# Design and validation of Bellows as per EJMA-FEA

Shukla Kaushal[1], Patel Sagar[2], Shah Priyansh[3], Vegad Krunalkumar[4], Mr. Mitesh patel[5]
[1,2,3,4]*Department of mechanical Engineering, Bhagwan Mahavir college of engineering and technology, Surat, Gujarat, India*
[5]*Guide, Department of mechanical Engineering, Bhagwan Mahavir college of engineering and technology, Surat, Gujarat, India*

***Abstract*- 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. Bellows are special structures that require high strength as well as good flexibility. 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 and FEA simulation. 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. In this work A finite element analysis (FEA) of bellows proposed.**

## INTRODUCTION

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.

Any device containing one or more bellows used to absorb dimensional changes such as caused by thermal expansion or contraction of pipe line, duct or vessels or engineering system. An expansion joint or movement joint is an assembly designed to safety absorbs the heat-induced expansion and contraction of various construction materials, to absorb vibration, to hold certain parts together, or to allow movement due to ground settlement or earthquakes. They are commonly found between sections of sidewalks, bridges, railway tracks, piping systems, ships, and other structures.

Most bellows fail by circumferential cracking resulting from cyclic bending stresses, or fatigue. Since the best design is a compromise, or balance, between pressure strength and flexibility considerations, it can be concluded that their designs have had lower margins of safety regarding fatigue than they had regarding pressure strength. The years of experience of the engineers who developed these bellows assures that the designs contained in this catalog and those offered to satisfy customer specifications, will have the performance reliability which yields trouble free, safe use.

## DESIGN OF BELLOW ASSEMBLY

The equation for un-reinforced bellows are based on those shown in Atomic International report NAA-SR-4527 “Analysis of stresses in bellows 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.

Bellow Assembly :-

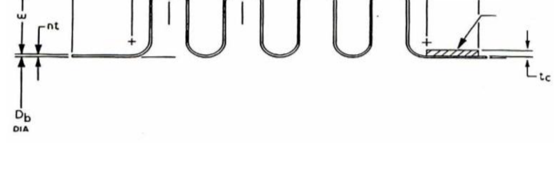

Fig 1: Schematic Diagram Of Metal Expansio Bellows

Db = Inside diameter of bellows

,n = Number of plies,

w = Height of convolution ,

Lt = Tangent length of bellow,

N = Number of Convolutions ,

Do = Outside diameter of bellows

t = Thickness of material = Pitch of convolutions

Lc = Collar length of bellows = Radius of root & crest (U type)

