Design of Centrifugal Separator for Dehydration

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Abstract - **Centrifugal Separators are used in various areas such as sugar industry, paper and pulp industry, in clinical laboratories, for isotope separation, drying in washing machines to name a few. Here centrifugal separator machine is used for the separation of solid and liquid phases present in a mixture of waste, by the virtue of centrifugal force acting on it. This research paper provides the design overview of a Centrifugal Separator along with its basic concept, construction, and its design surveys and specifications. The basic technology used in this project makes use of a rotating mesh. Then the centrifugal force is used to separate water and other fluids from the solid content in order to carry out dehydration. This is an economical device for domestic use and can be used for small scale waste management such as sewage water treatment, manure treatment and filtration in India.**

Keywords: Centrifugal Separator, Dehydration, Mesh, Auger, Waste management, Small scale applications, Reasonable price

I. INTRODUCTION

Centrifugal Separator is the machine used for separating liquid matter from solid. It can be used in domestic, sewage and livestock manure waste management. Design and manufacture a centrifugal separator machine based on customer requirements. This product can be found for the purposes like domestic waste management, paper and pulp industry, sugar industry, dairy industry, cutting oil filtration. Dehydration is the process of separation of liquid from solid matter. In Centrifugal Separator, the mixture of solid and liquid waste is poured in a vessel rotating at high speed. Due to this, the centrifugal force acts on the mixture. As liquid has less density than solid, it is thrown outside the vessel. Marcy Ford and Ron Fleming [1] provided information about effective treatment of livestock manure using centrifugal separation. Solid-liquid separation of livestock manure involves the partial removal of organic and inorganic solids from liquid manure. Effective solid-liquid separation can remove a substantial amount of the organic solids from fresh liquid (or slurry) manure and offers the benefits of the production of nutrient-rich solids. Roshan Ahire et al. [2] discussed the application of centrifugal separators for cutting oil filtration. A centrifugal oil- burr separator is a machine designed to separate oil from burr by centrifugal action. It's has a cylindrical shape of container that rotate inside larger stationary container. The cutting oil needs to be separate from burr after use which can be reuse for the further processes. Centrifugal oil burr separator is used for waste oil recovery and clean-up of oil. It is also used for filtering oil by removing waste particles and impurity from them. N. Horie et al. [3] proposed the use of rotary drum for water purification. This rotary screen is installed in a pumping station of a combined sewerage system to remove suspended solids from raw wastewater. When installed in a channel of the pumping station, the rotary screen traps suspended solids by perforated panels. The raw wastewater flows into the rotating screen and is filtered when leaving the screen from the inside to the outside. Suspended solids are trapped on the inside surface of the screen, and raked upward as the screen rotates. The solids collected at the top of the inside of the screen are flushed out with flushing water down into a discharge trough for collection. The rotary screen is available in two types, the drum-rotating and panel-running types, which should be selected according to the condition of the installation site. A market survey was conducted for the availability and specifications of existing centrifugal separator models. Tidy Planet, a UK based firm, manufactured two models by the name of 'Dehydra' belonging to the category of bench are surveyed having capacity 700 kg per hour, weight 150 kg and power 1.1 kW. The objectives of this article are effective management of waste, reducing degradation of land and water resources due to waste disposal, at low cost, suitability for small scale and domestic applications.

II. DESIGN OF CENTRIFUGAL SEPARATOR

Centrifugal Separator consists of inner shaft, outer shaft, driving and driven pulleys and V-belt. The static and dynamic design of aforementioned components is as follows

A. Design Concepts and Considerations

The design considerations and the material selection are based on the following concepts:

i. A hollow square bar of 40 x 40 mm cross section (M.S.) is used for mounting the entire assembly of the machine and to ensure substantial support and stability during operation.

ii. For the purpose of separating the liquid content and dehydration of household waste, a cylindrical mesh of outer diameter 140 mm, inner diameter 134 mm and 250 mm length is used. In order to ensure that the separated water does not accumulate and cause further leakage problems, this assembly is inclined at 45^0 with the horizontal.

iii. This design is based on the criteria of strength and refers to the ASME Code of design for shafts, in order to ensure safe operation. Also, dynamic analysis is performed to check the natural frequency of the machine during its operation.

B. Static Design

Static design of mechanical structures is aimed at finding the effect of constant loads on components neglecting the effect of inertia and shock. Following are the calculations for different parts of the assembly.

1. Design of Inner Shaft

The design of inner shaft is given as below. Shaft design is based on strength and stiffness criteria.

