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DESIGN OF BELLOWS: STRAIN BASED FATIGUE ANALYSIS OF BELLOWS

Harshvardhan P. Ghongade

Research Scholar, Department of Mechanical Engineering,

North East Frontier Technical University, (India)

&

Asst. Prof., Department of Mechanical Engineering,

Shatabdi Institute of Engineering & Research, (India)

ABSTRACT

Consideration of fatigue is an important aspect for the design of the metallic expansion joints. These components are subjected to displacement loading which frequently results in cyclic strain well beyond the proportional limit of the material. At these high strain-levels plastic strain concentration occurs which is the major cause of fatigue of bellows.

With the use of Finite Element Analysis fatigue life of bellows is predicted, in which bellow is considered as elastic-plastic shell of revolution subjected to completely reversed loading of displacement.

For FEA, strain-life approach is used to calculate fatigue life, which is comprehensive approach that calculates infinite to low fatigue life of component. The strain life approach considers the effect of plasticity which is main cause of fatigue of bellows. FEA gives realistic effect of various movements by different simulations. ANSYS Workbench is used for finite element analysis.

Hamada and Tanaka found out results for elastic-plastic shells of revolution by using numerical methods of finite difference technique. The extensive work carried out by Hamada and Tanaka provides the procedure to obtain plastic strain from the hysteresis loop which is very useful for extending the work to finite element analysis using strain life approach.

Keywords: Bellows, Fatigue, Life-Cycle, Plastic-Strain, Strain-Concentration,

I. INTRODUCTION

Approach for fatigue life calculations:

The strain-life method is based on the observation that, in many components the response of the material in critical locations is strain or deformation dependent especially in case of metals where the plastic strains are significant. The important strain-life equation as applied to metals developed by Coffin and Manson and the various models as proposed by Morrow and Smith, Watson & Topper (SWT) to account for the mean stress effects. This approach was extended to bellows by Hamada and Tanaka. Here the strain controlled fatigue behavior is modeled by the total strain amplitude into elastic and plastic components in a similar manner as that modeled for metallic materials. The mean stress/strain effects are also considered using the Morrow mean stress

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& Smith, Watson and Topper (SWT) model which are proposed for metals. Moreover, it is well known that a positive non-zero mean stress has a more detrimental effect on the fatigue endurance than a negative one.

The fatigue process can be simulated in most common cases by a linear elastic-plastic analysis and linear fracture mechanics.

II. LITERATURE REVIEW

C. Becht studied response of pressure and deflection loading for fatigue life. Plastic strain concentration is one of the parameter which is affecting fatigue life of bellows.

According to C. Garion, B. Skoczen, the damage rate is driven by the accumulated plastic strain rate.

Hamada and Tanaka have established numerical method of solution by the finite difference technique for general axisymmetric shell problems using the incremental theory of plasticity.

III. DISCUSSION/METHODOLOGY

The empirical fatigue curve in the EJMA inherently includes effect of plastic strain concentration and need not to determine analytically.

The procedure based on Finite Element Analysis is effective for the low cycle fatigue life of estimation bellows subjected to completely reversed displacement loading. Finite Element Analysis gives the relation between displacement amplitude, plastic strain range and fatigue life.

From graphs it is to be predicted that displacement & plastic strain are the factors which are reducing the fatigue life of bellows.

Plastic strain concentration depends on number of factors greater the displacement, greater the strain concentration. The higher value of convolution height reflected in a low value of QW$\left(\frac{2r_m}{w}\right)$, the greater the strain concentration.

It could be eliminated by incorporating a sufficient number of convolutions, or greater convolution depths, or reduced wall thickness, to keep the deflection stresses within the elastic range C. Becht [2000].