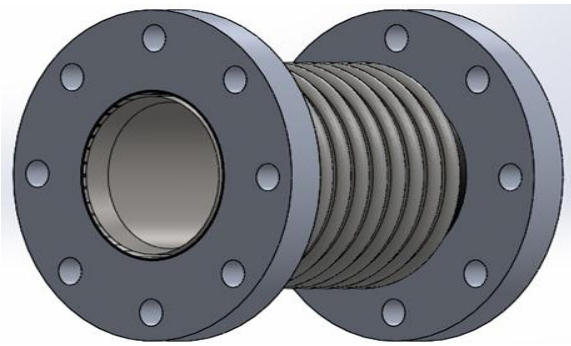

Fig 2:- Bellow assembly

Exploded view of bellow assembly:-

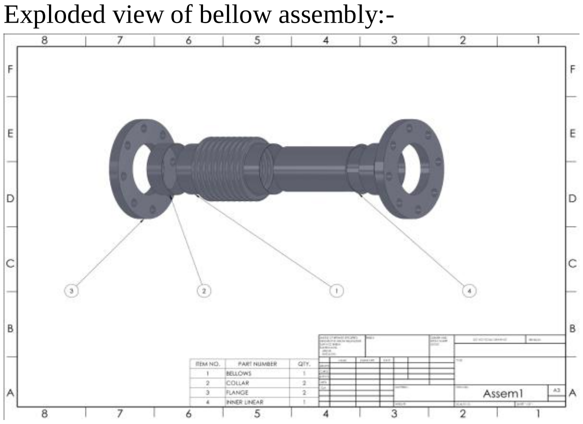

Fig 3:Exploded view of bellow assembly

Basic data input:-

| | | |
|---|---|---|
| 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 | No of plies = 2 | Inner liner: 1.2 mm thickness |
| Nominal diameter =100 | No of convolution = 9 | Collar thickness = 1.2 |
| Bellows internal diameter = 116 | Pitch of convolution = 15 | Liner size: 104.10 mm ID X 200 mm length |
| Plies thickness = 0.5 | SF = 45 | Velocity: 1.2 m/sec |

## CONCEPT OF INNER LINER

Description:

A sheet of metal rolled into a cylinder and seam welded using the long seam welding process. The cylinder is attached to the convolutions of the element so as to cover all the convolutions of the element to improve the performance of the expansion joint.

Fig 4:- Inner liner

Purpose:

- To ensure smooth flow of the media
- In minimize friction losses
- To minimize resonant vibration caused by high flow velocities
- To reduce the effect of turbulent flow upstream of the expansion joints
- To prevent erosion of the bellows wall from chemical and abrasive attack
- To reduce the temperature of the bellows in high temperature application

Material of construction:

The material of the internal liner is generally the same as for the bellows element it is to fit. The selection of' the material is generally dependent upon the temperature and corrosion resistance requirements of the application Typical materials include.

- Stainless Steel grades 304, 316, 321
- High Nickel Alloys eg. Incoloy, Inconel, Monel, 253MA, Hastelloy C (registered trade name), nickel.

Bore size:-

The Internal liner is generally sized to have a bore 10mm less diameter than the bellows element however if the joint is to use for lateral movement or angular rotation,  additional clearance will need to be allowed between the liner and the element to enable the element to move as required.

Criteria for determining the inner liners:-
Internal liners shall be specified for all expansion joints in the following cases:

- When is necessary to hold friction losses to a minimum and smooth flow is desired.
- When now velocities are high and could produce resonant vibration of the bellows. Internal sleeves are recommended when flow velocities exceeds the following values:

Table2: For air steam and other gasses

| Diameter | Velocity |
|---|---|
| Up to 150 mm | 1.2 m/s |
| Over 150 mm | 7.6 m/s |

Table 3: For water and other liquids

| Diameter | Velocity |
|---|---|
| Up to 150 mm | 500 mm/s |
| Over 150 mm | 3 m |

- An internal sleeve Liners must be used when the now velocity exceeds 75% of the values calculated above
- When there is a possibility of erosion, as m hues carrying catalyst or other abrasive media, heavy gauge sleeve must be used Al no time should the relatively thin bellows be directly exposed to erosion.
- When there is reverse flow, heavy gauge sleeve may be required, or the use of telescopic sleeve may be appropriate
- For high temperature application to decrease the temperature of the bellows and enable the bellows metal to retain as higher physical properties. The annual area between the bellows and liner may be packed with a ceramic fiber insulation or a gas purge may he installed to further reduce the bellows effective temperature.
- Internal sleeve should not be used where high viscosity fluids such as tars are being transmitted, since these fluids may cause premature expansion joint failure. Where the fluid is such that purging will effectively prevent the "packing up", internal sleeve may be used in conjunction with purge connections

Design Recommendation For Internal Sleeves / Liner:-
To minimize the possibility of flow induced vibration in the expansion joint, the following thickness that are empirically derived on air and steam shall be utilized.

- Following table shows the design data for inner liner.

