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# A Critical Review on Metal Expansion Bellows

Brijesh M. Patel[1], B.D.Patel[2], V.M.Prajapati[3]

***Abstract*— The flexible element of an expansion joints consisting of one or more convolutions with no more than five plies and the end tangent with length to diameter ratio not more than three. Any device containing one or more bellows used to absorb dimensional changes such as caused by thermal expansion or contraction of pipe line, duct or vessel or heat exchangers. Tubular bellows are one of the most efficient energy-absorbing elements for engineering system. Metal bellows have wide application in aerospace, micro electromechanical system, chemical plants, power system, heat exchangers, automotive vehicle parts, piping system, petrochemical plant, refineries, power stations, district heating installations, HVAC systems etc and wherever piping systems or ducts are subjected to movement through the effects of temperature, pressure or external forces etc. In this present Review the author have been found out the development of bellows, Forming Technology, analysis of movement test, buckling, Mechanical behavior, Design concept, Effective parameters and Analysis of the bellow by using commercial available software.***

*Keywords:* **Heat exchanger, I-DEAS, Expansion joint, EJMA.**

## I. INTRODUCTION

The flexible element of an expansion joints consisting of one or more convolutions and the end tangent with $L_b/D_b \leq 3$ with no more than five plies. as shown in the figure 1 with general terminology. Any device containing one or more bellows used to absorb dimensional changes such as caused by thermal expansion or contraction of pipe line, duct or vessel or heat exchanger. Tubular bellows are one of the most efficient energy-absorbing elements for engineering systems. An expansion joint or movement joint is an assembly designed to safely absorb the heat-induced expansion and contraction of various engineering materials, to absorb vibration, to hold certain parts together. The bellows is the flexible element of the expansion joint. It must be strong enough circumferentially to withstand the pressure and flexible enough longitudinally to accept the deflections for which it was designed, and as repetitively as necessary with a minimum resistance. This strength with flexibility is a unique design problem that is not often found in other components in industrial equipment. Metal bellows have wide application in aerospace, micro electromechanical system, chemical plants, power system, heat exchangers, automotive vehicle parts, piping system, petrochemical plant, refineries, power stations, district heating installations, HVAC systems etc and wherever piping systems or ducts are subjected to movement through the effects of temperature, pressure or external forces etc.

**Nomenclatures**

q = Convolution pitch
w = Convolution height
$D_b$= Inside diameter of cylindrical tangent and bellows convolutions
nt= No. of bellows material of plies thickness t
$t_c$=Bellows tangent reinforcing collar material thickness
$L_b$=Bellows convoluted length = Nq
$L_c$= Bellows tangent collar length
$L_t$= Bellows tangent length

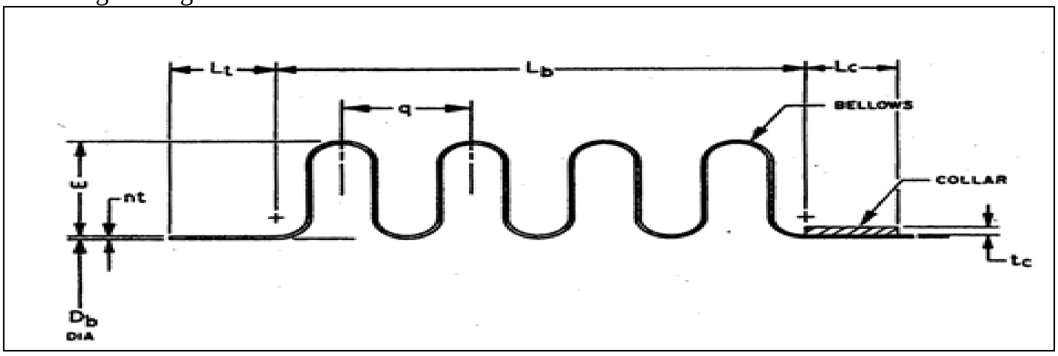


**Fig-1 Photograph of bellows**

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## II. DEVELOPMENT OF EXPANSION JOINT

