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A study on the applications of vibratory motor for material handling vehicles

This work aims at improving the efficiency and safety of the tipper trucks while in action. This project focused on performing a detailed analysis of the performance, safety, and cost aspects of the present techniques of achieving that. The pros and cons of incorporating a vibrator for the tipper truck are studied. This involved extensive FEA analysis in the preliminary stage. The structural, vibrational, and fatigue analysis is done for the critical components which helped in deciding the feasibility of incorporating such a mechanism. The critical components for the analysis are the base of the truck body, trunnion, brackets for mounting the telescopic cylinder, and the vibratory motor. The CAD models are prepared according to the industry standards and analyses are performed. Random data for forced vibration is generated, which is used to perform analyses on the components in FEA. Experimentation on a scaled-down model is also conducted to get the real-time data for the system. A vibration sensor would be incorporated using Arduino, and the acceleration data of vibration are recorded and compared by the theoretical values. A comparative study for the stability analysis is done, with and without the vibrator. A detailed report for the change in stroke length, pump pressure/flow requirement, etc. is formed and compared. The improvement in efficiency of dumping, time-saving and various other parameters is also considered. The cost aspect of rolling this system in the market is also studied.

Keywords: *Tipper truck, FEA analysis, CAD models, vibration sensor, Arduino, stroke length, pump pressure.*

1.0 Introduction

The tipper trucks are very important in the field of carrying a heavy material such as gravel, sand, coal, etc. Tipper trucks are improved version of conventional trucks. Conventional tippers are also used to carry heavy materials from one area to another are, but manpower is required to unload material in conventional trucks, this is the main disadvantage in these trucks. This requires more time to unload the material and extra cost is to be paid for the manpower[1].

To eliminate these problems hydraulic operated tipping system was invented. A dump truck is equipped with an open or closed bed body and is hinged at the rear end. It is equipped with a hydraulic cylinder to lift the front end, allowing the material in the bed to be dumped on the ground at the desired place of delivery. This truck is assembled to unload the material from rear end. This arrangement being assembled backside of the vehicle cabin, the PTO (power take off) unit which is coupled to the hydraulic pump it provides sufficient pressure to the hydraulic cylinder which is assembled exactly at front side mid portion of top of the trolley and the chassis frame. Trolley gets lifted upward with the assistance of hydraulic cylinder at the forward-facing which is allowed to the material in side of truck with empty at rare end. This type of truck is famous these days because of the unloading mechanism [3].

A standard tipper truck is a body mounted on to a truck case. The bed is raised utilizing a hydraulic cylinder which is mounted under the body in the front-end switch course of action between the undercarriage outline rails, and it is pivoted at the rear of the truck.

The tipper trucks are used to carry the material and dump them wherever necessary. Commonly used tipper trucks use an extending telescopic cylinder which tilts the truck body, and thus forcing the material down under the influence of gravity. There have been a lot of instances of the truck toppling over, because of instability caused during tipping, because of the raised centre of gravity. High wind velocity or inclination also adversely affects the tipping stability. Any material which is sticky by nature does not fall easily, increases the centre of gravity beyond the safe limit and the whole system becomes risky [2].

Today, all dump trucks are operated by hydraulics. They come in different configurations, each of which is designed to accomplish some specific task. But these trucks have some limitations. Before unloading the material truck must be parked as per the layout. It requires more fuel and time finally reduces

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the efficiency. Also, accidents may happen as there are chances of slipovers or turning, if the truck is not parked properly in uneven sites.

2.0 Objective

1. To study the damped forced vibrations this will be helpful in selecting the right vibratory motor for the application.
2. To comprehend the impact of vibration on the different segments of the trucks identified with the tipping framework, through static and vibrational examination.
3. To perform the experiment on a scaled-down model of the vibrator.
4. To study the merits and demerits of using a vibratory motor based on the cost and efficiency aspects.

3.0 Literature review

A study conducted by M. Paz, et. al. (1974) [1] regarding the application of vibration for material handling in the industry is being presented. The design criteria for selecting the vibrator type, number of vibrators, location of the vibrators and the structural design parameters were also discussed. The different types of vibrating equipment like vibrating screens, feeders, conveyors are discussed.

