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Design and Analysis of Rotor Assembly of Hammer Mill Machine

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ABSTRACT

The project deals with the Manufacturing with Design and Analysis of Hammer Mill Machine and Rotor Assembly of Machine of Capacity of 200 Kg/hr. Which is due to providing the transmission power of 5 HP to the machine.

In this project, the Hammer mill machine body structure, Angle Frame and foundation frame for machine is designed using Catia. Also each and every part or component is required for machine is designed. In the present work by using standard design procedures, Diameter of the rotor of shaft of machine has been designed. Theoretical calculations done by using PTC Mathcad software for new learning experience and ease. When the shaft of the rotor is rotated at the given speed (rpm i.e. 1728 rpm) and the load applied to the shaft it should not bend during rotation. When the shaft is rotated under free conditions deflections will be created due to critical speed of the shaft.

After Designing process, some of required drawings are converted into Ansys supported format i.e. drawings are imported into Ansys for further analysis. Meshing of the shaft model was done and the loads, stresses that were applied for the shaft to be checked out that the design should be safe one. The design should be safe when the values obtained from the design procedure were compared with the standard values and result obtained from the analysis using Ansys.

As per the designing, the required parts are fabricated such as side plates, bearing support, doors, hinge supports by using conventional methods like gas cutting, welding, drilling, shaft turning, slotting, milling, etc. and some hardware materials buy from stores which is used for further assembly process. At the final step all parts are assembled according as per requirements. At the end actual capacity of machine is calculated by using conventional method.

***Keywords*--** Hammer Mill Machine, Design, Crushing, Maize, Rotor, Electric Motor, Consumed Energy, Ansys2020R, Catia v5, PTC Mathcad

I. INTRODUCTION

A crusher is a machine designed to reduce large solid material objects into a smaller volume, or smaller pieces. Crushers may be used to reduce the size, or change the form, of waste materials so they can be more easily disposed of or recycled, or to reduce the size of a solid mix of raw materials (as in rock ore), so that pieces of different composition can be differentiated. Crushing is the process of transferring a force amplified by mechanical advantage through a material made of molecules that bond together more strongly, and resist deformation more, than those in the material being crushed do. Crushing devices hold material between two parallel or tangent solid surfaces, and apply sufficient force to bring the surfaces together to generate enough energy within the material being crushed so that its molecules separate from (fracturing), or change alignment in relation to (deformation), each other. The earliest crushers were hand-held stones, where the weight of the stone provided a boost to muscle power, used against a stone anvil. Querns and mortars are types of these crushing devices.

II. WORKING OF HAMMER MILL MACHINE

When feed is delivered to the hammer mill crusher, it is prepared for cyclone furnace firing by being crushed into 1/4 inch or smaller size feed. Feed enters from the top and is violently thrown against the breaker blocks by the hammers. The final crushing is done between the hammer faces and the screen bars. Then the crushed feed goes to the conveyors below and is carried to the storage bunker. Tramp iron or material that will not go out between the screen bars is dropped into the iron pocket and is later removed.

2.1 Hammer Mill Features

- Material is reduced by impact from free-swinging bar hammers.
- Finished Product size controlled by grates or crusher sizes.
- Materials can be reduced to granular powder at high rate.
- Heavy-duty cast-iron or carbon steel construction.
- Right-hand or left-hand machine available.
- Easy access for maintenance and crusher/grate change.

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2.2 Applications of Hammer Mill Machine

These machines have many sorts of applications in many industries, including:

- Ethanol plants (grains)
- A farm machine, which mills grain into coarse flour to be fed to livestock
- Fluff pulp defiberizing
- Fruit juice production
- Grinding used shipping pallets for mulch
- Milling grain
- Sawmills, size reduction of trim scrap and planer shavings into boiler fuel or mulch
- Shredding paper
- Shredding scrap automobiles (see automotive shredder residue)
- Shredding yard and garden waste for composting
- Crushing large rocks
- In waste management.

III. DESIGN OF SHAFT

Shaft is a rotating element, usually of circular cross-section. Shaft is used to transmit power, from one place to another. Power is delivered to the shaft by means of tangential force and resultant torque is setup within the shaft. To transfer the power from one shaft to another, the various components such as pulleys, gears, etc., are mounted on it, by means of keys and splines.

Generally, the power transmitting shaft are subjected to bending moment and twisting moment (torque). Hence, bending and torsional shear stresses are induced in the shafts. Bending moment caused due to mounting of pulleys, gears, sprockets and rotors, etc.

3.1 Essential Characteristics of Shaft Material

The essential characteristics of the shaft material are:

a) High strength
b) Good heat treatment properties
c) Good machinability
d) Low notch sensitivity factor
e) High wear resistant properties
f) Ductility
g) High resilience
h) High fatigue strength.

3.2 Material used for Shaft

Ordinarily carbon steels are used. For example 40C8, 45C8 and 50C4 etc. We used the 40C8 shaft in this project.