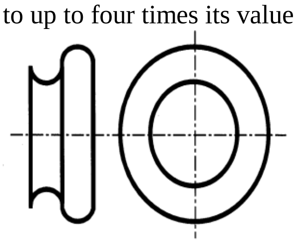
The development of 3D based metal expansion joint is done by **Hyun Wook Kang et. al [1]** Many micro-actuators have been developed for various applications in biotechnology, biochemistry, micro-sensors, etc. However, most of these actuators have been made using 2D-based micro-electro-mechanical systems (MEMS) technology, so they cannot perform long-travel 3D motion. This substantially limits the applications of these actuators. Auther developed a new bellows- shaped micro-actuator using micro-stereo-lithography (MSTL) technology with inclination angles of 44° and 0°, which makes it possible to fabricate complex 3D microstructures. The total travel and 3D motion of the new actuator could be easily adjusted during the design process. Using a finite element method (FEM) simulation, the actuation characteristics were analyzed and compared with experimental results. The analysis verified the adjustability of the total travel. Before fabricating a 3D bellows shape, a FEM simulation was used to analyze the effect of the design parameters, using the program ANSYS. The experiments show that there was a linear relationship between input pressure and displacement. Finally, to demonstrate the usefulness of our actuation principle in 3D space, a bending motion using a half-bellows shape was introduced. Micro-grippers with two and three tips were developed successfully.

## III. MECHANICAL BEHAVIOR OF EXPANSION JOINT

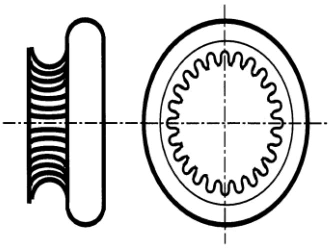
After development of 3D metal expansion joint there are number of different variety of the bellows are developed. Among them one of the new concepts by considering mechanical behavior is done by **Satoshi Igi et. al [2]** Piping systems for industrial plants often suffer excessive deformations or displacements caused by heat expansion, vibration, non-uniform subsidence of ground, etc. Bellows have the function to absorb regular or irregular expansion and contraction in such piping systems. Conventional bellows, however, have difficulties such as the instability of deformations under cyclic loadings, and the inability to absorb torsional deformations. In order to solve these problems, a new type of bellows, so-called ‘‘double convolution bellows’’ (DCB), were proposed and shown in the figure-2 . This new type of bellows has convolutions in two directions the first convolutions in the longitudinal direction are the same as the conventional bellows and the second convolutions are added in the lateral direction. This paper presents a study on the mechanical behaviors of the new type bellows and conventional bellows to examine the deformation behaviors under repeated axial loading, internal pressurizing and torsional loadings, and the results show an improvement in thickness distribution, instability and torsional flexibility. The comparison of the SCB & DCB are shown in the table 1.

## IV. BUCKLING OF METAL EXPANSION JOINTS

**D.E.Newland [3]** Developed the Corrugated bellows expansion joints may buckle under internal pressure in the same way as an elastic strut may buckle under an axial load. This paper is concerned with the analysis of this phenomenon for the ‘universal expansion joint’ which incorporates two bellows joined by a length of rigid pipe. And he developed the principal conclusion is that, by providing a correctly designed supporting structure, the critical buckling pressure can be increased to up to four times its value for the same system with no supports.



(a) Conventional bellows



(b) New type bellows

**Fig-2 SCB and DCB**

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**Table 1**

| | SCB | DCB |
|---|---|---|
| Convolution | Main circular convolution | main circular convolution sub lateral/root reinforcement |
| Thickness at the crest | Reduced | Nearly equal to that of root |
| Instability in the deformation | Unstable deformation | Stable: no instability disappeared even without ring spacer |
| Advantage and disadvantage in design | Simple, less flexibility | More flexible, but more complex in shape |
| Torsion | Less flexible | More flexible |
| Fatigue | Short life | Longer life |

## V. ANALYSIS OF METAL EXPANSION JOINTS MOVEMENT TEST

Analysis of two types (hinged & gimbal) of metal expansion joints movement test are done by **Jorivaldo Medeiros [4].** The Turbo-expander is an equipment that works under very critical conditions requiring very low allowable nozzle forces and moments. A solution to minimize the piping loads transmitted to the equipment is the use of expansion joints. A usual piping stress analysis normally is not enough to guarantee the turbo-expander reliability. This paper shows the results obtained in a movement test realized on metallic bellows expansion joints (EJ) used in a turbo-expander piping system. The EJ were designed according to the expansion joints manufacturer association code (EJMA), the diameters range from 457 to 2,898 mm, the material of the bellows is Inconel 625 LCF and the shell materials are "killed" carbon steel, for refractory lined EJ or stainless steel 304H. A special test device was developed to apply the design movements on the EJ at the factory. A digital dynamometer was used for data acquisition and the tests were performed on 16 expansion joints of two distinct types: hinged and gimbal. The EJ were pressurized with water during the test. The reactions and corresponding displacements for each step of the test were recorded during loading and unloading.