A patent awarded to John C. O'Connor (1950) [2] proposes a concept of vibratory dump trucks which would facilitate the loading and unloading of freight. The principal objective of the invention is to provide a self-dumping truck and promoting uniform distribution of the material over the area of the truck bed.

A study by Vanliem Nguyen et. al. (2018) [3] concentrated on modelling and vibration analysis of a vibratory roller for rough terrain application which was outfitted with various Cab Isolation Mounts, in which a unique model of vibratory roller was proposed. The separation mounts considered by them were elastic, hydraulic powered and pneumatic.

An examination by Nitinkumar Anekar et. al. (2014) [4] concentrated on designing and testing of uneven mass mechanical vibration exciter. They looked at the exploratory outcomes against the hypothetical counts. They created uniaxial vibration which comes in low recurrence run.

Studying the effects of vibration on the truck, can be studied and modelled using the "Quarter-car model" described in Vehicle Dynamics by Thomas Gillespie. [5]

N. Siva Naga Raju et. al. (2012) [6] with reference to this paper observed the modelled and analyzed and confirm to Innova car chassis which is made of frame by varying of the cross section of this frame. To watch all the outcomes and think about the various sorts of cross-sectional body outline individuals in ANSYS. The rectangular segment confirmed by the ansys von mises stress is obtained to 68.838 N/mm^2 and to get the C-type of segments also be indicated of von mises stress values is 146.255N/mm^2. C-type cross segment von mises stresses are higher than the rectangular segment however is inside as far as possible. The C-type cross segment diminishes the weight, creation time and assembling cost. Akash Singh Patel et. al. (2014) [7] studied of this paper modelled, analyzed and optimized of the TATA 2518TC manufacturing of truck chassis frame elements which is using the CAD software. The existing chassis is very heavy for TATA 2518 TC, so is taken for design and analysis. A comparison is made between preexisting structural chassis member of steel and alloy steel with respect to deformation and stresses, to choose the appropriate one. The required changes are done in the design using reinforcement optimization technique and boxing optimization technique. The analysis is performed to observe the changes in the stress levels. The gaps in literature obtained are:

1. Several theoretical calculations are done for various types of vibrating mechanism, but the question remains, that how much of the vibration is practically transferred to the vibrating body.
2. The life of the vibratory in operation compared to the cost of it is also an aspect which is not dealt with in detail.

4.0 Design approach and details

Design methods being applied in almost all the cases was to do basic calculations and then make a tentative model of it. After this, verify the design using simulation software like Ansys.

Truck body

Capacity - 10 Cu.M.

Dimensions - 3877×2280×1180 mm

Channels section used - 120×55×9 mm (depth × width × thickness)

Design process for the truck body

Considering how Indian drivers overload their trucks, weight of the material in the body was taken to be 5,00,000 N (50 tonnes) The number of channels to be used was decided based on the existing designs.

Fig.1 shows truck body base channel design

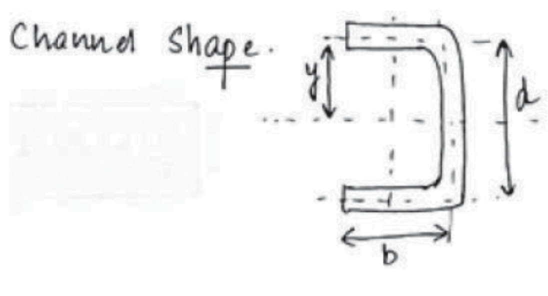

Fig.1: Truck body base channel design

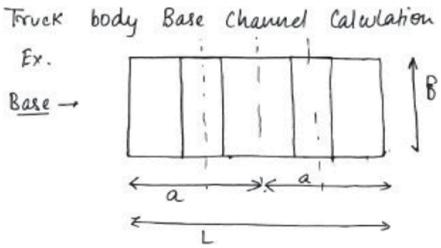

Fig.2: C channel section

Fig.2 shows moment of inertia for a C-channel is given by

Bending moment equation: distribution of the load is assumed to be uniformly distributed

where *w*, for the figure above would be

where, *W* = weight of the truck body with material

a = Total length of the truck body, B = width of the truck body

Designing the Unbalanced Mass

The unbalance system is the greatest extensively recognized foundation of vibration in machine with the turning part elements. The particularly significant and considering these factors in present day machine design plan especially where fast and dependability are critical parameters. Adjusting of propellers to exact position controls extreme loading of bearing and finally avoids failure, in this manner expand the life of machinery.

