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Study of the Stress Distribution Around a Micro Hole on a Flexible Tube under Lateral Deflection with a Positive Rotation Angle Towards the Micro Defect

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Abstract

Objectives: This study was conducted for the effects of micro holes to stress distribution acting on bellows under lateral deflection with a positive rotation angle toward the micro defect. **Methods/Statistical Analysis:** Stress was analyzed by F.E.M. (Finite Element Method) and the chosen mesh consisted of 112,800 elements or more. Shell element and non-linear method were used. The micro hole was located at the top of the first root of the neck. **Findings:** The results show that the stress in the bellows is affected by not only non-symmetrical deformation but also by a combination of the rotation angle and the deflection deformation of the hole as well as the micro hole. The elastic-plastic range around the hole and its relation to the upward lateral deflection and the positive rotation angle was obtained for the bellows in this study. **Improvements/Applications:** The results are important as they identify the relation between a micro hole and the deformation conditions, and it can be used to improve the quality of bellows.

Keywords: Angular Movement, Flexible Tube, Lateral Displacement, Micro Hole, Stress Distribution

1. Introduction

Because of its inherent anti-vibrational properties and flexibility, bellows are used widely. Although considerable effort has gone into protective covers, packaging and educational programs regarding the seriousness of bellows damage, they are still not 100-percent effective in preventing the use of damaged bellows. There are several common defects in bellows. These bellow's defects, shown in Figure 1, can be split into two categories: (1) manufacturing defects, which are those more or less consistently produced by a deficiency in the manufacturing process; and (2) accidental defects, those which occur as the result of a human element. Manufacturing defects (examples of which are tool marks and orange peel) can eventually be reduced to an acceptable level by appropriate changes to processes and process control. The stress analysis for the bellows with the defects is very important and several papers are published for bellows with defects. However, most of the studies for defects have looked at the case of a defect on the flat panel, while research looking at flaws on the rounded surface such as the bellows is rare. As the maximum stress is concentrated at a defect, it is necessary to analyze the effects of micro defects on the maximum stress. In this study, F.E.M. is utilized to analyze the von Mises stress for a curved plane weakened by arbitrarily oriented defect subjected to lateral deformation in the direction of the hole

Bellows have been used in many engineering

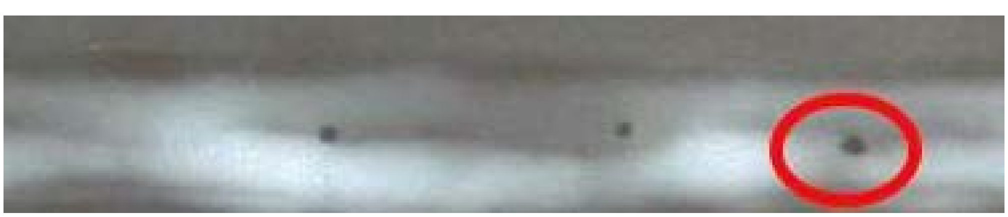

Figure 1. Block diagram of the proposed algorithm.

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applications, and numerous studies have investigated the properties of bellows. Several formulae for flexible tube is in ASME code[1]. There are lots of technical data for the flexible tube design in E.J.M.A.[2]. Hanna compared E.J.M.A. and A.S.M.E. and it is well conformed between both. Experimental[3] analyses and finite element were compared with the EJMA standard sin some papers. It was found that the equations in E.J.M.A. include excessive S.F. and errors. In order to improve the reliability, practical factors are considered in some studies[4]. As the flexibility is necessary to absorb dynamic energy, it consists a thin shell of revolution. Because of complex in geometry, analysis of the stress behavior of bellows is difficult. Some studies have investigated axis-symmetrical deformation problems of flexible tubes[5], usually using the finite difference method[6]. In case of analysis, as it should consider the shape and thickness with plasticity, there are few papers employing a computerized analysis technique. It is more complex than an elastic analysis and experimental test is necessary to solve the design problem. Also a bellows design should be based on the actual bellows metal temperature expected during operation. Design of bellows includes evaluation of the major stresses in the circumferential membrane and longitudinal membrane and bending stress with reference to pressure and deflection. Bellows are loaded with combined tensile and compressive stresses during their service life[7]. Bellows may fail due to various reasons such as stress-corrosion[8], fatigue failure[9], carbide precipitation, squirm failure, and rupture failure, etc. during their use.

