Effect of Liner in a Bellow using ANSYS software

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Abstract- **The flexible part of an expansion joint consisting of one or more convolutions and the finish tangent with the ratio of the length of the bellows to the diameter of the bellows should be less or equal to three with no more than five plies. Bellows are one of the most effective energy absorbing components for an engineering system. Bellows have a function to absorb the regular or irregular expansion and contraction in the piping system, it is widely used as the element of expansion joint in the various piping system, aerospace, microelectromechanical and industrial system. Bellows are unique structures that require high strength as well as excellent flexibility. The most industrial piping system often suffers extreme deformation, displacement, heat expansion, vibration, and other causes are accountable for the failure. The failure of bellows extension joints made of SS 304 has been analysed. Overpressure, Vibration of steam in piping is accountable for the failure. After complete scrutiny of the bellows, we found that wrong design data are presumed at the time of bellows fabricating, and finally, these bellows are failed within one year of service. Based on these design data, we have improved the design and its re-design the metal expansion bellows by using EJMA code and FEA simulation. To avoid bellows failure possibilities, we have to provide liner in the bellows. Further, it has many benefits such as: to make sure smooth flow of media, minimize friction losses, minimize resonant vibration caused by high flow velocity, decrease 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 anticipated. In this paper, for the validation of the software results and EJMA design calculated results bellows with optimisation result.**

Index terms- bellow, ANSYS, collar, structural analysis, liner, elastic material

I. INTRODUCTION

The bellows are the flexible component of the expansion joint. It must be sturdy enough circumferentially to hold out the pressure and flexible enough longitudinally to take the deflections for which it was designed, and as repetitively as necessary with minimum resistance. This strength with flexibility is an exceptional design problem that is not regularly found in other components in industrial equipment. Any device is containing one or more bellows used to enchant dimensional changes such as produced by thermal expansion or contraction of the channel, duct or vessels or engineering system. An expansion joint or movement joint is an assembly designed to safely absorb the heat-induced expansion and contraction of several construction materials, to absorb vibration, to grasp certain parts together, or to permit movement due to ground settlement or earthquakes. They are usually found between sections of sidewalks, bridges, railway tracks, piping systems, ships, and other structures. Most engineered structures are designed to prevent deflection when acted upon by outside forces. Since the bellows must accept deflections frequently, and deflections consequence in stresses, these stresses must be kept as little as possible so that the recurring deflections will not result in early fatigue failures. Reducing bending stress bring about from a given deflection is easily' achieved by merely decreasing the thickness of the bending component, which in the situation of the bellows, is the convolution. Most bellows fail by circumferential cracking developing from cyclic bending stresses, or fatigue. Since the most elegant design is a compromise, or balance, amongst pressure strength and flexibility considerations, it can be decided that their designs have had more inadequate margins of safety concerning fatigue than they had about pressure strength. The years of understanding of the engineers who established these bellows assures that the designs contained in this catalogue and those offered to satisfy customer specifications will have the performance reliability which yields trouble-free, harmless application.

Occasionally, a bellows will seem to cultivate a fatigue crack in advance, i.e., after being exposed to fewer cycles than analysis indicates they should. These early failures usually are the result of one or more of the following causes:
The insufficient margin of safety in the design permitting approval of a unit fabricated within a portion of the dimensional tolerance limit to yield a component which will not gratify the design. Metallic bellows bending stresses are exceptionally sensitive to changes in some dimensions; for instance, the thickness and the height of the convolution. These dimensional features often affect the numerous bending stresses by the square or cube of their differences. An understanding of these dimensional aspects and how they can be organised during design and production is the key to avoiding this cause of early failure. Poorly fabricated bellows or one that is prepared to the "wrong" side of the dimensional tolerances will disappoint the best design and analysis. The insufficient margin of safety concerning stability under pressure is described in additional detail below, is a distinctive of all bellows exposed to internal pressure. Each bellows has a critical pressure at which the convolution side walls begin to deform, or the real bellows shape begins to variation. These deformations ground the bellows to accept the imposed deflections in a different way than they are generally expected to and they can no longer carry out according to the design formulas. The critical pressure is a job of the bellow's shape and actually can reform during deflection.

