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Design, Manufacturing and Analysis of Metal Expansion Bellows

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Abstract*— The flexible element of an expansion joints consisting of one or more convolutions and the end tangent with the ratio of length of the bellows to the diameter of the bellows must be less or equal to three with no more than five plies. Bellows are one of the most efficient energy absorbing elements for engineering system. Bellows have a function to absorb regular or irregular expansion and contraction in piping system, its are widely used as the element of expansion joint in various piping system, aerospace, micro electromechanical and industrial system. Bellows are special structures that require high strength as well as good flexibility. Most industrial piping system often suffer excessive deformation, displacement, heat expansion, vibration, and other causes are responsible for the failure. The failure of bellows expansion joints made of SS 304 has been analyzed. Over pressure, Vibration of steam in piping are responsible for the failure. After complete observation of the bellows we found that wrong design data are assumed at the time of bellows manufacturing and finally these bellows are fail within 1 year of service. Based on these design data we have improve the design and its re-design the metal expansion bellows by using EJMA code adding with inner liner. To prevent the bellows failure chances we have provide internal liner in the bellows which has many advantages such as: to ensure smooth flow of media, minimize friction losses, minimize resonant vibration caused by high flow velocity, reduce the effect of turbulent flow upstream of the expansion joint, prevent erosion of the bellows wall from chemical and abrasive attack, reduce the temperature of the bellows in high temperature application. The manufacturing process of metal bellows consists of the four main forming processes: deep drawing, ironing, tube bulging, and folding. Forming process of the metal bellows is very sensitive. In the present study a new method has been proposed for manufacturing of the metal bellows. A single step hydro forming process is used to make metallic bellows with simultaneous control of internal fluid pressure and compressive axial feeding. A number of convolutions of bellows have formed with the use of various hydro forming die shapes. and important parameters such as initial length of tubes, internal pressure, axial feeding, velocity, mechanical properties, types of material used are also studied. In this work A finite element analysis (FEA) of bellows proposed in this paper to for the validation of the software results and EJMA design calculated results bellows with the inner liner. Finally the validation of results of EJMA design calculated value and FEA value shows a very good agreement. Here by adding the inner liner in the bellows gives the better results and performance achieved then the conventional bellows.

Keywords: **Bellows, Design, Manufacturing process, effective parameters, modeling, Solid works analysis, Concept of inner liner.**

I. INTRODUCTION

The un-reinforced of U-shaped bellows are defined as the flexible element of an expansion joints consisting of one or more convolutions and the end tangent with the ratio of length of the bellows to the diameter of the bellows must be ≤ 3 with no more than five plies. The bellows is the flexible element of the expansion joint. It must be strong enough circumferentially to withstand the pressure and flexible enough longitudinally to accept the deflections for which it was designed, and as repetitively as necessary with a minimum resistance. This strength with flexibility is a unique design problem that is not often found in other components in industrial equipment. Bellows are frequently used in the pressure vessels or piping system, aerospace, micro electromechanical and industrial system etc. it has the function to absorb regular or irregular expansion and contraction in the system. Since bellows require high strength as well as good flexibility. The design, manufacturing and analysis of bellows are more complicated than other general tubes. Numerous papers have dealt with various aspects of bellows failure, design, forming process and analysis: Kaishu Guan [01] Failure of 304 stainless bellows expansion joints in his work SS 304 bellows has been analyzed and found the most probable reason for the failure. C. Becht IV [02] Fatigue of bellows a new design approach Shen Zupei [03] Approximate Calculation of U-shaped Bellows. W. Rimkus [04] Design of load curves for hydro-forming application. Tsuyoshi Furushima [05] Development of semi-die less metal bellows forming process. G.Wang [06] Super plastic forming of bellows expansion joints made of titanium alloys. T.Y.Chen [07] Study of mechanical behavior of bellows by digital image correlation and strain gages. S. W. Lee [08] Study on the forming parameters of the metal bellows. Boo Hyun Kang [09] Forming various shapes of tubular bellows using a single step hydro forming process. Satoshi Igi [10] Evaluation of mechanical behavior of new type