3.3 Types of Shaft

Shafts are classified into following types:

(a) Transmission shafts:

It is used to transmit power from one point to another.

Example: Line shaft, counter shaft and overhead shaft, etc.

(b) Spindle:

A spindle is a short rotating shaft, which forms the integral part of machine.
It is used in all machine tools.

(c) Axle:

An axel is a non-rotating element. It supports a rotating element like wheel, hoisting drum, etc.

(d) Machine shafts:

They are integral part of a machine itself.
For example: hammer mill machine rotor, crankshaft etc.

3.4 Design of Shaft

Shaft may be designed on the basis of (a) Strength, (b) Rigidity and (c) Stiffness

While designing the shafts on the basis of strength, the following cases may be considered:

(a) Shaft subjected to twisting moment only
(b) Shaft subjected to bending moment only
(c) Shaft subjected to combined twisting and bending moments.

3.5 Theoretical Calculations

In order to transfer the power to the main shaft of the hammer mill, the various members (such as pulleys, and bearings) are mounted on it. The design of shaft is based on combined shock and fatigue, bending and torsional moment (Fig. 3.1). The diameter of the main shaft was calculated as following:

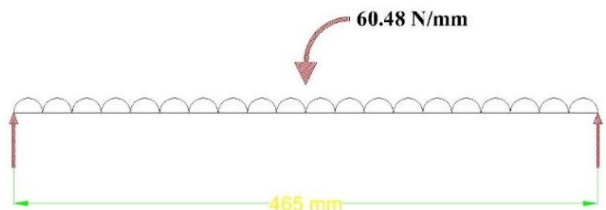

Figure 3.1: Simply supported beam with uniformly distributed load

$$\tau_{max} = \frac{16}{\pi d^3}\sqrt{(k_b \times M)^2 + (k_t \times T)^2} \quad \textbf{(1)}$$

$$d^3 = \frac{16}{\pi \tau_{max}}\sqrt{(k_b \times M)^2 + (k_t \times T)^2} \quad \textbf{(2)}$$

d: Diameter of shaft, mm
M: Bending moment, N-mm
T: Torsional moment, N-mm
Kb: Combined shock and fatigue factor applied to bending moment
Kt: Combined shock and fatigue factor applied to torsional moment
τmax (τs): Allowable shear stress for shaft material, N/mm2
Where,

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Type of Load	k_b	k_t
Gradually applied load	1.5	1.0
Suddenly applied load (Minor shock)	1.5 – 2.0	1.0 – 1.5
Suddenly applied load (Heavy shock)	2.0 – 3.0	1.5 – 3.0

The values of Kb and Kt were taken as 1.5 and 1.0 respectively for the gradually applied load on the rotating shaft and the allowable shear stress of the shaft (τ_s) as 105.6 N/mm^2 based on Machine Design Data Book by V B Bhandari.

M_b was calculated by using formula for simply supported beam with uniformly distributed load (Fig. 3.1). Which is given by,

$$M = \frac{W \times l^2}{8}$$

Where,

W : Uniformly distributed load, 60.48N/mm^2

(3)

L : Span length, 465 mm

Therefore,

$$M = 1.635 \times 10^6 Nmm$$

And T was calculated by the following equation:

$$P = \frac{2\pi NT}{60}$$

$$T = \frac{(P \times 60)}{2\pi N} \quad \textbf{(4)}$$

Where,

P = Transmitted power inW, 5hp = 3.728 × 10^3 W
T = Twisting moment in N-m,
N = Speed of the shaft in rpm, 1728 rpm

$$T = \frac{(3.73 \times 10^3 \times 60)}{2\pi \times 1728}$$

$T = 20.6128$ N-m
$T = 20.6128 \times 10^3$N-mm
Therefore,
Putting all values in equation (2) we get,

$$105.6 = \frac{16}{\pi d^3}\sqrt{(1.5 \times 1.635 \times 10^6)^2 + (1 \times 20.6128 \times 10^3)^2}$$

$$d = 47.684\ mm$$

Diameter of main shaft (d) should be equal to or more than d=47.684 mm

Therefore we have rounded up and chosen the diameter of shaft is equal to 50 mm

$$d \approx 50\ mm$$

Factor of Safety (FOS) is given by,

$$FOS = \frac{\sigma_{yt}}{\tau_{max}} = 3.056$$

$$\boldsymbol{FOS = 3.056} \quad \textbf{(5)}$$

Which is feasible for rotating shaft.

Deflection of shaft is given by,

$$\delta = \left(\frac{5 \times w \times L^4}{384 \times E \times I}\right) \quad \textbf{(6)}$$

Where,

W : Uniformly distributed load, 60.48 N/mm
E : Modulus of Elasticity, 2.07 x 10^5 N/mm^2
d : Diameter of main shaft, 50 mm
l : Length of shaft, 465 mm
I : Moment of inertia

$I = \frac{\pi \times d^4}{64} = 3.068 \times 10^5$mm^4

$$\delta = \left(\frac{5 \times 60.48 \times 465^4}{384 \times 2.07 \times 10^5 \times 3.068 \times 10^5}\right)$$

$$\delta = 0.58\ mm$$

Therefore, the maximum deflection in the shaft is 0.58mm.

