Design Optimization of Vibratory Screen Assembly for Dynamic Loads

Basawaraj S Hasu[1], Dr. B Nageswara Rao[2], K Vinod Kumar[3]
[1, 2, 3] Department of Mechanical Engineering
[1, 2, 3] AVN Institute of Engineering & Technology, Hyderabad, India

***Abstract*-** *Vibrating screens are used to separate bulk materials in a mixture of different sized particles. For example sand, gravel, river rock and crushed rock, and other aggregates are often separated by size using vibrating screens. These vibrating screens adopt two motors. These motors are the main source of vibrations. The raw materials will be up-threw with the vibrating forces and self-gravity and start a skipped movement straightly to achieve the purpose of the screening and grading. The vibratory screen designed in this project is used in power plants to separate coal particles of a 6mm size from a mixture of different sized coal particles. The separated coal particles are then sent to a furnace through a conveyor. This process results in efficient burning of the coal. Because of the above application, the design of the vibrating screen is very important. As per the design of the existing vibratory screen, the life of the vibratory screen is more than ten years, but most of the vibratory screens get failed within one year due to the occurrence of resonance. The target of this project is to execute a 3D model of the existing vibratory screen (reference design taken from a conveyor fabrication company) and study the dynamic behavior of the screen by performing the finite element analysis. After determining the cause of the failure of the existing vibratory screen through finite element analysis, an alternative design is proposed, which will be resonant free and also meet the design requirement. The modal and harmonic analysis is performed to analyses and optimize the dynamic behavior of the vibratory screen. NX-CAD software is used for 3D modeling and ANSYS software is used to do finite element analysis.*

I. INTRODUCTION

VIBRATING SCREEN ASSEMBLY

Vibrating screens are used to test the material to different sizes with the help of the screen the material that is crushed are categorized into various as per the requirement, and then sent to further processes. These are used in cement industries and thermal plants to screen the various sizes of the coal that comes to the screen from the crusher. The required size of the coal is filtered to the bottom of the screen and sent to the next processing section, and the remaining material is sent again to the crusher.

Operating Principle

It modifies the amplitude by tube-shaped violent vibration screen of the eccentric shaft and eccentric blocks. The body moves like a circle, to make the materials screened.

Construction of machine

The display basket is of welded, riveted bolted construction. The vibrator assembly consists of a shaft on which unbalanced weights are fixed. This shaft frequently runs into first self-aligning spherical roller bearing sealed in a housing. The spring assembly normally consists of helical spring or combination of both. Screening decks consist of knitted wire screen cloth or perforated plate and grizzly bar type construction. The screen gets its motion from an electric motor through a v-belt drive.

II. LITERATURE REVIEW

The influence of screen design parameters on the operation efficiency of secondary crushing plants by J. A. Meech and R. J. Tucker, An analysis of screen design options on the operating efficiency of secondary crushing plants has been conducted using a dynamic computer model. The model allows for the simulation of a wide variety of crushing circuits and can be run on either a microcomputer (IBM PC/XT) or a large time-sharing mainframe computer. Separation characteristics and size reduction of crushers and screens are based on standard manufacturer design and performance data. Input/output routines are available in tabular, alarm or strip chart recorder modes to facilitate operation of the program. Some alternate circuit designs are compared to show the influence of surge capacity, screen size and area, screen deck location, and closed side crusher settings on the operation of a 10,000 ton per day plant. The program is currently in use at Queen's University to teach plant operations and control. It has potential to be a valuable tool for operator training.

