A Case Study of Design of Circular Type Universal Bellows

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Abstract: In this paper a case-study of a circular type universal bellows is done and the bellows is re-designed with several improvements in the existing bellows model which failed in short period within warranty period after it's commissioning in the plant. The bellows is used in the furnace ash drain line where the working temperature is about 920˚C and the pressure inside the bellows is 1090-1122mmWC due to which there is an appreciable amount of thermal expansion of the bellows material. In the existing model of universal expansion joint due to various reasons viz. inappropriate overall length, absence of vent holes, inappropriate lateral movement consideration, wrong selection of design parameters etc. it failed from the bellows convolution section during operation within couple of weeks after it was installed which is a lot early than its' proposed/rated life cycle period.

IndexTerms **- Bellows, Universal Expansion joint, Convolutions, Spring-rate, SA240 Gr.321/310/304.**

1 INTRODUCTION

Expansion joints are used in the piping system to avoid stresses due to temperature and pressure variations. The function of expansion joint is to provide flexibility to the piping system. Bellows is the most critical part of an expansion joint, which should be able to accept longitudinal, lateral and angular movements. The movements are due to differential variation in pressure and temperature inside the pipes. Expansion joints possess several advantages like, inherent flexibility, absorb movement in more than one direction, and require less space. The design of bellow is critical as fluctuation of pressure induces differential growth and variation in temperature causes thermal expansion and contraction in the long piping system. (The Expansion Joint Manufacturer Association, Standards Of The Expansion Joint Manufacturer Association, Inc. EJMA Code 2016)

In this paper (case-study) a circular type universal bellows is re-designed with several improvements in the existing bellows model which failed in short period within warranty period after it's commissioning in the plant. In the existing model of universal expansion joint due to various reasons viz. inappropriate overall length, absence of vent holes, inappropriate lateral movement consideration, wrong selection of design parameters etc. it failed from the bellows convolution section while operation within couple of weeks after it was installed which is a lot early than its' proposed/rated life cycle period.

The bellows is used in the furnace ash drain line where the working temperature is about 920˚C and the pressure inside the bellows is 1090-1122mmWC due to which there is an appreciable amount of thermal expansion of the bellows material.

2 FAILURE ANALYSIS

2.1 Overall length of the expansion joint:

Existing Design = 1142 mm
Proposed design = 1234 mm

Overall length of the expansion joint is increased in Proposed design in-order to reduce the pre-stressing of bellows at the time of installation which was observed in Existing design. As the length was less in Existing design it was installed after adjusting the overall length with the help of tie rods. The length was increased by expanding the bellows which led to generation of stress in convolution before operation. This stress generation before bellows operation is known as pre-stressing.

2.2 Number of convolutions in bellows:

Existing Design = 6 + 6
Proposed design = 7 + 7

Increase in number of convolutions in bellows increases the flexibility of expansion joint and also the lateral movement per convolution of the bellows. It also reduces the circumferential stress factor K_{sr}.

2.3 Number of plies in bellows:

Existing Design = 02
Proposed design = 03

Increase in number of plies results provides strength to the bellows structure against increased flexibility due to increased number of convolutions.

2.4 Length of center spool/center pipe:

Existing Design = 02
Proposed design = 03

Increase in centre spool length will increase the lateral movement capacity of the expansion joint and also the lateral movement per convolution of bellows.

2.5 Application of tie rod:

Existing Design: Tie rods on overall length of the bellows.

Proposed design: Tie rods on individual bellows of expansion joint.

Application of tie rods on individual bellows provides more strength than application of tie rods on overall length of the expansion joint. In tie rods on overall length of the bellows the rod stops are engaged by a plate or lug attached to the centre pipe portion and movement of this part beyond its design deflection is restrained. Whereas in tie rods on individual bellows of expansion joint rods are used spanning each of the bellows in the expansion joint. Stops are provided on the rods so that, once the expansion joint has reached its rated lateral deflection, the stops will be engaged by members rigidly fastened to the pipe portions of the expansion joint.

2.6 Presence of vent hole in bellows:

Existing Design: Vent hole absent

Proposed design: Vent hole present

Presence of vent hole in bellows allows the air in-between the plies to escape during bellows operation and eliminates the bulging of convolution due to expanded air at high temperature which is one reason of bellows failure.