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bellows with two directional convolutions. Gh. Faraji [11] Experimental and finite element analysis of parameters in manufacturing of metal bellows. Gh. Faraji [12] Evaluation of effective parameters in metal bellows forming process. Byoung-Gab Ko [13] Mechanical behavior of U-shaped bellows and shape optimal design using multiple objective optimization method. T L Englund [14] Dynamic Characteristics of a Combined Bellows and Liner Flexible Joint. G.I.Broman [15] Determining dynamic character of bellows by manipulated beam finite element of commercial software. EJMA code [16] Expansion Joint Manufacturing Association Ninth Edition. [17] ASME Section VIII Division-1 Appendix 26, 2010. G.I. Broman [15] (2002) has mentioned that, the bellows with the inner liner are the further studies. Based on my literature review I would like to work in design of unreinforced metal expansion bellows, development of manufacturing process up to 50 NB to 600 NB diameter of bellows, concept of inner liner and its experiment test, analysis of bellows with inner liner and study of Von mises stress value, displacement, strain and factor of safety etc.
We have modified design of failure bellows and one more component are added in the bellows assembly and that is the inner liners which has many advantages in engineering application like: (1) smooth flow of the media, (2) minimize friction losses, (3) minimize resonant vibration caused by high flow velocities, (4) To reduce the effect of turbulent flow upstream of the expansion joints, (5) To prevent erosion of the bellows wall from chemical and abrasive attack, (6) reduce the temperature of the bellows in high temperature application. Further more to develop the single step hydro forming process of bellows of size up to 50 NB to 600NB , study of effective parameters and solid works analysis are done with and without inner liner and we have found the stress results, deformation, strain, F.O.S etc.

II. DESIGN AND MANUFACTURING WITH INNER LINER

This paper is a study of the cause of an accident in which SS 304 bellows was damaged from an accident. Bellows serves as a conduit for a steam pipe line. The bellows expansion joints are made of 0.5 mm thickness with two plies SS 304 sheet. The plies are welded at both ends with ID 116 mm and OD of bellows 118 mm. These bellows was made by India flex engineering-Ahmadabad, India and supplied to Oracle Auto Pvt Ltd, Jamshedpur, India. but After 1 year of service bellows was getting an accident. The design temperature is 300ºC and Design pressure 0.72 Mpa. The flow through the pipe line was mainly steam with a velocity of 1.2 m/s. The schematic diagram of bellows depicts the location of explosion photograph as received sample in figure 1. Several small cracks are observed. Based on these data we have revised the design and calculate its complete stress value, axial and lateral movement, cross sectional area, fatigue life, lateral spring rate.etc.

Fig 1: Sample photograph of fail bellows

The equation for un-reinforced bellows are based on those shown in Atomic International report NAA-SR-4527 “Analysis of stresses in bellows part 1 design criteria and test results” with modification and additions by the association to reflect the experience of the members. These equations are based on elastic shell theory and consider the parameters involved for bellows of the “U” shaped configuration. The equation are taken from the EJMA, ASME section VIII division I, and an atomic international report with modification such that the calculated stress equation can be directly compared to the bellows material allowable stress at the design temperature published in the ASME piping codes and the ASME boiler and pressure vessel codes.

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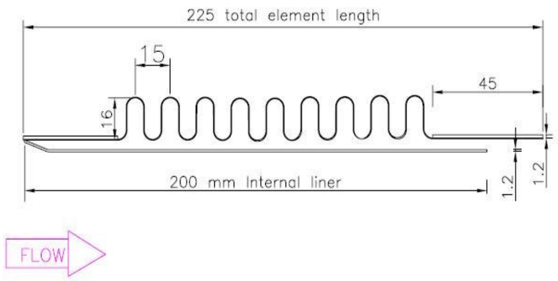

Fig 2 Bellows with inner liner

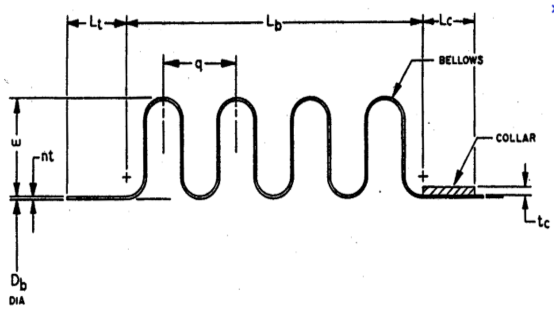

Fig 3 Schematic diagram of bellows

Design Data Table:

