Improving Product Design Quality of Material Handling System by Using Crowd-Source Based Design Environment

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***Abstract*: Small and medium-sized enterprises rely heavily on a skilled, technical and professional workforce to increase product design quality and remain globally competitive. They do not have enough employees and related resources to produce high quality products design with limited budget and time. Crowdsourcing offers an opportunity for them to improve their product design quality by leveraging the knowledge of a large community of crowd. In this study the focus is to improve product design quality of material handling system with the help of crowdsourcing based design environment. First the improving product design quality task is defined and its evaluation criteria's are set. Then we decide the crowd from whom we get design inputs and specification for design. Once we got design quality improvement inputs we analyse the inputs and modified the design. After the modification we achieve significant reduction in weight of the system and increase in the system performance.**

Index Terms: Crowdsourcing, Material Handling System, Product Design Quality, Quality Control, Conveyor, Finite Element Analysis.

I. INTRODUCTION

Crowdsourcing

Crowdsourcing is the collection of information, opinions, or work from a group of people. Taxonomy Howe popularized the term crowdsourcing and defines it as the act of a company or institution to outsource a function usually performed by its employees to an undefined network of people (generally large) in the form of an open call. This work can be done collaboratively or by single individuals (expert or novice). The fundamental prerequisite is the use of an open and wide call. The generic definition of crowdsourcing is the act of outsourcing a task to a 'crowd' rather than an 'agent' designated as contractor in the form of an open invitation". If an organization is sufficiently large and heterogeneous; its 'pool' of employees can also act as a crowd.

The crowdsourcing process consists of four key elements: the requester, the crowds, the task which needs to be crowd sourced and the crowdsourcing platform. The platform provides the requester a way to get access to large crowds conveniently and involve them into their production process and decision-making process. A simplified crowdsourcing process is shown in Fig. 1. "Interactions 1" mainly means task input and the feedback from the platform, while "Interactions 2" refers to the broadcast of a task to crowds and crowd′s submissions of the performed task (including other communications with the platforms). In the process, "Requester" refers to an individual or institution seeking help from crowds. "Crowds" refer to a large group of people working on an internet-based crowdsourcing platform or offline platform and they take on tasks that are advertised via an open call. Only when the crowdsourcing task is well-defined, then the proper crowds with specific knowledge and skills will be selected. The crowdsourcing task proposed by the requester needs to be mapped from the high-level goal to specific subtasks to be completed by the crowds. The crowdsourcing form depends on the nature of crowdsourcing tasks. Before crowdsourcing the task, an open call including the specific task and its evaluation criteria need to be defined first. The evaluation criteria can be provided by the requester directly or be collected through crowdsourcing.

Material Handling System

Material handling systems is mechanical equipment used for the movement, storage, control, and protection of materials, goods and products throughout the process of manufacturing, distribution, consumption, and disposal. The different types of handling equipment can be classified into four major categories: transport equipment, positioning equipment, unit load formation equipment, and storage equipment.

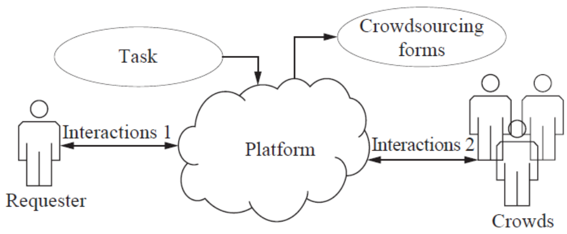

Figure No. 1 A simplified crowdsourcing process

Design Considerations of Flat Belt Conveyor

A belt conveyor is an endless belt operation between two pulleys with its load supported on idlers. The belt conveyor consists of a belt, drive mechanism and end pulleys, idlers and loading and discharge devices. Belt conveyors have antifriction bearing; therefore, these have a high mechanical efficiency. Material carried by belt conveyor lie still on the surface of belt or there is no relative motion between the product and belt. This results in generally no damage to material. Some of important considerations that may be taken for designing are as follows: Space available, Characteristic of the material to be conveyed, capacity requirement, conveying length, conveyor speed.

II. PROBLEM IDENTIFICATION

We all know the phrase "There is always room for improvement". Existing design conveyor system was design by in-house design team with all the inputs from different departments. As per phrase there is room for improvement in existing designed conveyor.