The Exerted Centrifugal Force by the Hammer

Centrifugal force of the hammers can be calculated by following equation (*Hannah and Stephens, 2004*):

$$\boldsymbol{F_h = \frac{m_h \times {v_h}^2}{r_h} = N_h \times m_h \times r_h \times {\omega_h}^2}$$

Where,

F_h = Centrifugal force, N
N_h = Number of hammers = 12
m_h = Hammer mass, kg
r_h = Radius of hammer, 0.150m
ω_h = Angular velocity of hammer, $180.956 \frac{rad}{sec}$
N = velocity of the hammer, 1728 rpm

For the hammer,

Mass (m_h) = ρ × v_c

Where,

ρ = Density of the material, (For steel = 7800 kg m^{-3})

v_c = Volume of the hammer, (dimensions of 0.12 m x 0.05 m x 0.01 m)

Each hammer was drilled at the bottom (hole of 10 mm), to enable to be put it into position on the hammer shaft.

Mass of each hammer = 0.468 kg, number of hammers 12, so the centrifugal force exerted by the hammer = 27.58kN (upward).

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IV. SELECTION OF BEARING

Bearing is a mechanical element the permits relative motion between two parts, such as the shaft and the housing, with minimum friction.

Bearing are classified in different ways. Depending upon the direction of the force that acts on them, bearing are classified into two categories- radial and thrust bearing.

A radial bearing supports the load, which is perpendicular to the axis of the shaft.

A thrust bearing supports the load, which acts along the axis of the shaft.

The most important criterion to classify the bearing is the type of friction between the shaft and the bearing surface.

Depending upon the type of friction, bearings are classified into two main groups – sliding contact bearings and rolling contact bearings.

Sliding contact bearings are also called as plain bearings, journal bearings or sleeve bearings.

Sliding contact bearings are used in the following applications:

i. Crankshaft bearing in petrol and diesel engines;
ii. Centrifugal pumps;
iii. Large size electric motors;
iv. Steam and gas turbines; and
v. Concrete mixers, rope conveyors, etc.

Rolling contact bearings are used in the following applications:

i. Machine tool spindles;
ii. Automobile front and rear axles;
iii. Gear boxes;
iv. Small size electric motors; and hammer mill machine rotor, etc.

In this project we used the Rolling Contact Bearing, named as UCP209 Bearing which is in the size type of mm, having inner diameter is 45 mm.

This type of bearing is also known as Pillow block bearing or Pedestal bearing.

Another size type is available as inch type bearing.

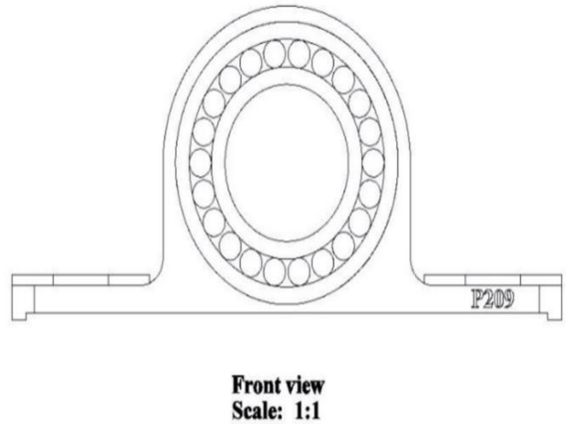
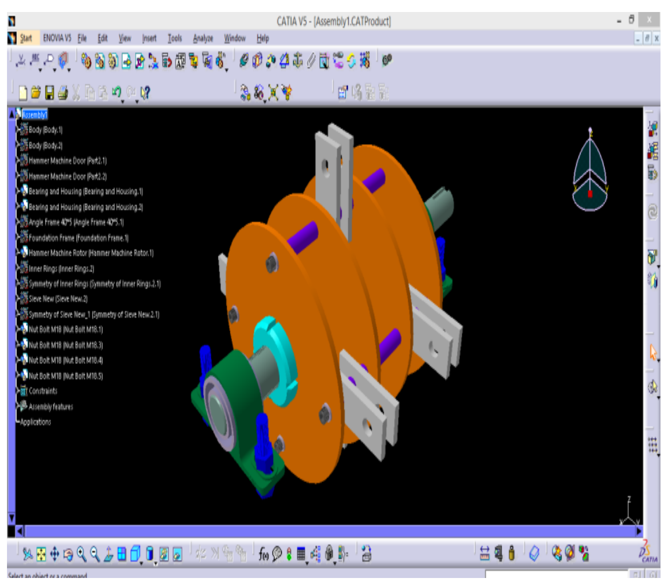


Figure 4.1: Pillow Block Bearing

4.1 Bearing Life Calculation

Type of bearing used: Pillow Block Bearing
Diameter of Shaft: 45mm
Speed of Shaft, N= 1728 rpm
Nominal or Rated speed in hours,
L_h = 10000 hrs. 10 hrs. Per a day heavy shock load.
Then the life of bearing in millions of revolutions
$L = 60\ N\ L_h / 10^6$
$L = (60 \times 1728 \times 10000)/10^6$
L = 1036.8 millions of revolutions.
Where L is life that 90% of a group of apparently identical group of bearings will complete.



