skin. The critical load for this problem is shown in equation

$$P_{cr} = (\pi^2 E_i) / 4I^2 \quad (1)$$

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$$P = n^2 \pi^2 EI / l^2 \tag{2}$$

The symmetry condition allows the finite element model to be simplified. A free beam will have a rigid body motion due to the lack of constraint in one direction. Thus this simplified symmetric model is better suited for numerical analysis when applicable. The problem under consideration is not a 2D structure but rather a complex 3D part that contains an isogrid pattern. As previously stated the isogrid is used to reduce the weight of the structure while still maintaining the isotropic material properties of a single sheet of material. A typical isogrid structure can be seen below in figure.

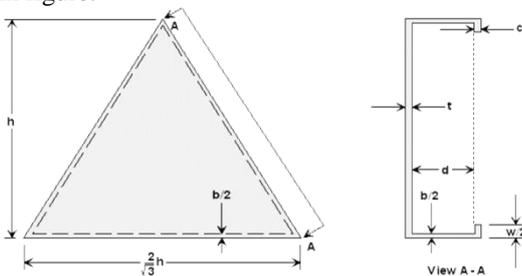


Fig:3.1.1 Typical view of flanged isogrid

- b - Rib thickness
- c - flange thickness
- d - rib height
- h - cell height
- t - face sheet thickness
- w - flange width

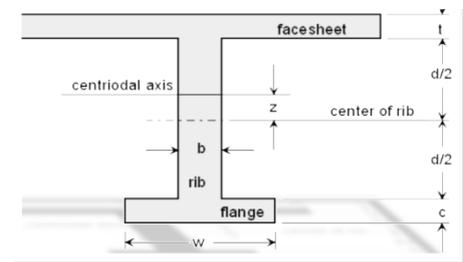


Fig:3.1.2 Transformed view of flanged isogrid

Table 3.1.1 Transformed section properties using parallel axis theorem

Part	A_i	ζ_i	$A_i \zeta_i$	$A_i \zeta_i^2$	I_0
1	t	$\frac{t}{2}(1 + \delta)$	$\frac{t^2}{2}(1 + \delta)$	$\frac{t^3}{4}(1 + \delta)^2$	$\frac{t}{12}t^2$
2	$t\alpha$	0	0	0	$\frac{t\alpha}{12}(\delta t)^2$
3	$t\mu$	$-\frac{t}{2}\mu(\delta + \lambda)$	$-\frac{t^2}{2}\mu(\delta + \lambda)$	$\frac{t^3}{4}\mu(\delta + \lambda)^2$	$\frac{t\mu}{12}(\lambda t)^2$
Total	$t(1 + \alpha + \mu)$		$\frac{t^2}{2}[(1 + \delta) - \mu(\delta + \lambda)]$	$\frac{t^3}{4}[(1 + \delta)^2 - \mu(\delta + \lambda)^2]$	$\frac{t^3}{12}[1 + \alpha\delta^2 + \mu\lambda^2]$

The plate will not have the same geometric dimensions as the isogrid but it will have the same stiffness in both the tensile and bending directions. This simplification allows multiple design iterations to be completed by changing only the stiffness of the part and not the model geometry. The simplification also allows for a reduction in computational time. Assuming the isogrid plate is in a state of uniaxial stressing it can be shown that the structure is equivalent to a single sheet in plane stress. The process to simplify the sheet uses several non-dimensional parameters ($\delta, \lambda, \alpha, \mu, h$) for a unit width of isogrid. The procedure also uses the parallel axis theorem to reduce the isogrid to a single sheet. The non-dimensional parameters are defined in equation 3. The single sheet will have an equivalent tensile stiffness (K) and bending stiffness (D), where ν is the material Poisson's ratio and E_0 is the material elastic modulus. The different stiffness equations are shown in equation 4 and equation 5.

$$\delta = d / t, \lambda = c / t, \alpha = bd / th, \mu = wc / th, h = a\sqrt{3}/2 \tag{3}$$

$$D = 1 / (1 - \nu^2) E_0 I \tag{4}$$

$$K = 1 / (1 - \nu^2) E_0 A \tag{5}$$

To complete the transformation the individual areas (A_i), centroids (ζ_i) and moment of inertia (I_0) are calculated with the equations in the table. This table contains all the required information to calculate the appropriate stiffness

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properties for the equivalent thickness plate. The final stiffness for the plate is calculated from the total section properties. These are seen in equations 6, 7 and 8.