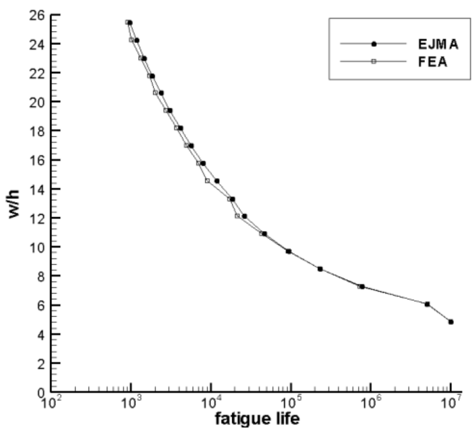

Figure:7.10 Fatigue life vs. Displacement amplitude

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Figure 7.9 are the graphs for fatigue life vs. displacement for three specimens. Here the w/h is normalized parameter in which ‘w’ is the displacement amplitude and h is the thickness of ply. In Fatigue life vs. Displacement amplitude graph it is found that fatigue life and displacement are in inverse relation and the trend for EJMA and FEA compared which is found to be closer to each other.

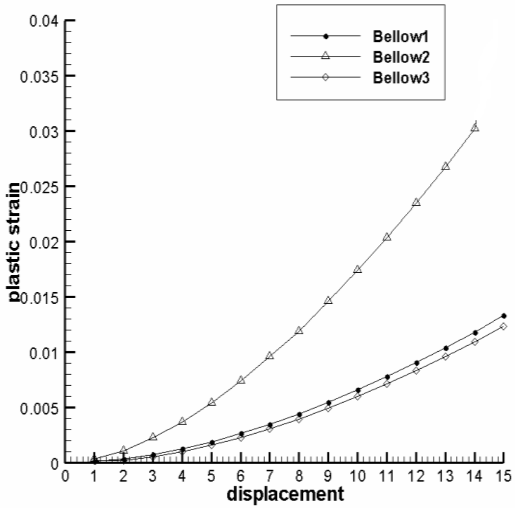

Figure: 7.13 Displacement vs. Plastic strain

Figure 7.13 shows Displacement vs. Plastic strain curves for different specimen C. Becht [2000] extensively worked and investigated the effect of thickness of ply and displacement on bellows fatigue life. Bellows are subjected to displacement loading which frequently results in cyclic strain well beyond the proportional limit.

The thickness of ply for second specimen is much large as compared first and third specimen. Due to much large thickness high level plastic strain is accumulated.

The plot 7.14 gives the relation between fatigue life and plastic strain. The accumulated plastic strain reduces fatigue life of bellows.

As per discussion in 7.5 plastic strain is one of the factor which reduces fatigue life of bellows from graph it is to be observed that life get reduced as the plastic strain increased.

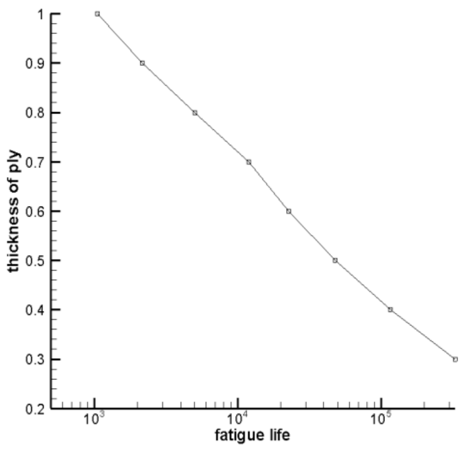

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Figure: 7.15 Fatigue life vs. Thickness of ply

Figure 7.14 plot for varying thickness of ply & fatigue life which depicts that as the thickness of ply increased, fatigue life also decreases.
To minimize the plastic strain concentration thickness of ply should be reduced.

IV. CONCLUSION

Strain-life fatigue life calculation is a criterion which holds good agreement with the curves behavior for displacement amplitude, plastic strain and fatigue life of bellows. These parameters are important at the preliminary stage of design. The main findings are as follows

- The deflection amplitude has significant effect on fatigue life of bellows, which depends on geometry parameters.
- The root and crest are high stress zones and local regions through which crack get emanates.
- The plastic strain is predicted to be important parameter which reduces fatigue life of bellow.
- As per the discussion it is found out that thickness of ply is significant factor for fatigue of bellows.
- Plastic strain can be lowered down by incorporating number of convolutions, reduced wall thickness.

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