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V. MODAL ANALYSIS

5.1 Analysis of Shaft and Rotor of Machine

5.1.1 Modal Analysis of Shaft

(a) Meshing of Shaft

Meshing Method	Automatic Meshing Method
Size of Element	5 mm
No of Nodes	12164
No of Elements	6650

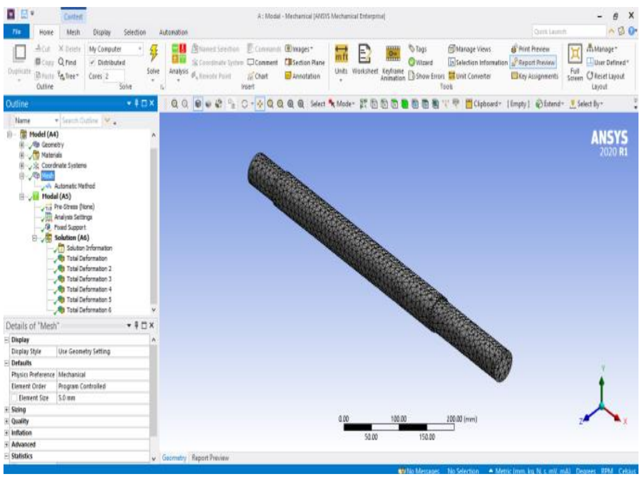


Figure 5.1: Meshing of Shaft Model

Max Modes to find	6
Support	Fixed support at both ends of shaft

(b) Mode Shapes of Shaft

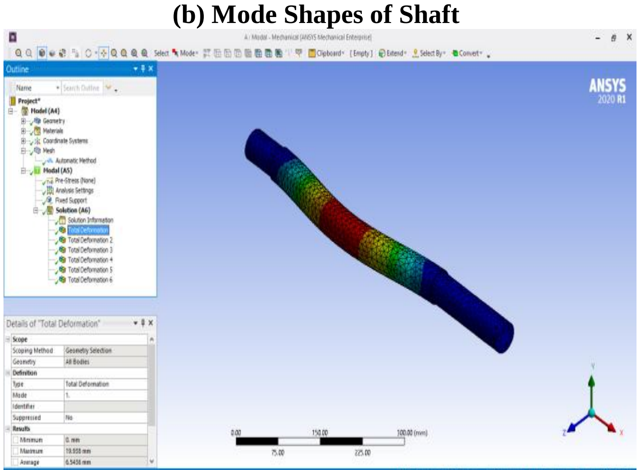


Figure 5.2: Total Deformation

5.1.2 Modal Analysis of Rotor

(a) Meshing of Rotor model

Meshing Method	Automatic Meshing Method
Size of Element	Default size
No of Nodes	15320
No of Elements	6890

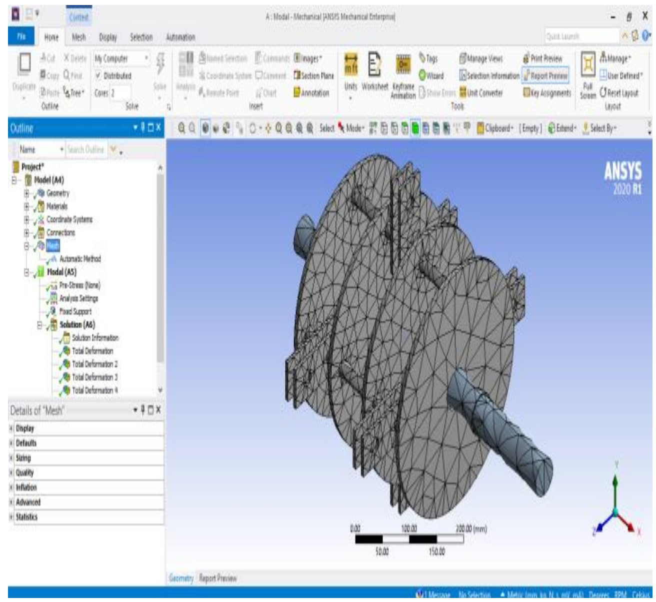
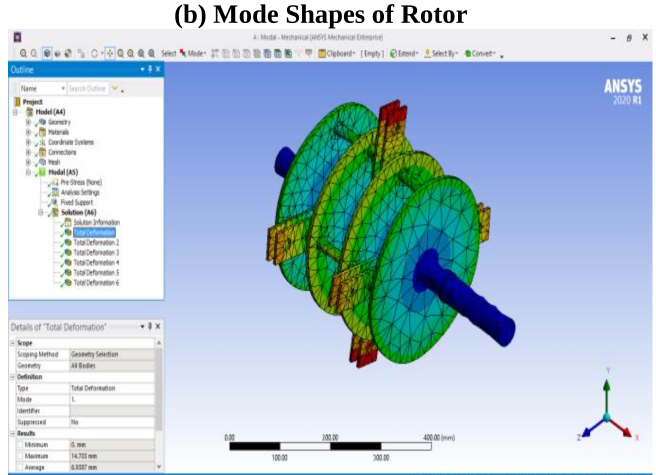


