Design & Validation of Feeding Mechanism for Porous Raw Material: A Case Study in Chemical Processing Company

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Abstract. With the growing revolution in technology, quality is always being considered a major point of concern and developing countries like India where number of small and medium enterprises are working contributing for major part of employment, these quality concern need to be focussed. The present work involves the case study which has been conducted in one of small scale industry dealing with chemical processing, in Nagpur. The objective is to find out the solution for one of the problem discussed by production manager of the company. The problem is related to feeding of raw material into the processing plant which have been done manually and cause of quality issue and serious work hazard. So we have suggested a design of setup of feeding mechanism for pouring the raw material. While designing, first the survey has been conducted where it was found that different types of hoppers are available in market based in different size and shape. The hopper which we supposed to design should fulfill the requirement of the manager and all the technicalities. In order to do so we have studies number of design parameter and formulate the design procedure for each and every aspect right from calculation of mass flow rate, hopper angle, exit rate, wall friction angle, design of bevel gear, different force acting on hopper surface. The design of the hopper and the complete setup for the pouring resin is carried out by considering only porous raw material. So, comprehensive approach for designing the hopper as a solution have been done and proposed to company. Similarly the design is being validated using ANSYS software package.

1. Introduction
The case company named, RSA Industries Pvt. Ltd. Is located in, M.I.D.C. Hingna industrial estate, Nagpur-440028, who deals with production of chemicals used in textile industries. The products are water soluble polyester resin, carboxylate polyester resin for powder paint, low molecular weight water soluble polyesters and fatty acid esters and surfactant formulations. The company is having total 70+employees including R&D team, having turnover of 36 crores per annum. As discussed with production manager the company presently facing with the issue of increased work processing time and work hazard for which, as a solution the company want a well-designed hopper for pouring the resin into the processing plant of chemical i.e chemical reactor. Designing a hopper involve number of decision parameter right from material properties to peat, rock, flour—no matter which material you process, the proposed hopper should move it to the feeder at required flow rate with maintaining the quality of same.
your hoppers must move it to feeders at an optimal flow rate without damaging it. To accomplish this, both the hopper and the feeder need to work together. Some decision parameters are discussed below which we have taken for designing the hopper in our case. These are:

(a) **Type of Material** Polyester resin is used by the company in making the textile chemicals products. It is in the form of granules. It reacts with water in chemical reactor. The physical properties of the resin are given by the company.

(b) **Use of Material.** The company works 24hrs and has three shifts of 8hrs each. The resin is mixed with water to form chemical products. The pouring of resin in the reactor should be continue till 8hours so calculation of discharge & flow rate is the major requirement of the work.

(c) **Hopper Blockage** When the resin is pour in the hopper there is possibility of hopper blockage the particles of the resin get clogged in the lower end of the hopper. Due to this problem the process time increases, to avoid this blockage we have incorporated small rod at the lower end of the hopper. The rod will crush the clogged particles and thus will prevent blockage in the hopper.

![Figure 1. Manual Pouring of Resin into chemical reactor-Major source of Work Hazard (Photo captured during analysis of work area)](image)

Hence for designing the hopper according to the company’s requirement we have used methodology which is discussed in next section.

2. **Design Methodology**

As the company is a small-scale industry the design of chemical hopper which we suppose to design must be durable and cost effective. The challenging task before designing the mechanism is the specific time at which the hopper attain the required flow rate.

The mechanism which we plan to design have following number of parts which are discussed below:

**Hopper** – Store resin in large quantity  
**Fan** – breaking of some solid resins particle come from hopper  
**Bevel Gear** – Bevel gear assembly transmit power towards fan  
**Cam Follower** – Cam connected to the follower which reciprocate follower.  
**Curved Plate** – Curved plate evenly spread resins.  
**Support** - It provide base to the mechanism
3. Design Procedure

3.1 Designing of Hopper [1]
An effective and well-designed hopper will contribute a lot in solving most of the issue presently faced by company. For this we have gathered the data from company’s production manager of all the parameter which we required for designing.

