# Behavior study of vibration in expansion bellow system under different types of support

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**Abstract**

In this study, an experimental study was investigated to analyze the influence of the temperature and flow rate on the frequency in expansion bellow conveying fluid in three types of support (simply-simply, fixed-free and fixed-fixed). Two expansion bellows were fabricated as: (10 mm inner diameter, 300 mm length and 111 number of convolutions) and (20 mm inner diameter, 300 mm length and 82 number of convolutions). The results show that the frequency was increased with increasing the flow rate of fluid and temperature. In addition, the y-displacement was recorded about $21\times10^{-3}$ mm at the beginning of the bellow and then drop to $14\times10^{-3}$ mm at the end of bellow. While, in case of fixed -free the y-displacement was recorded $22\times10^{-3}$ mm and $12\times10^{-3}$ mm at the beginning and end respectively. Moreover, the behavior of y-displacement in case of fixed-fixed was increased to maximum value about $22\times10^{-3}$ mm near the middle point of bellow.

***Keywords:*** Bellows, support, convolution.

## 1. Introduction

The study of the behavior of the flexible pipe in flow systems is very important in order to test the extent to which the flexible pipe bears stresses and frequencies under the influence of flow characteristics (temperature and flow rate) and design parameters of pipes (diameter, length, thickness, number of convolutions). Pipe supports are designed to restrain the movement of pipes caused by sudden flow, which causes large dynamic loads, restrain pipe movement caused by operational flow induced vibrations, restrain pipe movements caused by outside sources, such as wind and seismic events, Provide stability to the pip. A little studies were dealt with the types of support and the comparison between them in flexible pipe systems and most of these studies relied on the theoretical aspect in analyzing the behavior of flexible pipes. Al-Baheli et al.[1] studied the dynamic behavior of a tube conveying a fluid using three types of supports (simple- simple, fixed-fixed, fixed-free), concluded that values of natural frequencies for(fixed-free) support are less than for(simple-simple and fixed-fixed)support because of the (fixed-free)support has ability to move in y-direction. Zhao and Sun.[2] investigated the flow-induced vibration problem of curved pipe conveying fluid by using the Laplace transform . The critical velocity of the flow was calculated and its effect on the natural frequencies for cantilevered, fixed and periodic cantilevered pipes. Hunain.[3] used the finite element method (FEM) technique to study the dynamic behavior of the stepped pipe of fluid conveying with simply supported and the influence some design factors such as the ratio of length ,diameter and thickness of pipe. Concluded if flow velocity increased the natural frequency of stepped pipe decreases also the natural frequency increase as length ratio and diameter ratio decrease. Avinash et al.[4] studied the natural frequency of straight pipe made of steel conveying turbulent water with boundary condition(fixed fixed)and (fixed- free) using finite element (FE) simulation. Concluded in(fixed- free) boundary condition the natural frequency of pipe decreased with increasing of pipe thickness while natural frequency of pipe increased with increased thickness of pipe in (fixed-fixed)boundary condition. M. Nikolic et al.[5] used of Lyapunov–Schmidt reduction and singularity theory resolved bifurcation points of fluid-carrying pipes supported at both ends. Huang et al.[6] used the Ferrari method to calculated natural frequencies in pipeline conveying fluid with both end supported. concluded that (fixed-free) supported is less stable than (fixed-fixed) supported and more stable than (simply-simply)supported. Alnomani.[7] investigated the dynamic behavior of the simply supported pipe conveying fluid using finite element (FE) technique. Concluded when using spring an additional support the dynamic behavior of simply supported pipe conveying fluid will obviously change, the frequency of the pipe depends on the spring constant and flow velocity and spring location. Ying jie wang et al.[8] investigated the dynamics and stability of fluid-conveying corrugated pipes. concluded that flexible pipes will loss stability by flutter if it has been supported in both ends. Imran Shaik et al.[9] used Euler-Bernoulli and Hamilton's energy expressions of fluid conveying iron pipe with (fixed-fixed) boundary condition for studied of vibration analysis and mathematical model. Concluded that natural frequency of the pipe increase when fluid flow velocity increased for(fixed-fixed)ends. Long Liu et al.[10] investigated the dynamic analysis of supported pipes conveying fluid by using precise integration method (PIM).Concluded that (PIM) is fast and effective method for dynamic analysis of flow induced in supported pipes. B. Mediano et al.[11] investigated the dynamics as well as stability of (fixed-pinned) pipeline conveying fluid. Concluded that dynamic and stability of pipe conveying fluid not depends only on boundary conditions but also depends in avery important way on the material of pipe and the pressure produced by the fluid flow. Adekunle O. Adelaja.[12] studied the nonlinear traverse vibration of flexible pipe conveying hot pressurized fluid in (pinned-pinned) end conditions. Kesimli et al. [13] discussed linear vibration of pipe conveying fluid .They study a (fixed-fixed) pipe with intermediate supported in the middle section. Nabeel K et al.[14] investigated the vibration and stability of straight pipe made of mild steel, conveying turbulent steady water with different velocities and boundary conditions (fixed-fixed, fixed-pinned).They proved that the natural frequency of pipe conveying fluid for both boundary conditions reduced in welded pipe and affected by the position of welded. Huang Yi-min et al.[15] investigated the effect of boundary conditions(simple-simple, fixed-fixed, fixed-free) of pipeline on natural frequency by eliminated element-galerkin method. The main objective of this study was to compare the vibration in two expansion bellows with different inner diameter, length and number of convolutions under the effect of temperature and flow rate. In addition, the comparison took in consideration the effect of support type on the vibration.