2.7 Allowable stress value(S_{ab}) was considered less with respect to the higher design temperature for bellows:

Existing Design: Design Temperature = 920℃ and $(S_{ab}) = 0.21$ kg/mm^2

Proposed design: Design Temperature = 552℃ and $(S_{ab}) = 7.69$ kg/mm^2

The design temperature of bellows was more in existing design due to which the allowable stress value of bellows material was less and this was the major reason behind design failure because it didn't satisfy the equation $S_3 + (S_4/1.25) \leq S_{ab}$. Now in the proposed design as the design temperature of bellows is considered 40% less (i.e 552℃) than the previous design temperature the allowable stress value of bellows material has increased and it also validates the design by satisfying the above equation.

The reason for considering the reduced design temperature is a survey which proposes that the temperature at the bellows convolution surface is 40%-60% less than the temperature at the centre of the expansion joint (INC. 2004) (i.e the temperature of the flowing media) and this reduction in temperature happens due to application of inner sleeve in the expansion joint. The survey was done by an American bellows manufacturing company named "PATHWAV BELLOWS INC".

3 Design of Expansion Joint

In this section the design methodology of an universal expansion joint is discussed.

3.1 Abbreviations:

- A_c = Cross sectional area of one bellows convolution.
- C_m = Material strength factor at temperatures below the creep range.

$$C_m = 3. \tag{1}$$

- C_θ = Column instability pressure reduction factor based on initial angular rotation. It is equal to **1** for presence of concurrent lateral deflection.
- C_{wc} = Longitudinal weld joint efficiency factor from applicable code. Subscripts b, c, f, p and r denote the bellows reinforcement collar, fastener, pipe, and reinforcing ring material respectively.
- C_f = Factor used in specific design calculations to relate U-shaped bellows convolution segment behaviour to a simple strip beam.
- C_d = Factor used in specific design calculations to relate U-shaped bellows convolution segment behaviour to a simple strip beam.
- C_p = Factor used in specific design calculations to relate U-shaped bellows convolution segment behaviour to a simple strip beam.
- D_b = Inside diameter of cylindrical tangent and bellows convolutions.
- D_c = Mean diameter of bellows tangent reinforcing collar.

$$D_c = D_b + 2nt + t_c. \tag{2}$$

- D_m = Mean diameter of bellows convolutions.

$$D_m = D_b + w + nt \text{ for "U" profile.} \tag{3}$$

- E = Modulus of Elasticity at design temperature, unless otherwise specified, for material. Subscripts b, c, f, p and r denote the bellows, reinforcement collar, fastener, pipe and reinforcing ring material, respectively.
- e_x = Axial movement per convolution resulting from imposed axial movement, x. This movement may be measured as compression or extension.
- e_y = Axial movement per convolution resulting from imposed lateral deflection, y.
- e_c = Equivalent axial compression per convolution.
- F_a = Axial force at the end of the convoluted length of an expansion joint resulting from axial deflection x.
- f_{iu} = Bellows theoretical initial axial elastic spring rate per convolution.
- f_w = Bellows working spring rate (kg/cm. of movement per convolution).

$$f_w = f_{iu} \quad for\ S_t \leq 1.5S_y. \tag{4a}$$

$$f_w = 0.67 f_{iu} \quad for\ S_t \geq 1.5S_y. \tag{4b}$$

- K_{sr} = Overall bellows spring rate.

$$K_{sr} = \frac{f_i}{N} \tag{5}$$

- K_i= Influence factor depending on the flow media.
- K_r = Circumferential stress factor. Select greater of the following but not less than 1.