Small and medium-sized enterprises rely heavily on a skilled, technical and professional workforce to increase product design quality and remain globally competitive. They do not have enough employees and related resources to produce high quality products design with limited budget and time. Due to constraints in thinking, ideas or thought process they cannot observe or predict the improvement in existing conveyor. So crowdsourcing concept was used. Crowdsourcing offers an opportunity for them to improve their product design quality by leveraging the knowledge of a large community of crowd. Therefore the current research deals with improvement in conveyor design quality using the crowd source based design platform.

III. WORK METHODOLOGY

From different material handling system conveyor was selected for design quality improvement. Original equipment manufacturer (OEM) and its customer, employees, operators will be considering as a crowd. Conveyor design quality improvement specification and inputs will be collected from them. FEA will be used with help of analysis package Autodesk Inventor Nastran and weight of roller was reduced by iteration method.

- From different material handling system selection of conveyor for design quality improvement.
- Practical implementation of crowdsourcing process
- Product design concepts from crowds and its evaluation for shortlist of better design concept.
- Modification in exiting design conveyor and design calculation.
- Finite element analysis.
- Analysis of the results.

IV. CROWDSOURCING BASED DESIGN METHODOLOGY

When designing a specific product on a crowdsourcing platform that supports product design, a team consisting of crowds with various skills and experience work collaboratively. Since product design heavily depends on information sharing and intermediary results, the crowd sourced product design processes need to put more emphasis on communication and information sharing, design evaluation and integration with evaluation results during the design process. The cooperation effectiveness plays a vital role on the output quality.

Steps of the crowdsourcing product design process are shown as follows –

- Product design inputs (Speed, capacity, material, length and width)
- Define crowdsourcing task on crowdsourcing platform
- Crowd selection from large group of people (OEM, Customer, operators)
- Design solutions from crowd
- Evaluation process
- Evaluation result and design feedback

Design solutions from crowd –

- Increase capacity of conveyor
- Reduce weight of conveyor
- Reduce belt width
- Reduction downtime of maintenances

In this study we focused on conveyor weight reduction and belt width reduction.

V. DESIGN AND STUDY OF EXISTING CONVEYOR SYSTEM

The existing conveyor is designed in 3D cad software Inventor 2020. Major components of conveyor are Side plates, drive and driven rollers, skid plate, belt, motor, side covers. The total weights of these components are 174.85 Kg found from the cad software.

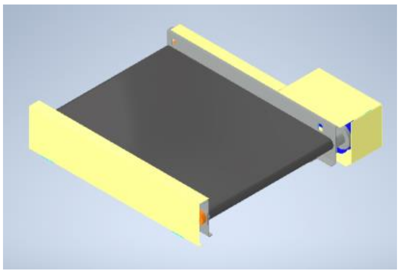

Figure No. 2 Existing conveyor

Design Calculation

- ***Stress analysis of Roller Drum***

Design Specifications –
Material of roller – Mild Steel
Modulus of Elasticity $E = 2.080 \times 10^5$ N/mm^2 …….PSG TECH 1.1
Density of MS = ϱ_r = 7840 Kg/m^3
Yield Strength S_{yt} = 590 Mpa
Factor of Safety = 2
Considering Uniform Distributed Load on the roller and roller as a simply supported beam

$\sigma_{all} = \frac{S_{yt}}{FOS} = \frac{590}{2} = 295$ MPa
m = 69 Kg = 676.89 N
D_o = 72 mm
D_i = 61.6 mm
L_d = 1000 mm = 1m
y = Distance from neutral axis = $\frac{y}{2} = \frac{72}{2}$ =36 mm = 0.036 m …….PSG TECH 6.5

Maximum moment (M_{max}) = $\frac{m \times L_d^2}{8} = \frac{676.89 \times 1^2}{8}$ = 84.61 Nm…….PSG TECH 6.5

Moment of Inertia (I) = $\pi \times \frac{(D_o^4 - D_i^4)}{64} = \pi \times \frac{(0.072^4 - 0.0616^4)}{64} = 6.1237 \times 10^{-7}$ m^4

Max. Bending stress (σ_b) = $\frac{M_{max}}{I} \times y = \frac{84.61}{6.1237 \times 10^{-7}} \times 0.036 = 4974082.03$ N/mm^2
Max. Bending stress = 4.974 MPa
Factor of safety of design (F_s) = $\frac{\sigma_{all}}{\sigma_b} = \frac{295}{4.974}$ = 59.30
As Calculated F_s is greater than assumed F_s, Selected Material can be considered as safe.