II. DESIGN AND MANUFACTURING

A. Fatigue design of bellow

Consideration of fatigue is generally an essential characteristic for the design of metallic bellows expansion joints. These parts are subject to displacement loading, which results typically in cyclic strains well beyond the proportional bounds for the material. At these high-strain points, plastic strain concentration occurs. Contemporary design practice relies on the use of empirical fatigue curves based on bellows testing. Prediction of fatigue behaviour based on the mish-mash of analysis and polished block fatigue data is not considered to be reliable. One of the whys and wherefores for the unreliability is plastic strain concentration. It is made known that the difference between bellows and polished bar fatigue behaviour, as well as the difference amongst reinforced and unreinforced bellows, can be primarily attributed to this strain concentration. Further, it is made known that the fatigue life of bellows can be well predicted by partitioning the bellows fatigue data founded on a geometry parameter.

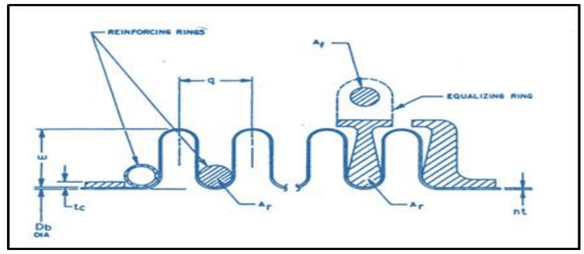

Figure 1.1 Fatigue design of bellow

B. Practical and Analytical study of bellow joint

The study of Bellows' joint is a critical element of an underground pipeline system, which can undergo serious damage such as breaking, crushing, and bending under a strong earthquake. In our examination work, finite element analysis (FEA) of the bellows joint was studied using ANSYS. Single and multi-convolution bellows joints applied with dissimilar loadings were examined. Force-displacement curve, plastic strain distribution and bending moment – angular displacement curve were obtained. Furthermore, low-frequency recurring experiment on 4-convolution bellows joints was accompanied, and the results from the experiment were matched with the outcomes from FEA. The capacity of the multi-convolution bellows joint was just about the same as the single convolution bellows joint, and the energy absorption amplified with the number of the convolution linearly.
The FEA was based on the finite element software ANSYS to establish the model of the single convolution and multi-convolution bellows joints. One end of the joint was fixed, and the other end was loaded with axial tension, axial compression, bending, loading, one step cyclic loading and multi-step cyclic loading. Force-displacement curve, plastic strain distribution, and bending moment-angular displacement curve were obtained. Furthermore, the low-frequency cyclic loading experiment on the 4-convolution bellows joints was conducted.

C. Ways to improve bellow joints

- To design a Un-reinforcement bellow.
- To develop the single step hydroforming method of 50 NB to 600 NB.
- To improve the efficiency of metal expansion bellow with the aid of inner liner.

D. Design of bellow

The formulas for un-reinforced bellows are creäte on those shown in Atomic International report NAA-SR-4527 “Analysis of stresses in bellows design standards and test results” with upgradation and add on by the association to point towards the experience of the members These formulas are based on elastic shell concept and consider the parameters included for bellows of the “U” shaped arrangement.