Design temp = 300 °C	DP (Extr) = ---	Vibration = No
Design pressure = 0.72 Mpa	Axial Movement (Extr) = ---	Axial Movement (Comp)= 20
Weld factor=1.0	Angular rotation = 00	Torsion rotation =
Min. fatigue cycle = 10000	Lateral deflection in Z plane:0	Lateral deflection in y plane=3
Fatigue safety factor = 1	Annealed bellows = No	Vaccum condition = No
Nominal diameter =100	No of convolution = 9	Collar thickness = 1.2
Bellows internal diameter = 116	Pitch of convolution = 15	Collar length = 40
Bellows outside diameter =150	Height of convolution = 16	Spool length = ---
Plies thickness = 0.5	SF = 45	Spool mass = ---
No of plies = 2	Weld ends thickness = ---	Weld ends length = ---
Inner liner: 1.2 mm thickness	Velocity: 1.2 m/sec	Liner size: 104.10 mm ID X 200 mm length
Bellows = SA240GR304	Collar = SA240GR304	Weld ends = No
Bellows the creep range =Yes	Inner Liner: SS 304	End fittings = IS2062

A Calculation as per EJMA code

Convoluted length = 135 mm	Bellows meridional bending stress due to deflection = 12.81 Mpa
Mean diameter of bellows convolution = 133 mm	Total stress range = 1192.516 Mpa
Mean radious of bellows convolution = 3.75 mm	Fatigue life = 11482
Axial movement per convolution = 22.22 mm	Limiting internal design pressure based on column instability = 1.27 Mpa
Equivalent axial compression per convolution = 2.22 mm	Limiting design pressure based on inplane instability and local plasticity = 1.44 Mpa
Equivalent axial extension per convolution = 2.22 mm	Lateral spring rate = 215.75 N/mm
Axial movement per convolution resulting from lateral deflection = 1.156 mm	Angular spring rate = 0 N/mm

Axial movement per convolution resulting from imposed angular rotation = 0	Outer diameter of bellows = 150 mm
Total axial movement = 23.378	Length of convolution = 365.085 mm
Mean diameter of bellows = 119.2	Bellows effective area = 13892.91 mm^2
Bellows tangent circumferential membrane stress due to pressure = 37.57 Mpa	Thrust force at design pressure = 10.002 KN
Collar circumferential membrane stress due to pressure = 38.29 Mpa	Percentage of elongation = 0.27 = 27 %
Column instability pressure reduction factor based on initial angular rotation = 1	Over all length of bellows assembly = 225 mm
Bellows theoretical initial axial elastic spring rate =	Tooling circumference = 464.72 mm

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1444.5 N/mm	
Axial spring rate of whole bellows = 160.50 N/mm	
Cross sectional area of one bellows convolution = 37.87 mm^2	
Bellows circumferential membrane stress due to pressure = 18.97 Mpa	
Bellows meridional membrane stress due to pressure = 6.17 Mpa	
Bellows meridional bending stress due to pressure = 124.81 Mpa	
Bellows meridional membrane stress due to deflection = 12.81 Mpa	

B. Manufacturing Process

The manufacturing processes of bellows diagram are shown below:

➢ **Process-1 Selection and identified proper material as per design criteria:** The selection of material as our design and manufacturing requirement is SS 304 (UNS S30400) because these material have a the most versatile and most widely used stainless steel, It has excellent outstanding forming and welding characteristics, Good oxidation resistance, maximum tensile strength, maximum yield strength, elongation up to 55%.