2. Analysis Model

The bellows structure is as shown in Figure 2. The micro hole is located on the top of the first root of the neck. The bellows are modeled using F.E.M and shell element with plastic range is performed. Dimensions and properties in the study are as shown in Table 1. The yield stress is 350MPa. The height of 1st convolution is 4mm and others are 10mm. It is used 112,800 elements or more in the analysis. The movement types of the bellows are as shown in Figure 3 and the lateral displacement is varied at a certain angular movement. One side is fixed and lateral displacement varies from 0 mm to 21mm, angular movement is set to 4 angles up to 0.12 degrees in the non-fixed area. The upward direction in the study is defined as the lateral axis moves towards micro hole. Analysis is performed with 3 types of bellows as shown in Table 2. Type A is bellows without a hole. Type B is bellows with a hole at the tip. Type Cis bellows with a hole undergoing upward deflection.

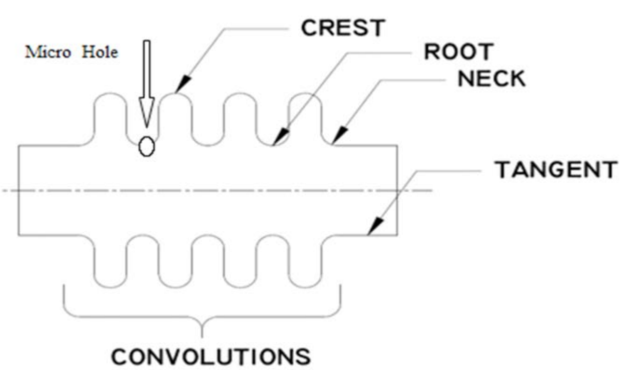


Figure 2. Terminology of bellows.

Table 1. Geometric dimensions and material properties

Tangent Modulus [GPa]	Young's Modulus [GPa]	Inner Diameter of Tube[mm]	Thickness [mm]	Diameter of Micro Hole [mm]	Quantities of Flexible tube [ea]	Type of Element
1.880	188	64.32	0.315	0.05	23	8-node shell

* Height of first convolution : 4mm, Height of other convolutions : 10mm

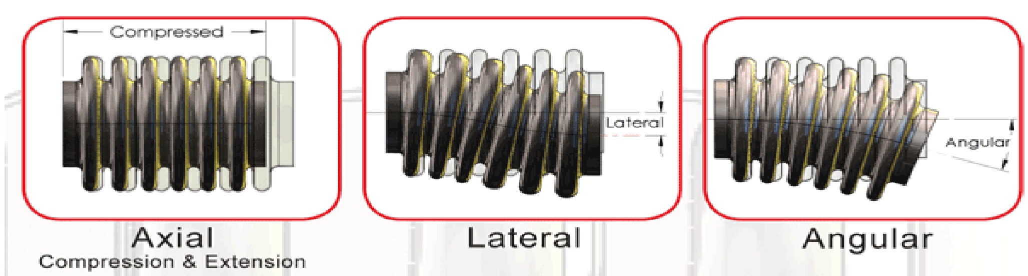
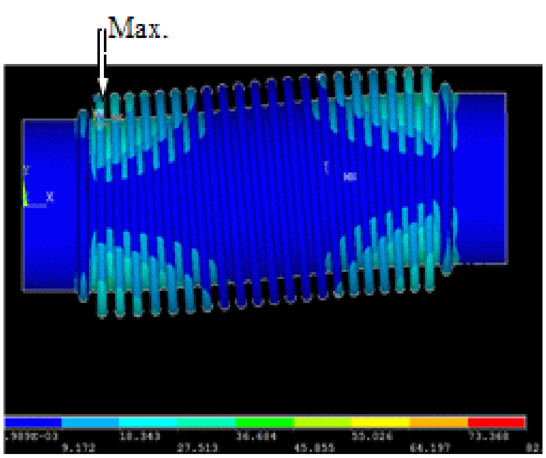


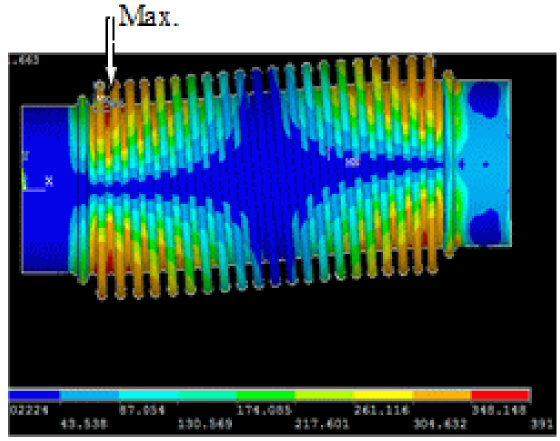
Figure 3. Movement type of bellows.