  Here e_x and e_y are based on axial extension concurrent with pressure P.

$$\frac{2(q+e_x)+\frac{e_\theta}{k_\theta}+e_y}{2q}. \tag{6a}$$

Here e_x and e_y are based on axial compression concurrent with pressure P.

$$\frac{2(q-e_x)+\frac{e_\theta}{k_\theta}+e_y}{2q}. \tag{6b}$$

- K_u = Factor establishing relationship between equivalent axial displacement per convolution due to lateral deflection and the ratio $L_u/2L_b$.
- k = A factor which considers the stiffening effect of the attachment weld and the end convolution the pressure capacity of the bellows tangent.
- L_b= Bellows convoluted length.

$$L_b = Nq. \tag{7}$$

- L_c = Bellows tangent collar length.
- L_u= Distance between outermost ends of the convolutions in a universal Expansion joint.
- L_s = Mean length of short side of rectangular bellows.

$$L_s = \text{short inside length + convolution height.} \tag{8}$$

- D_b = Inside diameter of cylindrical tangent and bellows convolutions.
- L_t = Mean length of long side of rectangular bellows.

$$L_t = \text{long inside length + convolution height.} \tag{9}$$

- M = Mass of bellows including media fluid.
- M_l = Moment at the ends of the convoluted length of an expansion joint resulting from lateral deflection, y.
- M_θ = Moment at the ends of the convoluted length of an expansion joint resulting from angular rotation, B.
- m = Mass of the spool pipe + one bellows including reinforcement + any attachments to the spool pipe in·c1uding liners, covers, lugs, nozzles, refractory, and insulation.
- m_{eff}= The effective mass of the bellows including reinforcement and the mass of liquid contained between the convolutions.
- N= Number of convolutions in one bellows.
- n = Number of bellows material plies
- P = Pressure.
- q = Convolution pitch.
- r_m = Mean radius of bellows convolution.
- S_{ab} =Allowable material stress at design temperature, unless otherwise specified, from the applicable code (psi.). Subscripts b, c, f, p and r denotes bellows reinforcement collar.
- t = Bellows nominal material thickness of one ply.
- t_p = Bellows material thickness for one ply, corrected for thinning during forming.

$$t_p = \sqrt{\frac{D_b}{D_m}}. \tag{10}$$

- V_l = Lateral force at the ends of the convoluted length of the expansion joint resulting from lateral deflection, y.
- v = Velocity of media flow.
- W_{cs} = Total dead weight of the centre spool including pipe, refractory, insulation, attachments and media.
- w = Convolution height.
- x = Applied axial movement in compression or extension.
- y = Applied lateral movement in compression or extension.
- Z = Length of centre spool
- θ = Applied angular rotation per individual bellows (radians).
- θ_u = Angle of the universal expansion joint centreline with respect to horizontal.

3.2 Design Equations:

3.2.1 Movement Equations:

Expansion joint in this case is subjected to axial movement. This also applies to displacement of bellows assemblies such as universal, swing and universal pressure balanced expansion joint. (The Expansion Joint Manufacturer Association, Standards Of The Expansion Joint Manufacturer Association, Inc. EJMA Code 2016)

$$e_x = \frac{x}{2N}. \tag{11}$$

The angular movement of any convolution maybe expressed as follows.

$$e_\theta = \frac{\theta D_m}{4N}. \tag{12}$$

Lateral deflection of an expansion joint is a special case of angular rotation. The two bellows in a universal type expansion joint rotate in opposite directions to produce the total lateral deflection y. Lateral deflection results in unequal movement distribution over the bellows, the amount of displacement increasing with the distance from the centre of the expansion joint.

The displacement per convolution resulting from applied lateral deflection y is as follows. (The Expansion Joint Manufacturer Association, Standards Of The Expansion Joint Manufacturer Association, Inc. EJMA Code 2016)

$$e_y = \frac{3D_m y}{2NL_b}\frac{1+{L^*}/{L_b}}{1+3({L^*}/{L_b})^2}\frac{L^*}{(L^*+x/2)}. \quad \text{(For extension)} \tag{13a}$$

$$e_y = \frac{3D_m y}{2NL_b}\frac{1+{L^*}/{L_b}}{1+3({L^*}/{L_b})^2}\frac{L^*}{(L^*-x/2)}. \quad \text{(For compression)} \tag{13b}$$

3.2.2 Combining Movements:

The combined movement may be calculated as follows.

$$e_c = e_y + e_\theta + |e_x|. \text{ (For compression)} \quad (15)$$

$$e_e = e_y + e_\theta - |e_x|. \text{ (For extension)} \quad (16)$$

The following limits should be observed to prevent excessive movements which could permanently damage the bellows.

$$e_c(\text{maximum}) = q - 2r_m - nt. \quad (17)$$

$$e_e(\text{maximum}) = 6r_m - q. \quad (18)$$

The design of every Expansion joint must be such that the total displacement per convolution from all sources does not exceed the rated values.

$$e_{c(\text{calculated})} \le e_{c(\text{rated})} \le e_{c(\text{maximum})}. \quad (19)$$

$$e_{e(\text{calculated})} \le e_{e(\text{rated})} \le e_{e(\text{maximum})}. \quad (20)$$

3.2.3 Cold Springing of Circular Expansion joint:

There are basically two reasons for cold-springing of bellows which are.

