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Review on Expansion Joints for Process Equipment and Piping Systems

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Abstract: *Expansion joint is a highly engineered mechanical component designed to compensate thermal expansions and stresses in various thermo-mechanical systems. Hence expansion joint are always considered as a crucial element in utility systems. This paper presents review of different types of expansion joints used in process equipment and piping systems. Various codes and standards such as American Society of Mechanical Engineers (ASME) and Expansion Joint Manufacturers Association (EJMA) are established to provide design guidelines for the expansion joints. These standards are used as per the utility under consideration or as per the customer requirements. Paper also presents the significance of these standard codes in design of expansion joints. This focused review will provide a guideline to the designers and practitioners in this field for better understanding of expansion joint.*
Keywords: *ASME, EJMA, Expansion joint, process equipment, thermos-mechanical system*

I. Introduction

Process equipment such as pressure vessels and piping systems are used widely in industry for various applications. These systems handles mechanical parameters such as pressure, temperature flow etc. These parameters induce thermal expansion and vibrations. If these are not handled properly they may introduce stresses in the system if provision for thermal expansion/contraction compensation is not considered. If such compensation is not provided it may result in failure of utility system. To avoid such conditions, expansion joints are used to compensate for the thermal expansions/contractions in the system while sustaining the other service conditions. Thus the study of such vital components in process/power industry is necessary.The expansion joints are assembly of components intended to absorb the deformation produced due to the thermal effects and vibrations. For an expansion joint bellow is the component that actually absorbs the regular or irregular expansions and vibrations.

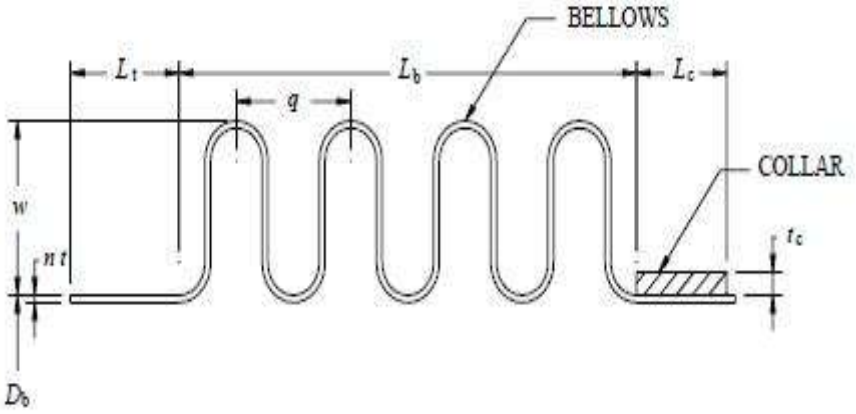

Fig.1 Bellows various geometrical parameters [1]

Figure 1 of bellow depicting various geometrical parameters. The study of effect of these geometrical parameters on the performance of bellows is presented by Kim [2]. The study reveals that the principle stresses increases with increase in the radius of bellow also the life of bellow decreases linearly. The stress concentration effect decreases as the radius of convolution crown increases. Which results into decrement in stress concentration effect and increment in life of bellow. With increase in the deflection of expansion joint end cap tip increases the principle stresses increases and the life of bellow decreases. Study on strength analysis of variants of expansion joints is also important along with parametric analysis. Towards this direction Ando, M., Yada et al. [3, 4] performed a study on ultimate strength of single and double bellow expansion joint. This study has revealed important correlation between the pressure and the life of bellow. In another study they discussed

about the failure causes in expansion joints, the bellow was tested beyond the designed internal pressure to get the behavior of bellow. Support mechanisms are provided for the proper working of expansion joints such as gimbals, pantographic projections etc. Veiga, J. C. et al [5] studied the reaction moments produced in gimbal and hinged type expansion joint. They form a method through which the actual reaction loads can be estimated in gimbal and hinged metal bellow expansion joints. The total moment includes the movement due to spring rate, pressure thrust, friction in internal components and lateral pressure force. The focus of researchers was seems to be more on the pin/sleeve friction loads. Similar type of study was carried out on gimbal and hinged type expansion joints by Veiga, J. L et al [6], in which they studied the behavior of gimbal and hinged type of expansion joints for different pressure conditions. In which the effect of peak value of pressure waves on dynamic behavior of bellow for different cases were discussed. Torsional stiffness and natural frequency was studied by Lu, C. L., et al [7].