Dynamic design theory and application of large vibrating screen by Zhao Yue-mina, Liu Chu-sheng, He Xiao-mei, The reliability is a key factor for the design and manufacture of a large vibrating screen. In this paper, we recognized a new large vibrating screen with hyperstatic net-beam structure. Dynamic characteristic of the vibrating screen was researched, and dynamic simulation method of large screening machines was explored. We used finite element method (FEM) to analyze a dynamic characteristic of the large vibrating screen with hyper static net-beam structure. Dynamic response, natural modes of vibration and Multi natural frequency of the vibrating screen are calculated. The structures of stiffeners on the side plate is optimized under many frequencies constraints, and an adaptive optimization criterion is given. The results show that the increase in vibrating screen's structural strength and the enhancement of natural frequency of bending deformation. From working frequency, the modal frequencies are far, and thus the structure can avoid resonance successfully and reduce the destructiveness. The high transverse displacement of the considered vibrating screen is 0.13 mm, the maximum dynamic stress is 16.63MPa, and the maximum variation in vibration amplitude of corresponding points is 0.44mm. The structural optimization represents that 194.50kg reduces the mass of the side plate, the second and third modal frequency is raised by 1.73% and 2.91% respectively, and a better optimal effect is received.

III. PROBLEM DEFINITION AND METHODOLOGY

The only aim of this present work is to make a 3D model of the existing vibratory screen (reference design taken from a conveyor fabrication company) and study the dynamic behavior of the screen by performing the finite element analysis. After determining the cause of the failure of the existing vibratory screen through finite element analysis, an alternative design is proposed, which will be resonant free and also meet the design requirement. The modal and harmonic analysis was performed to understand and optimize the dynamic behaviour of the vibratory screen. NX-CAD software is used for 3D modeling, and ANSYS software is used to do finite element analysis.

THE METHODOLOGY FOLLOWED IN THE PROJECT ISAS FOLLOWS

3D model of the generator frame is done in NX-CAD

This 3d model is converted into Parasolid and imported into ANSYS to perform finite element analysis. The static structural analysis is performed with a generator weight as static load, and stresses and deflections are documented. Modal analysis of the generator frame is carried out to calculate natural frequencies and their mode shapes and evaluate the dynamic characteristics. Spectrum analysis is performed to check the frame behaviour due to random vibrations as per the input PSD curve. One sigma deflections and stresses are plotted. Design changes are made to strengthen the generator frame structure for operating conditions. The static structural analysis is performed with a generator weight as static load, and stresses and deflections are documented on the modified generator frame. Modal analysis is carried out to calculate natural frequencies and their mode shapes and evaluate the dynamic characteristics of the modified generator frame. Spectrum analysis is performed to check the modified generator frame behavior due to random vibrations as per the input PSD curve. One sigma deflections and stresses are plotted.

IV. 3D MODELING OF VIBRATORY SCREEN ASSEMBLY

Vibrating screens are used to separate bulk materials in a mixture of different sized particles. For example sand, gravel, river rock and crushed rock, and other aggregates are often separated by size using vibrating screens. These vibrating screens adopt two motors. These motors are the main source of vibrations. The raw materials will be up-threw with the vibrating forces and self-gravity and start a skipped movement straightly to achieve the purpose of the screening and grading.

The 3D model of the vibratory screen assembly is created using UNIGRAPHICS NX software from the design calculations. UNIGRAPHICS NX is the world's leading 3D product development solution.

NX is used in a vast range of industries from manufacturing of rockets to computer peripherals. With more than 1 lakh seats installed in worldwide many cad users are exposed to NX and enjoy using NX for its power and capability.

