Computer simulating of strength characteristics for deformable chambers and most loaded mixer elements with a vertical shaft

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Abstract. The article presents computer simulating of strength characteristics in deformable chambers and loaded mixer elements with a vertical shaft to determine structural parameters of a bearing frame and a deformable chamber regarding strength and rigidity conditions.

1. Introduction

Construction materials industry acceleration is one of the most important issues [1–3], which is solved by equipment upgrading, modernization and re-equipment of the plants.

The process of design in machine-building can be divided into several main stages: pre-design works, design works; expert review of the project and its approval. The stage of project works is the longest, to be precise, the stage of creating engineering documentation. Nowadays, CAD/CAM/CAE systems are used to foster the process. They allow following the whole life-circle of the product, from the conceptual design, projecting, engineering analysis to the production, service and utilization.

2. Computer simulating of strength characteristics for deformable chambers

NX projecting is done as follows, at first, 3-D models of all parts are created, then they are assembled and a 3-D model of the product is received. After that, strength of all details and assemblies is calculated by final elements method in "Structure" module, details' sizes are specified, materials for their production, different parameters of the future product can be specified. Then, kynematic and dynamic analyses in "Motion" module of the whole mechanism and its assemblies are done in order to check its performance. After that, engineering drawings of all parts and machine components are created in "Drafting" module.

A universal multi-purpose batch operation [4,5] has been suggested. Its construction is given in Figure 1. This device consists of a deformable chamber 4, in the form of half-barrel, fixed to the supporting frame, consisting of the footing 1 and a shaft 2, fastened to each other. The supporting frame allows changing the chamber deformation vertically.
The material is fed through the hollow pivot 6, with a driver bearing 9. A shaft 10 is fixed onto the driver bearing 9, providing chamber motion with eccentricity. Also, inside chamber 4, onto the pivot 6 the blades 7 are fixed, which mix the material. A bearing assembly with a snap ring 11 is set onto the shaft 2.

The device operates so: the hollow pivot, eccentricity fixed at the top of the chamber, is rotated with a drive and the chamber deforms. If the chamber is filled with grinding pearls (balls) and material, than it operates as a grinding mill for superfine grinding, which completes only crashing and abrasive actions. If two or more blades 7 are fixed to the pivot, (depending on the size of the working chamber), the device works as a mixer after filling the chamber.

The device can be mixing-grinding of the batch action. When blades and grinding bodies are used in the chamber the grinding bodies and the material are moved that intensifies mixing and grinding. The advantages of this device are: it can operate as a mixer or a grinder, or combined; simple assembly; small amount of metal per structure; the weight of the loaded material does not affect the chamber.

The rigid body geometry was constructed with the CAD/CAM/CAE system NX for further analysis of the device performance ability. With the development of the construction materials industry the design-engineer encounters more complex problems which require serious funding. One of them is: calculating strength, rigidity, firmness and so on.

The purpose of the calculating is determining maximal and minimal stress, maximum deflection, deformation character and strength factor of the supporting structure, as well as tension in the chamber appearing during operation. The initial data for calculating strength are: designed models of the supporting structure (Figure 2) and the case (Figure 3) of the mixer with a deformable chamber, detail material characteristics in this assembly; loads and displacement constraints for the assemble elements in planes with the account of the construction operation in constructing material industry. The supporting structure consists of the footing and the rod.

As the footing thickness is 15 mm due to constructional aims (with 3-times assurance factor), as it is planned to use the footing for semi-industrial installation and to prevent vibration, then the forces acting on the footing can be neglected.
To determine the strength of the supporting structure and the case it is important to determine forces acting on them [6].

The permissible maximum deflection of the bar is determined from the condition:

\[ f_{\text{max}} = 0.1l, \]  

(1)

where \( l \) is the bar length.

The bar is made from steel St3 with yield limit \( \sigma_y = 160 \text{ MPa}. \)

\[ \sigma_y = 0.45 \sigma_t = 0.45 \cdot 450 = 203 \text{ MPa}. \]  

(2)

4 forces act on the rod:
1) rod weight, equals \( 3.9812 \text{ Н} \);
2) weight of the bearing with the snap ring;
3) pivot weight;
4) driver weight.

Let’s do calculations for the supporting structure. Two bearings are fixed to the supporting structure, each weighs \( G_p = 1.137 \text{ Н} \), they are in the snap ring, it weighs \( G_{\text{s.r.}} = 0.4161 \text{ Н} \); also the supporting structure is acted on by the rod weight \( G_r = 0.8607 \text{ Н} \), which is firmly fixed to the driver \( G_d = 8.023 \text{ Н} \).

The total weight of bearings, a snap ring, a rod, and the driver is calculated by the formula:

\[ \sum G_i = 2G_p + G_{\text{s.r.}} + G_s + G_d = 2 \cdot 1.137 + 0.4161 + 0.8607 + 8.023 = 11.5738 \text{ Н}. \]  

(3)

The case weight acts on the footing. As the case weight is small it can be neglected.

The case is acted on by:
- the resulting force \( F \) of materials mixture onto the case during mixing,
- the torque of the eccentricity \( M \).