Fig. 5.3 Meshing of Rotor Model

Max Modes to find	6
Support	Fixed support at both ends of shaft of rotor

(b) Mode Shapes of Rotor



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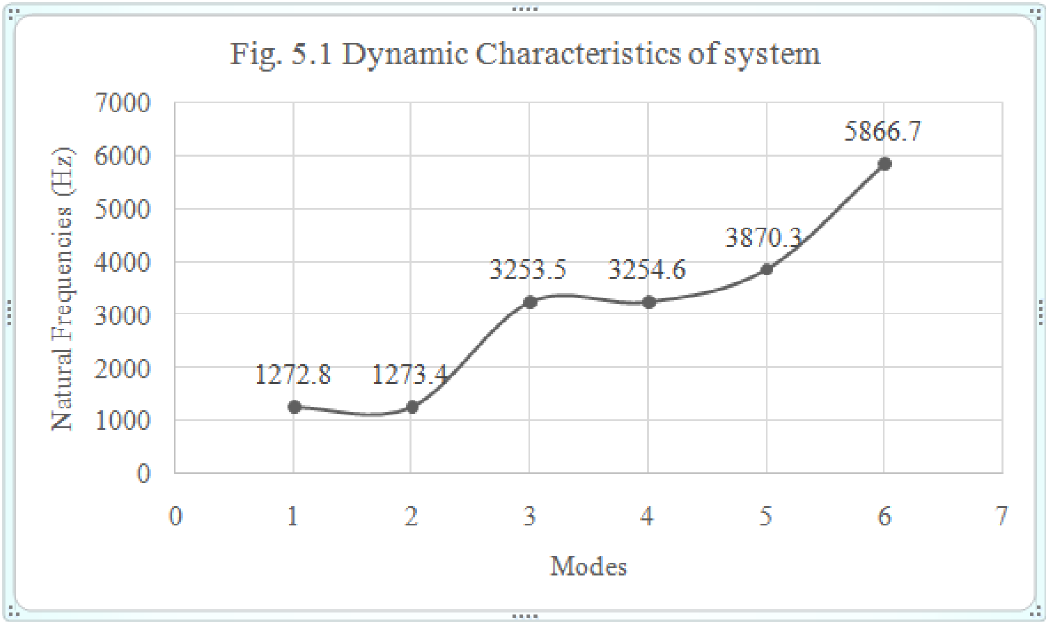
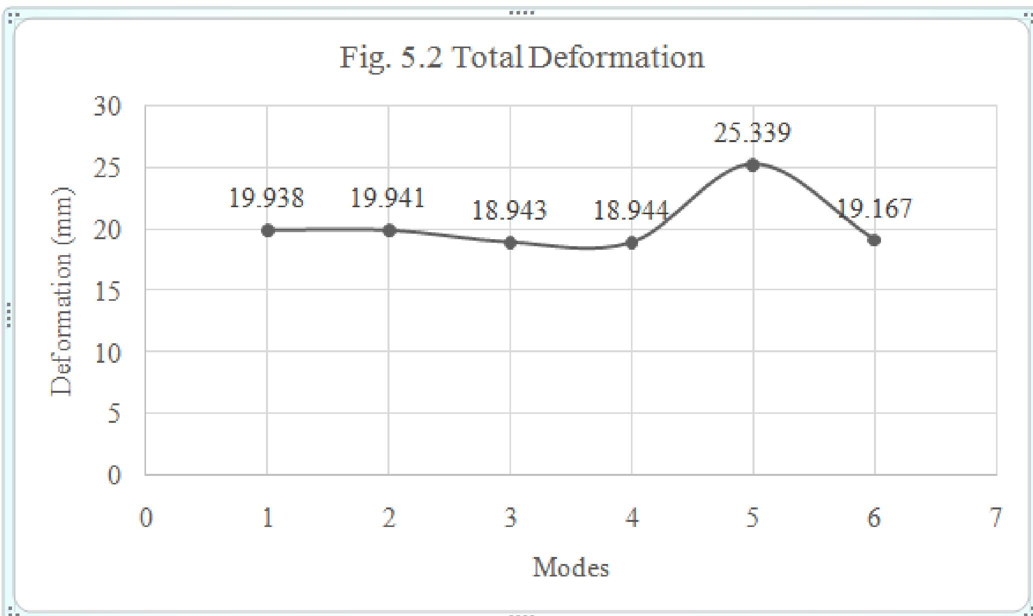
V. RESULT AND DISCUSSIONS

- Modal analysis calculates natural frequencies and mode shapes of the structure.
- Graphs below shows the mode shapes number, total deformation, and natural frequencies respective to each of them.
- The curved line graph represents the modal frequencies with respect to deformation, which is known as the frequency response curve graph.
- Participation factor shows the most prominent modes in certain direction that will be excited by forces in that direction.
- Effective mass can be useful for confirming that enough modes have been extracted for further analysis.