3. Results and Discussions

The Figures 4 (a) and (b) represent the von Mises stress (S.V.) distribution for 1mm and 21mm upward lateral deflection without any angular rotation at the end. If the flexible tube is only deflected in the upward direction and there is no angular rotation, S.V. is distributed symmetrically over all four corners. As the deflection increases from 1mm to 21mm, this distribution pattern remains continuous and only the stress increases. However, when angular rotation is generated, the symmetry of the stress distribution is changed. Figures 5(a) - (d) show S.V. distributions for 0.07° angular rotation with an upward lateral deflection from 1mm to 21mm.If the rotation angle is constant; the point at which the maximum von Mises stress (M.S.V.) is generated changes according to upward lateral deflection magnitude. The point at which M.S.V. is generated is thought to be a hole tip, but it can be seen that it is actually around the hole tip in most of the results. M.S.V. for 1mm upward lateral deflection and positive 0.07° angular rotation is 357MPa and occurs around the hole tip, as shown in Figure 5(a). In the case of Figure 5(a), M.S.V. at the hole tip is 332MPa. If the upward lateral deformation is more than 7mm, as shown in Figure 5(c) and 5(d), M.S.V. occurs around a hole tip as in the case of Figure. 5(a). M.S.V. for 5mm upward lateral deformation and 0.07° angular rotation is 150MPa and it occurs at the point shown in Figure. 5(b). In the case of Figure 5(b), M.S.V. at a hole tip is 14MPa.

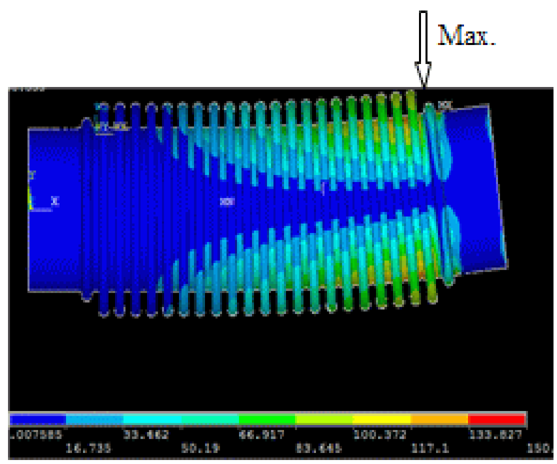


(a)

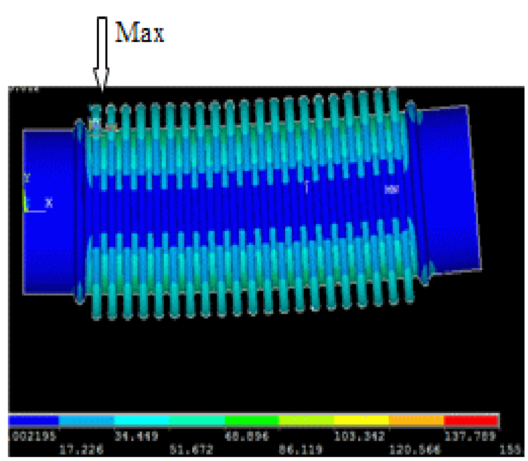


(b)

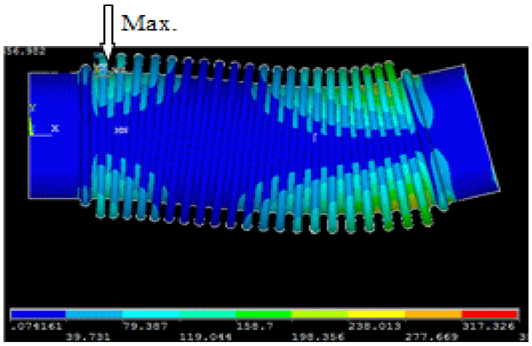
Figure 4. (a) 0° 1mm (79.5MPa-upward) (b) 0° 21mm (376MPa-upward).