For calculations in NX NASTRAN system we admit that the deformable case is filled with water with mixture density. Then the resulting force is:

\[ F = \sqrt{F_f^2 + F_{\text{in}}^2 + F_0^2}, \]  

(4)

where \( F_f \) is friction force appearing when intersectorial layers are displaced;
\( F_{\text{in}} \) is friction force of the mixture movement relative to internal surface of the case;
\( F_0 \) is friction force at translational movement of the load heightwise in the chamber.

\[ F_f = 0.006 \pi n f_h \delta \rho (d_e + d_r) L (D^2 + 0.5D + 5.7) \]  

(5)

\[ F_{\text{in}} = 0.048 \pi c \omega_0^2 \rho (d_e + d_r) LD^2 \]  

(6)

\[ F_0 = \frac{\pi}{6} f_r \omega_0^2 \rho (d_e + d_r) L \left( 2.4D^3 - 3d_e \right), \]  

(7)

where \( f_h, f_r = 0.015 \) is materials friction-sliding coefficient on the blades, \( f_r = 0.055 - 0.08 \) is friction of the material on the case, \( \omega_0 \) is material angular speed, \( c^{-1} \); \( \rho = 1400 \text{ mixture density, kg/m}^3; d_e \) – eccentricity,
m; \( D \) – case diameter, m; \( d_p \) – particle size of the basic mixture component, m, thus, \( F_n = 1.561 H \), \( F_d = 4.041 H \), \( F_i = 1.88 H \), \( F = 22.3014 H \).

Eccentricity torque:
\[
M = e \cdot F = 20 \cdot 22.3014 = 446.028 H \cdot \text{mm} \tag{8}
\]

Before calculations it is necessary to simplify the supporting structure model, it will enhance the speed of calculation. Due to simplification such model parts as bendings, facets, holes whose diameter is too small in relation to the surface area, slots, bins, cavities whose sizes allow doing it are not taken into account.

As material for the supporting structure we take Steel 3. The material for the case is polyurethane.

**Table 1.** Common steel characteristics.

| Property               | Value       |
|------------------------|-------------|
| Density                | 7826 kg/m³  |
| Elasticity modulus     | E=206000 MPa|
| Shear modulus          | G=74000 MPa |
| Chemical composition   | Silicon: 0.17-0.37, Manganese: 0.50-0.80, Cuprum: 0.25, Nickel: 0.25, Sulfur: 0.04, Carbon: 0.32-0.40, Phosphorus: 0.035, Chromium: 0.25, Arsenic: 0.08 |

The snap ring which contains bearings, is in the hole on the horizontal rod of the supporting frame. A rod is incerted into the bearing and a driver is rigidly fixed to the rod. That is why the total weight is on the periphery of the hole. And the sole weight of the rod is evenly distributed alongside.

The frame is rigidly fixed to the footing, which is also rigidly fixed, consequently, as boundary conditions we choose rigid restrain at the bottom footing, that provides immobility of this plane in all axes. Basing on the mentioned above let’s make a calculation scheme (Figure 4) to determine maximal deformation stress and support reactions of the rod under the action of the forces enumerated above.

Before applying the scale of the final elements it is necessary to determine connections between the details models for the assembly to operate as a system and not a set of separate elements. Let’s apply 3D-tetrahedral scale (TETRA 10) with the size of the final element 17.2 mm, apply all the forces and fastenings according to the calculation scheme and do calculations.

![Figure 4. Frame calculation scheme.](image)

The case is rigidly fixed to the footing, consequently, as boundary conditions we choose rigid restrain at the bottom of the case, thus providing immobility of this plane in all axes. The resulting force \( F \) and a torque act on the case \( M \).

Further, let’s apply 3D-tetrahedral scale (TETRA 10) with the size of the final element 3.2 mm (Figure 5), apply all the forces and fastenings according to the calculating scheme and do calculations.

The supporting frame:
- maximal strain for steel St3, which is used in a rod is 5.054 Pa, coefficient of resistance \( \sigma / \sigma_{\text{max}} = 2.54 \), hence the frame has high strength assurance factor (Figure 6);
– maximal displacements for steel St3, which is used for the rod is 1.521 mm (Figure 7), consequently the frame has sufficient rigidity, and large rigidity assurance factor (maximal displacements received do not exceed 2 mm).

The case:
– maximal stress for the polyurethane which is used for the case is 0.02 MPa, strength assurance factor is $\frac{\sigma}{\sigma_{\text{max}}}=3.68$, consequently the case has big strength assurance factor (Figure 8),
– maximal displacement for the case 3 mm thick is 4 mm, hence the case has sufficient rigidity assurance factor (Figure 9),
– maximal reaction of the case footings is 0.18 H (Figure 10).

3. Conclusion
The following results were received:
- assembly elements and parts have been designed according to the constructive requirements;
- assembly elements for further engineering analysis have been manufactured;
- strength characteristics are calculated with CAD/CAM/CAE system NX;
- the supporting frame and the deformable chamber meet strength and rigidity requirements.

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