## 2. Experimental Description

### 2.1. Preparation of expansion bellows

Two expansion bellows 304 L type U-shaped were prepared in length 300 mm. The first one with inner diameter 20 mm and number of convolutions 82 while the second one with diameter 10 mm and number of convolutions 111 as shown in Figure 1. The specifications of the chemical composition of bellow material were tested and represented in Table 2.


Figure 1. Types of expansion bellows

Table 1. Specifications of expansion bellows

| Parameter | Bellow(1) | Bellow(2) |
|---|---|---|
| Expansion joint material | St. St. 304 L | St. St.304 L |
| Modulus of elasticity | 193000 $N/mm^2$ | 193000 $N/mm^2$ |
| Bellow Yield stress | 215 $N/mm^2$ | 215 $N/mm^2$ |
| Poisson's ratio | 0.275 | 0.275 |
| Bellow type | U-Shaped | U-Shaped |
| Length of expansion bellow | 300 mm | 300 mm |
| Outer diameter | 13.6 | 25.2 mm |
| Inner diameter | 10 mm | 20 mm |
| Thickness | 1.0 mm | 1.0 mm |
| Convolution depth | 0.8 mm | 1.6 mm |
| Convolution pitch | 2.5 mm | 3.8 mm |
| Total number of Convolution | 111 | 82 |
| End tangent length | 40 mm | 15 mm |

Table 2. Chemical composition of bellow material

| C % | Si % | Mn % | P % | S % | Cr % | Mo % | Ni % | AL % | C0 % | Cu % | Fe % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.042 | 0.61 | 1.36 | 0.0060 | 0.0020 | 23.66 | 0.0070 | 6.38 | 0.0040 | 0.0113 | 0.089 | 67.5 |

## 2.2. System description

As shown in Figure 2, the system is consisted from test section, storage tank, pump, piping, fitting and supports. The test section was fabricated to replace the expansion bellow easily. The storage tank was selected with 50 L capacity with electrical heater 1200 W to heat the water. In addition, a safety valve was fixed at the top of the tank to use it in case of overpressure. Water pump with maximum flow rate 33 LPM, 12 m head and working pressure 1.2 bar was used to circulate the heating water between the tank and the test section. A set of fitting equipment were used to complete the installation and assembly of the system. For example, the ball valve used to control the flow of water. A number of supports was fabricated from steel to use in testing of the system in cases of free-fixed and fixed-fixed. Additionally, two triple connections were used before and after the test section to install the pressure sensors.