➢ **Process-2 Marking & cutting :** The marking and cutting of plate as per below formula

Width = SF (two sides) + [(0.571 * q + 2w)] * No of convolution

Length of bellows = $\pi * D_b$

Size of bellows plate = 0.5 T x 450 W x 368 Cir and 363 Cir (02 nos)

Size of inner liner plate = 1.2 T x 200 W x 320 Cir

➢ **Process-3 Metal bending process:**

➢ **Process-4 Welding process (Long seam welding)**

➢ **Process-5 Hydraulic Forming process:**

A cylindrical shell is placed in a hydraulic spindle or bellows forming machine. Circular external die rings of suitable contour are placed outside the cylindrical shell at longitudinal intervals approximately equal to the developed length of the completed convolutions. The cylindrical shell is filled with a medium such as oil and pressurized until circumferential yielding occurs. This forming operation continues with a simultaneous circumferential yielding and controlled longitudinal shortening of the until the proper configuration is obtained. Individual or multiple convolutions may be formed by this method. Depending on the bellows configuration, several partial forming steps with intermediate heat treatment may be required. Reinforced bellows may be formed by utilizing external reinforcing rings that act as part of the forming dies. After completion when the dies are removed, the rings remain as an internal part of the bellows. These hydro forming machine can forming the bellows of size 50 NB to 600 NB easily and less consumption of time. The hydro forming pressure is calculated by

$$\frac{[310(\text{Bellows thk} * \text{No of plies}) * 2]}{\text{ID of bellows}} \times 1.8 \times 10$$

= 96.20 Bar

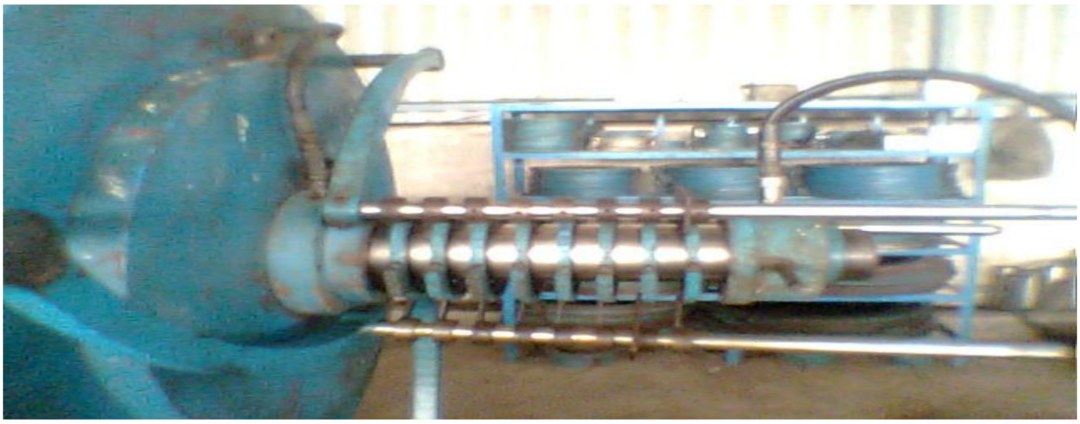

Fig 4. Hydro forming machine

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➢ **Process-6 Re-rolling process:**

➢ **Process-7 Attachment of other accessories:** The attachments of other accessories are fitted after completion of the re-rolling or finishing process. The accessories are like internal liners, collar and flanges. etc.

Fig 5: Actual photograph of bellows with liner

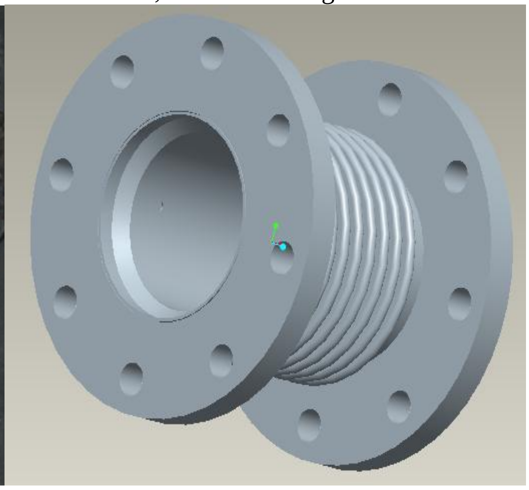

Fig 6: Pro-e model view

The above manufacturing process is same as the bellows size of 50 NB to 600 NB.