The researchers found that the EJMA formula for calculation of torsional natural frequency were not appropriate, so they made some simplified formulae to calculate torsional natural frequency of bellow with the help of thin walled pipe model and applying Chien's integration method. For validation FEA of model was carried out and the results were quite satisfactory. But significant change may happen in the cross section under torsion condition due to the thin-walled nature of bellows which can also reduce the torsional stiffness. K. Makke et al [8] studied the fatigue behavior of the metal bellows, they gave analytical calculations and its validation to calculate the fatigue life of bellow structure of expansion joint. Dynamic behavior of bellow structure of expansion joint was studied by Morishita, M. et al [9]. They proposed a simplified method to study the dynamic characteristics and seismic response of metal bellows. By considering axial and lateral vibration. A series of tests were performed to verify the proposed method. They found that the fundamental modes governs the response.Zhaoai Li et al [10] studied the failure analysis of expansion joint of gas line buried under ground, one of the cause of failure was studied based on practical incident. Some expansion joints are buried under ground has cracks on their surface extended up to 48% of circumference after only 1-2 year of use after installation. This study was actually carried out in multiple stages. During analysis it was found that the chlorides and sulphides caused stress corrosion cracks in bellow. The repair of bellow structure of expansion joint was also disused by Merrick, E. A et al [11] they suggested three different methods for the repair of expansion joints and shows experimental validation for these different repairing techniques. Some of the researchers like Tsukimori, K. et al [12] studied the behavior of multiply expansion bellows for different loading conditions.These papers will provide the understanding about expansion joints that are used in process equipment and piping systems. Also give introduction about various design standards of expansion joints.

II. Types Of Expansion Joints

In order to present review of expansion joint used in utility systems it is important first to understand types and different configurations of expansion joints that are available. Figure 2 depicts the summery of types of expansion joints according to different configuration.

The various type of expansion bellows are discussed as below:

Types based on thickness of ply

1. Thick expansion joint (formed head.)
2. Thin expansion joint (formed membrane.)

Types based on number of ply/layer

1. Single ply/layer
2. Multi ply/layer

Types based on shape of bellow

1. Round expansion bellow
2. Rectangular expansion bellow

a) Round corners
b) Single Miter corners.
c) Double Miter corners
d) Camera corners