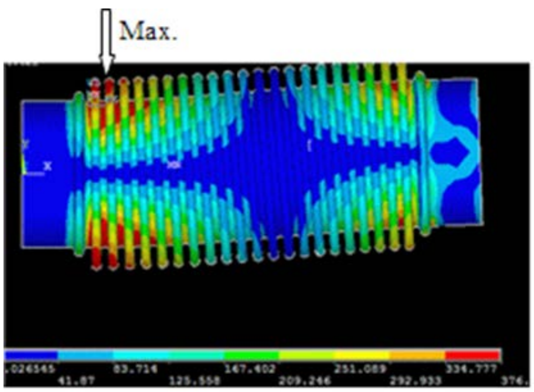
(a)



(b)



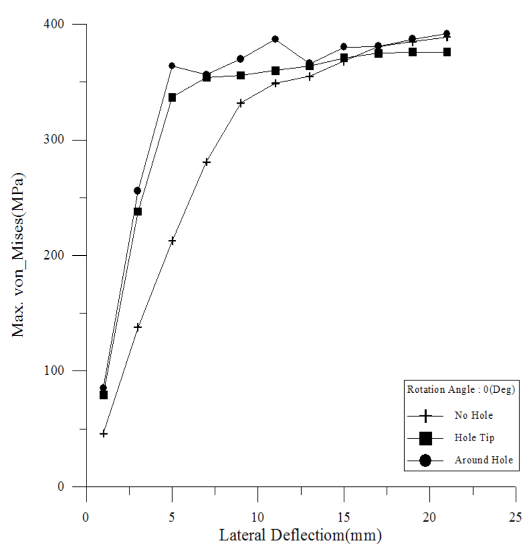
(c)



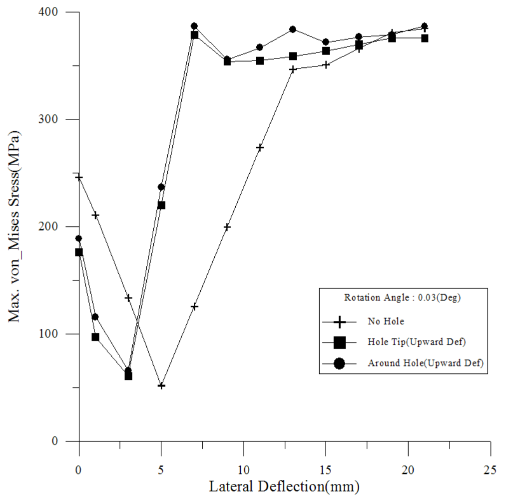
(d)

Figure 5. (a) 0° 1mm (79.5MPa-upward) (b) 0° 21mm (376MPa-upward).

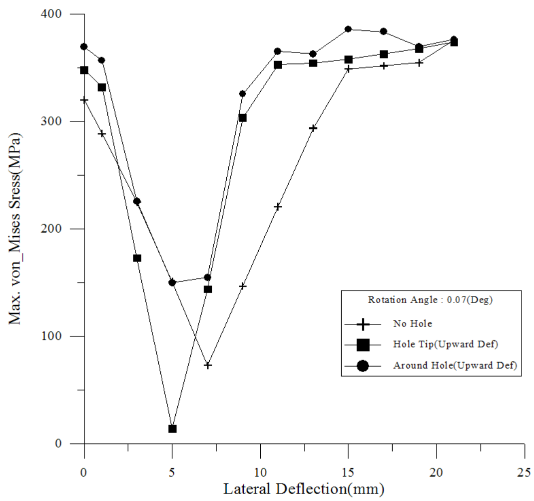
Figure 6 shows M.S.V. versus upward lateral deflection for each positive angular rotation of the bellows. The + symbol shows MS.V. Without micro hole and the ▪symbol indicates M.S.V. at a micro hole tip. Besides, ●symbol shows M.S.V. surrounding a micro hole. Figure 6(a) shows M.S.V. with upward lateral deflection for the case where the angular rotation is zero. M.S.V. at the micro hole tip is larger than M.S.V. of the defect free bellows. There is a difference between M.S.V. of the bellows with a micro hole (defective bellows) and those without a micro hole (non-defective bellows) until 13mm upward lateral deflection. After 13mm upward lateral deflection, M.S.V. is substantially equal. Figure 6(b) represents M.S.V. with upward lateral deflection and a +0.03° angular rotation. Comparing M.S.V. of the non-defective bellows and the defective bellows, the stress of the non-defective bellows is larger than M.S.V. of the defective bellows until 3mm upward lateral deflection. After 3mm upward lateral deflection, M.S.V. of the defective bellows is higher than the stress of the non-defective bellows. M.S.V. of the A type bellows are almost same as M.S.V. of the type C bellows until 5mm upward lateral deflection at a +0.07° angular rotation, as represented in Figure 6(c). In addition, M.S.V. of the type B bellows is smaller than M.S.V. of the type A and type C bellows until 7mm upward lateral deflection is reached. M.S.V. of the type B and type C bellows is larger than M.S.V. of A type bellows after 7mm upward lateral deflection. The upward lateral deflection range where M.S.V. is almost the same between A type and C type bellows and increases gradually as the angular rotation increases. M.S.V. of the type A and type C bellows is higher than M.S.V. of the type B bellows until 12mm upward lateral deflection. After 12mm upward lateral deflection M.S.V. of the type B and type C bellows is higher than M.S.V. of a type bellows, as shown in Figure 6(d). Comparing the results, M.S.V. that affects stability of a bellows is generated around the hole tip as well as in the hole tip itself. From these results, it can be concluded that M.S.V. occurs at the point where the deformation is a maximum given the external conditions. The reason is that the non-symmetrical deformation by a combination of the rotation angle and the upward lateral deflection causes a deformation of the bellows. Elastic-plastic range around the hole on the 1st convolution in the analysis model varies according to the relation between the upward lateral deflection and rotation angle as shown in Figure. 7. If the upward lateral deflection and rotation angle is inside the line, the region around the hole is an elastic zone. In addition, if the upward lateral deflection and rotation angle is outside the line, the region around the hole is a plastic zone.