C. Study of effective parameters

We have studied the bellows most sensitive effective parameters which affect the final shape of the convolution**.** Few researchers have studied on bellows effective parameters. In this state, precise control of the parameters is very important in order to form high-quality metal bellows with good thickness distribution and desirable dimensions and resilience. this paper, a new method has been proposed for manufacturing of the metal bellows and important parameters such as initial length of tube, internal pressure, axial feeding and velocity, mechanical properties and the type of materials The results of the present work could be used as a basis of designing a new type of the metal bellows. It was observed that mechanical properties of material have considerable effect on final dimensions of bellows. it can be seen that when Young modulus is increased, spring back of the manufactured bellows is decreased. These results showed that mechanical behavior of the material used, conformed to spring back value. Investigation of die stroke showed that increasing the die stroke leads to excessive thinning in every zone of the bellows section with greater effect in the Crown Point zone. Increase in die stroke leads to increasing bellows diameter and spring back.. The process is more sensitive to pressure variation with increase in die stroke. Increase in internal pressure leads to excessive thinning of the bellows and increase in spring back. Sensitivity of spring back increases by increasing the pressure. The influence of feeding was investigated and it was observed that an increase in feeding leads to excessive thinning especially in the Crown Point zone, but in the inner point zone, increase in feeding has no effect on thinning. The representatives are the wall thickness of the perform tube, the pressure applied during the tube-bulging and the die stroke for the folding stage. the most important factor influencing the final shape of convolution of the metal bellows is found out. The results of the present study could be used as a basis of designing a new type of the metal bellows. The radius of the crown point increases logarithmically as the internal pressure increases at the tube-bulging stage. Meanwhile, the crown point moves almost linearly at the folding stage. The amount of spring back of the inner point along the height direction is much more than that of the crown point along the radial direction. The factor of die stroke among the three factors is the most influencing one on determining the final convolution shape of the metal bellows.

III. FEM ANALYSIS

Solid Works Simulation uses the displacement formulation of the finite element method to calculate component displacements, strains, and stresses under internal and external loads. The geometry under analysis is discretized using tetrahedral (3D), triangular (2D), and beam elements, and solved by either a direct sparse or iterative solver. Solid Works Simulation can use either an h or p adaptive element type, providing a great advantage to designers and engineers as the adaptive method ensures that the solution has converged. Integrated with Solid Works 3D CAD, finite element analysis using Solid Works Simulation knows the exact geometry during the meshing process.

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And the more accurately the mesh matches the product geometry, the more accurate the analysis results will be achieved. Solid Works Simulation uses FEA methods to calculate the displacements and stresses in product due to operational loads such as: Forces, Pressures, Accelerations, Temperatures, and Contact between components. Loads can be imported from thermal, flow, and motion Simulation studies to perform multi physics analysis. Finite element analysis is a numerical method for solving problem of engineering and mathematical physics. Solid works FEM Procedure: Solid Works is a 3D mechanical CAD (computer-aided design) program that runs on Microsoft Windows and is being developed by Dassault System Solid Works Corp Solid works software is a mechanical design automation application that takes advantage of the windows graphic user interface. The software makes it possible for designer to quickly sketch out ideas, experiment with features and dimension and produce models as well as detail drawings. Solid works 2007 is an user friendly and have a large configuration and feature. There are few steps for the analysis. (1) Create 3D model (2) Give the boundary condition (3) meshing (4) Input parameters. (5) Get the results. The FEM analysis has mainly distributed in three sections such as: Pre processor, Solver and Post processor. Here we have shown the comparison of the bellows (1) Bellows with inner liner (2) Bellows without inner liner.

FEA Resulted table

Description	**SS 304 with inner liners**	**SS 304 without inner liners**
No of element	14142	31075
No of nodes	26177	62260
Von mises stress: $\sigma_{Von\ mises} / \sigma_{Limit}$	Max: 3.08234e+007 N/m^2	Max: 5.61228e+007 N/m^2
Displacement	Max: 1.80924e-006 Min:0 m	Max: 1.44905e-005 Min: 0 m
Strain	Max: 9.6763e-005 Min: 6.09071e-007	Max: 0.000224174 Min: 6.4602e-013
Design check / F.O.S	6.70	3.685

EJMA calculated value for FEA comparison

Maximum stress value: 1088.02 Mpa
Minimum stress value: 6.17 Mpa
Displacement or Axial and lateral movement: 2.222 mm
Strain value: 0.016

