Modal analysis of the vibratory feeder unit and its structural elements through FEM technique

This paper explains modal analysis of individual structural element of a vibratory feeder as well as complete vibratory feeder unit using FEA technique. The analysis of the individual structural element helps in detecting those sections which might failed in the complete unit under working conditions, if excited with their natural frequencies. These elements are the helical spring, the trough, and the structure on which it is mounted. 3D models are developed using CATIA V5 software and imported into ANSYS Workbench 14. The weaker sections of each element is identified by observing the amplitude of vibration at particular natural frequency.

Keywords: *Modal analysis, natural frequency, mode shape, vibratory feeder, trough, support structure, helical spring and finite element analysis (FEA).*

I. Introduction

A vibratory feeder is used in many industries to convey material in a controlled manner. Electromagnetic type and mechanical type feeder are most common. They have wide applications in mineral processing plant, food processing plant, petrochemical plants, mining plants etc. They are considered as the critical equipment in the line of operation of the plant. Any sudden failure of its components will lead to stoppage of the plant operation. These sudden failures occur due to the components which become weak during operation. If regular monitoring of such weaker section is done, the sudden failures can be avoided. The paper delineates these techniques and identifies the weaker sections using FEA method and relevant software.

The section 2 gives brief highlight of the recent research work done using the FEA technique in various fields. The section 3 explained about the common procedures followed in the modal analysis using FEA for various parts of the vibratory. Section 4 describes the observations obtained for the helical spring, trough, support structure and vibratory feeder unit. Section 5 emphasized on the comparative study between individual parts and complete unit of vibratory feeder. Finally, section 6 described the final concluding remarks followed by references in section 7.

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II. Modal analysis and FEA method

The modal analysis through FEA is considered as an effective tool for structural element due to its reliability and economical availability as it uses only virtual environment in the software [1-2]. Modal analysis through FEA is widely used for evaluating the designs and modifications of structural problems. For investigating structural problems, for the continuous structural problems, a numerical approximation is obtained by developing model in design software and importing into finite element analysis through discretizing the structure in a finite number of physical coordinates [3].The modal analysis determines natural frequencies and mode shapes of a dynamic structure [4]. A few numbers of initial mode shapes with their natural frequencies are sufficient to describe the dynamic characteristics of the structure. Symmetrical structures produces multiple modes in different directions with similar natural frequencies [5-6]. The structural modal analysis can be used in detecting the failures in the structure and in its components [7-12]. FEA method is used for the harmonic response analysis of a vibratory feeder. Harmonic analysis is used to determine the steady-state response of a structure to overcome resonance and fatigue induced by forced vibrations [13].

III. Modal analysis using FEM method

3D models of the vibratory feeder unit, helical spring, trough and the supporting structure have been developed in CATIA V5 and imported in the ANSYS Workbench 14 to determine the modal parameters. The standard properties of the mechanical components have been assumed and the detailed is given in Table1.

TABLE 1: MATERIAL PROPERTIES OF VIBRATORY FEEDER PARTS

Part name	Young's modulus (E) GPa	Poisson's ratio (μ)	Density (ρ) kg/m^3
Support structure	210	0.3	7800
Helical spring	211	0.28	7920
Trough	210	0.3	7800

Three dimensional models are imported and meshed in Workbench 14 using tetrahedral structural solid 187 element. Modal analysis is carried out by Black Lanczos mode extraction method for determining the modal parameters. This method is found useful for obtaining natural frequencies of the structural elements. In plants, the trough is fixed on the end of the spring, which does impart three degree of freedom (x, y and z directions) to the trough under natural conditions. However, due to elliptical motion of the trough at the time of vibration caused due to rotation of unbalanced mass, the trough will have displacement in x and y directions only. The bottom ends of the springs are fixed with the on top of the supporting structure. The supporting structure are grouted with ground. The same boundary conditions, that is ground support structure is assumed as having zero DOFs, the bottom ends of the springs are assumed fixed with the support structure and top ends of the springs are given DOFs similar to the trough, which has been assigned 2 DOFs in x and y directions only to the model. The frequency range is considered between 1-500 Hz, as only initial six number of mode shapes are considered for analysis.