(a)



(b)



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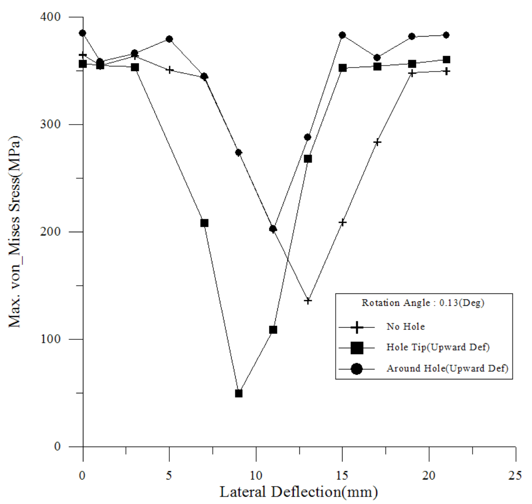

(d)

Figure 6. (a) 0° rotation (b) +0.03° rotation (c) +0.07° rotation (d) +0.13° rotation.

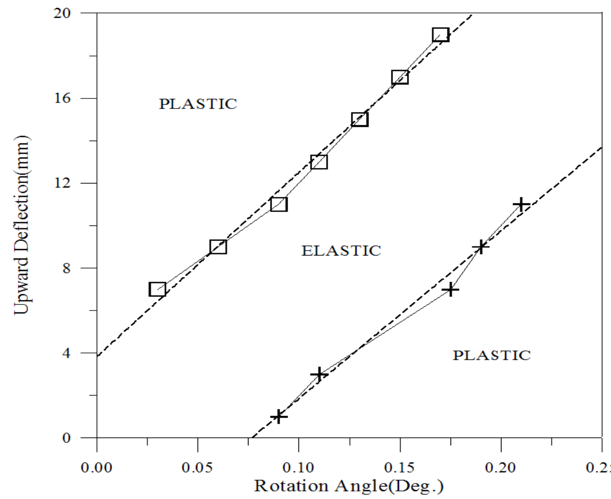

Figure 7. Elastic-plastic range around hole according to upward lateral deflection and positive rotation angle.

4. Conclusions

In this work, stress distribution around a micro defect in a bellows under several boundary condition is presented. If the flexible tube is only deflected in the lateral direction and there is no angle of rotation, the overall S.V. is distributed symmetrically in the four corners of the bellows. The point at which M.S.V. is generated is not only at a hole tip, but also around a hole according to the set boundary conditions. Owing to the non-symmetrical deformation of the bellows by a combination of the rotation angle and the lateral deflection, M.S.V. affecting stability of a bellows is generated around the hole tip as well as in the hole tip itself. The elastic-plastic range around the hole according to the upward lateral deflection and the positive rotation angle is obtained for the bellows in this study.

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