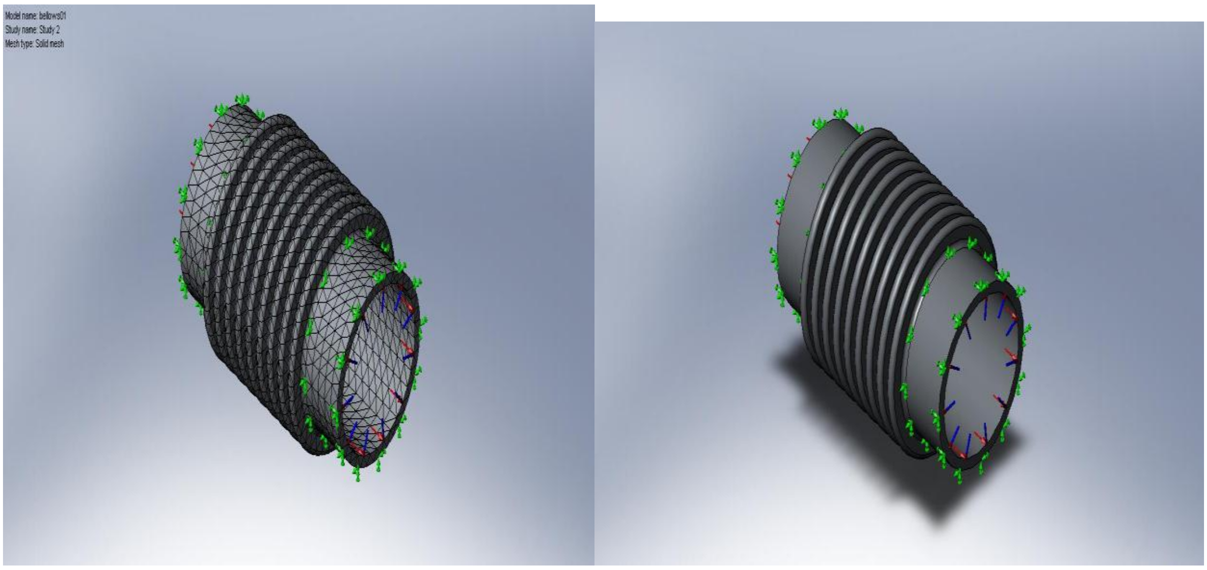

Fig 7: Meshing view & Boundary constraint view

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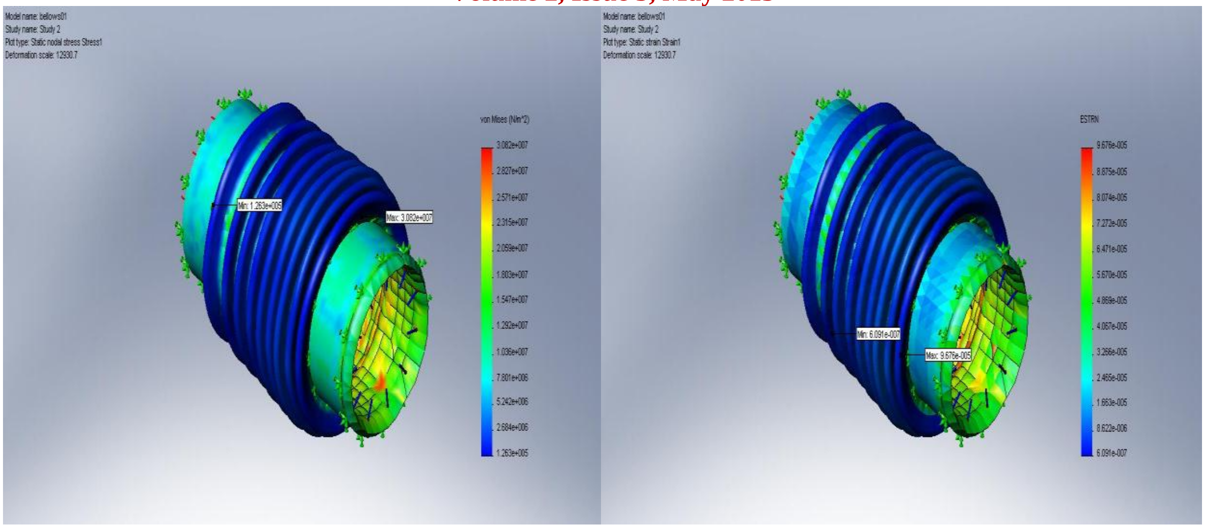