Table 3: Design Data For Inner Liner

| Nominal expansion joint diameter (Inch) | Min Internal sleeve thickness (Inches) |
|---|---|
| 2-3 | 0.024 |
| 4-10 | 0.036 |
| 12-24 | 0.048 |
| 26-48 | 0.060 |
| 50-72 | 0.075 |
| Over 72 | 0.090 |

- Sleeve length, flow velocity, and media temperature can increase the minimum internal sleeve thickness requirement listed above. Thickness increase factors shall be calculated in accordance with the following sections and multiplied together. The product shall then be multiplied times the above thickness to obtain the minimum internal sleeve thickness for the application.
- Drain holes should be provided for verticals installations where liquid could become trapped inside the sleeve, Internal liners are designed only to minimize the possibility of flow induced vibration and The material of inner liner may be the same or different from the bellows material.

Analysis results:-

- ➢ As mentioned in subject above, Finite element analysis is to be performed for given design of bellow under design loading conditions.
- ➢ After performing definite FEA of the system, obtained results for stresses will be justified with data available for maximum allowable values in properties data base mention below.
- ➢ Mechanical properties of SS 304 are shown in below.

Properties:-
Density : 7850 kg/m3
Modulus of Elasticit : 193 GPa
Poisson’s Ratio : 0.29
Tensile Yield Strength : 240 Mpa
Ultimate Tensile strength: 515 Mpa

Coefficient of thermal expansio : 17.8 C-1
Basic input in Ansys:-
Design pressure: 0.72 Mpa
Design temperature: 300 c
Fatigue safety factor: 1

Geometry for simulation

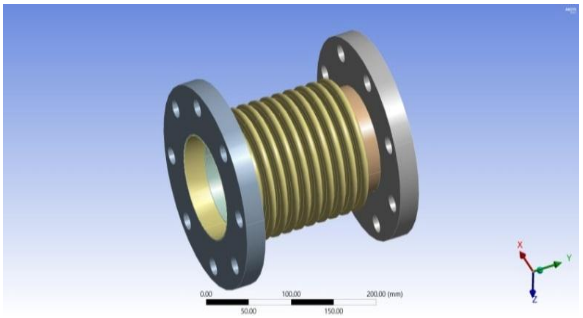

Fig 5: Geometry for simulation

Table 4.:Geometry properties

| Bounding Box | |
|---|---|
| Length X | 318.35 mm |
| Length Y | 223.3 mm |
| Length Z | 318.35 mm |
| Properties | |
| Volume | 1.5421e+006 mm³ |
| Mass | 12.115 kg |
| Scale Factor Value | 1. |

Bellow without inner liner:
Stress on assembly:-

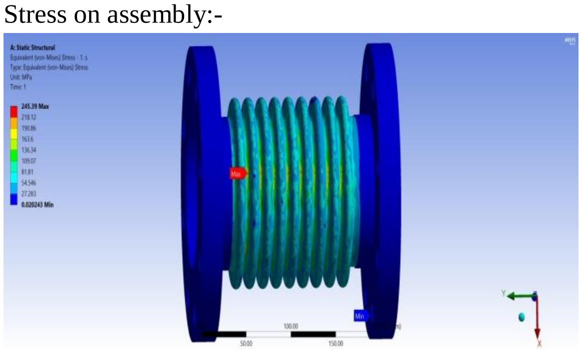

Fig 6: stress on bellow assembly

Table 5: stress on bellow assembly

| Time [s] | Minimum [MPa] | Maximum [MPa] |
|---|---|---|
| 0.33333 | 6.7477e-003 | 81.796 |
| 0.66667 | 1.3495e-002 | 163.59 |
| 1. | 2.0243e-002 | 245.39 |

Total deformation on assembly

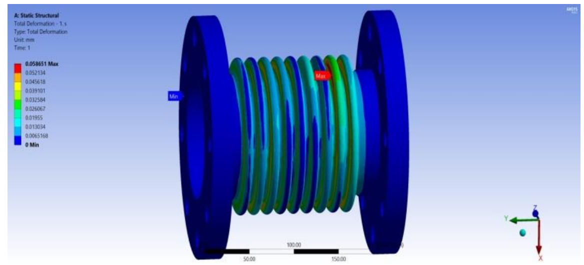

Fig 7: Total deformation on bellow assembly

Table 6: Total deformation on bellow assembly

| Time [s] | Minimum [mm] | Maximum [mm] |
|---|---|---|
| 0.33333 | 0. | 1.955e-002 |
| 0.66667 | | 3.9101e-002 |
| 1. | | 5.8651e-002 |