## 2.3. Measurements and instrumentations

A set of instrumentations were connected to observe the input and output parameters including the temperature, pressure, flow rate and the acceleration as shown in Figure 3. Two digital thermometers type DS18B20 ranged between (-55 to +125) °C with an accuracy ±0.5°C was installed to measure the water temperature before and after the inlet and outlet of section test. Water flow sensor model YF-S201 with flow rate ranged between (1 to 30) LPM and with an accuracy about ±10% was installed to measure the water mass flow rate. The water flow sensor operates with liquid temperature and pressure until 120°C and 1.7 Mpa. In addition, two pressure sensors type PIA (0 to 16) bar were installed before and after the inlet and outlet section test. Vibration meter GM63B (Piezoelectric ceramic accelerometer (shear-type) was used to measure and represent the behavior of the expansion below as acceleration, velocity and displacement. The specifications of vibration meter is concluded by: the range of acceleration is 0.1 to 199.9 $mm/s^2$, the range of velocity is 0.1 to 199.9 mm/s and the range of displacement is 0.001 to 199.9 mm/s with measurement accuracy ±5% ± 2digits and measurement frequency of velocity and displacement 10Hz～1KHz. The data obtained from experimental measurement are collected by uno-arduino and then send to the computer.


Figure2. Photograph of system

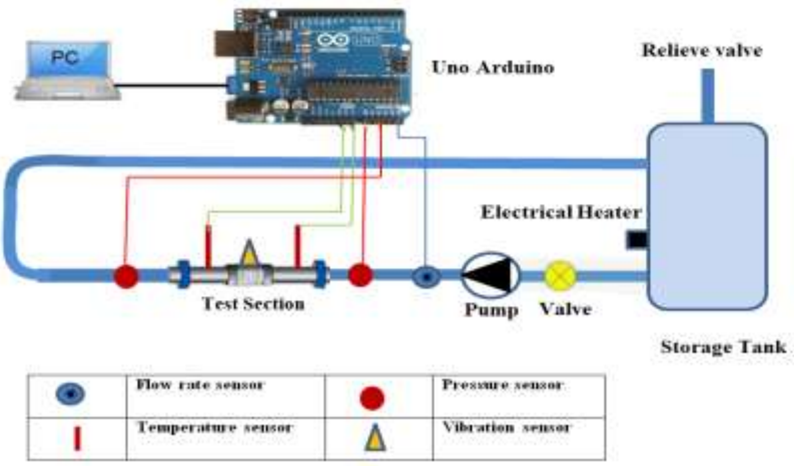


Figure 3. Schematic diagram of system

## 3. Results and discussion

The experimental study was investigated to analyze the influence of the temperature and flow rate on the frequency in expansion bellow conveying fluid. The test system was fabricated to use a two different expansion bellows with three types of supported (simply-simply, fixed-free and fixed-fixed). The first bellow with 10 mm inner diameter, 300 mm length and 111 number of convolutions. While, the second bellow with 20 mm inner diameter, 300 mm length and 82 number of convolutions.

### 3.1. Frequency

Figures 4 and 5 show the variation of frequency with flow rate at flow temperature 80 ºC. As shown in figure 4, the frequency in expansion bellow with diameter 20 mm was increased with increasing the flow rate of fluid in case of simple–simple. Where, the frequency was recorded 110 Hz with 1 LPM and increased to 136 Hz with 14 LPM. While in case of fixed-fixed, the frequency was began from 126 Hz with 1 LPM and drop to 90 Hz with 7 LPM and then increased to a maximum value about 109 Hz at 14 LPM. In the same manner, the frequency was began from 133 Hz with 1 LPM in case of fixed-free and then drop to a minimum value about 83 Hz at 7 LPM and increased to a maximum value about 123 Hz with 14 LPM.