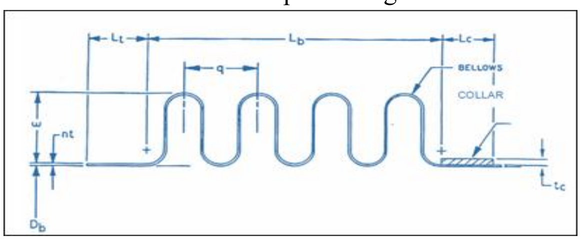

Figure 1.2 Schematic layout of bellow

III. PARAMETRIC MODELLING


Figure 1.3 Assembled bellow

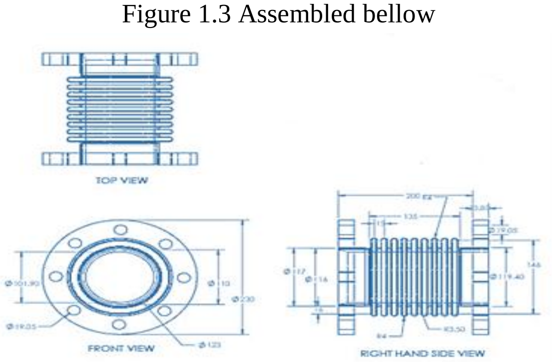

Figure 1.4 Drafting of bellow

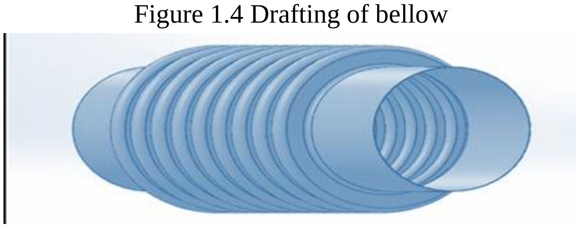
Figure 1.5 Bellow

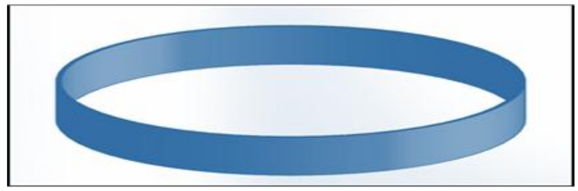
Figure 1.6 Bellow ring

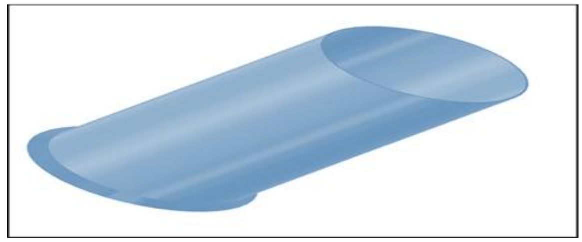
Figure 1.7 Liner

IV. PARAMETRIC MODELLING

NAME	DIMENSION
Bellows Inside Diameter	116mm
Bellows Outside Dia.	150mm
No. of Convolution	9
Pitch of Convolution	15
Height of Convolution	16mm
Plies of Thickness	0.5mm
No. of Plies	2
Length of Plies	45mm
Convolution Length	135mm
Collar Inside Diameter	117mm
Collar Outside Diameter	119.4mm
Flange Inside Diameter	119.4mm
Flange Outside Diameter	230mm
Pitch hole Dia. (Flange)	190mm
No. of Holes(Flange)	8
Hole Diameter(Flange)	19.05mm
Inner Liner Length	200mm
Inner Liner Thickness	1.2
Inner Liner inside Dia.	101.9

V. DESIGN CALCULATION FOR UN-REINFORCED BELLOWS AS PER EJMA

1) Convoluted Length
   Lb= q*N = 135 mm
2) Mean dia. of the bellows convolutions [D_m]
   $D_m = D_b + w + n*t$ = 133 mm
3) Mean Radius of bellows convolutions [r_m]
   $\frac{q}{4}$ = 3.75 mm