Vibratory screen side plate

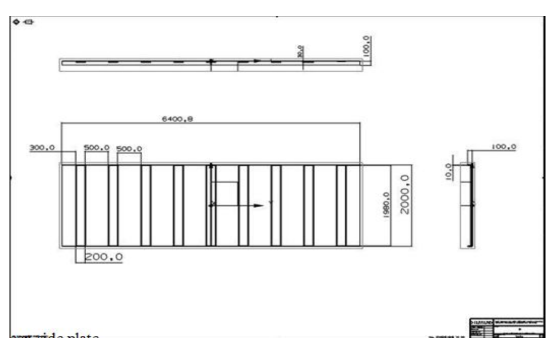

Figure 1. shows the 2D drawing of Vibratory screen side plate

Vibratory screen front end support

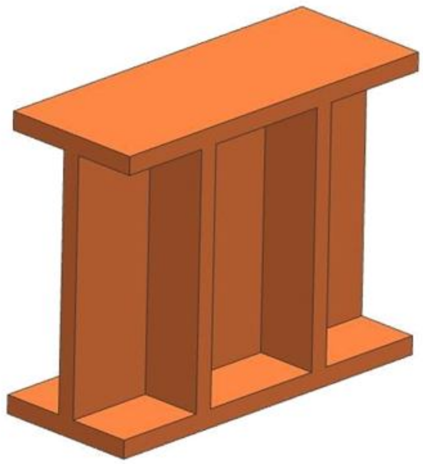

Figure 2. shows the 3D model of Vibratory screen front end support

Vibratory screen Base

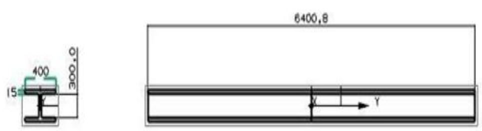

Figure 3.

Vibratory screen support spring

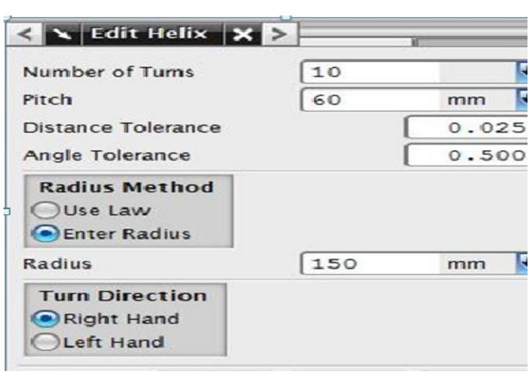

Figure 4. Shows the 2D data of Vibratory screen support spring

V. FINITE ELEMENT ANALYSIS OF VIBRATORY SCREEN

Structural Analysis of Vibratory Screen Assembly

Finite Element Modeling (FEM) and Finite Element Analysis (FEA) are two most popular mechanical engineering applications offered by existing CAE systems. This is attributed to the fact that the FEM is perhaps the most popular numerical technique for solving engineering problems. The method is general enough to handle any complex shape of geometry (problem domain), any material properties, any boundary conditions and any loading conditions. The generality of the FEM fits the analysis requirements of today's complex engineering systems, and designs, where closed form solutions are governing equilibrium equations, are not available. Also it is an efficient design tool by which designers can perform parametric design studying various cases (different shapes, material loads etc.) analyzing them and choosing the optimum design.

FINITE ELEMENT METHOD

The FEM is numerical analysis technique for obtaining approximate solutions to wide variety of engineering problems. The method originated in the aerospace industry as a tool to study stresses in complicated airframe structures. It grew out of what was called the matrix analysis method used in aircraft design. The method has gained popularity among both researchers and practitioners and after so many developments codes are developed for the wide variety of problems.

The geometry, node locations, and the coordinate system for this element are shown in the above Figure. The element is defined by four nodes, four thicknesses, elastic foundation stiffness, and the orthotropic material properties. The thickness is assumed to vary smoothly over the area of the element, with the thickness input at the four nodes.

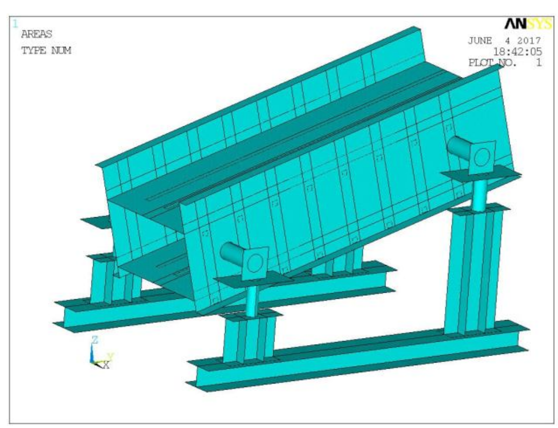

Figure 5. Shows the Infinite model of the Vibratory screen assembly

VI. STATIC ANALYSIS OF VIBRATORY SCREEN ASSEMBLY

Static analysis can, however, include steady inertia loads and time varying loads that can be approximated as static equivalent loads. Static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. The kinds of loading that can be applied in the static analysis include:

