

Fatigue Analysis of the Unreinforced V-shaped Rectangular Universal Joints using EJMA standards

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Abstract: *The design of the universal expansion joints is a critical task in the piping/duct industries. For fatigue life considerations bellows design plays a vital role for the system designers as they are subjected to cyclic loading and unloading. The present paper focuses on the fatigue analysis of the V-shaped rectangular unreinforced universal expansion joints using EJMA standards. The EJMA standards are used to design the bellows for the minimum of 10,000 cycles then using the FEA, the fatigue analysis is carried out. The EJMA analysis and the FEA simulations are found to have very small discrepancies which can be neglected.*

Keywords: *Bellows; EJMA (Expansion Joint Manufacturers Association); FEA (Finite Element Analysis)*

1. Introduction

Piping systems are critical and important in the chemical and process industries. When the temperature and pressure of the fluid in the pipe/duct changes; the piping material responds to that change either by extension or contraction. This repeated heat-induced extension or contraction exerts cyclic force on the anchors and supports which results in noise and vibrations. To avoid this danger of the anchor failure which will lead to the system failure, the suitable compensating device is needed to absorb the thermal displacements, as well as to withstand high pressure; to reduce noise and unwanted vibrations and to provide the compensation for ground disturbances. In most of the modern process industries, having piping/ducting systems, metal expansion joints are employed at regular intervals between the anchors for providing strength and compensation as the metal expands/contracts with increase/decrease of temperature. Expansion joints play the vital role in such systems. Bellows being the most important elements acts as spring due to its flexibility and provides elasticity to the component. The design of the bellows is important from the

fatigue life consideration, as the bellows are subjected to cyclic loading and unloading. These expansion joints possess several advantages like flexibility, ability to absorb movement in more than one direction and to reduce noise and vibrations in very less space requirement. The bellows are made of corrugated shapes. These bellows corrugations are of different shapes like U, V, Rectangular, Toroidal etc. These corrugation design is a critical part for the design engineer as it is responsible for the flexibility of the bellows. The system designers use EJMA standards for the design and other purposes in case of expansion joints.

2. Literature review

EJMA (Expansion Joint Manufacturers Association) [1] provides guidelines for material selection, design of the expansion joint, analysis, manufacturing techniques, servicing and many more. Bellows can withstand internal as well as external pressure they can also be subjected to vacuum state [2]. Bellows is the most flexible element of the piping system, which are subjected to axial movement, lateral deflection and angular rotation [3]. Bellows when subjected to cyclic loading and unloading experiences fatigue. Hence in the design of expansion joints fatigue consideration is an important aspect [4]. In the industries, due to excessive manufacturing and maintenance costs the proper design of the bellows expansion joints is very necessary to fulfill the life expectancy [5]. Austenitic stainless steel is most widely used worldwide for the manufacture of the bellows expansion joints, as it provides superior characteristics like high strength, weld, cold deformation and oxidizing ability of heat resisting [6]. Bellows provide flexibility and act like spring but it is not a spring. The behavior of the bellows made of multilayer material is not linear [7].

3. Numerical simulation

The operating temperature of 340⁰C and operating pressure of 660 mm of H₂O (i.e. 6.4746 × 10⁻³ MPa) the young's modulus at design temperature of the austenitic stainless steel is 180200 MPa. Longer side (L_l) is 3500 mm and shorter side (L_s) is 3100 mm. The number of convolutions are 5 with height (w) 80 mm and pitch (q) 40 mm made of material of thickness (t) 1.5mm single ply. The total length of the universal joint (L_u) is 1050 mm. The EJMA formulae are used to calculate different stress values for the designed expansion joint. The following table summarizes the stress values:

Table 1. Stress values using EJMA formulae

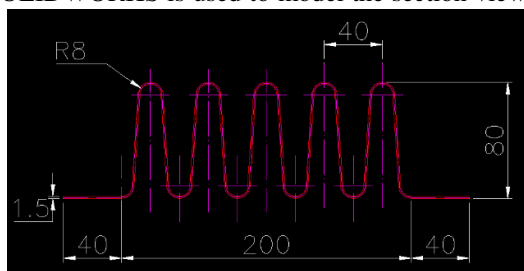
Sr. No.	Parameters	Symb ol	Results
1	Bellows Meridional Bending Stress due to Pressure (Sidewall)	S ₉	8.0112 MPa
2	Bellows Meridional Bending Stress due to Deflection	S ₁₀	593.6959 MPa
3	Total Stress	S _t	1083.07278 MPa
4	Fatigue Life	N _b	14923 cycles

4. FEA simulation

AUTOCAD is used for drafting the convolution sketch and the cross-section of the bellows and expansion joint.

Figure 1. Cross-section of the expansion joint bellows

SOLIDWORKS is used to model the section view of



the expansion joint which then will be meshed for the finite element analysis using ANSYS software.

Figure 2. Expansion joint model section view

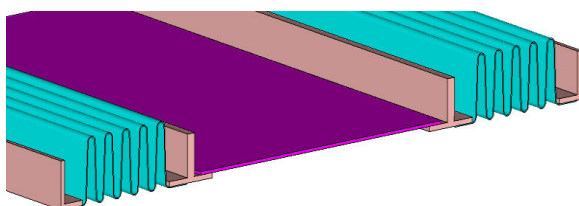
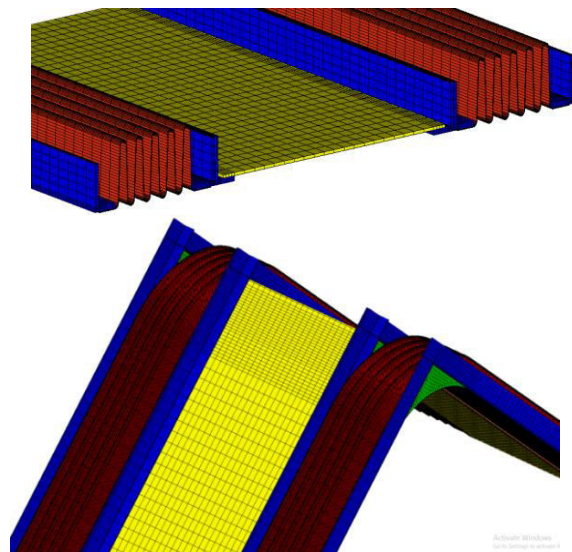


Figure 3. Hypermesh view of the expansion joint



No. of nodes 1667164

No. of Elements 1246464

The material properties selected are SA240 type 304 Austenitic stainless steel (32) with modulus of elasticity of 195000 MPa, yield strength of 205 MPa and Poisson's ratio 0.29.

5. Static structural analysis

660 mm of H₂O (i.e. 0.064746 MPa) pressure was applied on the inner surface of the expansion joint along with both the flange ends fixed in all degrees of freedom.

Figure 4. Boundary condition for Pressure case Pressure of 0.0064746 MPa is applied on inner surface. Both ends flanges are fixed in X, Y & Z direction.

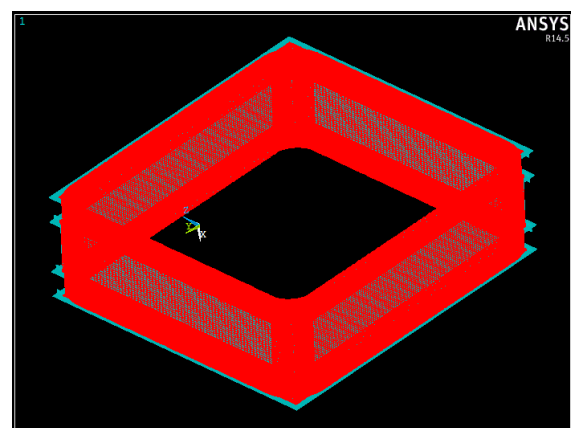


Figure 5. Displacement plot for pressure case:
 Maximum displacement of 70.92 mm was observed on
 the expansion joint assembly.