4) Axial movement per convolution resulting from imposed axial movement [e_x]
$e_x = \frac{X+Xcomp}{N} = $ 22.2222 mm
5) Equivalent axial compression per convolution [e_e]
$e_e = \frac{X}{N} = $ 2.222 mm
6) Equivalent axial extension per convolution [e_c]
$e_e = \frac{X\ comp}{N}$2.2222 mm
7) Axial movement per convolution resulting from lateral deflection [e_y]
$e_y = \frac{3*y*Dm}{(N*(L_b \pm x)}$ =1.156 mm
8) Axial movement per convolution resulting from imposed angular rotation etheta [$e\theta$].
$E\theta = \frac{\left(0*\frac{3.14}{180}\right)*d_m}{(2*N_1)}$ = 0 degree
9) Total axial movement per convolution [e]
E = $e_x + e_y +$ eθ = 23.378 mm
10) Mean diameter of bellows tangent reinforcing collar [Dc]
$D_c = D_b + (2nt) + t_c$ =119.2 mm
11) Bellows tangent circumferential membrane stress due to pressure (S_I)
$S_I = \frac{P(D_b+nt)L_tE_bk}{2(ntEbL_t(D_b+nt)+t_ckE_cL_cD_c}$ = 37.57 Mpa
12) Collar circumferential membrane stress due to pressure (S_I)
$S_I = \frac{P(D_c^2L_tE_ck)}{2(ntEbL_t(Db+nt)+t_ckE_cL_cD_c}$ = 38.29 Mpa
13) Column instability pressure reduction factor based on initial angular rotation [$C\theta$]
$C\theta$ = 0.1157*(θ*(3.14/180) =1
14) Bellows theoretical initial axial elastic spring rate [F_{iu}]
$F_{iu} = 1.7(\frac{D_mE_bt_p^2n}{C_fw^3})$ = 1444.5 N/mm
15) Axial spring rate of whole bellows [$F_{iu}1$]
$F_{iu}1 = \frac{F_{iu}*UNITFIUVAL}{N}$ = 160.50 N/mm
16) Cross section metal area of one bellows convolution [A_c]
$A_c = [2\pi r_m + 2\sqrt{[\frac{q}{2} - 2(r_m)] + [w - 2(r_m)]]} t_p n$ = 37.8716 mm^2
17) Bellows circumferential membrane stress[S_2]due to pressure
$S_2 = \frac{PD_mK_rq}{(2*A_c)}$ = 18.97 Mpa
18) Bellows meridional membrane stress [S_3]due to pressure
$S_3 = \frac{P*w}{(2n*t_p)}$ = 6.17 Mpa
19) Bellows meridional bending stress [S_4]due to pressure
$S_4 = \frac{P}{2n}\left(\frac{w}{tp}\right)^2 * Cp$ = 124.81 Mpa
20) Bellows meridional bending stress[S_5] due to deflection
$S_5 = \frac{E_bt^2p*e}{2W^3C_f}$ = 12.81 Mpa
21) Bellows meridional bending stress[S_6] due to deflection
$S_6 = \frac{5E_bt_p*e}{3W^3C_d}$ = 1088.02 Mpa
22) Total stress range [S_t]
$S_t = [0.7*(S_3+S_4) + (S_5+S_6)]$ = 1192.516 Mpa
23) Fatigue Life [N_c]
$N_c = (\frac{c}{S_{t-b}})^2$ = 11481.26
24) Limiting internal design pressure based on column instability [P_{sc}]
$P_{sc} = \frac{0.34\pi C0F_{iu}}{N^2q}$ = 1.27 Mpa
25) 25) Limiting design pressure based on in-plane instability and local plasticity [P_{S1}]
$K_2 = \frac{S2}{p}$
$K_4 = C_p/2n\ (w/T_p)^2$
$A = K_4/\ 3K_2$
α= 1+2A2+ (1-2A^2+4A^2)$^{0.5}$
P_{S1}= (1.3 Ac Sy) / (KrD$_m$qα^2) = 1.44 Mpa
26) Lateral spring rate [LSR]
LSR_{min}= ((F$_w$D$_m$e$_y$)/(2*(lb±X)))/(Y) = 215.75 N/mm
27) Angular spring rate [ASR]:
θ_{ar} = ((eθ*2*N1/D_m)*57.32
ASR = (($F_w D_m e\theta$)/4*1000))/θ_{ar} = 0 N/mm
28) Outer diameter of the bellows [OD]:
OD = (n2t) +92w) +d$_b$ = 150 mm
29) Length of convolution [LOC]:
LOC = ((0.571*q) + (2w))*N1 = 365.085
30) Bellows effective area [A_c]:
$A_c = \frac{3.1415D_m^2}{4}$ = 13892.91 mm^2
31) Trust force at design pressure [TF]
$TF = \frac{pa_e}{1000}$ = 10.0028952 KN
32) Percentage of elongation [PE]
$PE = \frac{2w}{d_p}$ = 27.5862 %
33) Overall length of bellows assembly [OLA]
OLA = (SF*2) +l$_b$ = 225 mm
34) Overall length of bellows element [OLE]