$$A = \sum A_i \tag{6}$$

$$\zeta_t = \sum A_i \zeta_i / A \tag{7}$$

$$I = \sum A_i \zeta_i + \sum I_{oi} - A \zeta_i^2 \tag{8}$$

The equations for both I and A are now in terms of variable t only. Thus with two equations for stiffness (K, D) and two unknowns (E, t) equation 4 and 5 are solved simultaneously to determine an equivalent thickness and stiffness. The solution of the two equations creates a sheet with an equivalent thickness (t*) and an equivalent elastic modulus (E*) that must be used together to create the required tensile and bending stiffness. By producing the correct stiffness with t* and E* these variables can be used together to predict loads but not stress. Thus the combination is used for the calculation of critical buckling loads. Equations for t* and E* are shown in equation 9 and equation 11. Equation 10 can be used to calculate the internal parameter β, which can be used to calculate t* from only non-dimensional parameters. The parameters E* and t* will be used when comparing an equivalent single sheet to the isogrid structure.

$$t^* = \sqrt{(12I/A)} = t \beta / (1 + \alpha + \mu) \tag{9}$$

$$\beta^2 = (1 + \alpha + \mu) [3(1 + \delta)^2 + 3\mu(\delta + \lambda)^2 + 1 + \alpha\delta^2 + \mu\lambda^2] - 3[(1 + \delta) - \mu(\delta + \lambda)]^2 \tag{10}$$

$$E^* = E_o A / t^* \tag{11}$$

With equation 9 and 11 it can be shown that equation 4 and equation 5 can be put in terms of both E* and t* where D and K are now represent the correct stiffness for the isogrid. These can be seen in equation 12 and equation 13.

$$D = E^* t^{*3} / 12(1 - \nu^2) \tag{12}$$

$$K = E^* t^* / (1 - \nu^2) \tag{13}$$

III. PRESENTATION OF THE MAIN CONTRIBUTION OF THE PAPER/SCOPE OF THE RESEARCH

In general, grid structures have been used in numerous applications. Most of the previous work has been directed to the study of static and buckling characteristics of grid structures. Very few articles discuss their performance in dynamic loading which may lead to a wide implementation in the field of vibration and noise control. Most of the modeling effort was not well suited to these specific structures which resulted in either oversimplified models dealing with the skin and the stiffeners as two independent problems or computationally intensive models with numerous 3D elements. A theoretical model that is able to accurately describe grid structures, without being too complicated to solve, is essential to work in **MATLAB** to get optimized grid structures.

To reduce design and analysis time, **MATLAB** tool helps to get more number of combinations. As per our requirement best set of combination can be selected easily to design. By giving input values Elastic Modulus “E₀”, poisson's ratio “ν”, length of rectangle “l”, width of rectangle “w”, face sheet thickness “t”, side of triangle “a”, rib thickness “b”, we can achieve output results bending stiffness “D”, tensile stiffness “K”, specific stiffness “Q”, “mass”. according to mass limitations and requirement of high stiffness best configuration can be selected easily.

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IV. METHODOLOGY AND DISCUSSIONS

UNFLANGED ISOGRID

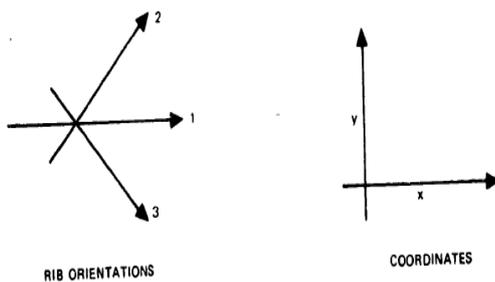


Fig.3.1.3 Rib orientations, coordinates

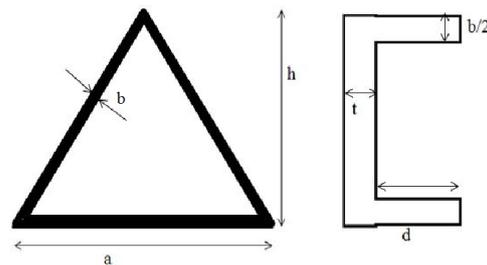


Fig.3.1.4 Typical view of unflanged isogrid

Elements for Fig 3.1.4

- b - Rib thickness
- a - side of triangle
- d - rib height
- h - cell height
- t - face sheet thickness