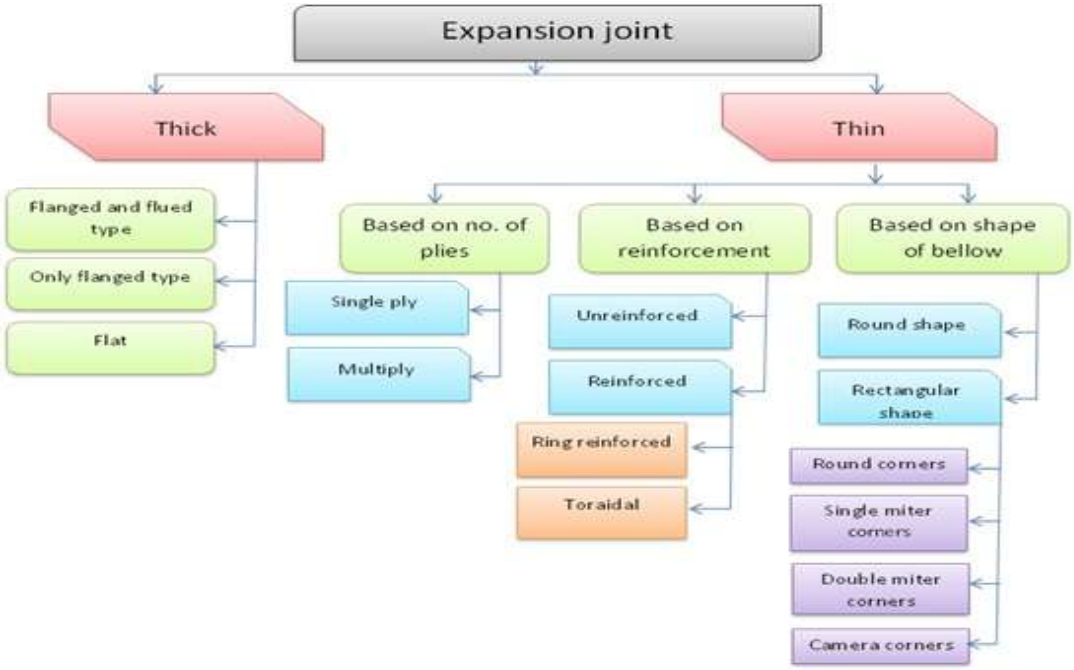

Fig. 2: Types of expansion joints expansion joints used for process equipment and piping systems

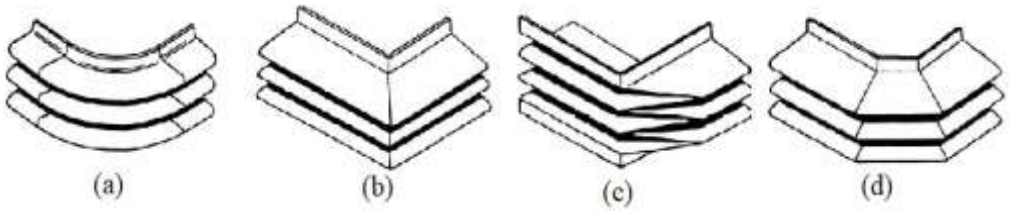

Fig. 3: Schematic diagram of Corner configuration for rectangular bellow [13].

Types of bellows based on reinforcement

1. Unreinforced expansion bellow joint
2. Reinforced expansion joint

- Conventional reinforced expansion joint
- Toroidal expansion joint
- Toroidal expansion joints.
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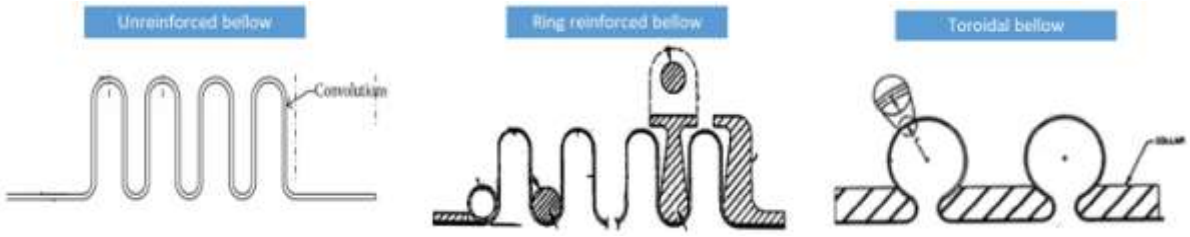

Fig. 4: Schematic diagram of (a) Un-reinforced bellow, (b) Ring reinforced bellow (c) Toroidal bellow [1]

III. Expansion joints used for process equipment and piping systems

A. Expansion joints used in process equipment

The expansion joints that are used to accommodate the expansion in process equipment are mainly thick expansion joints to sustain the required pressure. But as per requirement they may use thin expansion joints also with proper care.

a) Flanged and flued type expansion joint

Thick Wall type, Flanged and Flued expansion joints are made in two halves from flat annular plates. These may be a cost-effective option for large-diameter piping systems which operate at low pressure.

b) Flanged type

These are same as above but the outside edges of the plates are formed in one direction and the inside edges are kept straight. Because of the higher wall thickness, they are rugged but has limited flexibility.

c) Flat type expansion joints

In this case, both the outside edges and the inside edges of the plates are kept straight welded directly to the shell. These are simple type of expansion joints [13].