Project demonstration

Vibratory motor

Vibrator model

Weight of unbalanced masses - 750 grams

Eccentricity - 5cm

Shaft diameter - 20mm

Model vibrator

Fig.3 shows the model vibrator which will be used for the experimentation purpose and to collect the data of vibration produced by the unbalanced mass is shown in the figure.

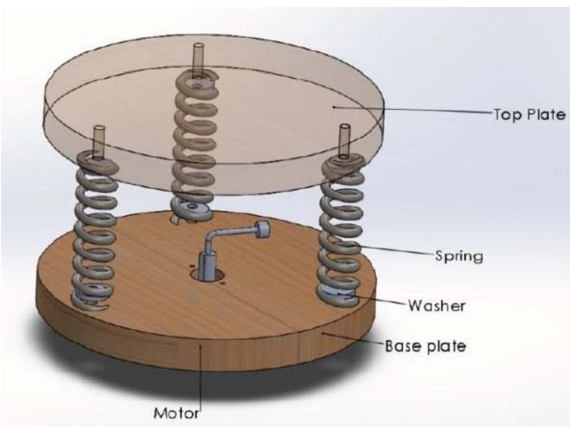

Fig.3: CAD model – vibratorused for experimentation

The model vibratorhas two wooden blocks with springs connecting them. The spring is attached to the wooden blocks via metal washers that are connected using nuts and bolts. The vibratory mass is connected to the motor using a shaft coupling made of aluminium.

The two wooden blocks at the top and the bottom serve as the connection point for the springs. The springs are used to transmit the vibration from the unbalanced mass, connected to the motor. This unbalanced mass will be producing the vibration.

Spring Stiffness calculation

As the springs are not all of equal stiffness. The individual stiffness is calculated by the formula:

N - Number of active turns

G- Shear modulus of elasticity, G = 84 GPa

D - Mean diameter of the spring elements in mm

d - Diameter of the wire in mm

$K = K1 + K2 + K3$ $K = 6589.63$ N-m

Calculation to perform the stress analysis and to understand the direction of force on the shaft carrying the unbalanced mass.

Unbalanced mass, m = 5 grams radius of revolution, r = 10 mm angular velocity, w = 200 rad/sec force, F = m x r x w2 = 2 N eccentricity, e = 10 mm

Moment = F x e = 20 N-mm

Fig.4 shows in the actual migrator for the unbalance mass shaft. A screw was heated using anoxy acetylene flame and then bent to 90°

Figs.4 and 5 show the mesh has 2013 nodes and 993 elements.

Rotational velocity – 500 rpm or 52.36 rad/sec

The maximum rotational velocity of the motor is 500 RPM, hence the selection of the speed for the FEA analysis.

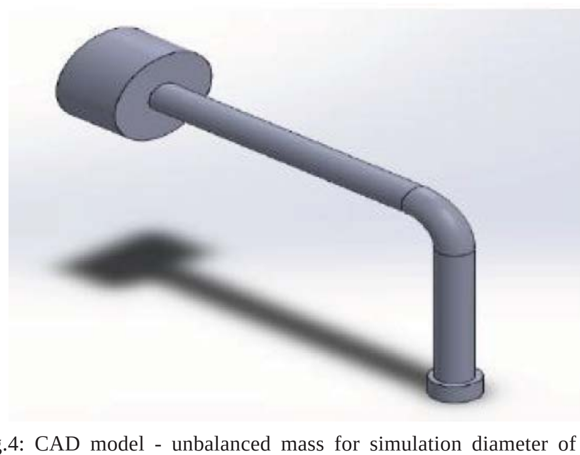

Fig.4: CAD model - unbalanced mass for simulation diameter of the shaft - 1.5 mm material - structural steel