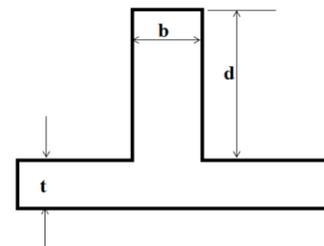


Fig.3.1.5 Transformed view of unflanged isogrid

$$\alpha = bd / th, \delta = d / t, h = a\sqrt{3}/2$$

For unflanged isogrid, $\lambda = \mu = 0$ in the equations developed for flanged isogrid on the preceding pages.

$$\beta = \beta(\alpha, \delta) = [3\alpha(1+\delta)^2 + (1+\alpha)(1+\alpha\delta^2)]^{1/2}$$

For construction consisting of skin alone (monocoque),

$$\alpha = \delta = 0, \beta = 1$$

In terms of α and β ,

$$K = E^*t^*/(1-\nu^2) \times (1+\alpha)$$

$$D = E^*t^{*3}/12(1-\nu^2) \times \beta/(1+\alpha)$$

now, Equivalent t^* and E^*

$$t^* = \sqrt{(12I/A)} = t \beta/(1+\alpha)$$

$$E^* = E_o A / t^* = E_o (1+\alpha)^2/\beta$$

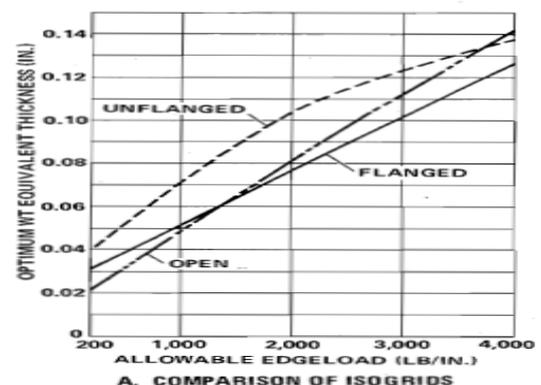


Fig.3.1.5 graph showing comparison of isogrids

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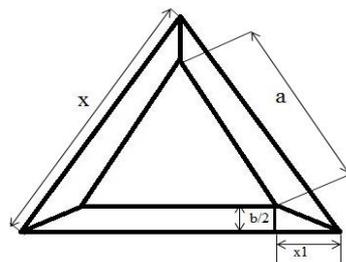
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Optimization of isogrid using MATLAB

For an isogrid rib-pattern implemented housing, considering the limitations in mass and specific stiffness it is difficult to assume a set of combinations of dimensions to design a component using design tool. No. of iterations on design tool and then analyzing consumes a lot of time. So, by using MATLAB we can generate a code in which all set of combinations can be easily sorted out and can go directly to design with a good set of dimensions in isogrid rib-pattern.

Testing scope involved in MATLAB:

- Step-1: selection of material with elastic modulus E_0 , Poisson Ratio ν and density value
- Step-2: required length and width of one surface of isogrid housing
- Step-3: assumed values of "a" side of the triangle
- Step-4: assumed values of "t" face sheet thickness
- Step-5: assumed values of "b" rib thickness
- Step-6: to the given input value "a", formulating find out area of equilateral triangle and "h" height of the triangle
- Step-7: to the given input value "b", formulating find outside of isogrid triangle "x" and total area of trapezoidal shapes $3Tr$
- Step-8: formulating to find out area of isogrid triangle and no. of isogrid triangles
- Step-9: formulating to find out area of grid structure
- Step-10: formulating to summation of volumes of "skin" and "grid"
- Step-11: formulating to code for non-dimensional parameters delta, alpha and beta
- Step-12: formulating to find out area of unflanged isogrid transformed structure
- Step-13: formulating E^* and t^*
- Step-14: formulating bending stiffness "D".
- Step-15: formulating tensile stiffness "K".
- Step-16: finding out mass of isogrid plate
- Step-17: formulating specific stiffness "Q"
- Step-18: plotting the results



V. EXPERIMENTAL RESULTS

fig:3.2.1 Showing side of isogrid cell "x"

- Step-1: selection of material with elastic modulus $E_0 = 70 \times 10^3$ aluminum alloy(7075-T6) Young's modulus (N/mm²), Poisson Ratio $\nu = 0.34$ and density value 2.7×10^{-6} (kg/mm³)
- Step-2: length=200 and width=200
- Step-3: $a = [13 \ 15 \ 17 \ 19]$
- Step-4: $t = [1 \ 2 \ 3 \ 4 \ 5 \ 6 \ 7 \ 8 \ 9 \ 10]$, ($d = 10 - t$)
- Step-5: $b = [1 \ 2 \ 3]$
- Step-6: area of equilateral triangle "area" = $\sqrt{3}/4 \times a^2$ and "h" height of the triangle $\sqrt{3}/2 \times a$