Force Reduction: To minimize the force required to deflect an expansion joint.

Stability: The maximum displacement per convolution is reduced by half and, consequently, the expansion joint becomes far more stable.

3.2.4 Forces and Moment Equations:

To evaluate the loads upon the expansion joint, it is necessary to determine the forces and moments required to move it.

$$F_a = f_w e_x. \quad \text{(kg)} \quad \text{(For axial movement)} \quad (21)$$

$$M_l = \frac{f_w D_m e_y}{4}. \quad \text{(kg. mm)} \quad \text{(Lateral moment)} \quad (22)$$

$$M_\theta = \frac{f_w D_m e_\theta}{4}. \quad \text{(kg. mm)} \quad \text{(Angular moment)} \quad (23)$$

$$V_l = \frac{f_w D_m e_y}{2(L_u \pm x)}. \quad \text{(kg)} \quad \text{(For lateral movement)} \quad (24)$$

3.2.5 Vibration:

Natural frequencies for axial and rocking vibration may be calculated using the following given equations. Resonant vibration of dual bellows assemblies may be very severe, particularly at lower frequencies, resulting in large displacements of the centre spool pipe. To avoid a resonant response in the bellows, the bellows natural frequency shall be less than 213 of the system frequencies or greater than twice times the system frequency. (The Expansion Joint Manufacturer Association, Standards Of The Expansion Joint Manufacturer Association, Inc. EJMA Code 2016)

Axial Vibration: Vibration occurring in axial direction of the expansion joint (Bellows).

$$f_n = 7.13\sqrt{\frac{K_{sr}}{m}}. \quad \text{(Hz)} \quad (25)$$

Rocking Vibration: Lateral vibration with ends of spool pipe out of phase, one end up and one end down.

$$f_n = \frac{15.1 D_m}{L_b}\sqrt{\frac{K_{sr}}{m}}. \quad \text{(Hz)} \quad (26)$$

3.2.6 Inner Sleeve:

It is a protective layer of alloy steel placed concentrically inside the expansion joint that prevents the direct interaction of flowing media with the bellows. It is incorporated in-order to avoid the trapping of flowing media in between the bellows convolutions. It also conducts heat dissipated by the flowing media. (The Expansion Joint Manufacturer Association, Standards Of The Expansion Joint Manufacturer Association, Inc. EJMA Code 2016)

3.2.6.1 Criteria for Determining the Need for Internal Sleeves:

Internal sleeves shall be specified for all expansion joint in the following cases

- When flow velocities are high and could induce resonant vibration of the bellows.
- When it is necessary to hold friction losses to a minimum and smooth flow is desired.
- When there is a possibility of erosion, as in lines carrying catalyst or other abrasive media, heavy gauge sleeves must be used.
- When there is reverse flow, heavy gauge sleeves may be required.
- Internal sleeves should be used for high temperature applications to decrease the temperature of the bellows.
- Internal sleeves should not be used where high viscosity fluids such as tars are being transmitted.

3.2.6.2 Limits for flow velocity:

Values for allowable velocities V_{alw} can be found from empirical data given in the table. (Refer Table 1)

Table 1 - Allowable Flow Velocity (The Expansion Joint Manufacturer Association, Standards Of The Expansion Joint Manufacturer Association, Inc. EJMA Code 2016)

Fluids	Liquid				
Number of plies n	1	2	3	4	5
Nominal Diameter in mm	Allowable flow velocity (m/sec)				
50	1.22	1.83	2.13	2.44	2.74
100	2.13	3.05	3.66	4.27	4.88
≥150	3.05	4.27	5.18	6.10	6.71