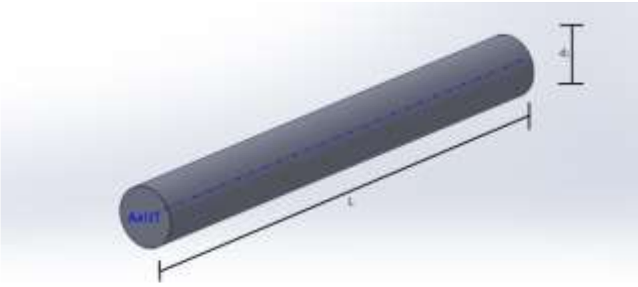

Fig.1: Inner shaft [14]

$$\tau_{max(permissible)} = \text{minimum of} \begin{cases} (0.18S_{ut}) = 108\ MP \\ (0.3S_{yt}) = 93\ MPa \end{cases} \quad (1)$$

$$\tau_{max} = \frac{16T}{\pi d_1^3} \quad (2)$$

The above equation gives the diameter of inner shaft which is useful for further calculations.

2. *Design of Outer Shaft (Compound Shaft)*

The design of stepped shaft is given as below. The step diameters are calculated by using below equations.

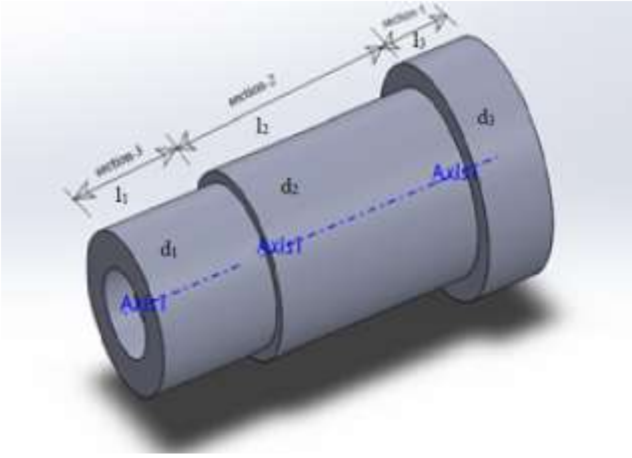

Fig.2: Outer Shaft [14]

$$\tau_{max(permissible)} = \text{minimum of} \begin{cases} (0.18S_{ut}) = 108\ MP \\ (0.3S_{yt}) = 93\ MPa \end{cases} \quad (3)$$

$$\tau_{max} = \frac{16T}{\pi(D^4 - d_2^4)} \quad (4)$$

The above equation gives the diameter of outer shaft which is useful for further calculations.

3. *Selection of Belt*

Fig.3: Cross-section of belt (TYPE-A) [14]

Assuming steady load, V-belt (Cross-section: Type A) was selected from SKF manufacturer's catalogue [11].

4. *Selection of Pulley*

The outer and inner driven pulleys were used in Centrifugal Separator with driving pulley. There are two driving pulleys mounted on motor shaft and two driven pulleys mounted on inner and outer shaft respectively. The power is transmitted from driving pulleys to driven pulleys. The driven pulleys further transmit the power to inner and outer shaft respectively.

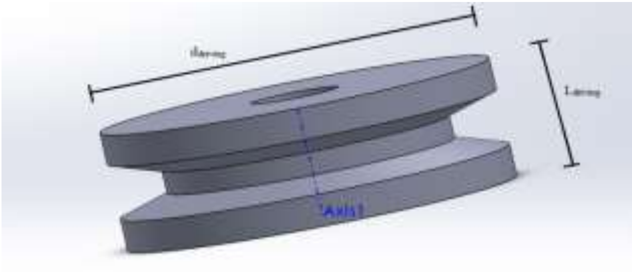

Fig.4: Driving pulley [14]

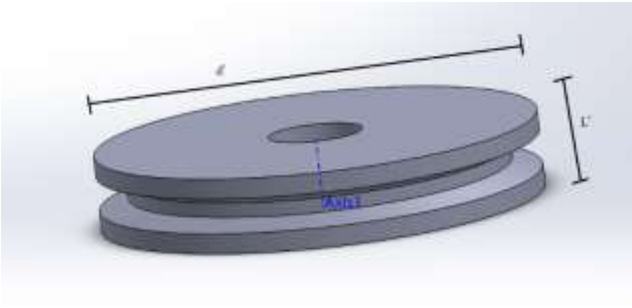

Fig.5: Outer Driven Pulley [14]