Objective

To Objective of this analysis is to check the High stressed locations and deflections on the Vibratory screen assembly for the applied loads and inertia load.

Boundary conditions applied on the Vibratory screen assembly
Coal Max. Weight on screen is = 679kg
Force = 679*9.81 = 6664N (on top plate)
Force = 679*9.81/2 = 333N (on bottom plate)
Gravity = 9.81m/s.

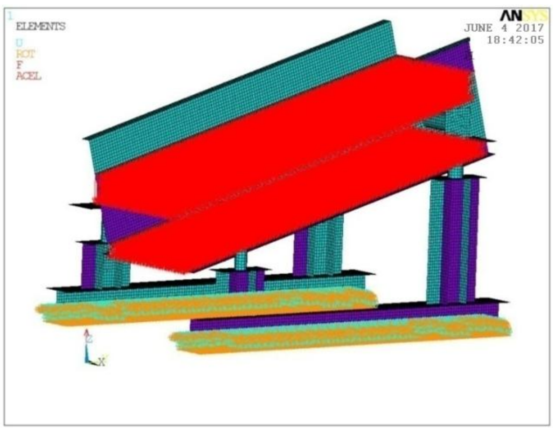

Figure 6.

DYNAMIC ANALYSIS OF VIBRATORY SCREEN ASSEMBLY

MODAL ANALYSIS

Modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis, or a seismic analysis.
Max. Deflection and stress of frequency @ 8.5Hz

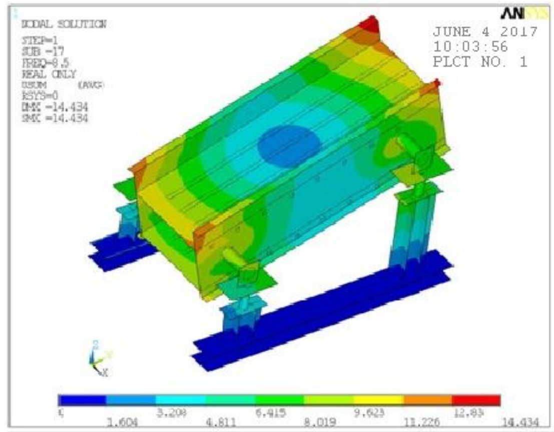

Figure 7. shows the deflections and von mises stress for critical frequencies

Table 1.

S.no	FREQUENCY	DEFLECTIONS (mm)	VON MISES STRESS (MPa)
1	2.5	2.14	64
2	8.5	14.4	383.9
3	10.5	15.5	554.9
4	13.5	142.1	5040

From the above results, it can be observed that the at the critical frequencies 8.5 Hz, 10.5 Hz, and 13.5 Hz the stresses 383 MPa, 554 MPa and 5040 MPa respectively. To overcome that high stress and deflections, modification of design is required. Hence according to the VonMises Stress Theory, the VonMises stress is more than the yield strength of the material at three operating frequencies. Hence the design of vibrating screen assembly is not safe for the above operating loading conditions.

The modifications are made by observing the deflections obtained from the corresponding mode shapes from the modal analysis at different frequencies. The modifications are made on the vibrating screen assembly by adding gussets on side plate, and additional rib for screen supports.

MODIFIED 3D MODEL OF VIBRATING SCREEN ASSEMBLY

The modifications are made on the vibrating screen assembly by adding supports and gussets as shown in the below figures.