IV. Results of FEA modal analysis

The results of individual parts associated with the vibratory feeder are presented in the form of mode shapes along with displacement contour to indicate maximum (anti-node) and minimum (node) amplitudes. The results are presented in two steps – in first step, the results of all the individual parts are illustrated and explained. In the second step, results of the complete vibratory feeder are explained.

4.1 Modal analysis of helical spring

In this part, a 3D model of a helical spring is imported and meshed in ANSYS. A point load of 200N is applied in downward direction considering the weight of the trough used in the feeder along with the vibratory motor as shown in Fig.1. The fixed base - fixed top boundary conditions of a helical spring have been applied considering it is installed in the vibratory feeders.

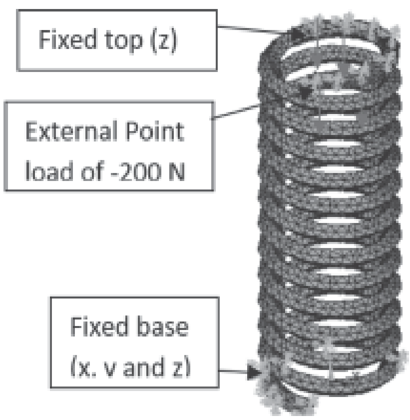

Fig.1 Meshed model of a helical spring using fixed base- fixed top boundary conditions

Results obtained from modal analysis through FEA of a helical spring are presented in the form of mode shapes corresponding to their natural frequencies as shown in Fig.2 along with their displacement contours.

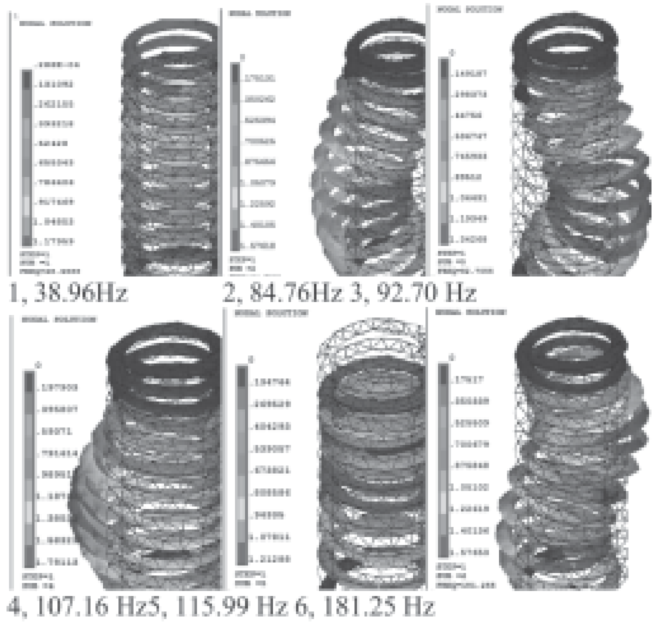

Fig.2 Mode shapes of helical spring using fixed base- fixed end boundaries

The mode 1 is illustrating the longitudinal elongations corresponding to the natural frequency of 38.96 Hz. This is the most common mode shape that developed in the helical spring under fixed base – fixed end boundary conditions when subjected to axial loads. Mode 2 and mode 3 are producing the bending effects corresponding to their natural frequency of 84.76 Hz and 92.70 Hz respectively. Two different mode shapes can occur in any symmetrical structural element with very narrow range of natural frequencies which are also known as repeated natural frequencies as observed in mode 2 and mode 3 in Fig.2. Mode 4 is producing another very unique type of expansion in which spring expanding least at the bottom and then gradually expanding outward from fixed base up-to middle coil of the spring which can be described as conical effect in the spring at natural frequency of 107.16 Hz. The mode 5 is showing the compression effect along the axial direction corresponding to the natural frequency of 115.99 Hz. This is too one of the basic mode shape and usually occurs when helical spring subjected to compression load under fixed base fixed end boundary condition. Mode 6 is clearly a flexible mode in which multiple modes are observed. The spring is found deformed in opposite directions one in fixed-base and other is in fixed top corresponding to the natural frequency of 181.25 Hz.

The various mode shapes of the spring under fixed base - fixed end boundary conditions revealed that most of the deformations occurred in the middle coils and least deformations are observed both end during actual working conditions. Therefore, it is concluded that maximum stresses developed only in the middle sections of the coils in the spring and likely to fail this sections only.

