Modal Analysis of Vibratory Bowl Feeder Machine

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Abstract: Automation, or automatic control of different mechanisms plays a important role in today's fast-moving, competitive industrial world where there is an highly increasing demand to run processes with minimum human involvement. Mechanical feeders are mostly used when small components are to be fed in a machine or automation line one-by-one, oriented in a particular manner from a randomly distributed bulk of components. Feeder causes a coupled rotation around its vertical axis due to constraining motion of the leaf spring. The feeder is activated by electromagnet mounted on the base.Main objective of paper if to design, analyze and fabricate a vibratory bowl feeder for small components like washer for automation. The model has been verified by modal analysis in ANSYS Workbench 16.0 and validated through experimental setup using DEWESoft software.

***Keywords**: Modal analysis, Fundamental frequency, Leaf spring, Washer*

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I. Introduction

Vibratory bowl feeders (VBF) are common devices used to feed different individual component parts for assembly on in various industries for production lines. They are mostly used when many small components are to be feed to another machine or production line one by one, oriented in a particular shape and orientation.

Vibratory feeders depend on the mechanical behaviour of a part, such that when gently shaken down a conveyor chute that is shaped to fit the part, they will gradually be shaken so that they are all aligned. They thus leave the feeder's conveyor one-by-one, all in the same orientation [1]. Vibratory feeders, commonly known as a bowl feeder consisting of a specially shaped bowl designed to orient the parts to a specific orientation. A vibrating drive unit upon which the bowl is mounted is used to cause vibrations in the bowl shown in fig. 1. Bowl usually includes a special spiral track to convey parts along and discharge into the assembly machine which comes in many shapes and sizes depending on application. The drive unit available may be electromagnetic and a pneumatic drive which vibrates the bowl, forcing the parts to move up a circular inclined spiral track [3].

The springs constrain the bowl so that its vertical displacement causes a coupled rotation around its vertical symmetry axis. One or more electromagnets generate the force which drives the bowl, commonly they are either vertically or tangentially housed between the base and the bowl. Each electromagnet has two parts: one, fixed to the base, carries a coil supplied by an electric circuit, and the other, fixed to the bowl support and moves with the bowl. The current in the coil generates a concatenated magnetic flux which accordingly, causes an interaction force between the two parts of the electromagnet. This force induces the movement of the spare parts along an inner spiral track of the bowl [4].

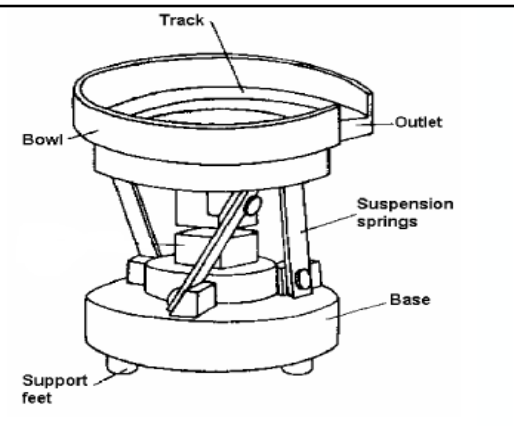

Figure 1: Schematic of VBF

II. Design of Bowl feeder:

2.1 Design of bowl

Bowl is specially designed with a helical spiral track which may be cylindrical, conical or cascade in shape. The bowl is connected to a base by three or four inclined leaf springs. The excitation to the bowl is given by the drive unit through leaf springs. Bowl is designed for feeding a washer of outer diameter 16mm and sorting out the washer of size 10mm shown in figure 2.

Figure 2: Experimental setup

2.2 Design of Leaf Spring

Leaf spring takes the drive unit forces acting on the bowl i.e. dynamic forces and also the weight of the bowl with workpiece which is static force. Hence the tensile strength, compressive strength and deformability of the material should be higher. Drive unit continuously vibrate the bowl within the frequency range of 100-200 Hz, so to withstand such high range and also having good elasticity the material chosen for the leaf spring is **G 10- grade Epoxy Glass Fiber** [6].Epoxy glass fiber (or glass fiber) is a material consisting of 'numerous extremely fine fiber of glass. Glass fiber has roughly comparable mechanical properties to other fibers such as polymers and carbon fiber [10].

As support system mainly consists of column we need to study design procedure for designing column. A column or strut is slender machine component which has considerable length in proportion to its width, depth or diameter. A column is also called strut or pillar or stanchion [9]. Connecting rods and supporting rods are examples of columns in this project.