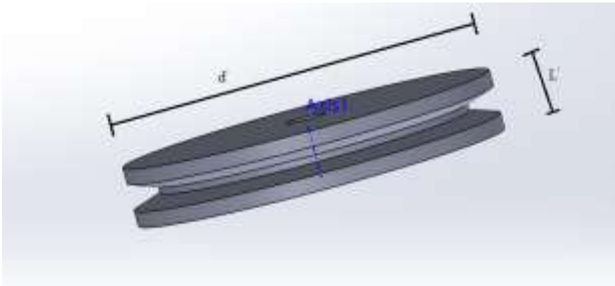

Fig.6: Inner Driven Pulley [14]

Assuming centre distance as 200 mm and using below formulae pulley dimensions are calculated and respective pulleys are selected from SKF manufacturer's catalogue [11].

$$L_{approx} = 2c + \pi \frac{(d' + d_{driving})}{2} + \frac{(d' - d_{driving})^2}{4c} \quad (5)$$

$$\theta_s = \pi - 2\sin^{-1}\left(\frac{d' - d_{driving}}{2c}\right) \quad (6)$$

$$\text{Modified Power Rating} = \text{P.R.} \times f_d \times f_c \quad (7)$$

C. Estimation of Load on Machine

The load on the centrifugal separator machine was estimated by preparing a slurry of the working fluid out of the kitchen waste generated in a day for a family of 4 people. Depending upon the waste generation rate, this machine can be used for handling the waste from a single household or multiple households.

Table 1: Waste Contents used for Weight Estimation

Ingredient	Quantity of waste obtained
Carrot	1 unit
Cabbage leaves	5 leaves
Leftover from Capsicums	8
Onion Peels	5 onions
Waste onion	1
Coriander stems	25 stems
Potato Skin	3 potatoes
Leftover Tea Powder Extract	1 cup
Tomato Skin	1 tomato

The above waste generated was crushed using a kitchen mixer/grinder for the purpose of weight measurement.

Fig. 7: Weight of Slurry

The resulting volume of the waste generated was 500 ml.
Mass of waste measured = 0.768 kg
Volume of Mesh container of the centrifugal separator

$$V_{mesh} = \frac{\pi}{4} * D_{mesh}^2 * L_{mesh}$$

Hence load acting on the machine having above volume will be, $M_{fluid} = 5.91$ kg ≈ 6kg.

D. Dynamic Analysis

The dynamic analysis is used to calculate the impact of temporary loads and vibrations including the effect of inertia. The critical speed of shaft is calculated to check resonance speed. Resonance speed is avoided for safe working of centrifugal separator.

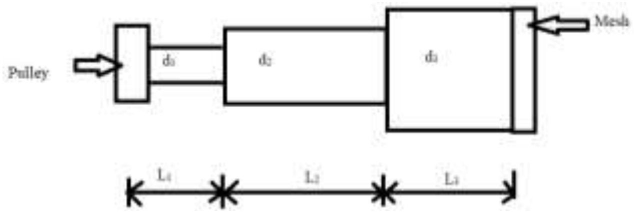

Fig. 8: Dynamic Analysis of shaft using two rotor system

$$I_{(without\ slurry)} = I_1 = \frac{1}{2} m_1 (r_2^2 - r_1^2)$$

$$I_{(with\ Slurry)} = I_2 = \frac{1}{2} m_2 r_1^2$$

$$I_{M(total)} = I_1 + I_2 \quad (8)$$

$$I_p = \frac{1}{2} m r^2 \quad (9)$$

By assuming,

$D_e = D_1 = 0.035$ m

Shear Modulus for Stainless Steel (G) = 84 × 10^9 N/m^2 (material of shaft)

$$l_e = l_1\left(\frac{D_e}{D_1}\right)^4 + l_2\left(\frac{D_e}{D_2}\right)^4 + l_3\left(\frac{D_e}{D_3}\right)^4 \quad (10)$$

$$l_e = l_p + l_m$$

$$l_p * I_p = l_m * I_m$$

$$J_e = \frac{\pi}{32} D_e{}^4$$

$$\omega_n = \sqrt{\frac{K_t}{I}} = \sqrt{\frac{GJ_e}{l_p I_p}}$$

(11)

$$f_n = \frac{\omega_n}{2\pi}$$

Calculation shows that natural frequency for system is greater than vibrational frequencies of both mesh and pulley, the design is safe.

E. Selection of Bearing

The deep groove ball bearing selection process from SKF catalogue is given as below.