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Step-7: side of isogrid triangle “x” = $a + 2 \times x1$ since $x1 = \frac{b}{2} \times \frac{\tan \pi}{6}$ and total area of trapezoidal shapes $3Tr = a + (a + b \frac{\tan \pi}{6}) \frac{b}{4}$

Step-8: total area of isogrid “A” = $3Tr \times area$ and no. of isogrid triangles $N1 = l \times w \div A$

Step-9: area of grid structure “N2” = $l \times w - N1 \times area$

Step-10: volume of “skin” vol 1 = $N2 \times d$ and volume of “grid” vol 2 = $l \times w \times t$

Step-11: $\alpha = bd / th$, $\delta = d / t$, $h = a\sqrt{3}/2$

Step-12: $\beta = \beta(\alpha, \delta) = [3\alpha(1+\delta)^2 + (1+\alpha)(1+\alpha\delta^2)]^{1/2}$

Step-13: formulating $E^* = E_0 A / t^* = E_0 (1+\alpha)^2 / \beta$ and $t^* = \sqrt{(12I/A)} = t \beta / (1+\alpha)$

Step-14: formulating bending stiffness “D” = $E^* t^{*3} / 12(1-\nu^2) \times \beta / (1+\alpha)$

Step-15: formulating tensile stiffness “K” = $E^* t^* / (1-\nu^2) \times (1+\alpha)$

Step-16: finding out mass of isogrid plate “mass” = density \times volume

Step-17: formulating specific stiffness “Q” = $\sqrt{\frac{k}{m}}$

Step-18: plotting the results

When a=13

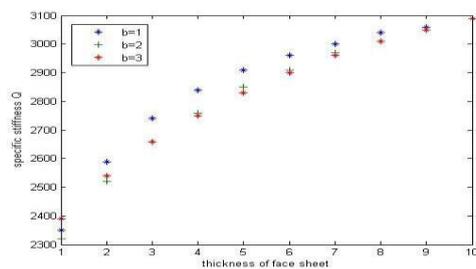


Fig:3.2.2 Graph specifying specific stiffness of Q vs t (mm)

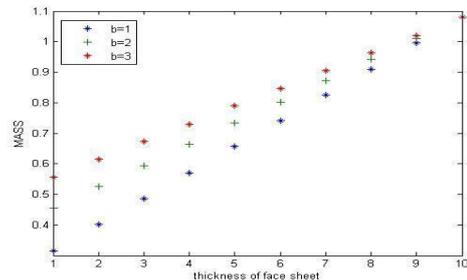


Fig:3.2.3 Graph specifying mass(kg) vs t(mm)

when a=15

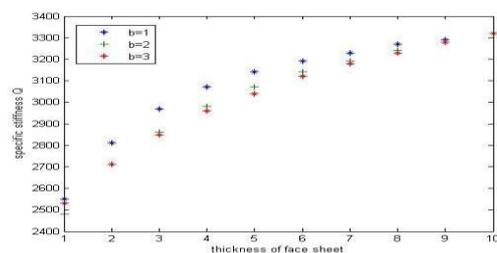


Fig:3.2.4 Graph specifying specific stiffness of Q vs t(mm)

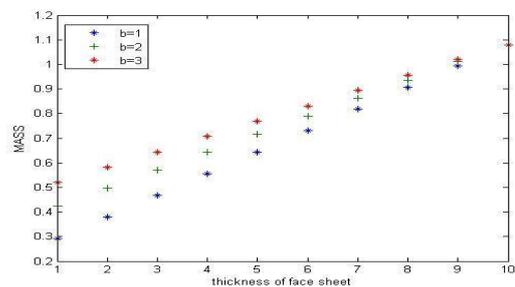


Fig:3.2.5 Graph specifying mass(kg) vs t(mm)

when a=17

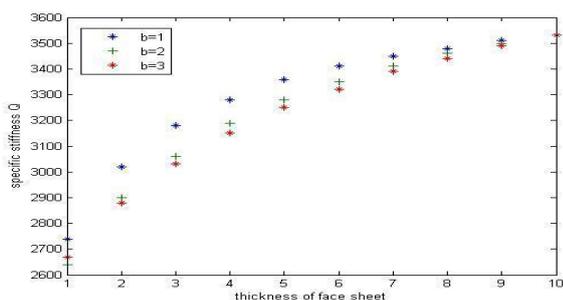


Fig:3.2.6 Graph specifying specific stiffness of Q vs t (mm)