## VI. FORMING TECHNOLOGY

**G.Wang et al [5**] developed a new technology uses super-plastic forming (SPF) method of applying gas pressure and compressive axial load. It is developed and can be used to manufacture large diameter "U" type bellows expansion joints made of titanium alloys. The forming technology for bellows expansion joints made of titanium alloys is presented to make a two-convolution bellows expansion joint of Ti–6Al–4V alloy thin plate of 1.28mm thickness. Welded pipe bent by a hot bending method with a set of specific dies and welded by PAW was used as a tubular blank in the SPF. During the SPF process the tubular blank is restrained in a multi-layer die block assembly which determines the final shape of convolution. The forming load route is divided into three steps in order to obtain optimum thickness distribution. This technology can also be used to fabricate stainless steel bellows expansion joints. The super-plasticity of Ti–6Al–4V titanium alloy is the best among of them, for instance the elongation can exceed 1000%. The forming process of the bellows includes a tubular blank fabrication process and SPF process, as shown in figure-3 and final shape of the large diameter of bellows are shown in figure-4, their flow-process diagrams are as follows, respectively:

- Tubular blank fabrication process:

Cutting plate material → bending tubular blank → welding tubular blank → radio graphing → sizing tubular blank → welding cover with gas entrance connection

- SPF process:

painting graphite power on dies and high temperature anti-oxidize on tubular blank → assembling → bulging → furnace cooling → de-Moulding → turning the straight segment → grit blasting.

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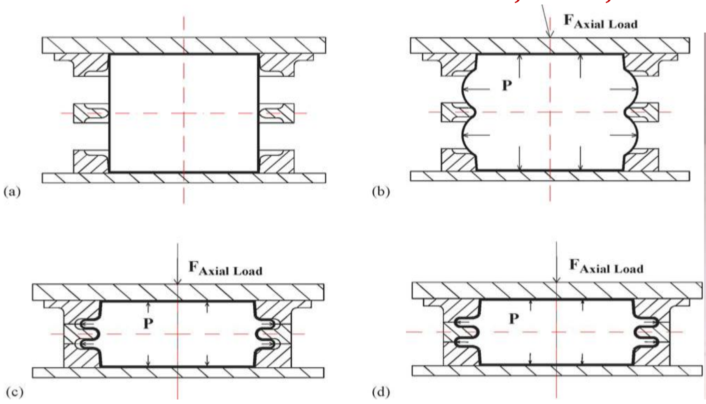


**Fig-3 SPF procedure** **Fig-4 Photograph of the formed bellows of Ti-6Al-4V alloy**

**Boo Hyun Kang et al [6]** Developed the conventional manufacturing of metallic tubular bellows consists of a four-step process: (1) deep drawing, (2) ironing, (3) tube bulging, and (4) folding. In the present, study, a single-step tube hydro-forming process is used to make prototype tubular bellows with simultaneous control of the internal pressure and the axial feed. A number of prototype tubular bellows were formed with the use of various hydro-forming die shapes, such as rectangular, circular, and triangular as shown in the figure-5. For each shape, the hydro-formability of the tubular bellows, in conjunction with the forming process, was evaluated. The effect of the friction was also investigated. Good lubrication is an effective method for improving the hydro-formability of metallic tubular bellows. This paper shows that a single-step hydro-forming process can be used to form tubular bellows with various shapes