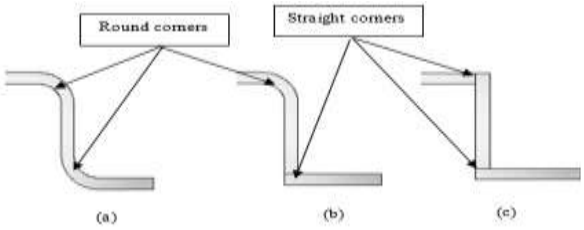

Fig. 5: Schematic Diagram of Thick expansion joints [14]

B. Expansion joints used in piping systems

- Single Bellows Expansion Joint

These are the most simplified design of bellow expansion joints, mostly used for piping applications requiring limited axial or lateral movements.

- Double Bellows Expansion Joint

These type of joints are nothing but two single bellows joined by central spool. They are used to accommodate more expansion than regular single expansion joints.

- Gimbal type Expansion Joint

These type is considered as most reliable type for absorbing angular movements in all plane. The construction mainly incorporates a pair of hinges connected to a common floating ring.

- Hinged type Expansion Joint (Single plane)

These joints are typically used in a set of two or three, to absorb movements in possible directions only in single plane. Each individual joint in the system is restricted to pure angular rotation about its hinge.

- Tied universal joint

It's same as double expansion joint but, they are supported by tie rods which provides it the ability to absorb movements in any direction. Tie rods are attached on the outer ends of flanges and center spool.

- Externally pressurized Expansion Joint

These type of expansion joint are built to avoid squirm failure of bellow using internal pressure. These type of joints can accommodate more displacements as compare to the regular single bellow expansion joint.

- Pressure balanced Expansion Joint

Pressure balanced expansion joints are custom designed pressure balanced elbow or tee expansion specifically designed to overcome the reaction load, due to internal pressure acting against turbine casings, pumps, structures and other equipment.

C. Selection parameters for expansion joints

The selection of bellows expansion joint for a particular application dependents on following parameters:

- Operating Pressure

The nominal pressure rating of an expansion joint vary according to type, material and size. But during actual working conditions, pressure may vary depending on other operating parameters.

- Operating temperature

As the material properties vary depending on temperatures, operating temperature is very important parameter. The temperature limits are decided based on the type, material, end fitting and method of fitting attachments.

- Size of expansion joint

The size of expansion joint is mainly specified by the nominal diameter. However, flow rate, velocity and pressure drop may also influence size selection of expansion joint.

- Media to be conveyed

The type of media being conveyed is an important consideration, as it may cause sevier corrosion problems and ultimately failure of expansion joint.

- Motion or Movements Required

The selection of expansion joint mainly depend on the type of movement required. Expansion joints are used to accommodate for axial, lateral, angular or combination of all three.

- End Fittings.

End fittings helps expansion bellow to merge with required system. They includes flanges, male female pipe threads, unions and weld joints

D. Manufacturing of expansion joints

1. Forming method

The expansion joints are manufactured from seamless tubes or longitudinally welded metal tubes by forming. Forming may include Elastomeric forming, Pneumatic forming, Roll or ring roll forming and Hydraulic forming.

2. Welding

In this process bellows are formed by welding thin metal plated at their inner and outer diameters [15].

E. Failure causes

1. Squirm failure

Squirm failure is commonly observed in expansion joints due to excess pressure. They are of two types, column and in-plane squirm failure. The failure caused due to shift of alignment of expansion joint in other plane is called as column squirm failure and the failure caused due to bending of convolutions in same plane is called in-plane squirm.

2. Fatigue failure

These type of failure occurs due to excessive vibrations or high cyclic applications. The bellow gets eroded with time and fails at the end.

3. Improper Usage/selection

The improper selection/installation of expansion joint mainly causes this type of failures.