Maximum Deflection (Y_{max}) = $\frac{5 \times m \times L_d^3}{384 \times EI} = \frac{5 \times 69 \times 9.81 \times 1^3}{384 \times 2.08 \times 10^{11} \times 6.1237 \times 10^{-7}}$ …….PSG TECH 6.5
(Y_{max}) = 6.92×10^{-5} mm
As compared to length 1000 mm deflection of 7.05×10^{-6} mm is very negligible. Hence roller can be considered as safe.

- ***Stress analysis of Shaft***

Design Specifications –
Material of roller – Mild Steel
Modulus of Elasticity $E = 2.080 \times 10^5$ N/mm^2 …….PSG TECH 1.1
Density of MS = ϱ_r = 7840 Kg/m^3
Yield Strength S_{yt} = 590 Mpa
Factor of Safety = 2
Considering Uniform Distributed Load on the shaft and shaft as a simply supported beam

$\sigma_{all} = \frac{S_{yt}}{FOS} = \frac{590}{2} = 295$ MPa
Weight of product, belt and drum roller = 78 Kg = 765 N
D = 35 mm
Length of the drive shaft = L_{Ds} = 1281 mm
y = Distance from neutral axis = $\frac{y}{2} = \frac{35}{2}$ = 17.5 mm = 0.0175 m…….PSG TECH 6.5

Maximum moment (M_{max}) = $\frac{m \times L_d^2}{8} = \frac{765 \times 1.281^2}{8}$ = 156.92 Nm…….PSG TECH 6.5

Moment of Inertia (I) = $\pi \times \frac{D^4}{64} = \pi \times \frac{0.035^4}{64} = 7.37 \times 10^{-8}$ m^4
Max. Bending stress (σ_b) = $\frac{M_{max}}{I} \times y = \frac{156.92}{7.37 \times 10^{-8}} \times 0.0175 = 37042062.42$ N/mm^2
Max. Bending stress = 37.04 MPa
Factor of safety of design (F_s) = $\frac{\sigma_{all}}{\sigma_b} = \frac{295}{37.04}$ = 7.96
As Calculated F_s is greater than assumed F_s, Selected Material can be considered as safe.

Maximum Deflection $(Y_{max}) = \frac{5 \times m \times L_d^3}{384 \times EI} = \frac{5 \times 78 \times 9.81 \times 1.281^3}{384 \times 2.08 \times 10^{11} \times 7.37 \times 10^{-8}}$ …….PSG TECH 6.5

$(Y_{max}) = 0.00137$ mm

As compared to length 1281 mm deflection of 0.00137 mm is very negligible. Hence shaft can be considered as safe.

Finite Element Analysis

The stress analysis calculation is performing on the critical parts of the conveyor. In conveyor maximum failure occurs in the roller. So we decide to perform static structure analysis on roller. Static analysis calculates the effect of steady loading condition on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. Static structural analysis is carried out with the help of NASTRAN software.

Steps involved in finite element analysis are as follows –

- Prepare 3D model and import same in NASTRAN software
- Define the material properties
- Discretize the model
- Define the contact between the parts
- Specify load and boundary condition (677N UDL & anticlockwise moment 11787Nmm)
- Run simulation
- Analyze the results

Results for static analysis

Maximum stress – 4.19 MPa

Maximum displacement – 0.0008 mm

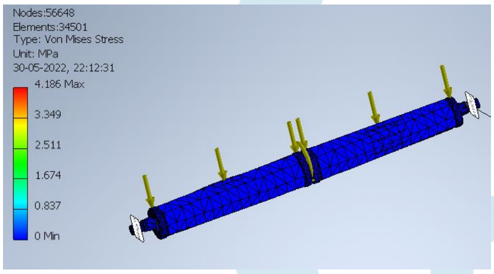

Figure No. 3 Stress plot of existing roller

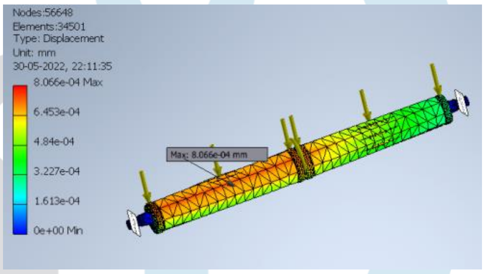

Figure No. 4 Displacement plot of existing roller

VI. DESIGN OF CONVEYOR SYSTEM AS PER CROWD SOURCING DATA

Changes are done in the existing conveyor as per crowd suggestions are 1) drum material is change from MS to Nitrile rubber to reduce the weight of roller. 2) Belt width is modified to 900 mm.