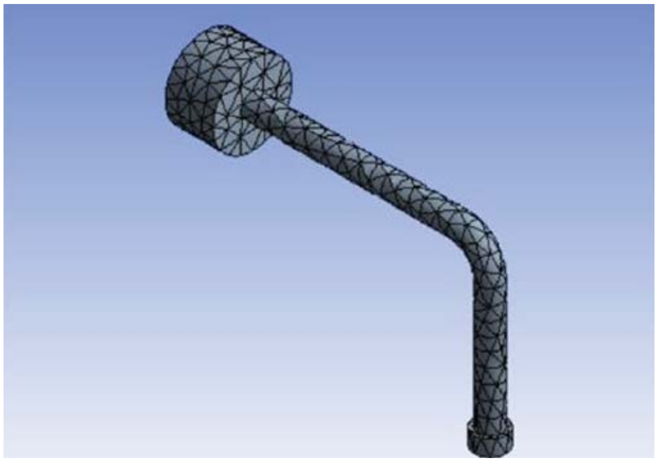

Fig.4a. FEA analysis – Mesh

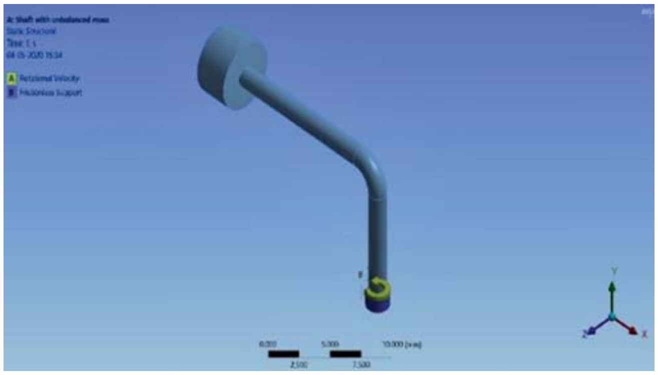

Fig.5: FEA analysis - constraints for analysis of the unbalanced shaft

The frictionless supports acts as bearings in the shaft which would provide the support and absorb the forces due to unbalances mass.

Fig.6 shows the centrifugal force due to the unbalanced mass would exert resultant force on the shaft bearings the direction of the force exerted on the shaft bearing is shown in the analysis above.

The direction of the moment reaction is right angled to the force reaction. This residual force causes the vibrations and reduction in the life of the bearing.

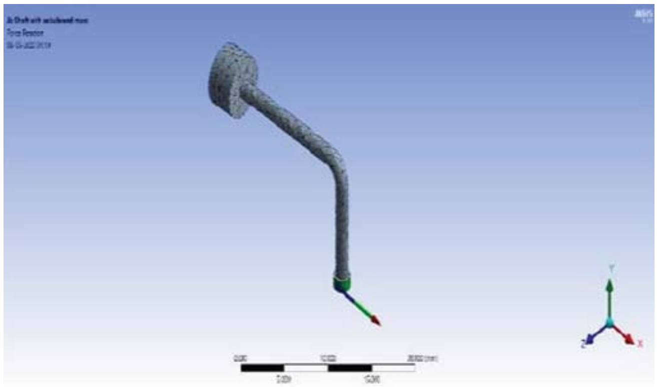

Fig.6: FEA analysis - unbalanced shaft - force reaction

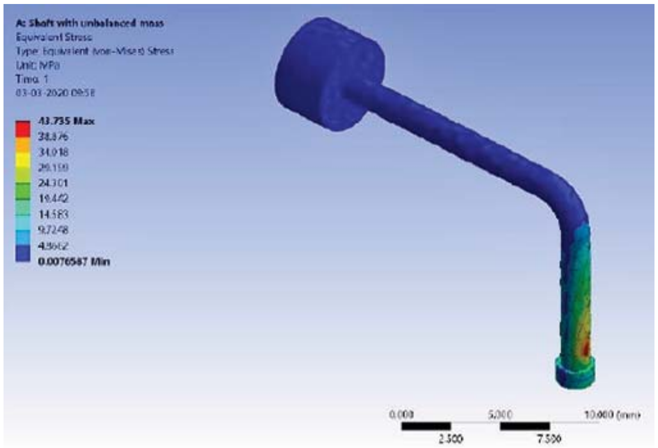

Fig.7: FEA analysis - stresses induced due to unbalanced mass

Fig.7 shows the simulation of the location of the maximum induced stress. In this case the shaft will not fail in particular, but the roller/ball bearings might.

