Design and Development of Bi-Directional Agitator using Scotch Yoke Mechanism

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Abstract— The conventional Agitators or the impellers of conventional agitator rotates in one direction only. These type agitators are commonly used in process industry for mixing of low viscous fluids. Due to rotation in one direction only it creates particular flow pattern in fluids hence the particles tend to stick to the walls of container. In order to have homogeneous mixing the impeller of Agitator must rotate bi-directionally i.e. during the one cycle this will form turbulent flow pattern leading to creation of irregular flow pattern and resulting into thoroughly mixed fluid mixture.

Key words: Unidirectional, Homogeneous Mixture, Periphery of Blades Shape, Oscillating Motion, Scotch Yoke Mechanism, Rack And Pinion

I. INTRODUCTION

Mixing, Stirring and blending of products are fundamentals operations in food and Beverage processing often a product consist of component that are either dissolve or contain a dispersion of particle of different sizes such as milk which consist of fat protein, carbohydrates, minerals and water.

In this case it is required to mix the heavy density metal powder in the fluid. The automobile industries uses low density evaporative fluid which when mixed with metal oxide powder gives good quality of paint. To ensure the good quality of paint it is necessary that the oxide powder is thoroughly mixed with low density fluid. The proper Homogenization of paint only possible by creating Turbulence in the content. To create high turbulence in fluid and powder mixture the impeller should rotate in forward and reverse direction. This bidirectional Agitator gives more effective agitating turbulence.

In this case to achieve the forward and reverse direction employed Scotch Yoke mechanism with proper arrangement of rack & pinion. Scotch yoke mechanism converts a constant rotational motion into reciprocating motion known as simple harmonic motion. In present case a rectangular cross- section bar is attached to the yoke as shown in fig 1.For this bar a rack is attached rack is a spur gear with any number of teeth with an infinite radius. As the rack reciprocates it drives the pinion attached to it.Again reciprocating motion converted into rotary motion. This rotary motion is then transfer to the impeller shaft.

For 0^0 to 180^0 revolution of the disk the impeller moves in forward direction and 180^0 to 360^0 the impeller moves in Reverse direction. Hence the high turbulence is created in the paint and help to maximize the Agitating performance.

It is also possible to control the degree of rotation of impeller just by changing the pinion attached to the impeller shafts with same module.

II. MECHANICAL DESIGN

A. *Design of Rack and Pinion*

Materials-
Rack - Plain carbon steel 40C8
Pinion - Plain carbon steel 40C8
S_{ut}-600 N/mm^2
σ_b = 30 N/mm^2

As the rack is consider as spur gear with infinite radius hence no. teeth on rack & pinion is same as well as module is same.

d = Pitch circle diameter = mz
d_a = Addendum circle diameter = m (z+2)

III. EXPERIMENTAL SETUP

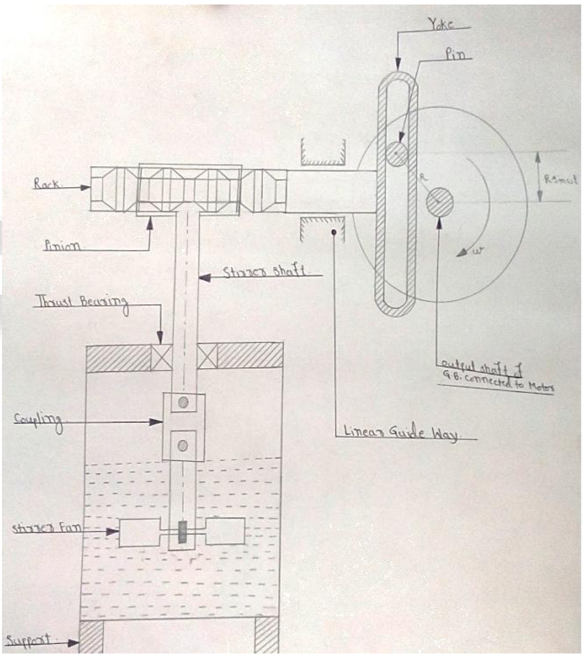

Fig. 1: Agitator with Scotch Yoke Mechanism

d_f = Dedendum circle diameter = m (z-2.5)
b = Face width
M_t = Transmitted torque (N-mm)
σ_b = Permissible bending Stress
S_{ut} = Ultimate tensile stress
F_s = Factor of Safety
Z_P = No.of teeth on pinion
Z_R = No.of teeth on rack
P_t = Tangential component
Pr = Radial component
Y = Lewis form factor
P_{eff} = Effective force
S_b = Beam strength of gear tooth
Cs = Service Factor
C_V = Velocity factor