5.1 Results for Shaft Analysis





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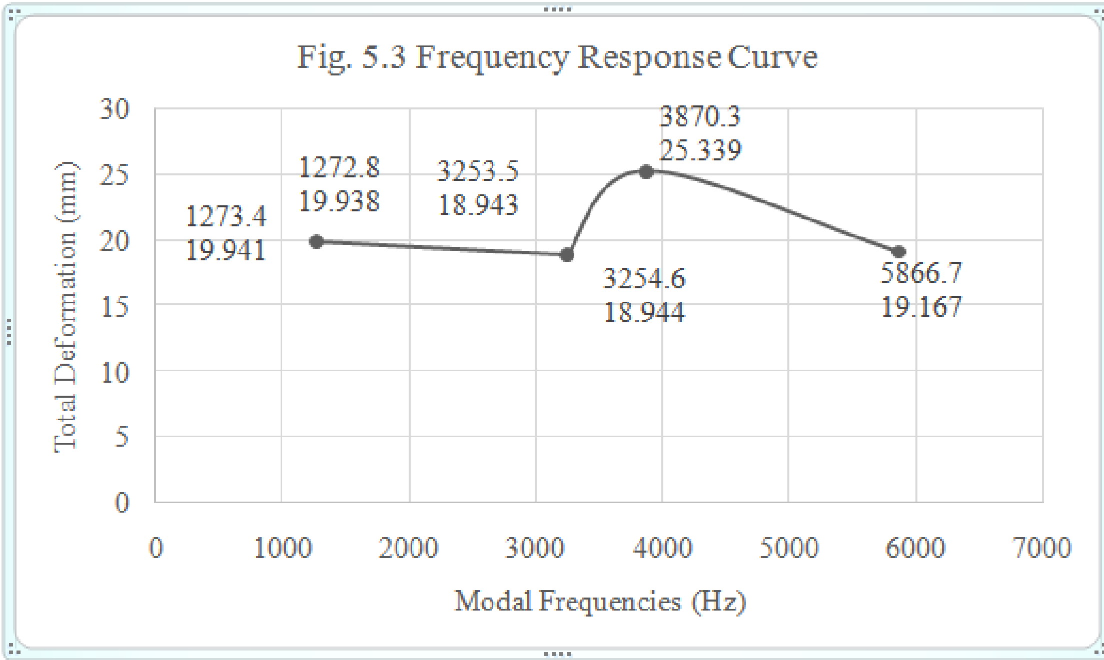
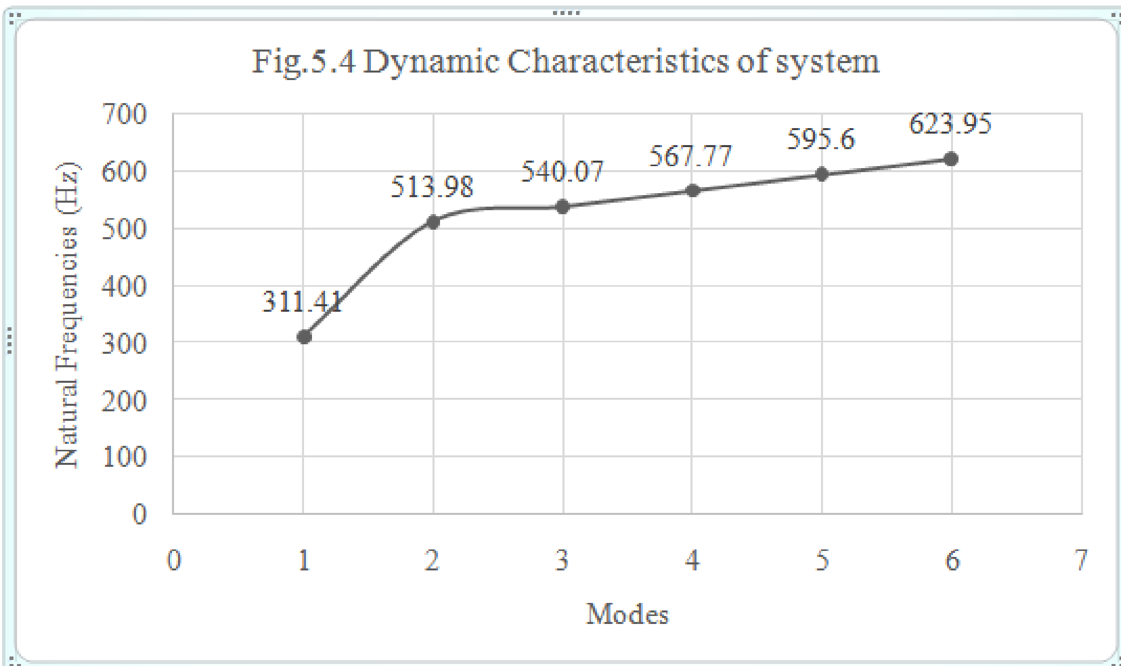