- Mass of bowl and fixture with parts = 10 kg
- Hence weight on each spring will be = 10/3 = 3.33 kg = 33.33 N
- Length of Leaf spring = 100 mm
- Dynamic load = 163.33 N

To find critical slenderness ratio the properties for Epoxy glass fiber are,
Syt Of Epoxy Glass fiber = 275 N/mm^2,
E Of Epoxy Glass fiber = 9650 N/mm^2,
Therefore equation gives us (l/k),

$$(l/k)_{cr} = 18.27$$

Now to find actual slenderness ratio for cross-section of (10mm × 5mm) is,

$$(l/k)_{ac} = 57.73$$

Where,

$k = \sqrt{\frac{I}{A}}$, radius of gyration, mm

$I = (10\times5^3)/12$,

$A = (70\times10)$,

(l) = 100 mm. (Approximated as support is fixed at bottom and height of drive unit is limited)

From graph, as actual slenderness ratio is greater than critical slenderness ratio (57.73 > 18.27) we need to use Euler's equation for designing of column.
Pcr = total load on spring which it can sustain without buckling, once we know total load on leaf we can calculate corresponding dimensions of plank.

$$P_t = \text{total load on each leaf;}$$

$$P_t = P_{static} + P_{dynamic} \text{(on each Leaf spring)}$$

$P_t = 33.33 + 163.33$

P_t= 196.66 = 200N

Now above load has to be divided into two components (because our column is at 70° with horizontal and load acting is vertical)

Therefore,

$$P_{cr} = 200 \cos 30 = 173.2 \text{ N}$$

And, P_b = bending force = 200 sin30

= 100 N

Therefore by putting value of k as $\sqrt{\frac{I}{A}}$ and,

n = 0.25 (end fixity coefficient for one end free and other end fixed column), we get equation for critical load as follow,

$$Pcr = (0.25\times\pi^2\times E\times I)/\,(l)^2,$$

Now put the values of Pcr, l, E, in above equation which will gives us value of I,

$$I = 75.5 \text{ mm}^4$$

Taking, FOS = 2

Now as we can't change length we have to choose cross-section by trial and error method which can satisfy above condition of moment of inertia (I)

Therefore,

For cross-section of (10 × 5),

$$I = 52.03 \text{ mm}^4$$

For cross-section of (15 × 8),

$$I = 150 \text{ mm}^4$$

From above calculations we can choose **(15 × 8)**, as cross-section of leaf spring plank to avoid buckling.

Now let us test above cross-section for bending under bending force P_b = 100 N,

Bending stress = (M × Y)/I,

Where,

M = force × length

= 100 × 80 (length is taken by excluding fixed part of column)

= 8000 N-mm

Y = 8/2 = 4

$$I = (15 \times 8^3)/12 = 320 \text{ mm}^4$$

Therefore,

Bending stress = (8000 × 4)/320

= **100 N/mm²**

As bending stress is less than 0.66 of Syt Of FRP i.e. 100 N/mm² < 275 N/mm², column is also safe for bending. Therefore the dimensions of leaf spring are **100mm×15mm×8mm.**

Leaf spring is used to support the bowl and base which restricts the motion of the bowl in vertical direction. According to the results of ANSYS the suitable combination by trial and error method, the natural frequency of bowl is low for the dimension 100*15*6 mm.

2.3 Specifications of Bowl feeder

The main objective of the project is to separate the 16 mm washer from 10 mm. Sorting of these two washer is done at the exit of the bowl. When the washer comes out of the track there is a plate at the exit with an elongated slot of 17 mm and having a slot in it of 12mm. Hence for the above mechanism the specification of bowl feeder is given below in table 1.

Table 1: Specification of vibratory feeder bowl

Sr. No.	Parts	Material	Dimensions (mm)
1	Bowl	SS 304	Diameter = 250, Height = 120, Thickness = 2, Pitch = 45
2	Washer	MS	Outer diameter = 16, Inside diameter = 8
3	Base Plate	MS	Diameter 280, Thickness = 40
4	3 leaf spring	Glass Fibre	Height = 100, Width = 20, Thickness = 8

III. Results and Discussion

3.1 Modal analysis results

Modal analysis is used to determine the natural frequencies and mode shapes of a structure. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions. They are also used in a harmonic or transient analysis. Mode shape describes the configuration into which a component will naturally displace [4]. ANSYS is used as the solver as well as