Force exerted on the bearing is the centrifugal force acting radially outward. This force will also create a moment due to the eccentricity. The combined action of this force and couple, along with their constantly changing direction would generate vibrations which would be transmitted to the truck body through the springs.

Actual vibrator unbalanced mass

The CAD model shown in Fig.8, is of a shaft with unbalanced mass at both the ends. Balancing is of two types – static and dynamic balancing. By placing the mass opposite to each other with respect to the plane of the shaft axis. Static balancing is achieved, and the dynamic balancing creates the vibration by the couple reaction.

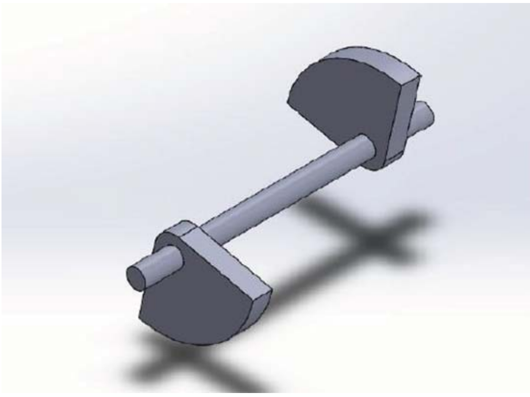

Fig.8: CAD model - shaft with unbalanced mass at bothends

In an actual vibrator there would be mechanism to rotate the shaft (electrical, hydraulic, or pneumatic) which would rotate the unbalanced mass. There will also be bearings and mounting positions to mount the vibratory motor on the truck. Here for concept demonstration only the unbalanced mass shaft is shown.

There are other ways of generating vibrations like using a piezoelectric material. But the most rugged and suitable for the truck vibratory application is the unbalanced mass system. The mode of activation may be different depending on the power required and mode of activation available. There are adjustable mass type vibratory motors which can generate different amount of forces depending on the application.

Fig.9 FEA analysis - Constraints for structural analysis - force and moment ideally shows only a portion of the shaft attached to the bearings which take the load, to make the analysis simpler and the whole shaft is considered as friction less support so that the force and moment exerted can be determined.

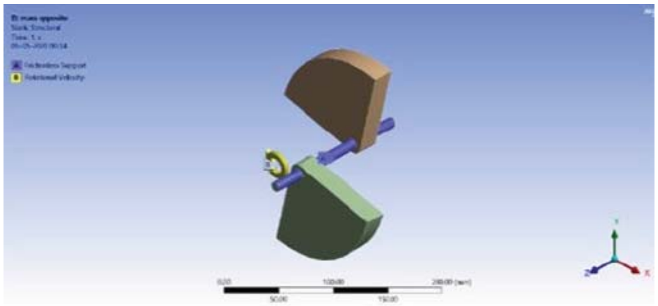

Fig.9: FEA analysis - constraints for structural analysis - force and moment

Fig.10 FEA analysis - force reaction - direction-X axis the direction of force exerted on the shaft due to the rotary unbalanced mass is shown in the figure and the direction of the couple moment is 90° to the direction of force.

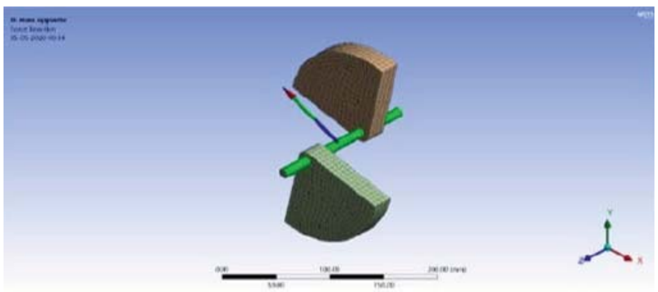

Fig 10: FEA analysis - force reaction - direction-X axis

Understanding the magnitude and direction of force and couple helps in better selection and calculation of bearings. after bearings of the existing vibrators can be enhanced by having a proper idea about the force and moment.