5.2 Results for Rotor Analysis



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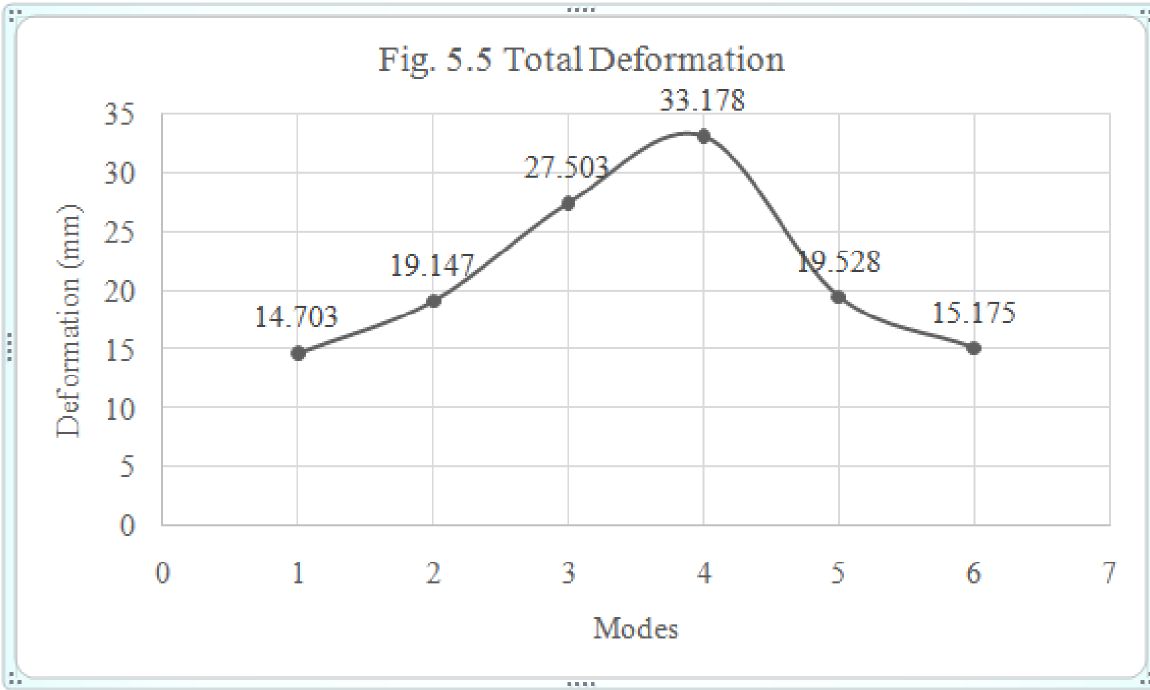