Bellow with inner liner:
Stress on assembly:

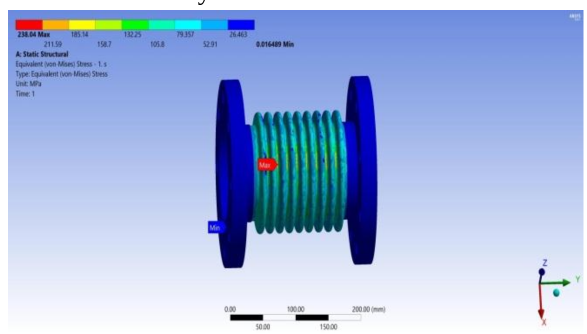

Fig 8: stress on bellow assembly

Table 7: stress on bellow assembly

| Time [s] | Minimum [MPa] | Maximum [MPa] |
|---|---|---|
| 0.33333 | 5.4962e-003 | 79.346 |
| 0.66667 | 1.0992e-002 | 158.69 |
| 1. | 1.6489e-002 | 238.04 |

Total deformation on bellow assembly

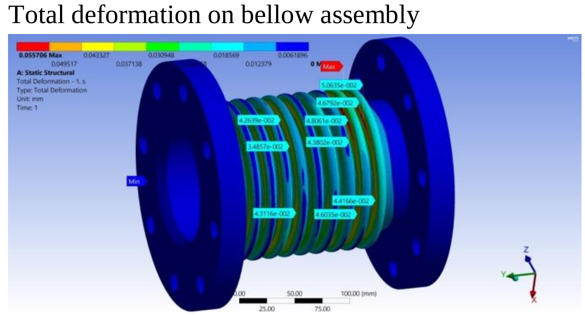

Fig 9: Total deformation on bellow assembly

Table 8: Total deformation on bellow assembly

| Time [s] | Minimum | Maximum [mm] |
|---|---|---|
| 0.33333 | 0. | 1.8569e-002 |
| 0.66667 | | 3.7138e-002 |
| 1. | | 5.5706e-002 |

FEA result table :-

Table 9:- FEA result table

| Description | SS 304 with inner linear | SS 304 without inner linear |
|---|---|---|
| Von-mises stress | Max 238.04 (Mpa)<br>Min0.016489 (Mpa) | Max 245.39 (Mpa)<br>Min 0.020243 (Mpa) |
| Strain | Max 1.6114e-003 m/m<br>Min 2.0338e-007 m/m | Max 2.1591e-003 mm/mm<br>Min 2.0781e-007 mm/mm |
| Design check/ F.O.S | Min 2.1635<br>Max 15 | Min 2.0987<br>Max 15 |

## SUMMARY

The purpose of FEA analysis is to investigate the bellows stresses, strain, factor of safety etc. and compared with the theoretical design calculated value. By comparison of the bellows FEA analysis we can conclude that the bellows with inner liner gives better results / performance than the conventional bellows.

## CONCLUSION

In the present study, the literature review has been studied for bellows, Also the design and manual calculation of bellows as per Expansion joint manufacturing association (EJMA) standards is carried out. By studying the circumscription in the recent invention of bellows, following conclusion is observed which is mentioned below.

We have study that by analyzing bellow with inner liner and without inner liner we came to conclusion that using optimum inner liner material for particular scope gives better efficiency and also decreases total deformation and stress in bellows.

From this study we are increasing the life of the bellows by using the different materials of inner liner which will lead to minimization of the friction losses, minimization of bellow wall from chemical and abrasive affect, minimization of resonant vibration and providing a smooth and efficient flow of media.

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