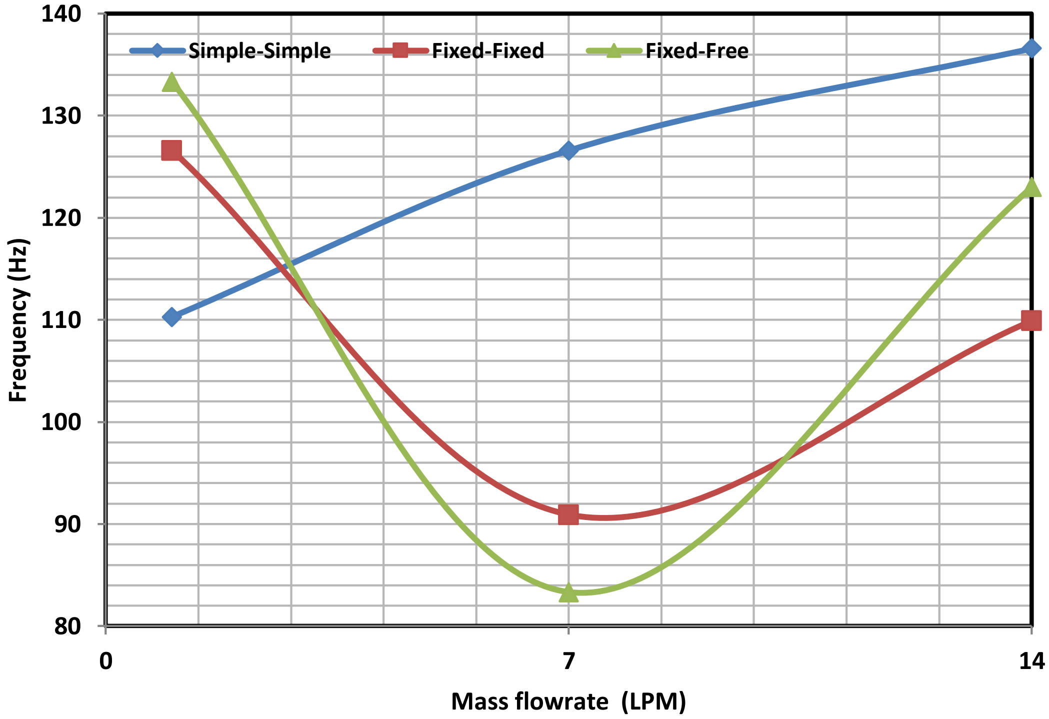


Figure 4. Variation of frequency with flow rate in bellow at diameter 20 mm in flow temperature 80 ºC

In Figure 5, the frequency in expansion bellow with diameter 10 mm show that in case of simple-simple was increased from 101 Hz to 120 Hz when the flow rate change from 1 LPM to 14 LPM. While, in case of fixed-fixed was increased from 92 Hz to 136 Hz. Case fixed-free show that the frequency was increased from 93 Hz to 113 Hz when the flow rate changed from 1 LPM to 7 LPM and then drop to 106 Hz with increased the flow rate to 14 LPM.