4.2 Modal analysis of the trough

The theoretical values of mode shapes corresponding to their natural frequencies of the trough are as presented in the Fig.3. The trough is one of the important part of the vibratory feeder andusually subjected to the maximum vibration. In this analysis, the natural frequencies of first six modes are considered for investigations since practically initial few numbers of mode shapes corresponding to their natural frequencies are sufficient for analysis to find out probable sections of failures.

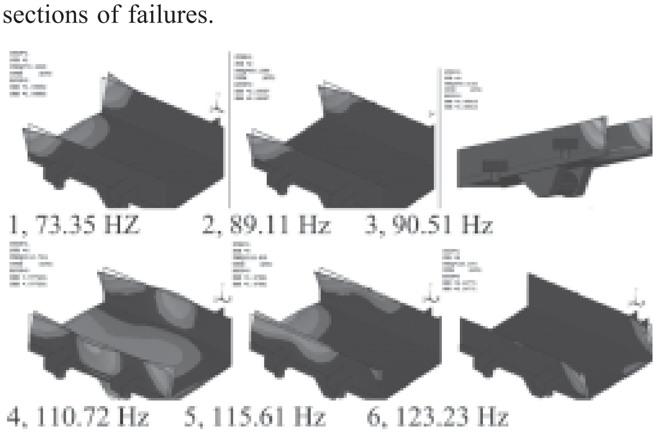

Fig.3 Mode shapes of trough along with vibratory motor

Mode 1 of a trough is occurred at natural frequency 73.35 Hz, which displayedflutter on corners of vertical plates along z-axis with deflection on each side of the plate as shown in Fig.3. It usually occurs due to the fact that corner plates are located at the free ends. Mode 2 of the trough is occurring in the same corners of the plates of the tough as it developed in the Mode1; but in the mode 2, direction of flutter is similar for both the plates along z-axis at natural frequency of 89.11 Hz. Mode 3 is developed in both two vertical plates and in horizontal plate of the trough as observed by the deformations. Outward flatter of vertical plates viewed in z-axis and hogging effect can be seen in the horizontal plate. Multiple numbers of nods and anti-nods can be seen in the mode 4 which occurred at natural frequency of 110.72 Hz. This usually happens in the higher mode shapes. The mode 5 showed the deformation in both vertical and horizontal plates together at natural frequency of 115.16 Hz. Mode 6 with respect to its natural frequency of 123.23 as shown in Fig.3 confirmed the fact that during normal operation of the trough under external sinusoidal vibration, the vertical plates are the most venerable to fatigue and often failed during the operations.

4.3 Modal analysis of the support structure

Results of modal analysis of the support structure with feeder obtained by FEA method are presented in form of mode shapes with respect to their unique natural frequencies shown in the Fig.4.