The data is as follows:

- Bulk density $\rho_b = 857\text{kg/m}^3$,
- Internal friction angle ($\delta$) = 40,
- Wall friction angle ($\delta_w$) = 18,
- Critical Applied Stress ($CAS, \delta_c$) = 0.26,
- From graph of wall friction and semi include hopper angle and flow factor $FF = 1.4$
  - $\theta = 30^0$ (Hopper angle)

3.2 Experiments with Shear

\[ \rho_b = 857\text{kg/m}^3 \] (Bulk density)

IF($\delta$) = 40
WF($\delta_w$) = 18
From chart
$\theta = 30^0$
$FF = 1.4$
CAS $\rightarrow$ Critical Applied Stress

From chart
CAS = 0.26
Minimum Outlet Diameter

\[ B = \frac{H(CAS)}{\rho_b \times g} \]
Assume H = 2.5
\[ B = \frac{2.5 \times 0.26 \times 1000}{857 \times 9.81} \]
\( D_0 = B = 0.0802 \text{m} \)
\( B = 8 \text{ cm (Outlet diameter)} \)

3.3 Calculation of discharge rate [3][4]

For Particle diameter less than 500\( \mu \text{m} \)
\[
W = C \times \rho g \frac{1}{2} D_0^2 = 0.13 \times 857 \times \sqrt{9.81} \times 0.0802^2
\]
\( W = 0.6316 \text{kg/sec} \)

Case 1- When we applied slider plate
the flow rate is reduced 25%
\[
W_1 = 0.6316 \times \frac{25}{100} = 0.1579 \text{kg/sec}
\]

Case 2- For 50%
\[
W_2 = 0.6316 \times \frac{50}{100} = 0.3158 \text{kg/sec}
\]

Case 3- For 75%
\[
W_3 = 0.6316 \times \frac{75}{100} = 0.4737 \text{kg/sec}
\]

3.4 Dimensions of bin and conical hopper[4]

\( V = \text{Volume of conical section} + \text{Volume of bin} \)

\[
V = \frac{\pi}{24 \tan \theta} (D^3 + B^3) + \frac{\pi}{4} D^2 \times H
\]
Assume \( \frac{H}{D} = 0.25 \)

Assuming volume 100m\(^3\)
\[
100 = \frac{\pi}{24 \tan 30} (D^3 - 0.0802^3) + \frac{0.25}{4} \pi D^3
\]
\( D = 0.514 \text{m} \)
\( D = 51.4 \text{cm} \rightarrow \text{Diameter of bin} \)
\( H = 0.25 \times D = 0.25 \times 0.514 = 0.1285 \text{m} \)
\( H = 12.85 \text{cm} \)

3.4.1 Calculation of \( h_0 \) \& \( h \)

\[
h = \frac{D}{\tan \theta} = \frac{0.514}{\frac{2}{\tan 30}}
\]
\( h = 0.4451 \text{m} \)

\( h_0 = 44.51 \text{cm} \)

\[
h_B = \frac{B}{\tan \theta} = \frac{0.0802}{\frac{2}{\tan 30}}
\]
\( h_B = 0.069 \text{m} = 6 \text{cm} \)

![Figure 4. Dimension of Hopper](image)
ho = h – h_B
ho = 0.4451 + 0.069 = 0.5141m
\[ \textbf{ho} = 51.41 \text{cm} \]

3.5 Design of Bevel Gear [6]
Normal range of gear ratio of Bevel Gear is from 3:2 to 10:1
So selecting Gear Ratio = \( \frac{3}{2} = 1.5 \)
Assuming teeth on pinion
Tp=19 (Minimum teeth for 20°full depth)