OLE = (SF*2) +l_b = 225 mm

35) Tooling circumference [TOC]

TOC = ((d_b+ (2w0)3.1415926) = 464.742 mm

VI. PARAMETRIC INPUT PARAMETERS

As we are performing computational analysis using ANSYS software, results for stresses will be justified with data available for maximum allowable values in properties database mention above.

Property related criteria such as Density is 7850 kg/m3, Modulus of elasticity is 193 GPa, Poisson's ratio is 0.29, Yield strength is 240 MPa, Ultimate tensile strength is 515 MPa, and Coefficient of thermal expansion is 17.8.

Input parameters for software like; Pressure are 0.72MPa, Temperature is 300oC, and Factor of safety is 1.

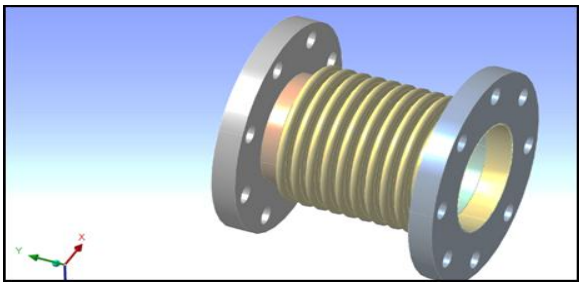

Figure 1.8 ANSYS assembled bellow

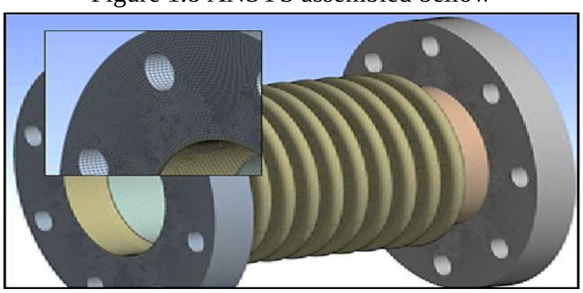

Figure 1.9 ANSYS meshed assembled bellow

VII. ANSYS OUTCOME

A. Bellow without liner

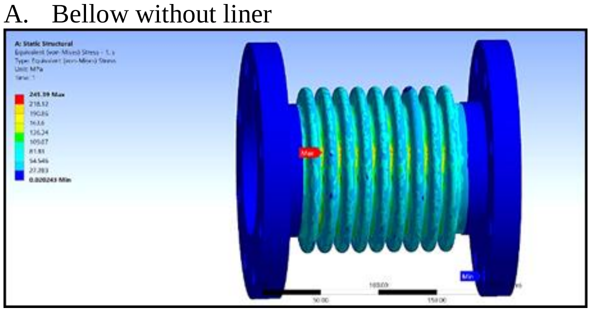

Figure 1.10 Equivalent stress of assembled bellow

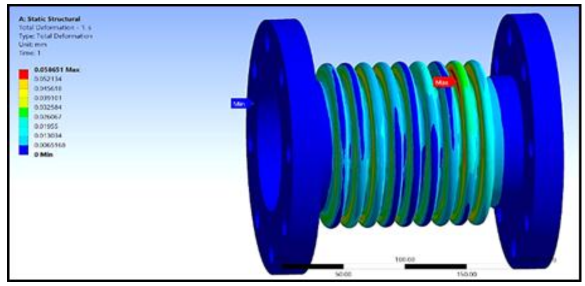

Figure 1.11 Total deformation of assembled bellow

B. Bellow with liner

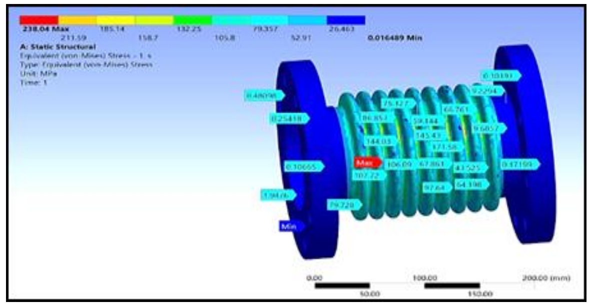