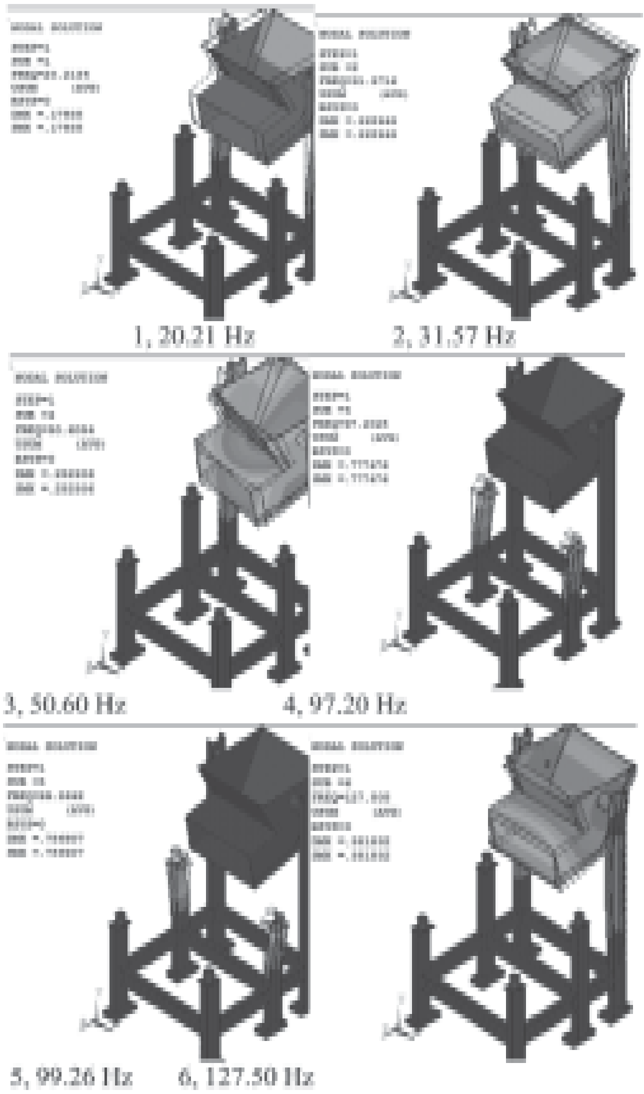

Fig.4 Mode shapes of the feeder structure with their natural frequencies

Observation of Fig.5, shows that the patterns of deformation in feeder structure is found maximum in the in feeder and almost nil deformation developed at the fixed ground supports. Mode1 corresponding to its natural frequency at 20.21 Hz shows maximum deformation of the support structure for feeder is in the direction of x-axis at the free end of the structural element. Similarly, mode 2 with respect to the natural frequency of 31.57 Hz produces maximum deformation in the feeder in z-axis. Mode 3 is inducing the deformation in the feeder structure at its natural frequency of 50.60 Hz. It in contrast with the mode 1 and mode 2 in which deformation induced in particular direction x and z, mode 3 produces a tortional effect, minimum deformation at the base of the feeder support and maximum at the feeder top. Mode 4 and mode 5 are clearly seen as equal and opposite deformation in the free ends of the spring support occurred due to repeated natural frequencies at 97.20 Hz and 99.26 Hz respectively. Mode 6 deformed in the y-axis at its natural frequency of 127.5 Hz and feeder structure observed compressed.

4.4 Modal analysis of the complete vibratory feeder

In this analysis, all parts are assembled together in form complete vibratory feeder model. During the theoretical modal analysis, all the grounded feeder supports are given zero degree of freedoms in line with actual boundary conditions of the vibratory feeder during normal operating condition.

The mode shapes of a vibratory feeder are shown in Fig.5 indicate that mode shapes are actually replications of modes formed in the individual parts of the vibratory feeder, but difference here is that these modes are formed at the natural frequencies of the vibratory feeder. Mode 1 of vibratory feeder which occurred at natural frequency of 6.02 Hz exhibiting the bending effect in helical spring, support structure with feeder presented the deformation in x-axis and the trough is showing the flutter effect at the corners of vertical plates. Mode 2 occurred in vibratory feeder at natural frequency of 12.18 Hz is quite resembled with the mode shape of individual parts at their respective second mode shape and its deformation observed in y-axis downward direction as well as flutter in vertical plates of trough. Mode 3 of a feeder at natural frequency of 15.16 Hz deformed in the direction of x-axis along with bending in a helical spring, maximum deformation in the feeder which is preset at the free end of the support structure and the deflection in the horizontal plate of the trough. Mode 4 of a vibratory feeder at natural frequency of 19.06 Hz is producing the torsional effect along with bending in the helical spring along with deformation in the feeder. Deformation in the vertical plates as well as horizontal plate in the trough can be observed clearly in y-axis. Mode 5 of vibratory feeder with its natural frequency of 35.15 Hz depicting the torsion in horizontal plate of the trough in anticlockwise direction. Mode 6 of a vibratory feeder illustrated explicitly bending effect in a helical spring with its support structure at natural frequency of 50.63 Hz.