Given motor power is 500 w
Motor speed is 480 rpm

Calculation: -

1. For calculating Speed
We have, GR = \( \frac{N_p}{N_g} \)
1.5 = \( \frac{480}{N_g} \)
Ng = 320 rpm

2. For Calculating Number of Teeth
We have, GR = \( \frac{t_g}{t_p} \)
1.5 = \( \frac{t_g}{19} \)
tg = 29

Therefore, No. of teeth on gear is 29

Now,

1] Design power
P_d = Pr * K_1
K_1 = Load factor (1.50 for light shock & continuous 24hrs/day)
P_d = 500 * 1.50
P_d = 750 Watt

2] Let ‘m’ be the module
Pitch circle diameter of Pinion
D_p = m * t_p = 19m

Pitch circle diameter of Gear
D_g = m * t_g = 29m

Pitch line velocity,
\[ V_p = \frac{\pi D_p N_p}{60 \cdot 1000} \]
\[ V_p = \frac{\pi \cdot 19 \cdot 480}{60 \cdot 1000} \]
V_p = 0.477 m/sec
3] Tooth load

\[ F_t = \frac{P_d}{V_p} \]
\[ F_t = \frac{750}{0.477 + m} \]
\[ F_t = \frac{1572.32}{m} \] N

4] Beam Strength

For pinion \( F_b = S_0 \cdot C_v \cdot b \cdot Y_p \cdot m \cdot (1 - \frac{b}{L}) \)

Cone distance \( L = 0.5 \cdot \sqrt{D_g^2 + D_p^2} \)
\[ L = 0.5 \cdot \sqrt{19^2 + 29^2} \]
\[ L = 17.33 \text{m} \]

Since \( L < 30 \text{m} \)

Selecting Width of Gear Face \( b = 6 \text{m to 7m} \)
So selecting \( b = 5 \text{m} \)

Selecting material For both gear and pinion as Cast Iron, High Grade
So= 105 Mpa

Assuming Velocity factor \( C_v = 0.5 \) For \( N_p < 1000 \text{rpm} \)

Pitch Angle, \( \gamma \)

\[ \tan \gamma_p = \frac{\sin \theta}{\frac{t_p}{c_s} + \cos \theta} \]
\[ \tan \gamma_p = \frac{\sin 90}{\frac{t_p}{c_s} + \cos 90} \]
\[ \tan \gamma_p = 0.6551 \]

Pitch Angle of pinion \( \gamma_p = 33.22 \)

\[ \tan \gamma_g = \frac{\sin \theta}{\frac{t_g}{c_s} + \cos \theta} \]
\[ \tan \gamma_g = \frac{\sin 90}{\frac{t_g}{c_s} + \cos 90} \]
\[ \tan \gamma_g = 1.526 \]
\[ \gamma_g = 56.76 \]

Formative no.of teeth

On pinion \( t_{fp} = \frac{t_p}{c_s + \gamma_p} \)
\( t_{fp} = 22.71 \)

On gear \( t_{fg} = \frac{t_g}{c_s + \gamma_g} \)
\( t_{fg} = 52.90 \)

Lewis form factor for 20° full depth

On pinion \( Y_p = 0.485 - \frac{2.87}{t_{fp}} \)
\( Y_p = 0.3586 \)

On gear \( Y_g = 0.485 - \frac{2.87}{t_{fg}} \)
\( Y_g = 0.4307 \)

For Pinion
\( F_b = 66.861 m^2 \) N

For Gear
\( F_b = 80.308 m^2 \) N

Selecting smaller value \( F_b = 66.861 m^2 \) N

Applying condition
\[
F_t \leq F_b
\]
\[
F_t = F_b \frac{1572.32}{m} = 66.861 m^2
\]
\( m = 2.86 \) mm

Taking Standard Module
\[
m = 3 \text{ mm}
\]
\[
D_p = 19 \times 3 = 57 \text{ mm}
\]
\[
D_g = 29 \times 3 = 87 \text{ mm}
\]
\[
V_p = 0.477 \times 3 = 1.431 \text{ m/sec}
\]
\[
F_t = \frac{1572.32}{3} = 524.106 \text{ N}
\]
\[
L = 17.33 \times 3 = 51.99 \text{ mm}
\]
\[
b = 5 \times 3 = 15 \text{ mm}
\]