3D model of modified vibrating screen assembly

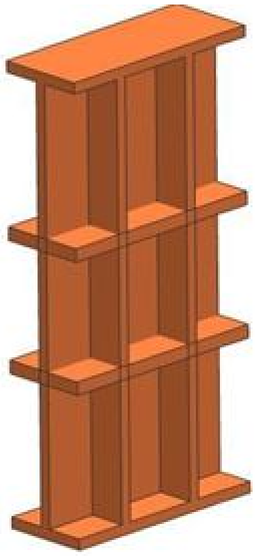

Figure 8. Shows the Vibratory screen supports back end

FINITE ELEMENT ANALYSIS OF MODIFIED VIBRATORY SCREEN ASSEMBLY FINITE ELEMENT MODELING

3D model of the modified vibratory screen assembly was developed in UNIGRAPHICS from the design calculations done. The model was then converted into a Parasolid to import into ANSYS. A Finite Element model was developed with shell elements. The elements that are used for idealizing the modified vibratory screen assembly were described below. A detailed Finite Element model was built with shell elements to idealize all the components of the modified vibratory screen assembly. Static analysis was carried on the modified vibratory screen assembly for operating loads (coal weight and gravity). Modal analysis was carried out to find the natural frequencies.

The elements that are used for idealizing the modified vibratory screen assembly are Shell 63.The description of each element are given below.

MATERIAL PROPERTIES

All the components of the modified vibratory screen assembly are made using hot-rolled structural steel IS 2062-1999, Grade A, Fe 410WA.All the components of the modified vibratory screen assembly are assigned as per the below material properties.

Steel IS: 2062-1999 Mechanical Properties:

Young's modulus = 200Gpa
Yield Strength = 250 Mpa
Tensile Strength = 410 Mpa
Density = 7850 kg/m3
SHELL63 Element Description
No of Nodes: 4
No. of dof: 6 (Ux, Uy, Uz, Rotx, Roty, Rotz)

SHELL63 has both bending and membrane capabilities. Both in-plane and normal loads are permitted. The element has six degrees of freedom at each node: translations & rotations in the nodal x, y, and z directions.

STATIC ANALYSIS OF MODIFIED VIBRATORY SCREEN ASSEMBLY

Static analysis can, however, include steady inertia loads and time varying loads that can be approximated as static equivalent loads. Static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. The kinds of loading that can be applied in the static analysis include:

Objective

To Objective of this analysis is to check the High stressed locations and deflections on the Modified Vibratory screen assembly for the applied loads and inertia load.
Boundary conditions applied on the Modified vibratory screen assembly
Coal Max. Weight on screen is = 679kg
Force = 679*9.81 = 6664N (on top plate)
Force = 679*9.81/2 = 333N (on bottom plate)
Gravity = 9.81m/s.

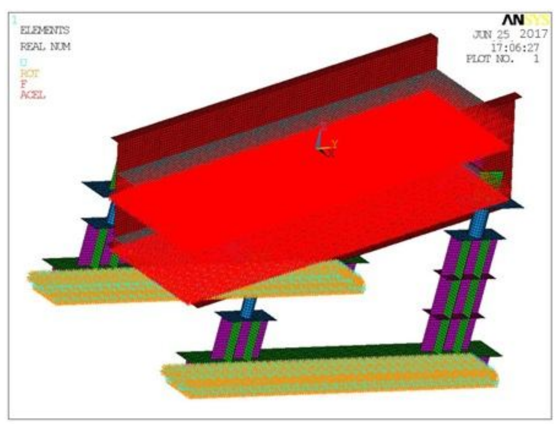

Figure 9. Shows Boundary conditions applied on the Modified Vibratory screen assembly

VII. RESULTS AND DISCUSSIONS

Static analysis was carried out on the original model for operating loads, the maximum stresses observed is 62Mpa which is less than a yield strength of the vibrating screen assembly material is 250Mpa. Hence according to the VonMises Stress Theory, the VonMises stress is less than the yield strength of the material. Hence the design of vibrating screen assembly is safe for the above operating loading conditions.