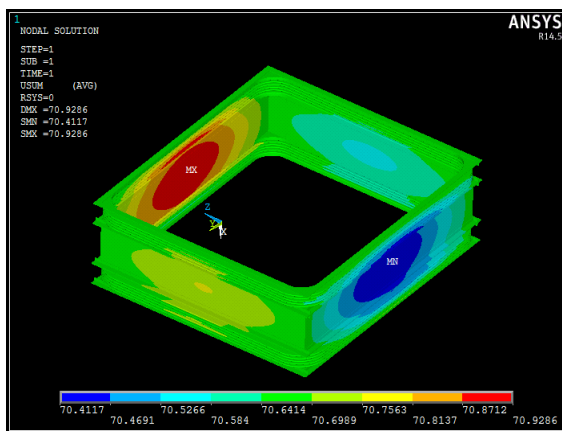


Figure 6. Displacement plot for pressure case:
 Maximum displacement of 70.92 mm was observed on
 the bellows convolutions.

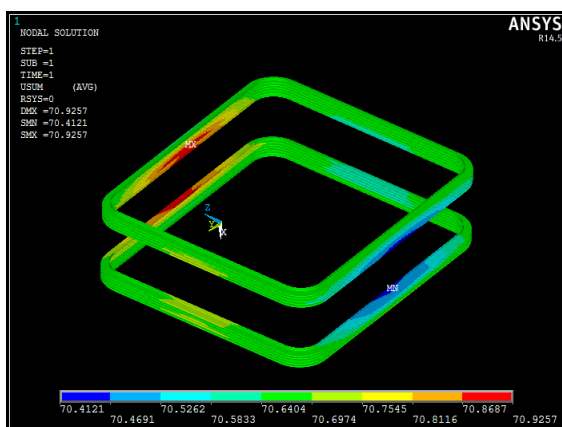


Figure 7. Stress plot for Pressure case: Maximum stress
 or peak stress is been observed at geometric
 discontinuity locations which can be neglected. The
 overall Von Mises stress on the assembly is within 16
 MPa.

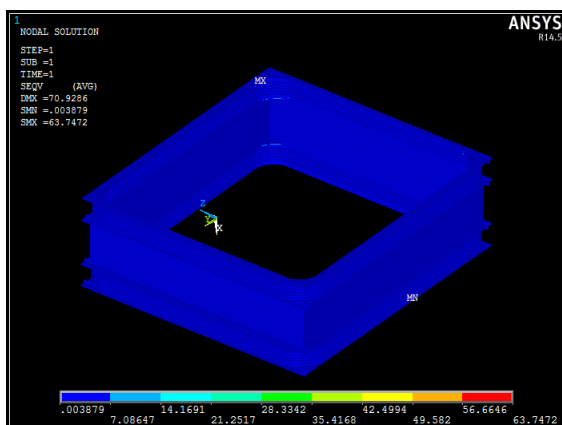


Figure 8. Localized high stress location on the bellows
 convolution.

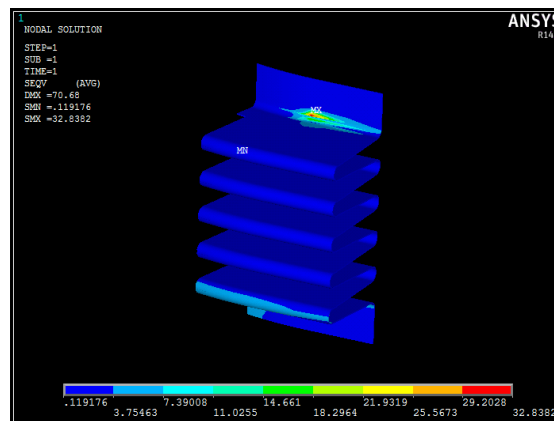


Figure 9. Stress linearization along the thickness of the
 convolution at the beginning of the convolution.