Now \( C_v \)
For \( V_p = 1.431 \) m/sec

Class of Gear, Commercially cut gears class I
\[
C_v = \frac{3}{3 + V_p} \quad V_p = 2.5 \text{ to } 5.0 \text{ m/sec}
\]
\[
C_v = \frac{3}{3 + 1.431} = 0.61
\]

Now \( F_{bp} = 66.861 m^2 \)
\[
F_{bp} = 601.749 \text{ N}
\]
\( F_t < F_b \)
\[
524.106 < 601.749
\]

Hence Design is safe

5] Limiting wear load
\[
F_w = \frac{k \times D_g \times b \times Q \cos \theta_p}{2 t f_g}
\]
\( K = 1.853 \) For 20° full depth Cast Iron both Pinion and Gear 180 BHN
\[
Q = \frac{2 t f_g}{t f_g + t f_p}
\]
\( Q = 1.399 \)
\[
F_w = 4043.893 \text{ N}
\]
\( F_t < F_w \)
\[
524.106 < 4043.893
\]

Hence Design is safe

6] Dynamic load
\[
F_d = \frac{F_t + \frac{21 \times V_p \times |C_{eb} + F_t|}{21 \times V_p + \sqrt{C_{eb} + F_t}}}{21 \times V_p + \sqrt{C_{eb} + F_t}}
\]
For CI 20° full depth

Deformation factor \( C = 5900 \) N
Probable error $e = 0.05$

$F_d = 2005.4234 \text{ N}$

$F_d < F_w$

$2005.4234 < 4043.893$

Hence Design is safe

3.6 Design of Vertical Shaft[3]

For designing of shaft first the reaction as well as the moment about the loading point must be calculated:

$$R_A = 134.44 + 39.36$$

$$= 173.8 \text{ N}$$

$$R_A + R_B = 134.44 + 39.36$$

$$39.36 \times 30.48 + R_B \times 60.96 = 134.44 \times 15.24$$

$R_B = 13.93 \text{ N}$

Moment at A

$$M_A = 134.44 \times 15.24 + 39.36 \times 91.44 - 13.93 \times 60.96$$

$$M_A = 4798.7712 \text{ N}$$

Figure 5. Load applied on vertical shaft

Moment at B

$$M_B = 39.36 \times 7602 - 13.93 \times 45.72$$

$$M_B = 2362.3524 \text{ N}$$

$$R_A = 134.44 +$$

$$39.36 = 173.8 \text{ N}$$

$$R_A + R_B = 134.44 + 39.36$$

$$39.36 \times 30.48 + R_B \times 60.96 = 134.44 \times 15.24$$

$$R_B = 13.93 \text{ N}$$

Moment at C.

$$M_C = 0$$

Considering highest moment = 4798.7712 N

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

$T = 14.92 \text{ N-m}$

$T = 1492 \text{ N-cm}$

Stress $\sigma_b = 183 \times 2 = 366 \text{ N/mm}^2$
\[
= 366 \times 10^2 N/cm^2
\]

Polar moment of inertia
\[
I = \frac{\pi}{64} \times d^4 \quad y = \frac{d}{2}
\]

\[
\frac{M}{I} = \frac{\sigma_b}{y}
\]

\[
\frac{4798.7712}{\frac{\pi}{64} \times d^4} = \frac{366}{\frac{d}{2}}
\]

D=11.01mm

Consider bending and Shear increase by 25

d=12mm

3.7. Design of Horizontal Shaft [3]

Type of shaft = solid shaft

Power (P) = 500w

Speed (N) = 480rpm

Weight of cam (w) = 58.59N

Safe stress = 61 \times 10^6 N/mm^2

Length of shaft = 0.61m

Shaft design for twisting & bending

\[
P = \frac{2\pi}{60} \times \frac{N \cdot T}{2\pi \times 480 \times T}
\]

\[
500 = \frac{2\pi \times 480 \times T}{60}
\]

\[
T = 9.947N-m
\]