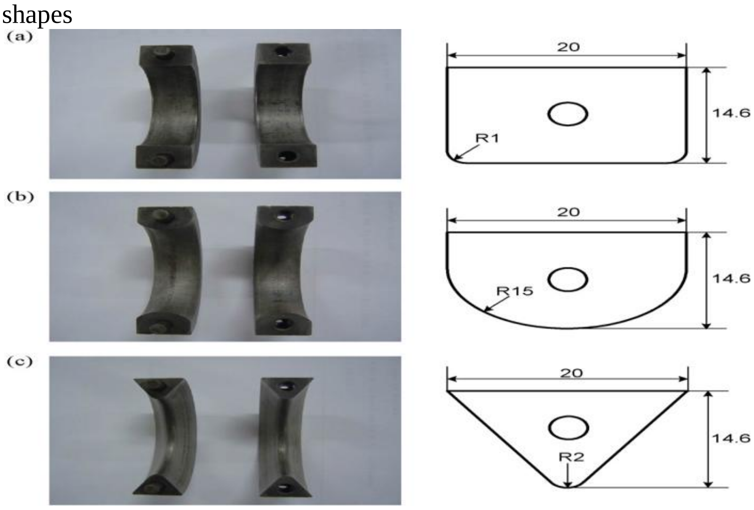


**Fig-5 Shapes of the dies (a) rectangular, (b) circular and (c) triangular rings**

## VII. EFFECTIVE PARAMETERS OF EXPANSION JOINT

**Gh. Faraji et al [7]** Forming process of the metal bellows is very sensitive to increasing the ratio of crown to root diameter. In this state, precise control of the parameters is very important in order to form high-quality metal bellows with good thickness distribution and desirable dimensions and resilience. In this paper, a new method has been proposed for manufacturing of the metal bellows and important parameters such as initial length of tube, internal pressure, axial feeding and velocity, mechanical properties and the type of materials were investigated by finite element (FE) analysis (LS-Dyna) and experimental tests. For a particular bellows, tube diameter and thickness cannot be changed so that the latter three parameters can be studied. The explicit time integration method is used for modeling the tube-bulging and folding processes. & the implicit time integration method is used for the spring back stage. Finally, the results of finite element method (FEM) and experiments show a very good agreement and Maximum deviation in thickness for FE solution versus experiment was 8%, which is acceptable from an engineering point of view. The materials that were used are phosphor bronze CuSn6, AISI304 and AL6016-T4. It was observed that mechanical properties of material used in manufacturing of the metal bellows

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have considerable effect on final dimensions of bellows. Comparison of three types of the material used, showed that the best material in this study is CuSn6

## VIII. SOFTWARE TECHNOLOGY IN EXPANSION JOINTS

**G.I.Broman et al [10]** developed a procedure for determining dynamic characteristics of bellows by manipulating certain parameters of the beam finite elements of I-DEAS Master Series 6 is presented. The method will work in any software in which these parameters can be set by the user. Compared to a shell elements model the model size is reduced by at least a factor of 100. This is especially advantageous when the bellows is only a part of a system to be optimized with respect to overall design parameters. Stress in the bellows cannot be predicted by this method, but when the dynamic behavior is known it can be used as input for stress calculations. In contrast to existing semi-analytical methods this method has the potential of considering axial, bending and torsion degrees of freedom simultaneously, and it facilitates the interaction between the bellows and the rest of the system, also modeled by beam or shell finite elements. The procedure is verified by experimental results from other investigators. If braid and inner-liner are present Fig-6 the dynamic behavior of the flexible connection will be influenced and the dynamic analysis will be more complicated. Most probably it will be necessary to consider non-linear effects. Some ideas regarding these complications have been discussed.

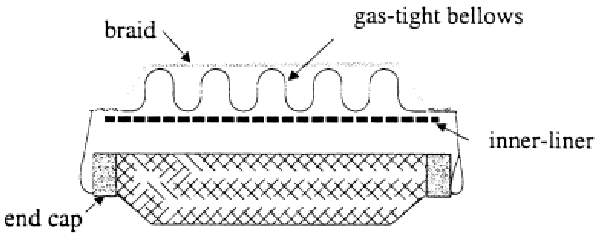


**Fig-6-Basic flexible connection design**

## IX. CONCLUSION

As a part of my research work, I carried out literature work on Metal Expansion Joints by studying numerous of research papers of well known journals. The most related research paper on metal expansion bellows are thoroughly studied & explained with most required details in this present work. The development of the metal expansion bellows with proper geometry is suggested by Hyun Wook Kang [1]. The forming technology with the mechanical behavior of the metal expansion bellow is also suggested by the [2],[5]&[6]. The analysis of buckling of metal expansion joints under internal pressure are suggested by D.E.Newland [3].The analysis of two types of metal expansion joints movement test are suggested by Jorivaldo Medeiros [4]. The main key parameter responsible in the design and analysis of the metal expansion joint is the effective parameters of the metal expansion bellow are suggested by Gh Faraji[7]. He suggested most effective parameters of the bellows are initial length of tube, internal pressure, axial feeding and velocity, mechanical properties and the type of materials by finite element (FE) analysis (LS-Dyna) and experimental tests. G I Broman [8] suggested I – DEAS software for the simulation of the metal expansion bellows before realization of the bellows. At the end of the review work now the author concluding that the remaining part of the metal expansion bellow is the key objective for the next research work.

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