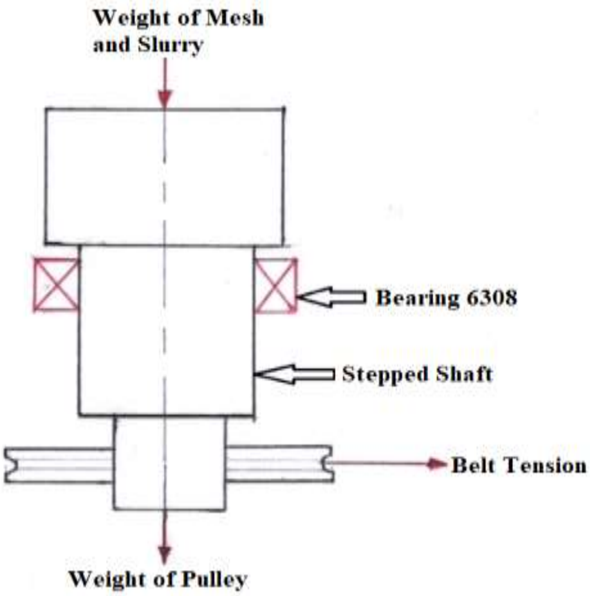

Fig. 9: Schematic for Bearing Selection

$$\text{Weight}_{pulley} = \frac{\pi}{4} * D^2 * w * \rho_{CI} * g$$

(12)

$$\text{Weight}_{mesh} = \left[\frac{\pi}{4} * (D_o^2 - D_i^2) * L * \rho_{MS} * g\right] + W$$

(13)

Angle of Contact $\theta_s = \pi - 2*\alpha$

Where, $\alpha = \sin^{-1}(\frac{D-d}{2c})$

$$\frac{Tft}{Tfs} = e^{\frac{\mu\theta}{\sin\phi}}$$

(14)

$$P = (Tft - Tfs) * V$$

$$F_r = R_H = (T_{ft} + T_{fs})$$

$$F_a = (M_{pulley} + M_{mesh}) * g$$

$P_e = (X * V * F_r + Y * F_a) * K_a$[12]

(15)

where X : Radial Load Factor, Y : Axial Load Factor and K_a: Load Application Factor

$$L_{10} = \frac{60 * N * L_{10h}}{10^6} \text{ million revolutions}$$

(16)

$$L_{10} = \left(\frac{C_{req}}{P_e}\right)^a$$

The above calculations show that the required dynamic load carrying capacity of the bearing was less than rated dynamic capacity. Hence bearing 6308 is safe for use. Rated life of the bearing is 6000 hours. If used for 5hr/day, then life of bearing will be 3.28 years. Hence, it is recommended to replace bearing after three years.

III. LAYOUT OF CENTRIFUGAL SEPARATOR BASED ON DESIGN

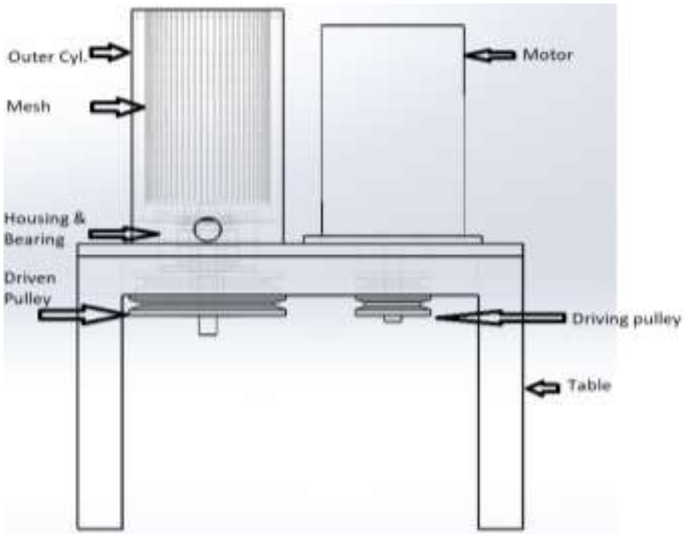

Fig. 10: Centrifugal Separator

The design steps and calculations give the layout of centrifugal separator as shown in fig. 10. It consists of a rotary mesh, surrounded by an outer cylinder, shaft and bearing assembly and motor-powered belt drive. The mesh is welded to a rotating flange of the outer shaft of the drive. The drive consists of a flange mounted induction motor which is bolted to the support table. The power is transmitted from the motor to the machine with the help of a V-belt pulley drive. There are two pulleys one on driving and other on driven side. The driven side of the machine consists of two shafts, concentric with each other. The inner shaft is used for providing rotation to the auger. On the other hand, the outer shaft is welded to the flange. The outer shaft a rotary seal is provided to prevent the flow of water inside the drive assembly. Two bearings are provided on the outer shaft. These bearings are held in place by providing a stepped diameter on the shaft on the upper side, whereas a spacer is provided on the lower side to provide positive restriction in the axial direction to the inner race of the bearings. The outer race of the bearings mounted is held in place by providing a bearing housing and a cover plate. The two driven pulleys are mounted on the inner and the outer shafts respectively and keyed to these shafts. The mesh is surrounded by a outer cylinder which is used to collect the water separated during the process of dehydration. The outer cylinder is provided with a drain hole in order to ensure that water separated can be easily drained. The entire assembly is mounted on a table and secured with the help of fasteners. The Centrifugal