Bending moment M

= 58.59 \times 0.35

= 20.5065 \times 10^3

= 20506.5 N-m

Equivalent Twisting moment is given by

\[
T_{eq} = \sqrt{T^2 + M^2}
\]

\[
T_{eq} = \sqrt{9.947^2 + 20.5064^2}
\]

\[
T_{eq} = \frac{\pi}{16} \times D^3 J
\]

For J

\[
J = \frac{\text{Sys}}{\text{FOS}}
\]

Assume F.O.S. = 3

From Data book

Material SAE 1030

\[
J = \frac{183}{3}
\]

\[
J = 61 \times 10^6 N/mm^2
\]

\[
22.79 = \frac{\pi}{16} \times D^3 \times 61 \times 10^6
\]

D=18.576 mm

D=16mm approx. from data books
3.8. Design of Key [3]
For design a square key By Selecting material SAE1030 (from data book pg. no. 39) for safe design of key the shear stress is 183Mpa and crushing stress of material is 366Mpa

Calculations:
\[ \tau = 183\, M_{Pa}, \sigma = 366\, M_{Pa} \]
Diameter of shaft =12mm
Let, 
T= Torque transmitted by the shaft
F= Tangential force acting at the circumference of the shaft
D= Diameter of shaft
l= length of key
w= width of key
T= thickness of key
\( \tau \) = shear stress for the material of key
\( \sigma_c \) = crushing stress for the material of key
A little consideration will show that due to the power transmitted by the shaft the key may fail due to shearing and crushing.
Let,
L=1.25D

**L= 20mm**

Considering key fail by shearing.
Torque transmitted by key
\[ T = t_f + R \]
\[ T = w \times l \times \tau \times \frac{d}{2} \] \hspace{1cm} (1)
Also Torque transmitted by shaft
\[ T = \frac{\pi}{16} \times d^3 \times \tau \] \hspace{1cm} (2)
By equating eq\( ^n \) (1)&(2)
\[ w \times l \times \tau \times \frac{d}{2} = \frac{\pi}{16} \times d^3 \times \tau \]
\[ w = 4\, mm \]
The width and thickness of square key are same.
W=t
Therefore t=1.88mm

For shaft the safe key dimension are –

Length of key 20mm, Width of key 4mm, Thickness of key 4mm

4. Validation of Design

In the previous section of the work we have designed mechanism for pouring of resin as a solution of increased processing time. The complete setup for pouring the resin into reactor automatically hence designed which is shown in following figure.

![Figure 8. Block Diagram of Proposed Mechanism for Pouring of Resin](image)

But the matter of major concern is to analyse the detail design of each and every component of the setup and validate the same before actual implementation.

In order to analyse the same we have used ANSYS 14.0 software the detail report of which is shown below.

| Component   | ANSYS Analysis                                                                 | Result                                                                 |
|-------------|--------------------------------------------------------------------------------|------------------------------------------------------------------------|
| Bevel Gear  | ![Bevel Gear Analysis](image)                                                   | As shown in fig. according to the color scale which show the failure analysis of the part Blue color shows the min failure criteria similarly Red color indicate Maximum failure. The gear we design for the set up is covering with maximum blue color hence the design is justified and successful with min failure criteria. |
5. Conclusion
The design of feeding mechanism by considering all the material and other parameters have been done and validation of the design has been done successfully using ANSYS 14.0 software and it has been observed that the design is safe in said cases. The designed mechanism along with all the possible solutions of the present problem of company related to work hazard and increased processing time is proposed to the management. Similarly, the proposed solution if implemented successfully will leads to reduce in processing time as automatic method is applies instead of manual work. Similarly the worker who is engaged in pouring the resin manually in the reactor can ideally be utilized in some other productive work as he is replacing with the mechanism in the same task.

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