Truck Body

Fig.11 shows the CAD model of the truck. The purpose of making this model was to understand the truck body which will be subjected to the vibrational loading.

For the truck body, first the channel section was selected. A ‘C’ channel was collected over a rectangular box section based on the bending stiffness and the torsional stiffness,

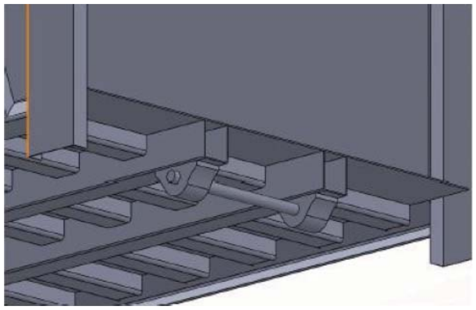

Fig.11: CAD model - gate side hinge

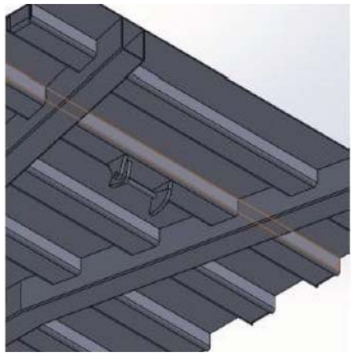

Fig.12: CAD model - position of the vibratory motor, with bearings mounted

which are especially important selection criteria for a truck on Indian roads. The sheet metal selected was of 1-millimetre thickness based on the common automotive standards. The number of horizontal members was selected based on the calculation shown in the technical specification section of this report. The base was created first as a separate solid works part. After that, the channel section for the side members were selected based on similar calculation and the modelling was done. The front section where the cylinder is mounted is designed according to the shape and size of the cylinder, bracket and the trunnion. Finally, all the separate parts were assembled.

There is a cylinder end which is lifted using the hydraulic power and the hinge end which is at the end of the truck body. In practical cases material left over material is mostly at the cylinder end. The cohesive and adhesive at the hinge end is broken down because of the flow of material from the top. Vibrator is needed for efficient removal. Figs.12 and 13 show the location of the vibrator. The way it is attached is also shown.

The design of the gate side hinge is based on the load bearing capacity of the shaft and it is designed to resist shearing.

The mesh has 165593 nodes and 66902 elements.

The modal analysis is one of the very good dynamic possessions of assemblies underneath vibrational excitation. A style of shape is a particular example of vibration