Separator works on the principle of centrifugal force exerted on a rotating body. Due to the rotating mesh, a centrifugal force acts on the mixture, causing it to be thrown in the radially outward direction. Due to the presence of the mesh, the water gets separated from the solid content, and this water is drained out from the drain hole provided on the outer cylinder. The solid matter is then pushed in the upward direction due to the rotation of the helical auger, which is then removed from the machine from the top. The cumulative effect of the entire process is the separation of water and solid content, resulting in an effective waste management technique.

IV. RESULTS

The results of the design procedure described in the previous articles are presented in this article.

Table 2: Summary of Design Data

Component	Input Parameter	Output Parameter
Inner Shaft	d_1= 19 mm L= 170 mm	$\tau_{max(permissible)}$ =93 MPa $\tau_{max} = 7.595$ MPa
Outer Shaft	d_2= 20mm D = 40mm L= 52mm	$\tau_{max(permissible)}$ =93 MPa $\tau_{max} = 1.338$ MPa
Pulley	$d_{driving}$=80mm d' = 160 mm d'' = 170 mm $C.D._{corrected}$=208 mm $L_{corrected}$=800 mm	L_{approx}=785mm $\theta_s = 2.7545\ rad$ P.R. = 0.726 kW
Bearing	ρ_{CI}=7500 kg/m^3 Ø=20 ^{0} μ = 0.25 C.D.= 208 mm N= 700 RPM P= 746 W D_o = 140 mm D_i = 134 mm L= 250 mm ρ_{MS}=7800 kg/m^3 W= 6 kg Bearing: 6308 Static Load Capacity= 24kN Dynamic Load capacity= 42.3kN	F_{deq} = 902 N L_{10}= 252 million revs F_{dcap}= 5.697 kN

V. DISCUSSIONS

The centrifugal separator machine was designed for separating household domestic waste, in liquid and solid form. This article gives conceptual design of centrifugal separator machine based on the concept of centrifugal force. The component-based design of this machine is done by using ASME code of design and standard design hand book data. Also, selection of some components like bearings, belts and pulleys is done based on standard catalogues taking care of design considerations.

APPENDIX

The nomenclature used in this article are given as below,

d_1 Diameter of Inner Shaft (mm)
L Length of Inner Shaft (mm)
d_2 Inner Diameter of driven shaft (mm)
D Outer Diameter of driven shaft (mm)
$d_{driving}$ Pitch Diameter of driving pulley (mm)
d' Pitch Diameter of driven pulley 1 (mm)
d'' Pitch Diameter of driven pulley 2 (mm)
P Power to be transmitted (kW)
P_d Design Power (kW)
L Length of belt (mm)
C Centre distance between pulleys (mm)
V_{mesh} Volume of Mesh (m^3)
D_{mesh} Diameter of Mesh (m)
L_{mesh} Length of Mesh (m)
m_1 Mass of Mesh without Slurry (kg)
m_2 Mass of Mesh with Slurry (kg)
I_1 Mass Moment of Inertia of Mesh without Slurry (kg.m^2)
I_2 Mass Moment of Inertia of Mesh with Slurry (kg.m^2)
$I_{M(Total)}$ Total Mass Moment of Inertia of Mesh (kg.m^2)
I_p Mass Moment of Inertia of Pulley (kg.m^2)
t Thickness of Pulley (m)
N_1 Speed of Pulley (RPM)
N_2 Speed of Motor (RPM)
D_e Effective Diameter of Shaft (m)
G Shear Modulus (N/m^2)
l_e Equivalent length of Shaft (m)
J_e Polar Moment of Inertia of Shaft (m^4)
ω_n Natural Frequency of Shaft (rad/s)
ω_1 Frequency of Pulley Shaft (rad/s)
ω_2 Frequency of Motor Shaft (rad/s)
f_n Natural Frequency of Shaft (Hz)
f_1 Frequency of Pulley Shaft (Hz)
f_2 Frequency of Motor Shaft (Hz)

ACKNOWLEDGMENT

First of all, we would like to extend our sincere thanks to Mr. Jitendra Kelkar, Partner, 'TECHNOVA', Pune, for sponsoring this research project. Also, we are grateful for all the support given by department of Mechanical Engineering, MIT College of Engineering, Pune.

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