Figure 1.12 Equivalent stress of assembled bellow

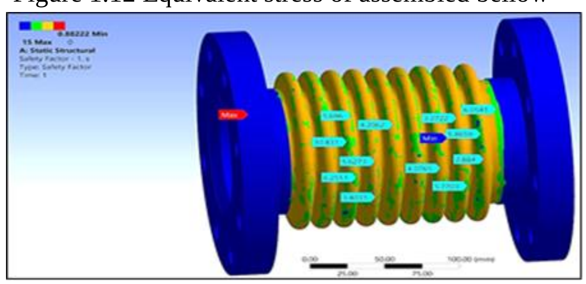

Figure 1.13 Total deformation of assembled bellow

C. Components

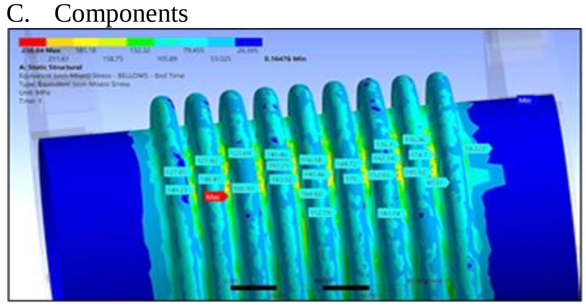

Figure 1.14 Equivalent stress of bellow

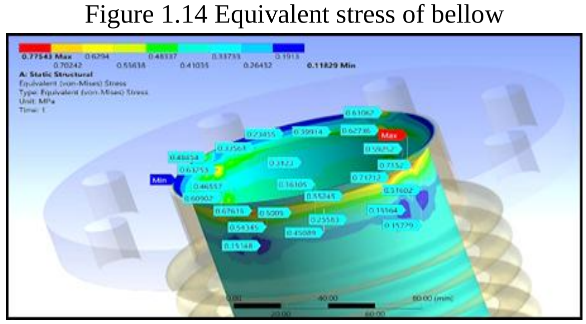

Figure 1.15 Equivalent stress of liner

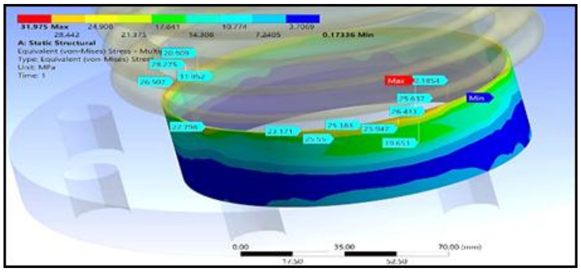

Figure 1.16 Equivalent stress of bellow ring

VIII. CONCLUSION

Thus, to conclude that by analysing bellow with liner and without liner we have come to know that using optimum liner material for particular scope gives better efficiency and also decreases total deformation, strain and stresses in bellows.

Furthermore, we have come to know that it is possible to increase the life of the bellows by using the different materials of the liner. Which will lead to the minimisation of the friction losses, bellows wall will have reduced effect of chemical and abrasive, reduces the chances of damaging the part by resonating vibrations and providing a smooth and efficient flow as a medium.

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