α = Pressure angle
As the material for Rack & Pinion is same. Therefor we assume Pinion is weaker than the Rack.
$Z_{p\,(min)} = 2/\sin^2\alpha = 17$
Zp = 18
Lewis form factor (Y) for 18 teeth is 0.308.
From recommended series of module take m = 4
Face width is lies between
8m < b < 12m
(8*4) < b < (12*4)
32 < b < 48
Take b = 40 mm.
The permissible bending stress is one third of S_{ut}. (600/3 = 200 N/mm^2)
$S_b = m*b*\sigma_b*Y$
= 4*40*200*0.30 = 9856 N

A. Static Load:

$P_t = \frac{2\,Mt}{d_p}$

$= \frac{2*60*10^6*kw*0.745}{m*Zp*2\pi*n_p}$ {n_P = 280 RPM because rack moves to & fro in scotch yoke mechanism so 140*2 = 280}

$= \frac{2*60*10\text{^}6}{4*18*2\pi*280}$

= 705.44 N

B. Effective Load:

$V = \frac{\pi*d_p*n_p}{60*10\text{^}3} = \frac{\pi*4*18*280}{60*10\text{^}3}$
= 1.055 m/s

$C_V = \frac{3}{3+V} = \frac{3}{3+1.055} = 0.739$

$P_{eff} = \frac{Cs}{Cv}*P_t = \frac{1}{0.739}*705.44 = 954.87$

C. Factor of Safety:

$F_s = \frac{S_b}{P_{eff}} = \frac{9856.87}{954.87} = 10.32$

D. Surface Hardness:

$S_w = P_{eff} * Fs = 954.87*10.32 = 9856.87$

$Q = \frac{2Z_g}{Z_g+Z_P} = 1$

$S_w = b*Q*d_P*[\frac{BHN}{100}]^2$

$9856.87 = 40*1*4*18*[\frac{BHN}{100}]^2$

BHN = 185
It is assumed that gears are manufactured according to Grade-6
For this grade -: e = 8+0.63Φ
For pinion –: $\Phi = m+0.25\sqrt{dp} = 5.06$
$e_p = 8+0.63*5.06 = 11.188$
For Rack -: $\Phi = m+0.25\sqrt{d_R} = 5.06$
$e_p = 8+0.63*5.06 = 11.188$
Total e = 11.188+11.188 = 22.38μm = 22.38*10^-3mm

E. Dynamic Load

$P_d = \frac{21V[C*e*b+Pt]}{21V+\sqrt{[C*e*b+Pt]}}$

$= \frac{21*1.055\,[11400*22.38*10^{-3}*40+706.44]}{21*1.055+\sqrt{11400*22.38*10^{-3}*40+706.44]}}$

= 1866.89 {C= Deformation constant and for material 40C8 it is 11400}
$Peff = Cs*P_t + P_d = 1*706.44 + 1866.89 = 2573.33$

$Fs = \frac{S_b}{P_{eff}} = \frac{9856}{2573.33} = 3.83$

Design is Safe
Basic Dimensions of Rack
d_R = 4*18 = 72 mm
Length = π*d_R or (π*m*Z_R) = 226.19
L = 226.19 + 35 **(Grinding Allowance)**
= 262mm
Mounting Distance (a) = Z*m/2+H+X*m
= 18*4/2+36+0.6*4
= 74.4 mm

F. Design of Scotch Yoke

For complete revolution of pinion ie.0^0 to 360^0 the rack should move 'L'. Hence the pin should be adjusted at R= 113 mm from the Centre of motor shaft.

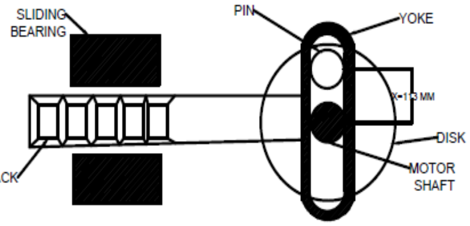

Fig. 2: Scotch Yoke Mechanism

The pin 'P' slides in the slot and Yoke oscillate up and down in vertical direction only. The motion of point P is SHM.