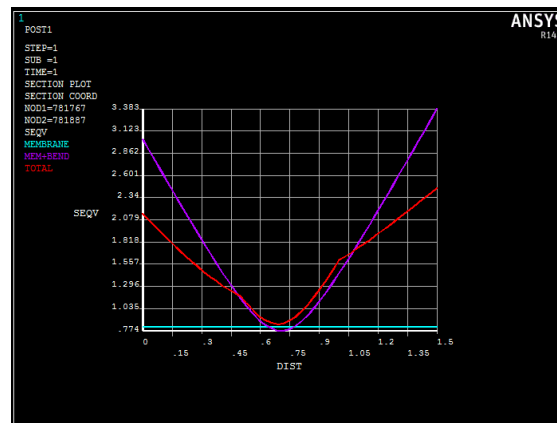
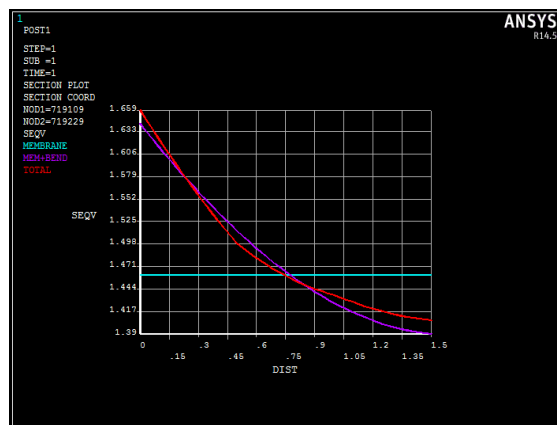


Figure 10. Stress linearization along the thickness at
 center convolution.



Bellows Meridional Bending stress due to Pressure (sidewall) S_9 found was 16 MPa and Bellows Meridional Bending stress due to Deflection S_{10} was 598 MPa. Total stress S_t was 1105.2 MPa. Fatigue life N_b was 13446.63348 cycles.

6. Results and Discussion

The results for EJMA calculations and FEA simulation is summarized bellows:

Table 2: Summary of the comparison of EJMA calculations and FEA simulation results

Sr. No.	Parameters	EJMA result	FEA result
1	S_9	8.0112 MPa	16 MPa
2	S_{10}	593.6959 MPa	598 MPa
3	S_t	1083.07278 MPa	1105.2 MPa
4	N_b	14923 cycles	13446.63348 cycles

The EJMA standards typical calculated stress range values are 344 MPa to 3445 MPa. Bellows Meridional Bending stress due to Deflection S_{10} is more dominant on fatigue life as Bellows Meridional Bending Stress due to Pressure S_9 has very less effect.

7. Conclusion

The percentage error is 49.93 in S_9 due to the consideration of the whole assembly in the FEA analysis while in numerical calculation only bellows convolution has been considered. Though the percentage error is very high the analytical and FEA output are much more within the yield strength of the material. Bellows Meridional bending stress due to deflection S_{10} the percentage error is 0.8361 which is very negligible, hence we have achieved the realistic calculated values in simulation which is within the specified standard range. Fatigue life is totally dependent on total stress S_t which is the sum of the S_9 and S_{10} . As there is huge percentage error in S_9 hence the fatigue life percentage error is 9.89. The fatigue life resulted in both EJMA calculation and FEA simulation are within the required life expectancy of the expansion joint (i.e. Minimum 10,000 cycles). Universal expansion joints are more efficient to absorb lateral deflections rather than single EJ hence wherever lateral deflection exists design of universal EJ to be preferred.

8. Acknowledgement

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9. References

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