Specific applications shall be evaluated by the following equation which includes a safety factor of **1.33**

$$V_{alw} = 0.026qK_i\sqrt{\frac{K_{sr}}{m_{eff}}}n \quad (27)$$

Here; K_i= 1 for liquids

3.2.6.3 Design Recommendation for Internal Sleeves:

To minimize the possibility of flow induced vibration of the inner sleeve a minimum sleeve thickness shall be designed. Sleeve length, flow velocity, and media temperature can increase the minimum internal sleeve thickness. Thickness increase factors shall be calculated in accordance with the following equations. The increased minimum internal sleeve thickness t_s is utilized in the following equation**:** (The Expansion Joint Manufacturer Association, Standards Of The Expansion Joint Manufacturer Association, Inc. EJMA Code 2016)

$$\boldsymbol{t_s = C_l C_v C_t t_{s,min}} \quad \text{(mm)} \quad (28)$$

Where; the empirically based minimum sleeve thickness $\boldsymbol{t_{s,min}}$ is given in the table. (Refer Table 2)

Table 2 - Empirical values of minimum internal sleeve thickness (The Expansion Joint Manufacturer Association, Standards Of The Expansion Joint Manufacturer Association, Inc. EJMA Code 2016)

Nominal expansion joint diameter (mm)	Minimum internal sleeve thickness (mm)
50-80	0.61
100-250	0.91
300-600	1.22
650-1200	1.52
1250-1800	1.91
>1800	2.29

The length factor is

$$C_l = \begin{cases} 1 & if\ L_{is} \le 450mm \\ \sqrt{L_{is}/450} & if\ L_{is} > 450mm \end{cases} \quad (29)$$

The velocity factor is

$$C_v = \begin{cases} 1 & if\ V_{max} \le 30m/sec \\ \sqrt{V_{max}/30} & if\ V_{max} > 30m/sec \end{cases} \quad (30)$$

The temperature factor is

$$C_t = \begin{cases} 1 & if\ T_{max} \le\ 150°C \\ E_{sc}/E_{sh} & if\ T_{max} > 150°C \end{cases} \quad (31)$$

3.2.7 Bellows Stability:

The two most common forms are column squirm and in-plane squirm.

Column Squirm: Column squirm is defined as a gross lateral shift of the section of the bellows. It results in curvature of the bellows line as shown in the Fig. 1 given below.

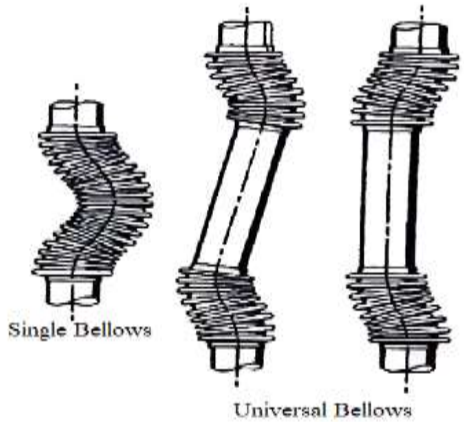

Fig. 1 - Column Squirm (The Expansion Joint Manufacturer Association, Standards Of The Expansion Joint Manufacturer Association, Inc. EJMA Code 2016)

In-plane Squirm: In-plane squirm is defined as a shift or rotation of the plane of one or more convolutions such that the plane of these convolutions is no longer perpendicular to the axis of an unreinforced bellows. It is characterized by tilting or warping of one or more convolutions as shown in Fig. 2 the given below. (The Expansion Joint Manufacturer Association, Standards Of The Expansion Joint Manufacturer Association, Inc. EJMA Code 2016)

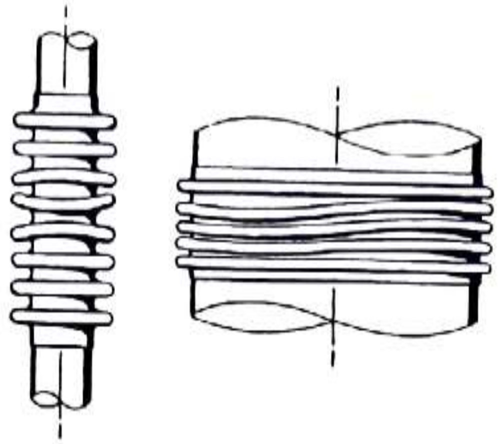

Fig. 2 - In-plane Squirm (The Expansion Joint Manufacturer Association, Standards Of The Expansion Joint Manufacturer Association, Inc. EJMA Code 2016)