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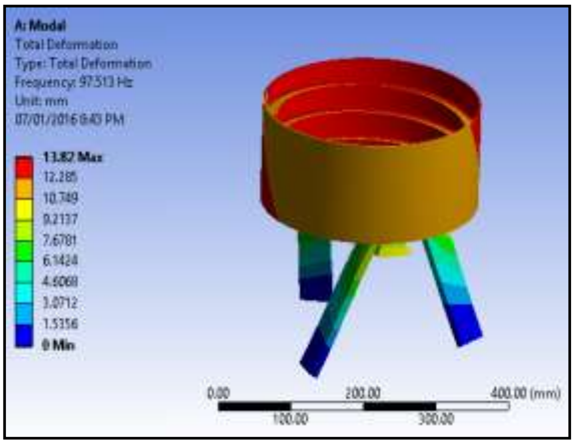
pre-processor and postprocessor. In FEM model has total node points 18267 and elements are 6387. The material used for feeder bowl is stainless steel, for fixture structural steel and for leaf spring glass fiber. Mode shapes taken from the ANSYS workbench. The motions of mode shapes and various mode frequencies are shown in table 2 and figure 3.

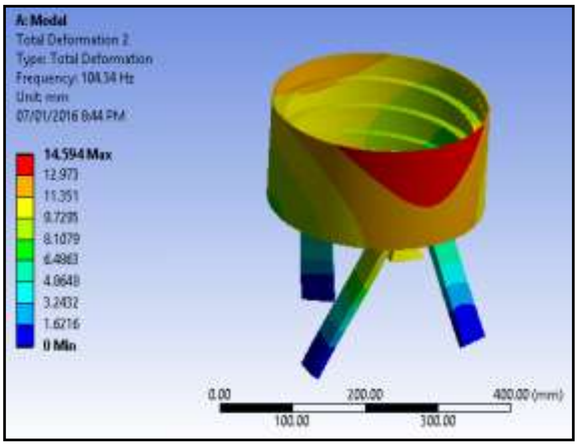
The motions of mode shapes for with modal frequencies are as follows

i. First mode: Rotary motion about Z axis (Torsional)
ii. Second mode: Back and forth motion along Y axis
iii. Third mode: Back and forth motion along X axis
iv. Fourth mode: Rotary motion about Y axis
v. Fifth mode: Rotary motion about X axis
vi. Sixth mode: Back and forth motion along Z axis

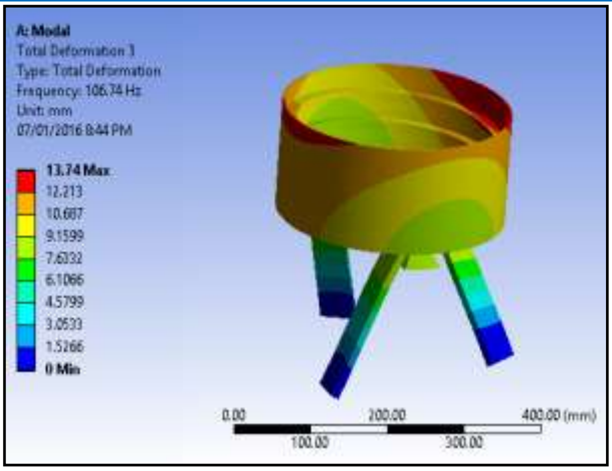
The various mode shapes results obtained in ANSYS workbench are as shown in figure 3.



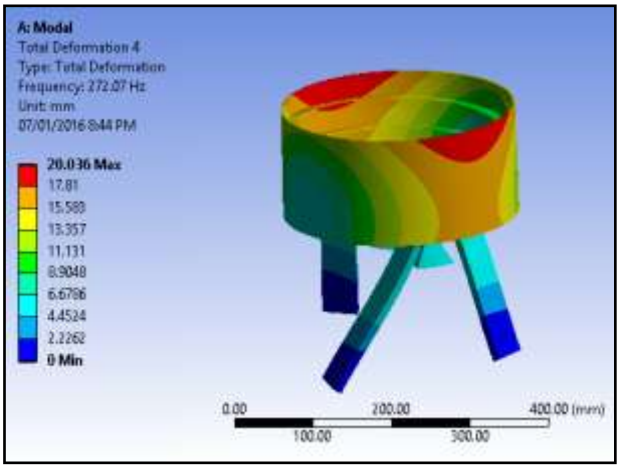
First Mode (97.51 Hz)