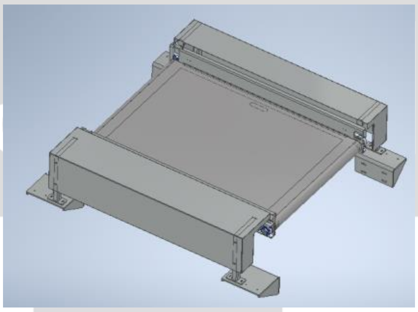
Figure No. 5 New design conveyor

Design Calculations of New Conveyor System

- ***Stress analysis of Roller Drum***

Design Specifications –

Material of roller – Mild Steel

Modulus of Elasticity E = 0.855 MPa

Density of MS = ϱ_r = 1000 Kg/m^3

Yield Strength S_{yt} = 15 Mpa

Factor of Safety = 2

Considering Uniform Distributed Load on the roller and roller as a fix beam

$\sigma_{all} = \frac{S_{yt}}{FOS} = \frac{15}{2} = 7.5$ MPa

m = 68.14 Kg = 668.45 N

D_o = 72 mm

D_i = 38 mm

L_d = 900 mm = 0.9 m

y = Distance from neutral axis = $\frac{y}{2} = \frac{72}{2}$ =36 mm = 0.036 m …….PSG TECH 6.6

Maximum moment (M_{max}) = $\frac{m \times L_d}{24} = \frac{668.45 \times 0.9}{24}$ = 25.066 Nm…….PSG TECH 6.6

Moment of Inertia (I) = $\pi \times \frac{(D_o^4 - D_i^4)}{64} = \pi \times \frac{(0.072^4 - 0.038^4)}{64} = 1.21 \times 10^{-6}\ m^4$

Max. Bending stress (σ_b) = $\frac{M_{max}}{I} \times y = \frac{25.066}{1.21 \times 10^{-6}} \times 0.036 = 745791.32\ N/mm^2$

Max. Bending stress = 0.75 MPa

Factor of safety of design (F_s) = $\frac{\sigma_{all}}{\sigma_b} = \frac{7.5}{0.75} = 10$

As Calculated F_s is greater than assumed F_s, Selected Material can be considered as safe.

Maximum Deflection (Y_{max}) = $\frac{m \times L_d^3}{384 \times EI} = \frac{68.14 \times 9.81 \times 0.9^3}{384 \times 0.855 \times 10^6 \times 1.21 \times 10^{-6}}$ …….PSG TECH 6.6

(Y_{max}) = 1.2 mm

As compared to length 900 mm deflection of 1.2 mm is very negligible. Hence design roller can be considered as safe.

- ***Stress analysis of Shaft***

Design Specifications –

Material of roller – Mild Steel

Modulus of Elasticity E = $2.080 \times 10^5\ N/mm^2$ …….PSG TECH 1.1

Density of MS = ϱ_r = 7840 Kg/m^3

Yield Strength S_{yt} = 590 Mpa

Factor of Safety = 2

Considering Uniform Distributed Load on the shaft and shaft as a simply supported beam

$\sigma_{all} = \frac{S_{yt}}{FOS} = \frac{590}{2}$ = 295 MPa

Weight of product, belt and drum roller = 70.78 Kg = 694.35 N

D = 38 mm

Length of the drive shaft = L_{Ds} = 1204 mm

y = Distance from neutral axis = $\frac{y}{2} = \frac{38}{2}$ = 19 mm = 0.019 m…….PSG TECH 6.5

Maximum moment (M_{max}) = $\frac{m \times L_d^2}{8} = \frac{694.35 \times 1.204^2}{8}$ = 125.82 Nm….PSG TECH 6.5

Moment of Inertia (I) = $\pi \times \frac{D^4}{64} = \pi \times \frac{0.038^4}{64} = 1.02 \times 10^{-7}\ m^4$

Max. Bending stress (σ_b) = $\frac{M_{max}}{I} \times y = \frac{125.82}{1.02 \times 10^{-7}} \times 0.019 = 23437058.82\ N/mm^2$

Max. Bending stress = 23.44 MPa

Factor of safety of design (F_s) = $\frac{\sigma_{all}}{\sigma_b} = \frac{295}{23.44} = 12.59$

As Calculated F_s is greater than assumed F_s, Selected Material can be considered as safe.