3.2.8 Bellows Spring Rate:

The force required to deflect a bellows axially is a function of the dimensions of the bellows and the material from which it is made. The curve of force v/s deflection for most bellows indicates motion extending into the plastic range as shown by the solid line in the given in Fig. 3. (The Expansion Joint Manufacturer Association, Standards Of The Expansion Joint Manufacturer Association, Inc. EJMA Code 2016)

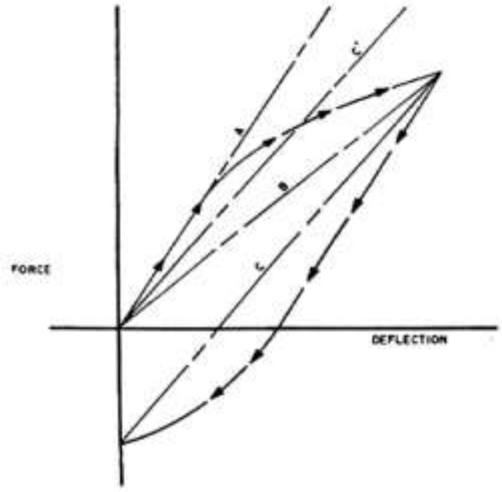

Fig. 3 - Force v/s Deflection Graph (The Expansion Joint Manufacturer Association, Standards Of The Expansion Joint Manufacturer Association, Inc. EJMA Code 2016)

Line A in the above given figure represents the bellows theoretical initial elastic spring rate f_{iu}. The bellows theoretical initial elastic spring rate f_{iu} is calculated in accordance with the below given equation.

$$f_{iu} = 1.7\frac{D_m E_b {t_p}^3 n}{w^3 C_f}. \ (kg/mm) \tag{32}$$

Lines B and C represent bellows resistance factors or working spring rates f_w for bellows with operating deflections in the plastic range.

3.2.9 Stress Equations:

Bellows Tangent Circumferential Membrane Stress due to pressure

$$S_1 = \frac{P(D_b+nt)^2 L_t E_{bd} k}{2(ntE_{bd}L_t(D_b+nt)+t_c k E_{cd} L_c D_c)}. \ (kg/mm^2) \tag{33}$$

Bellows Circumferential Membrane Stress due to pressure29

$$S_2 = \frac{PD_m K_r q}{2A_c}. \ (kg/mm^2) \tag{34}$$

Bellows Meridional Membrane Stress due to pressure

$$S_3 = \frac{Pw}{2nt_p}. \ (kg/mm^2) \tag{35}$$

Bellows Meridional Bending Stress due to pressure

$$S_4 = \frac{P}{2n}\left(\frac{w}{t_p}\right)^2 C_p. \ (kg/mm^2) \tag{36}$$

Bellows Meridional Membrane Stress due to deflection

$$S_5 = \frac{E_{br} {t_p}^2 e}{2w^3 C_f}. \ (kg/mm^2) \tag{37}$$

Bellows Meridional Bending Stress due to deflection

$$S_6 = \frac{5E_{br} t_p e}{3w^2 C_d}. \ (kg/mm^2) \tag{38}$$

3.2.10 Fatigue Life Expectancy:

Fatigue life is dependent upon the maximum stress range to which the bellows is subjected including various factors viz. operating pressure, operating temperature, the material from which the bellows is made, the movement per convolution, the thickness of the bellows, the convolution pitch, and the depth and shape of the convolution. (The Expansion Joint Manufacturer Association, Standards Of The Expansion Joint Manufacturer Association, Inc. EJMA Code 2016)

$$N_c = \left(\frac{c}{\frac{S_t}{f_c} - b}\right)^a . \text{ (Cycles)} \tag{39}$$

Here; a, b, and c are material and manufacturing constants.