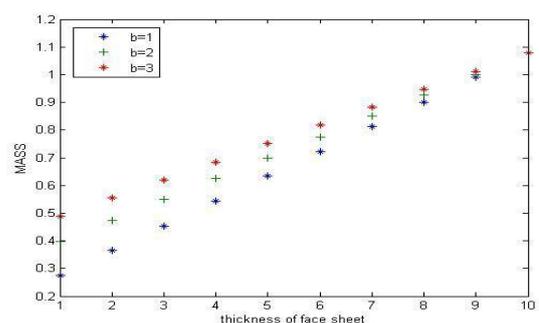


Fig:3.2.7 Graph specifying mass(kg) vs t(mm)

when a=19

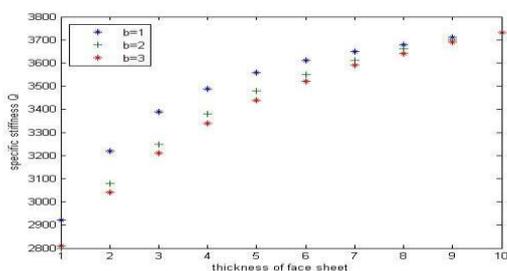


Fig:3.2.8 Graph specifying specific stiffness of Q vs t (mm)

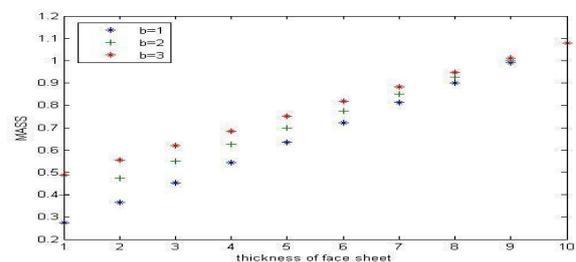


Fig:3.2.9 Graph specifying mass(kg) vs t(mm)

VI. CONCLUSIONS

By analysing, various grid structures, isogrid pattern is selected as a suitable structure for the high stiffness requirements of the mechanical housing. The overall weight of the housing is reduced by mounting the isogrid pattern on the outer faces of the housing.

Modal analysis is carried out for the housings of following dimensions :

1. Housing (with isogrid pattern) of (351*215*226) mm, with mass 5.7Kg,
2. Housing of (388*208*233) mm, with mass 6.5 Kg.

From the results of modal analysis, following observations are made.

Mode Of Displacements	Frequency on Chassis without Isogrid Structure (in HZ)	Frequency on Chassis with Isogrid Structure (in HZ)
Mode 1	460.335	578.026
Mode 2	502.209	671.595
Mode 3	548.606	708.091
Mode 4	670.961	725.902

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Mode 5	767.616	969.375
Mode 6	806.448	1063.47
Mode 7	888.170	1080.72
Mode 8	889.1538	1166.602
Mode 9	945.1795	1188.96
Mode 10	959.92	1227.308

From the data, observed that by mounting isogrid pattern, the performance of Inertial Measurement Unit and other electronic components placed in the housing, has been improved in the vibration environment. From the result of Random vibration analysis, observed that, overall vibration response for the given random excitation is less in the case of isogrid chassis, as compared to the normal chassis. By adopting isogrid Pattern on the structure of mechanical housing will be a better solution for the problems encountered in the mechanical design of Inertial Navigation Systems, in aerospace structures. The Vibration Isolator of Model GBC-136-284 of GAMMA, with frequency 80 HZ, has been selected for the IMU configuration. For an isogrid rib-pattern implemented housing, considering the limitations in mass and specific stiffness it is difficult to assume a set of combinations of dimensions to design a component using design tool. No. of iterations on design tool and then analyzing consumes a lot of time. So, by using MATLAB we can generate a code in which all set of combinations can be easily sorted out and can go directly to design with a good set of dimensions in isogrid rib-pattern. Optimization using MATLAB is a new way and it has more scope in future enhancement. Modelling on tools and changing configuration is a time taking process, so optimization with MATLAB is emerging trend.

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BIOGRAPHY



Vijay Thammisetty is presently carrying out research work in Mechanical Engineering. His area of research is Optimization of isogrid rib-pattern. His specialization is Advanced manufacturing systems in Master of Technology Degree.



Narashima Reddy obtained Master of Technology From JNTU Hyderabad, Mumbai. He has an experience of more than 11 years in the field. He has published more than 18 international publications in the field of Mechanical Engineering. His research interests are fluid mechanics, manufacturing systems, thermal engineering.