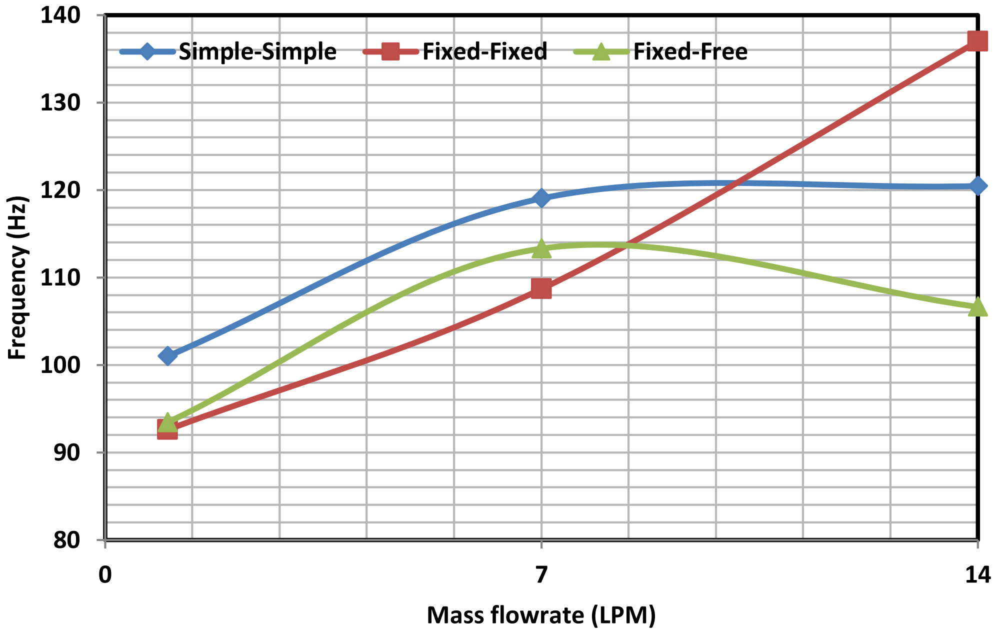


Figure 5. Variation of frequency with flow rate in bellow at diameter 10 mm in flow temperature 80 $^oC$

The influence of temperature on the frequency of bellows is represented in Figures 6 and 7. As shown in Figure 6, generally, the frequency of 20 mm bellows was increased with increasing the flow temperature in case of simple-simple and fixed-free. Where, the maximum frequency was recorded about 137 Hz at temperature 80 $^oC$ in case of simple –simple and was recorded a maximum value about 123 Hz in case of fixed free. On the other side, the frequency of fixed-fixed was increased to maximum value about 110 Hz. The influence of temperature on the frequency of 10 mm diameter bellows is represented in Figure 7. Generally, the frequency of bellows was increased with increasing the flow temperature in all cases of support. In case of simple-simple, the frequency increased from 101 to 120 Hz when the temperature changed from 30 to 80 $^oC$. In addition, the frequency of fixed-fixed was changed from 77 to 137 Hz while the frequency of bellow in case of fixed-free was changed from 67 to 104 Hz when the temperature increased from 30 to 55 $^oC$ and then slightly changed until to 106 Hz when the temperature increased to 80 $^oC$.

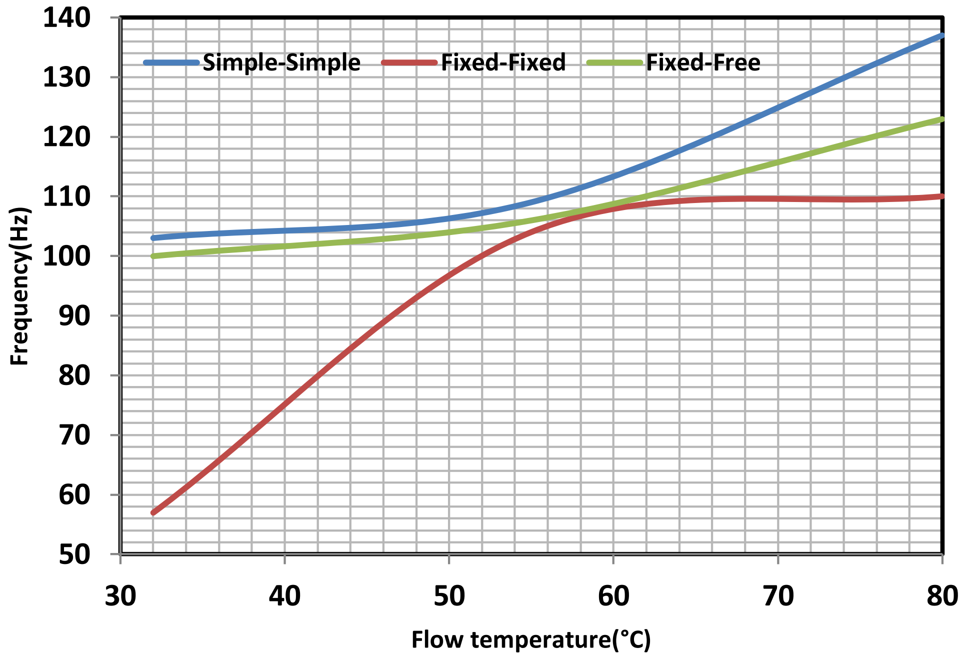


Figure 6. Variation of frequency with flow temperature in bellow at diameter 20 mm with flow rate 14 LPM