F. Various applications of expansion joints in process/power plant industries

- Air Ventilation and Exhaust lines,
- Gas Turbines, engines and other power producing devices,
- Boilers and other heat exchanging devices,
- Single Pipe or Pulse

IV. Design Standards/Codes For Thin Expansion Joints

Expansion Joint Manufacturers Association. (EJMA*):* This standard provieds the guidelines for stress evaluations in expansion joints that are used in piping systems.

Assumptions

1. Variations in thickness is negligible,
2. Variations in crest radius between ID and OD is negligible,
3. Sloping or shell curvature of the annular disc between crests is also negligible [16].

Parameters to be calculated:

Not only gudelines for stress evaluations, they also provide guidelines for forecs and movement calculations, Test requirements and installation of expansion joints. Other than EJMA, standards like European Norms (EN) and codes like ASME also provides guidelines about expansion bellow design. The procedure of design remains same but the equations may vary.

V. Conclusion

This paper has presented exhaustive review of different types of expansion joints and various geometries, the aspects to be considered for the selection of geometry and codes used in the design of expansion joints. This review is expected to benefit designer and consultants to know about different important factors required while selecting the appropriate geometry and code for the typical application under considerations. The process plan for design of expansion joint is expected to help designer to implement the selection and design methodology easily. Compiled study also presents further scope in bridging this gap by using FEA and comparative study of bellow with different types of reinforcement.

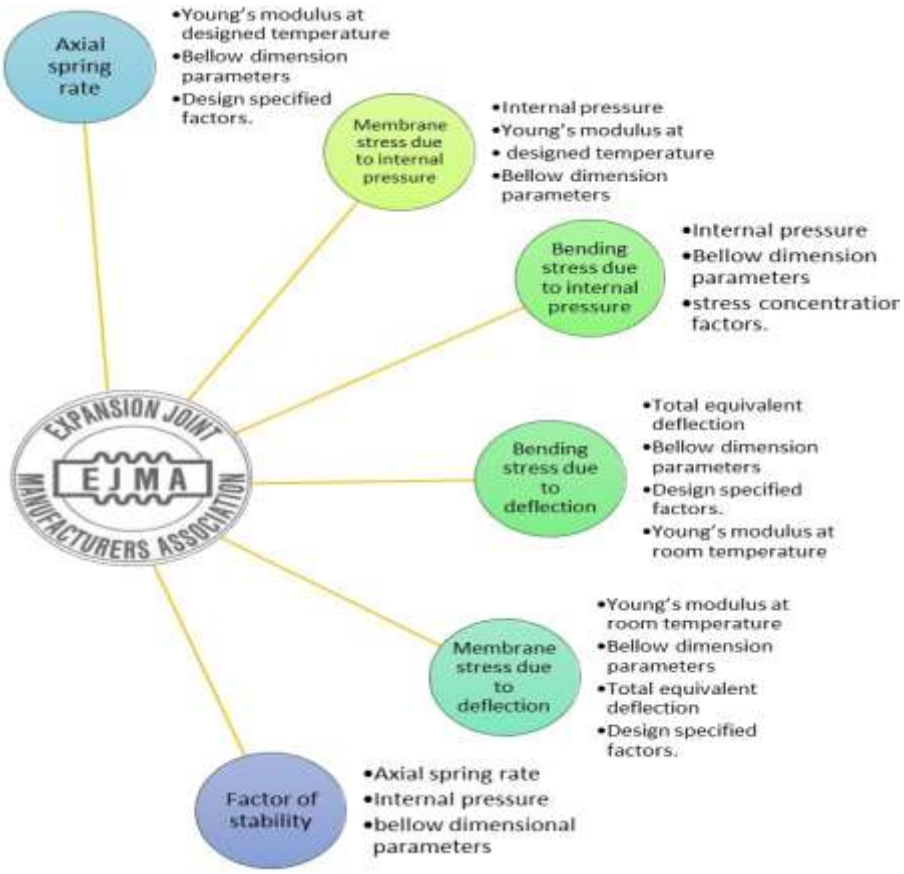

Fig. 6: Design calculations for expansion bellow design.

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Conflict of interest The authors declare that there is no conflict of interests regarding the publication of this paper.

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