Fig 8: Von misses stress and strain view

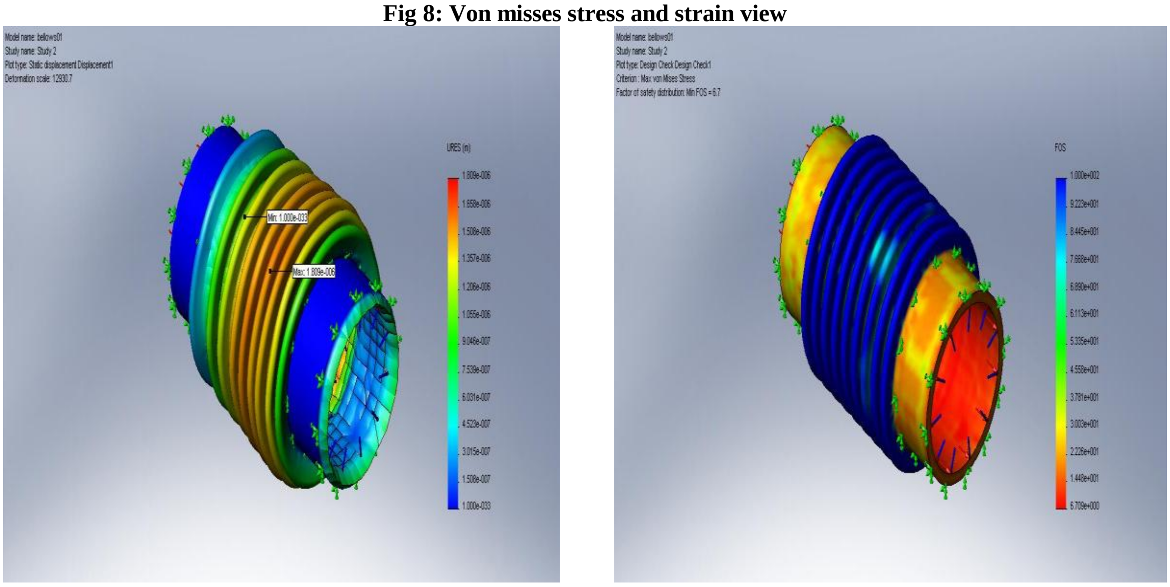

Fig 9: Displacement and factor of safety or design check view

IV. CONCLUSION

➢ The formulas for a U-shaped bellows with a thin shell derived in this paper are very simple and can be used for calculating bellows design. The formulas provide explicit relationship between the geometrical parameters. These formulas are very convenient for designing bellows and for determining the bellows corrugation parameters.

➢ A new forming technology was developed for bellows expansion joints. Which uses the method of applying fluid pressure and compressive axial load is developed. Metal bellows with a continuous shape can be achieved. It can be used to manufacture of size 50NB to 600NB diameter "U" type bellows expansion joints made of any material. A number of die structure piece increase the bellows convolution. A multi-layer die structure is adopted to determine the final shape of convolutions. When considering the effect of lubrication on the thickness profile, lubrication oil provides the most uniform thickness profile.

➢ Metallic tubular bellows without cracks can be made using a single step hydro forming process with controlled internal pressure and axial feeding. The role of lubrication is important for achieving high product quality.

➢ Here we have developed Double convolution bellows and it has many advantages compare to Single convolution bellows. The advantages of Convolution, Thickness at the crest and Stability in the deformation, more flexible, Torsion, Longer fatigue life etc.

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- In this work a FE analysis for metal expansion bellows by the solid works software has been carried out. Here we have done the finite element analysis (FEA) of metal expansion bellows with and without the inner liner / sleeves and its values are validated with the theoretical design data values.
- Comparison of the FE analysis of the bellows stresses, displacement, strain and factor of safety are shorn in the resulted table and finally we conclude that the stress induced in the conventional bellows are double than the inter liner bellows. The displacement and strain occurs in conventional bellows are much larger, finally the factor of safety of internal liners bellows are approximately double than the conventional bellows. Hence the bellows with inner liner gives very good results and performance than the conventional bellows.

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