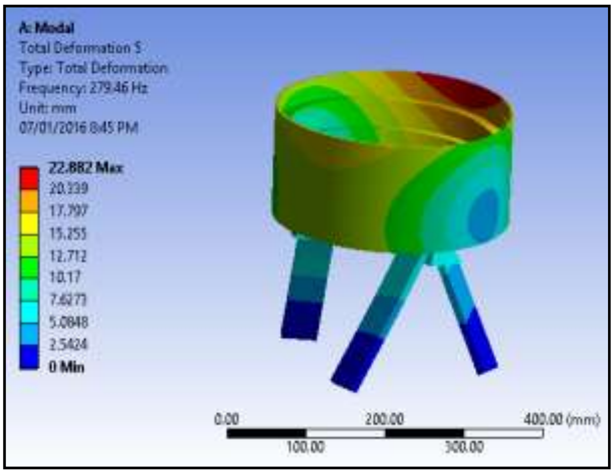
Second Mode (104.34 Hz)



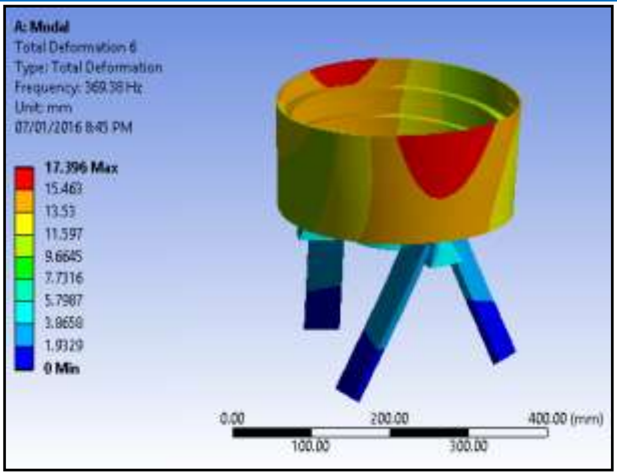
Third Mode (106.74 Hz)



Fourth Mode (272.07 Hz)



Fifth Mode (279.46 HZ)



Sixth Mode (369.38 Hz)

Figure 3: Mode Shapes

Table 2: Tabular data of various mode frequencies

Mode number	Frequency (Hz)
1	97.51
2	104.34
3	106.74
4	272.07
5	279.46
6	369.38

3.2 Experimental Results

Natural frequency of system is calculated by attaching the accelerometer at different positions of the bowl. Firstly the accelerometer was attached at the fixture the on base and bowl of the feeder.The experimental testing setup is shown in figure 4.

Figure 4: Testing setup (Accelerometer position at fixture)

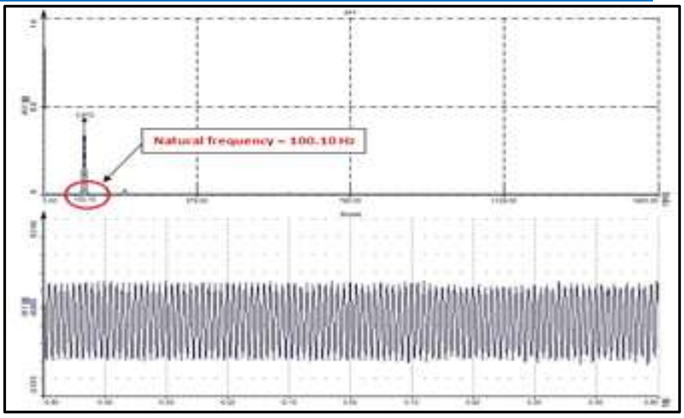


Figure 5: Natural frequency of Vibratory bowl feeder

From figure 5 it is seen that the natural frequency with which the bowl vibrates is 100.10 Hz.For different voltage we get different amplitude of vibrations, but natural frequency of bowl is same. If the location of accelerometer is changed and attached to the base we get same natural frequency.

IV. Conclusions

The experimental results are obtained by giving variable voltage by voltage controller between 85V to 260V. The fundamental frequency of vibration by modal analysis is 97.51 Hz. The natural frequency obtained experimentally is 100.10 Hz which exactly matches with that calculated by modal analysis. It suggests that feeder should be probably operated between the range 90 Hz to 110 Hz for better performance so that the natural frequency of exciter and bowl matches as shown in fig.(5).The maximum peak is seen at 369.38 Hz; therefore working of vibratory bowl feeder should be avoided at this frequency. Mathematical model predicts the motion of bowl using state space method for a model of bowl feeder having six degree of freedom.

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