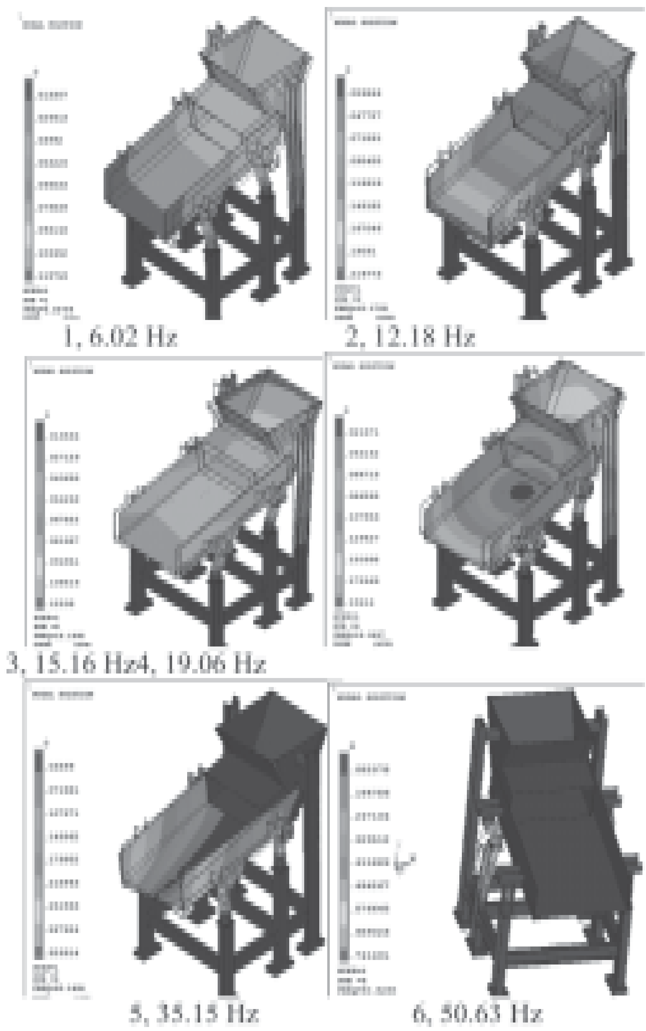

Fig.5.Mode shapes of a complete vibratory feeder

V. Comparative study of natural frequencies

The mode shapes of individual parts provided a complete overview of the number of probable sections at which failure could occur corresponding to their respective natural frequencies. The comparative study revealed that mode shapes of individual parts are also accompanying in the mode shapes of complete vibratoryfeeder associated with its natural frequency.

Therefore, it can be concluded, that even though mode shapes of individual parts remain present in the vibratory feeder. But these modes shapes are not destructive in nature, as they occurred at operating frequencies of vibratory feeder and do not coincide with any of the natural frequencies of individual parts. The natural frequencies are unique for individual parts as well as vibratory feeder due to different geometrical design, mass, and overall stiffness as shown in graph Fig.6. The decrement in natural frequencies of vibratory feeder is due to the increased in total mass of the system. The natural frequencies of every individual parts as well as of the vibratory feeder are observed unique as shown in the Fig.6.

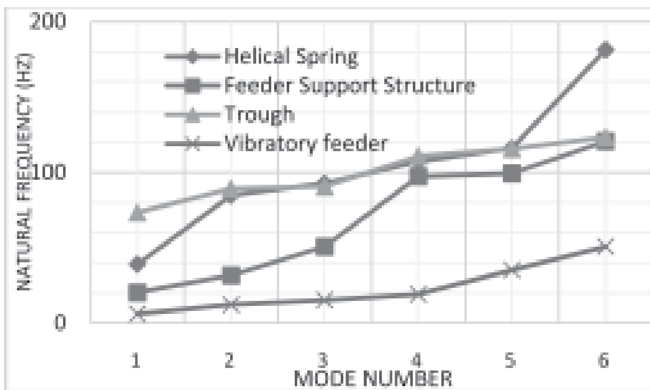

Fig.6 Comparison of natural frequencies of vibratory feeder and its parts

VI. Conclusions

The research is paper focused on analysis of mode shapes corresponding to the natural frequencies of individual parts and the whole vibratory feeder for identifying the probable weaker section.The mode shapes of the vibratory feeder revealed that the mode shapes induced in the individual parts are also present in vibratory feeder in tune with the natural frequencies of vibratory feeder.The unique natural frequencies are observed in all individual parts as well as in whole vibratory feeder. This uniqueness in natural frequencies of all the parts is due to different geometrical design, mass, and stiffness. Even though mode shapes of individual parts remain present in the vibratory feeder. But, these modes shapes are not detrimental in nature, as they occurred at operating frequencies of vibratory feeder and not coinciding with any of the natural frequencies of individual parts as well as vibratory feeder. The natural frequencies of the vibratory feeder is observed lowest due to the assembly of all the parts together and all the parts act as single unit, which increased the total mass the system.In future, these findings can be validated by experimental modal analysis.

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