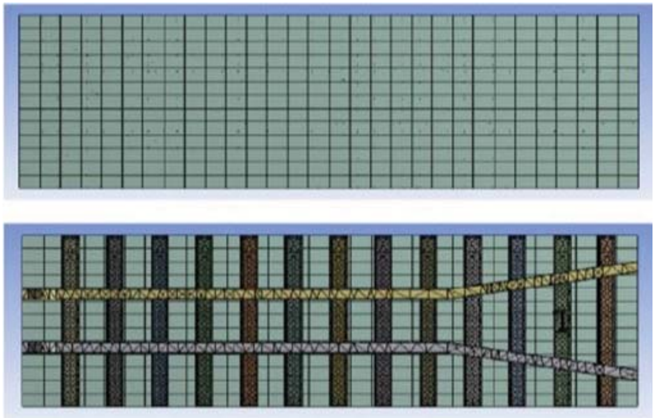

Fig.13: FEA analysis– constraints for base plate of truck body - modal analysis

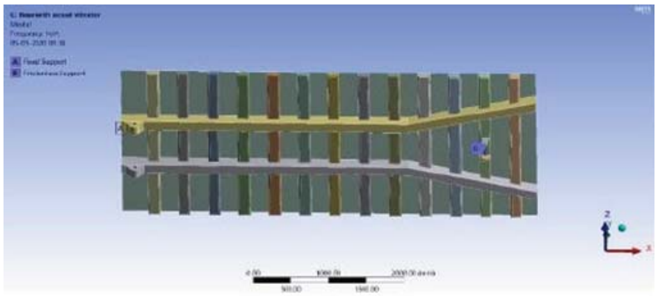

Fig.14: FEA analysis - constraints for base plate of truck body – modal Analysis

implemented by a mechanical arrangement at a particular frequency. Mode shape is twisted example (method) of object at this frequency. In the event that we change the input frequency, at that point item will distort at various pattern (mode). Mode shape partner with frequency. The exploratory or numerical policy of modal examination discoveries these mode forms (shapes) and the frequencies.

Modes 1 and 2 did not show notable deformation.

Closer the frequency ratio (w/w_n) to 1, higher will be the amplitude. If the frequency ratio is equal to 1, then resonance will occur, which is detrimental to the machine. But it should be close to 1, so that the amplitude can be maximized in safe range.

Fig.15 shows the deformation caused by vibrations at these natural frequencies are shown next.

Fundamentally, the modes state of a system are obtained when you compute its reaction because of beginning conditions only. Combination of these modes may also exist depending on the real time conditions. This modal analysis enlightens you regarding the modes which ought to be maintained a strategic distance from while designing a component to keep away from bigger reactions for realized excitation forces. Rather than quasi-static and dynamic, modal analysis gives an outline of the restrictions of the response of a system.

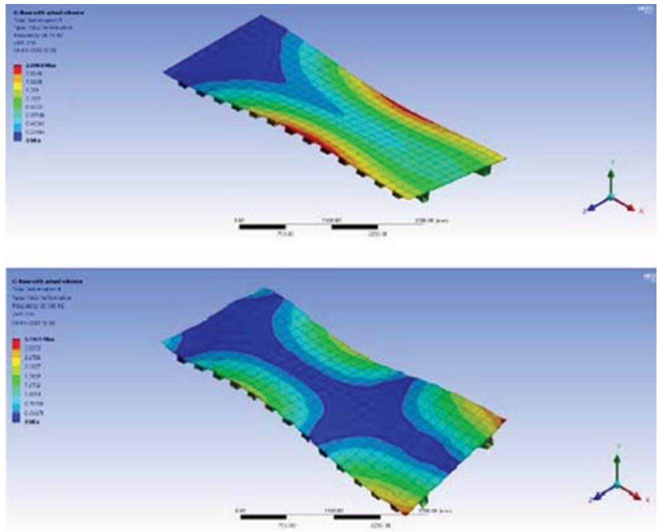

Fig.15: FEA analysis - base - mode shape 6

5.0 Result and analysis

Tipping Stability

Fig.16 shows the front view and side view of truck.

(a)

(b)

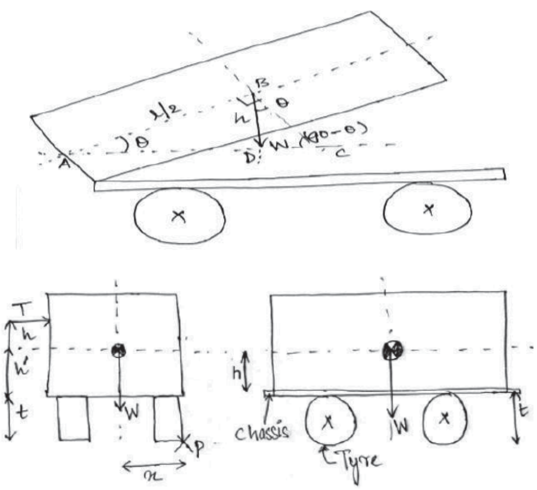

Fig.16: (a) Front view of truck (b) side view of truck

The high wind or an inclination can cause the tipper to tip sideways which can prove to be fatal.

For tipping, refer Fig.17(a) and when the tipper is in neutral position, the centre of gravity coincides with the tipping force's line of application.

But when tipping the distance from the ground can be increased by 'h' (Fig.17) when the body of the truck is about the, reaction force on one of the tyres would be zero. Balancing the moment as the value of h increases, the chances of tipping increases, which can be dangerous.