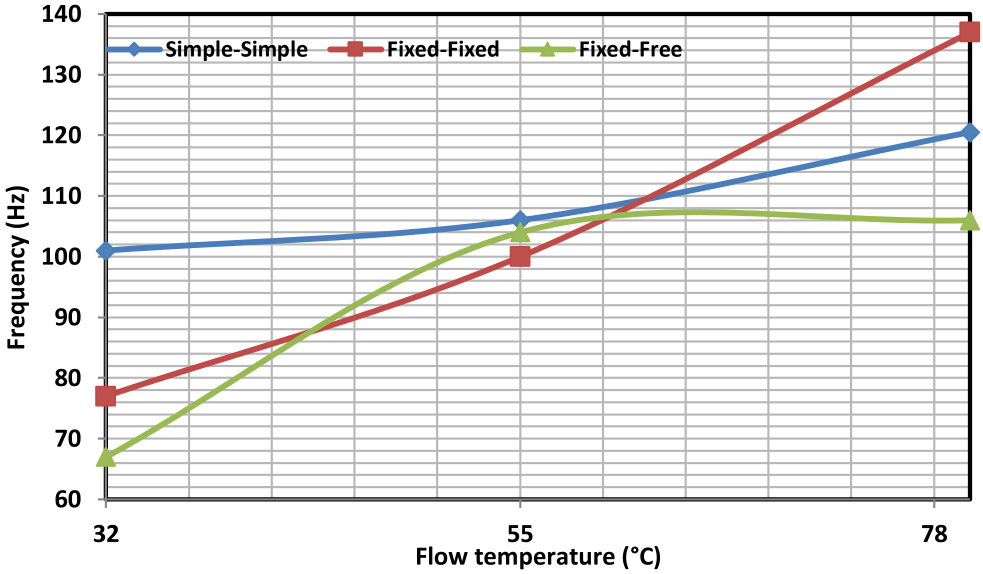


Figure 7. Variation of frequency with flow temperature in bellow at diameter 10 mm with flow rate 14 LPM

### 3.2. Y-displacement

The y-displacement along the expansion bellow of 20 mm diameter was represented in Figure 8. The tests of y-displacement were measured at maximum flow temperature 80 ºC and maximum flow rate 14 LPM with three cases of support. The probe of vibration meter was installed at the beginning of bellow in a 0-point and then moved it every 60 mm. As shown in Figure, the y-displacement in case of simple-simple and fixed-free was rapidly decreased. Where, the y-displacement was recorded about $21\times10^{-3}$ mm at the beginning of the below and then drop to $14\times10^{-3}$ mm at the end of bellow. While, in case of fixed -free the y-displacement was recorded $22\times10^{-3}$ mm and $12\times10^{-3}$ mm at the beginning and end respectively. Moreover, the behavior of y-displacement in case of fixed-fixed was increased to maximum value about $22\times10^{-3}$ mm near the middle point of bellow.