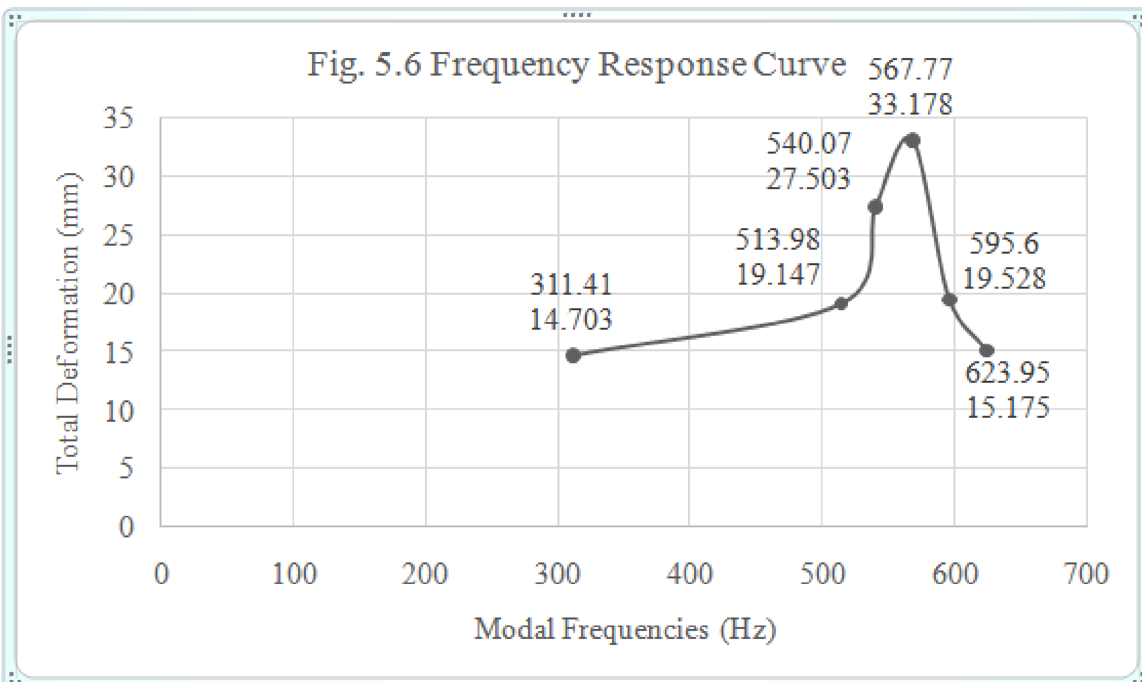

5.3 Machine Productivity

The crushing productivity increased with increasing feeding rate, screen holes diameter and hammer speed.

The machine productivity ranged from 150 to 250kg/h, with hammer rotor speed of 1728 rpm, screen holes diameter of 2 to 4 mm. It could be noticed that the lowest values of machine productivity were obtained at (RS) 1728 rpm, (Sd) 2 mmand (FR) 100 to 150kg/h, however the highest values of machine productivitywere obtained at (RS) 1440 rpm, (Sd) 4 to 6 mm and (FR) 200 to 250kg/h.

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5.4 Consumed Energy

The consumed energy decreased with increasing feeding rate, screen holes diameter and hammer speed.

5.5 Cost

The crushing cost increased with increasing of both feeding rate, screen holes diameter and hammer speed.

5.6 Manufactured Hammer Mill Machine

Figure 5.7: Hammer Mill Machine

5.7 Capacity of Machine (Simple Calculation by using Stopwatch)

To calculate the capacity of machine,

Practically, 10 Kg of feed is grinded in 3 Minutes then 200Kg feed material is grinded in 60 minutes.

Therefore capacity of Hammer Mill Machine is approx. **200Kg per Hour**.

The Capacity of output of production is depends on **types of feed material** and **the hole size in sieve**. In this project corn or Maize is used as a feed material, hole size of sieve is 2 to 4mm.

5.8 Balancing of Rotor

Balancing of rotor is necessary because a part is rotates at high speed needs to be properly balanced. If it is not balanced, the assembly of rotor will vibrate.

For Dynamic Balancing of a rotor, two balancing or counter masses are required to be used in any two convenient planes. This implies that the complete unbalance of any rotor system can be represented by two unbalances in those two planes.

Balancing is achieved by addition or removal of masses in these two planes, whichever is convenient. The Common type of dynamic balancing machine used is Pivoted-cradle Balancing Machine.

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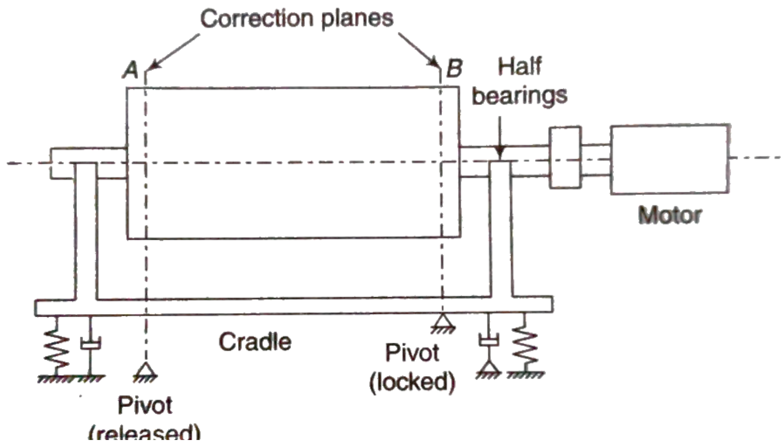

VI. CONCLUSIONS

As per Drawings and information provided, 3D models are developed in Catia V5 and the shaft of hammer mill machine is analyzed in Ansys package.

1. Based on calculations and analysis reports the safe diameter is selected as50mm, which is safe.
2. Factor of safety for selected diameter is 3.05.This factor of safety chosen for Hammer mill machine address sudden impact and shock loads created by the material.
3. Deflection of shaft as per theoretical calculations is 0.58mm.
4. Selected bearing for this application based on shaft diameter 50mm is heavy-duty Pillow Block or Pedestal bearings on adapter sleeve.
5. 3D models developed in Catia V5 and analyzed for designing construction.
6. We suggested to consider this analysis report to reduce the bearing diameter metal for optimizing the rotor design of the Hammer mill machine.
7. Bearing life for selected bearings is 1036.8 Millions of revolutions.
8. The validity of this research outcomes with different kinds of grains may be a valuable recommended for future studies.

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