Maximum Deflection (Y_{max}) = $\frac{5 \times m \times L_d^3}{384 \times EI} = \frac{5 \times 70.78 \times 9.81 \times 1.204^3}{384 \times 2.08 \times 10^{11} \times 1.02 \times 10^{-7}}$ …….PSG TECH 6.5

(Y_{max}) = 0.00074 mm

As compared to length 1281 mm deflection of 0.00074 mm is very negligible. Hence selected shaft can be considered as safe.

Finite Element Analysis of Modified Roller

- Applied load is 677N and anticlockwise moment 11787 Nmm.

Results obtained from static analysis of new design roller

Maximum stress – 1.065 MPa

Maximum displacement – 0.0871 mm

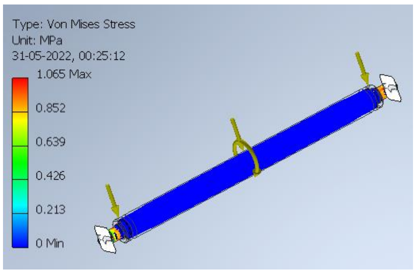

Figure No. 6 Stress plot of modified roller

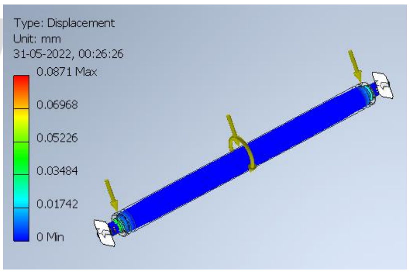

Figure No. 7 Displacement plot of modified roller

VII. ANALYSIS OF RESULTS

Iteration Results of Roller to find diameter of shaft

Table 1 Iterations carried out for various dimensions of roller

Sr. No.	Shaft Diameter (mm)	Bending Stress (MPa)	Deflection (mm)	Actual Weight (Kg)	Weight reduction (Kg)
1	30	1.167	1.449	8.763	10.614
2	32	0.9102	1.449	9.426	9.951
3	34	0.6604	1.449	10.131	9.246
4	36	0.4046	1.449	10.878	8.499
5	38	0.4204	0.08533	11.669	7.708
6	40	0.5685	0.08423	12.182	7.195
7	42	0.6469	0.01751	13.065	5.727

Result - By studying above iterations, having drum diameter 72 mm and shaft diameter 38 mm was selected as a best solution which is having good weight reduction. If we compare the weight reduction with existing one then it is 39.77%.

Comparison of results

Table 2 Theoretical stress analysis results

Parameter	Existing Design		New Modified Design	
	Deflection (mm)	***Stress (MPa)***	***Deflection (mm)***	***Stress (MPa)***
Drum	0.0000692	4.974	1.2	0.75
Shaft	0.00137	37.04	0.00074	23.44

Table 3 Nastran stress analysis results

Parameter	Existing Design		New Modified Design	
	Deflection (mm)	***Stress (MPa)***	***Deflection (mm)***	***Stress (MPa)***
Roller	0.0008	4.19	0.0871	1.065

The above table shows that deflection in new designed roller is more and stresses are less when we compare it with existing roller.

VIII. CONCLUSION

In this work the crowdsourcing technique have been utilize for the design quality improvement of conveyor. Diverse design concepts are submitted by crowd. Weight optimization of conveyor is done as per crowd concepts. Weight optimization of conveyor revels he following facts –

- A weight reduction of 21.79% is achieved in the major components of conveyor.
- Among the heavy component, the maximum reduction in weight was achieved in side plates and roller.
- The overall weight of roller was reduced by 39.77% and side plate was reduced by 40.90%.
- A stresses in the new design roller are less compared to existing roller.

IX. ACKNOWLEDGMENT

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