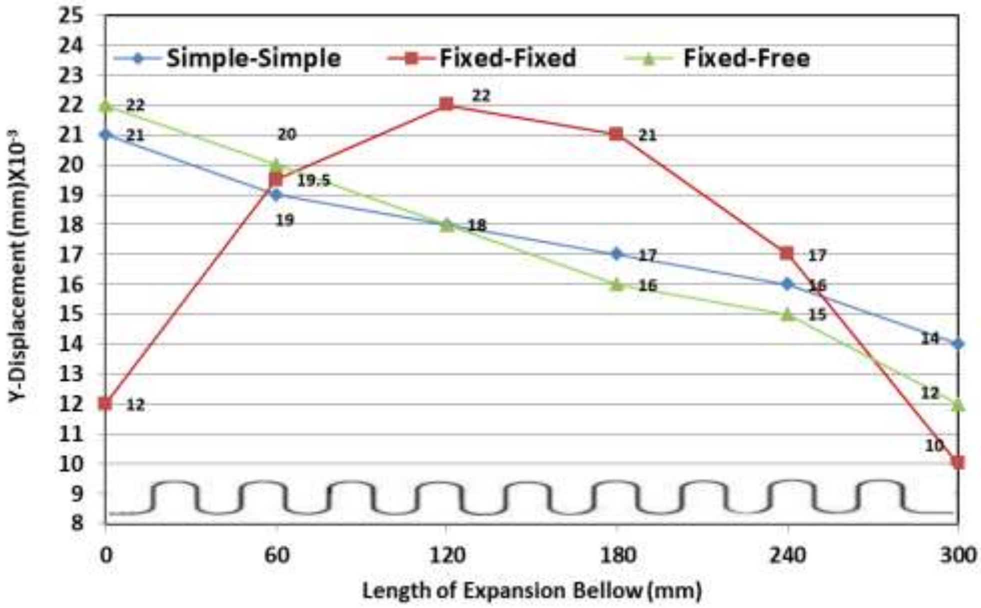


Figure 8. Variation of Y-displacement with the length of bellow at 20 mm diameter, 80 ºC and 14 LPM

## 4. Conclusions

In this study, an experimental study was investigated to analyse the influence of the flow temperature and mass flow rate on the frequency in expansion bellow conveying fluid in three types of support (simply-simply, fixed-free and fixed-fixed). Two expansion bellows were fabricated as: (10 mm inner diameter, 300 mm length and 111 number of convolutions) and (20 mm inner diameter, 300 mm length and 82 number of convolutions).According to the analysis of the results, the following conclusions are drawn:

1. In expansion bellow with diameter 20 mm, the frequency was increased with increasing the flow rate of fluid in case of simple–simple and recorded 110 Hz with 1 LPM and increased to 136 Hz with 14 LPM. While in case of fixed-fixed, the frequency was

began from 126 Hz with 1 LPM and drop to 90 Hz with 7 LPM and then increased to a maximum value about 109 Hz at 14 LPM. In the same manner, the frequency was began from 133 Hz with 1 LPM in case of fixed-free and then drop to a minimum value about 83 Hz at 7 LPM and increased to a maximum value about 123 Hz with 14 LPM.

2.In expansion bellow with diameter 10 mm, the frequency was increased from 101 Hz to 120 Hz when the flow rate change from 1 LPM to 14 LPM in case of simple-simple. While, in case of fixed-fixed was increased from 92 Hz to 136 Hz. Case fixed-free show that the frequency was increased from 93 Hz to 113 Hz when the flow rate changed from 1 LPM to 7 LPM and then drop to 106 Hz with increased the flow rate to 14 LPM.

3.Generally, the frequency of 20 mm bellows was increased with increasing the flow temperature in case of simple-simple and fixed-free. Where, the maximum frequency was recorded about 137 Hz at temperature 80 ºC in case of simple-simple and was recorded a maximum value about 123 Hz in case of fixed free. On the other side, the frequency of fixed-fixed was increased to maximum value about 110 Hz.

4.In diameter 10 mm, the frequency of bellows was increased with increasing the flow temperature in all cases of support. In case of simple-simple, the frequency increased from 101 to 120 Hz when the temperature changed from 30 to 80 ºC. In addition, the frequency of fixed-fixed was changed from 77 to 137 Hz while the frequency of bellow in case of fixed-free was changed from 67 to 104 Hz when the temperature increased from 30 to 55 ºC and then slightly changed until to 106 Hz when the temperature increased to 80 ºC.

5. The y-displacement was recorded about $21\times10^{-3}$ mm at the beginning of the below and then drop to $14\times10^{-3}$ mm at the end of bellow. While, in case of fixed -free the y-displacement was recorded $22\times10^{-3}$ mm and $12\times10^{-3}$ mm at the beginning and end respectively. Moreover, the behavior of y-displacement in case of fixed-fixed was increased to maximum value about $22\times10^{-3}$ mm near the middle point of bellow.

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