Pump Pressure Reduction

Figs.18 and 19 show the symbolic representation of three

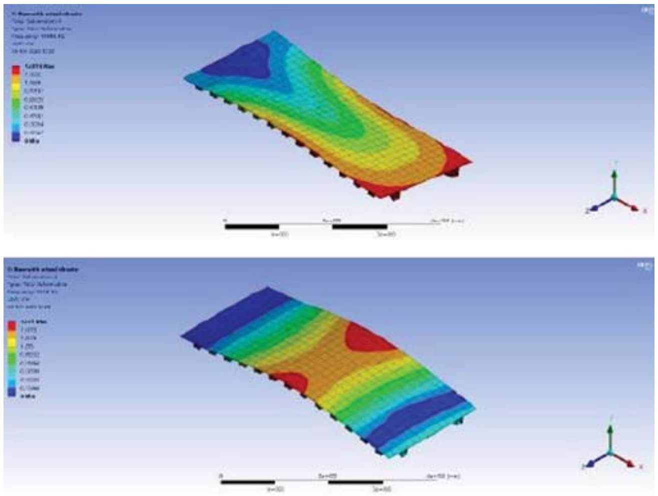

Fig.17: Truck in tipping position

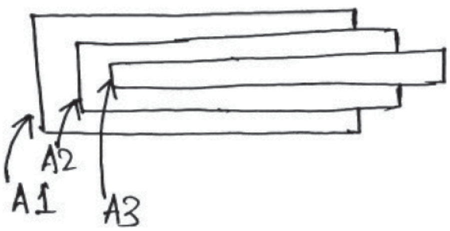

Fig.17: Symbolic representation of three stage telescopic hydraulic cylinder

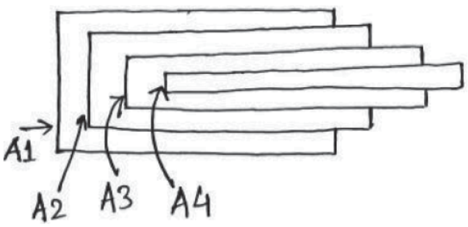

Fig.18: Symbolic representation of four stage telescopic hydrauliccylinder

stage telescopic hydraulic cylinder and symbolic representation of four stage telescopic hydraulic cylinder

Based on the data from the previous experimentation by the companies, the stroke required to unload the material from a tipper truck using a vibratory motor can be reduced drastically. This can reduce the maximum pump pressure required.

Let us suppose, the body is of 60 tonnes, and assuming that it is concentrated in the centroid. Then lifting force required would be 30 tonnes, based on balancing of moments.

In common telescopic hydraulic cylinder, the areas of the consecutive stages are reduced by a factor of 0.85, which means the pressure required to lift the same load increase by a factor of (1/0.85) every consecutive stage.

If the number of stages can be reduced, the maximum pressure of the pump can be reduced, resulting in cost saving overall. The material and processing related to the extra stage of the telescopic cylinder is also reduced.

Conclusions

A detailed study about the forced damped vibration is conducted which gives us a proper understanding about the functioning of vibratory motor and its application. Extensive numerical simulation has been performed to verify the existing structures used in the tipper. The simulation provides indication that the structures can withstand the induced vibration. Cost versus productivity of the vibratory motor in the truck tipping solutions need to be validated and experimented thoroughly before a conclusive result can be obtained. The data collected by the vibration sensors are relatively accurate and can give us an idea about the vibration generated when testing in an actual truck

The simulations done so far, indicates that the structures of the truck would be able to handle the vibrations will be subjected to. The hydraulic cylinders are already tested for the pulse test, which means they can absorb the vibration and can perform under this condition.

The analysis on the unbalanced mass would help us understand and select the proper mass setting. This also gives us an idea about static and dynamic balancing which would help us improve the productivity and enhance the life of the vibratory motor.

The modal analysis on the base of the truck body would help us take optimum use of the natural frequency and also help us save the machine from getting into resonance which would prove to be detrimental for the life of the components. The understanding and knowledge gained from this project will definitely help me understand the industry better and would allow me to post graduate engineer it in a way which would serve the world better.

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