We have $V = \frac{dx}{dt} = \frac{d(Rsinwt)}{dt}$ = wR coswt & $a = \frac{dv}{dt}$ = $-w^2R\sin wt$

IV. POWER REQUIRED TO RUN THE SYSTEM

A. Input Data

Kinematic viscosity of paint = 2.4 poise
= 2.4/0.01 centipoise
= 240 centipoise
Specific gravity of paint = 1.59 Kg/lit

First of all it is required to calculate the torque which is helpful for the stirring and based on this torque selecting an appropriate motor after incorporating a suitable factor of safety.
Total Torque Required =
Torque owing to viscous force + Torque owing to static Pressure

1) Calculation of Torque owing to Viscous Force

(Diameter of blade = 10cm)
Actual motor speed 1400 rpm.In this system we are using 10:1 reduction gear box. Hence speed of pinion is 140 rpm
Tangential speed of shaft = u=π*D*N/60 = π*0.10*140/60
= 0.733 m/sec

Now Shear Stress = $\mu\,\frac{\partial u}{\partial y}$ = 0.24 * [0.733/0.01] = 17.592 N/m^2
du = change in speed = u-0 = 0.733 m/sec
dy = Distance between shaft and journal = 0.01m.
Assuming flat blade having width 40 mm.
A = π*D*w = π*0.1*0.04 = 0.012 m^2
Shear Force (F) = Shear stress * shear Area
= 17.592*0.012
= 0.211 N
Power = F * u = 0.211 * 0.733 = 0.155 watt………. (1)

2) Calculation of Torque Owing to Viscous Force at Top and Bottom End of Blades –

Thickness of blade = 40 mm

Length of blade = 100 cm = 1000 mm
Viscosity (μ) = 2.4 poise
Area of blade that is exposed to this shear intensity will be
A= L * t = 1000 * 40
A= 40 * 10^3 mm^2 = 0.04 m^2.
Shear Force (F) = Shear Stress * Shear Area = 17.592 * 0.04 = 0.704 N.
Total shear force (F) = 3F = 3 * 0.704 = 2.111 N
Power = F * u = 2.111 * 0.733 = 1.547 watt……….. (2)

3) Calculation of torque owing to static total pressure acting on the blades by virtue of stationary fluid –

Specific Gravity = 1.59 Kg/lit = 1.59 * 1000 Kg/m^3
Pressure = ρ*g*h*A = 1590*9.81*1*0.04
= 623.916 N {h = 1m}

Torque that each pinion has to overcome to rotate about its own axis is given by
T = F * Distance (Radius) = 623.916 * 0.04
= 24.956 Nm

Power required at the output shaft to overcome the static resistance of fluid is

$$Ps = \frac{2\pi * N * T}{60} = \frac{2*\pi*140*24.956}{60} = 365.883 \text{ watt} \ldots\ldots\ldots (3)$$

The net power required at the output shaft is the summation of above three powers ie.Equation 1,2 & 3
P_{NET} = 0.155 + 1.547 + 365.883 = 368 watt.

The scotch Yoke mechanism used for converting rotary motion into oscillating motion is not tested for its efficiency so assuming only 50% efficiency. Also some power is loss in friction between Rack and Pinion assume it is 10%.So overall efficiency is 100 – 60 = 40 %
Total Power required for 40 % efficient mechanism is
P = 368 + 40 / 100 * 368
P = 515 watt. = 690.626 HP.

4) Design of Output Shaft

Material Selection
Designation-EN24
Sut = 900 N/mm^2
Syt = 700N/mm^2
According to ASME code permissible values of Shear stress planned from various relations
τ_{max} = 0.18*Sut=0.18*900 = 162 N/mm^2 OR
τ_{max} = 0.3*Syt = 0.3*700 = 210 N/mm^2
Considering minimum of the above values so τ_{max} = 162 N/mm^2.Shaft is provided with key way this will reduce its strength. Hence reducing above values of allowable stress by 25%.
τ_{max} = 121.5 N/mm^2 mm

B. Advantages

1) Stirrer has bi-directional ie,it rotates in both directions; this gives uniform mixing
2) Quality of mixing is very high.
3) Fast production rate

C. Applications

1) Mixing of multiple colour paint in paint industry.
2) Mixing of metallic powders in pigment in preparation of ionic paints.
3) Can be used as skimming machine
4) Dairy applications with suitable change in stirrer material 5. Mixing applications in pharmaceutical industry

V. Conclusion

Mixing process has been accomplished which follow that the proposed mixing prevent the formation of segregated region hence shorten the mixing time than other mixing method (constant speed, manual mixing, sinusoidal bidirectional). Also by using the bidirectional mixer in container create turbulent flow of mixture and we get the homogeneous mixture.

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