Modal analysis was carried out on the original model for natural frequencies and mode shapes, from the result, we it is observed that 1,2 and 4 natural frequencies are critical frequencies because they have high effective mass.

The harmonic analysis was carried out on the original vibrating screen assembly model for operating loading conditions. From the above results, it is observed that the at the critical frequencies 8.5 Hz, 10.5 Hz, and 13.5 Hz the stresses are 383 MPa, 554 MPa and 5040 MPa respectively. Hence according to the Von Mises Stress Theory, the Von Mises stress is more than the yield strength of the material. Hence the design of vibrating screen assembly was not safe for the above operating loading conditions. To overcome the high stress and deflections, modification of design was required. The modifications are made on the vibrating screen assembly by adding gussets on a side plate, and additional rib for screen supports.

Static analysis was carried out on the modified model for operating loads, the maximum stresses observed is 47Mpa which is less than a yield strength of the modified vibrating screen assembly material is 250Mpa. Hence according to the Von Mises Stress Theory, the Von Mises stress is less than the yield strength of the material. Hence the design of modified vibrating screen assembly is safe for the above operating loading conditions.

Modal analysis was carried out on the modified vibrating screen assembly model for natural frequencies and mode shapes, From the above modal analysis result, we can conclude that 1,2 and 4 natural frequencies are critical frequencies because they have high effective mass.

The harmonic analysis was carried out on the modified vibrating screen assembly model for operating loading conditions. From the above results, it observed that the critical frequencies 8 Hz, 13 Hz, 14 Hz and 15 Hz are having stresses of 60MPa, 100MPa 150MPa and 240MPa respectively. From the yield stress theory the max. Von mises stress less than the yield stress of existing material. Hence the modified vibrating screen assembly is safe under the operating loads

VIII. CONCLUSIONS

Modal test method with impact hammer is performed to understand the dynamic behavior of the large vibratory screens. But it is not a good method for larger equipment because using this method cannot obtain complete modes. In this project, dynamic analysis of the vibratory screen was performed by using finite element method. In this project, the 3D model of the existing vibratory screen (reference design taken from a conveyor fabrication company) was developed, and dynamic behaviour of the screen was studied by performing the finite element analysis. After determining the natural frequencies and their mass participations in the operating frequency range, the harmonic analysis was carried out to calculate the deflections and stresses at the particular frequencies and found that the design was not safe for the mentioned operating conditions. Later design modifications were incorporated, and dynamic behaviour of the modified model was studied and found the modified vibrating screen model was safe for the mentioned operating conditions. NX-CAD software was used for 3D modelling, and ANSYS software was used to do finite element analysis.

REFERENCES

[1] Screens, Johnson (2001). "Vibratory Screen Manuals", Johnson Screens (I) Ltd., Khatraj- Ahmedabad.

[2] Wills, Barry A. (1973). Mineral Processing Technology, Great Britain Scot Print Ltd., Musselburgh, 1973, pp. 177-179.

[3] Seiler, J.P., Valoski, M.P., and Crivaro, M.A., 1994, Noise Exposure in U.S. Coal Mines, U.S. Department of Labor, Mine Safety, and Health Administration, Informational Report No. IR 1214, 46 pp.

[4] Vipperman, J.S., Bauer, E.R., and Babich, D.R., 2007, "Survey of noise in coal preparation plants," Journal of the Acoustical Society of America, Vol. 121 pp. 197–205.

[5] Yantek, D.S., Jurovcik, P., and Bauer, E.R., 2005, "Noise and vibration reduction of a vibrating screen," Transactions of the Society for Mining, Metallurgy and Exploration, Vol. 318, pp. 201-213

[6] C. Zhang, One type of large vibrating screen with hyperstatic net-beam structure, China Patent No. 02112809.X(2003).