Also, $a = 3.4$

$b = 54000\text{psi}$

$c = 1.86 \times 10^6\text{psi}$

$f_c = 1$

$$S_t = 0.7(S_3 + S_4) + (S_5 + S_6). \tag{40}$$

3.2.11 Limiting internal design pressure:

Based on column instability for universal bellows (both ends rigidly supported.

$$P_{sc} = \frac{0.34\pi C_\theta f_{iu}}{(2N)^2 q} . \text{ (kg/mm}^2\text{)} \tag{41}$$

Based on in-plane instability and local plasticity at temperatures below the creep range.

$$P_{si} = \frac{1.3 A_c S_y}{K_r D_m q \sqrt{\alpha}} . \text{ (kg/mm}^2\text{)} \tag{42}$$

3.2.12 Validation of Design:

By verifying the calculated stress values for pressure capacity of the designed bellows. (The Expansion Joint Manufacturer Association, Standards Of The Expansion Joint Manufacturer Association, Inc. EJMA Code 2016)

$$S_1 \leq C_{wb} S_{ab}. \tag{43}$$

$$S_2 \leq C_{wb} S_{ab}. \tag{44}$$

$$S_1' \leq C_{wc} S_{ab}. \tag{45}$$

$$S_3 + (S_4/1.25) \leq S_{ab}. \tag{46}$$

By verifying the fatigue life cycle of the designed bellows.

It is considered valid in the range of 100 - 1000000 cycles. As the calculated value of N_c lies between the allowable range of cycles it can be said that the calculated fatigue life cycle is appropriate.

4 Results

$S_1 = 0.0607$ (kg/mm^2)

$S_1' = 0.063$ (kg/mm^2)

$S_2 = 0.0655$ (kg/mm^2)

$S_3 = 0.00933$ (kg/mm^2)

$S_4 = 0.2888$ (kg/mm^2)

$N_c = 11575$ (Cycles)

All the above stress values satisfy the equations mentioned above for validation of the proposed design. The number of cycles obtained lies between the range validating the fatigue life of proposed design. For visual appearance of designed bellows refer Fig. 4.

Fig. 4 - Universal Expansion Joint

5 Analysis of Universal Expansion using ANSYS

A combined simulation of thermal and structural analysis is carried out to check the structural deformation occurring due to the given temperature gradient and loading conditions using ANSYS Workbench 2020 R2 platform.

5.1 Simulated Model:

All the results are found to be satisfactory as required after simulation of the component model; refer the below given Fig. 5.

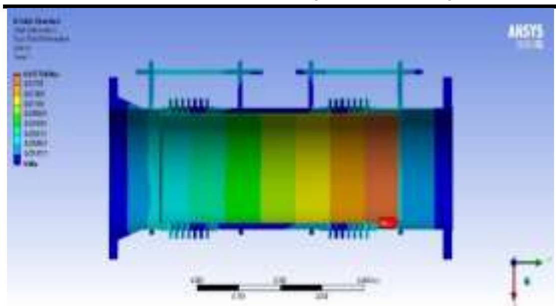

Fig. 5 - Total Deformation in Universal Expansion Joint

6 CONCLUSION

It is concluded that the design of expansion joint is prepared with eliminating the failure points. Now it is fully safe for operation. All the parameters compared with Existing and Improved expansion joint are as per standards (EJMA) and norms. The faults which were identified are sorted out and are incorporated. Hence, it can be concluded that the design is correct, validated and safe for its' application at the specified location in an industry.

7 ACKNOWLEDGEMENT

All activities associated with the design of expansion joint for full satisfaction of the client requires extensive planning and conducting various studies so that the optimum values of all variables can be achieved. Research and development is an essential and perpetual activity for all industries intended towards the eternal improvement of the product and growth of the society. The interactions and involvement of academic and industry people is always beneficial. Academic faculties require participation in the technical research era, with the industry people, and they should collectively contribute for the development of the society. This project is an example of industry – institute interactions. Study of design aspects and procedure, activities are carried out with association of an industry.

I express my sincere gratitude to my guiding professors Dr. V D Chauhan and Prof. K A Patel for their valuable guidance and continuous support during the study. They have always motivated me to study hard and doing some useful research work. They have encouraged me continuously towards the study and they always extended their support in technical difficulties and finding meaningful outcomes of the work. They have continuously supported me in publishing technical paper and spent their valuable time in editing of papers.

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