

Design and Optimization of Slat Conveyor System for Tractor Assembly Line

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Abstract - Material handling is loading, moving and unloading of materials. To do it safely and economically, variants of tackles, contrivances and equipment are utilized, when the materials handling is referred to as mechanical handling of materials. One of the definitions adopted way back by the American Materials Handling Society is, Materials handling is the art and science involving the moving, packaging and storing of substances in any form. A slat is fundamentally a thin narrow piece of metal, plastic or wood. A slat conveyor is one the type of material handling equipment which is utilized in many industrial applications. Slat conveyors are great for assembling products on either a moving assembly line or on the line at each works station while the line is ceased. Withal, they provide a great stable working surface. The above reason makes the slat conveyor famous in material handling industry. This paper describes the design calculation of slat conveyor system for the company who is in the process of automation of plant. Utilizer need dedicated conveyor system for 15 stations tractor assembly line. Apart from this the optimization of slat is done which was additionally the component of our work. With the proposed conveyor system physical work cost will be minimized withal the conveyance of material handling cost will be abbreviated.

Key Words: Introduction, problem statement, nomenclature, design calculations, slat optimization, result, conclusion, references.

1. INTRODUCTION

Conveyors are gravity or powered equipment commonly utilized for moving bulk or unit load perpetually or intermittently, unidirectional from one point to another over fine-tuned path, where the primary function is conveying of the material with the avail of kineticism of some components of the equipment. The slat conveyor is one of the types of conveyor system especially utilized for conveying heftily ponderous objects. They provide a rigid, flat surface for every item on the conveyor which is the deal for many kinds of products that cannot be utilized on rollers or belts due to their anomalous shape. Additionally, these slats are typically composed of engineering plastic or metal, which sanctions slat conveyors to function in hazardous, high weight, and high-temperature environments. Another major advantage is

that the slats can be built with unique shapes, giving them more use-cases than most conveyors. Slat conveyors are very well-suited for robotic loading and unloading functions as the fixtures are always in a repeatable location and with opportune sentinelning, human and robotic assembly work can be carried out on the same assembly line. Slat conveyors kenneed for long engenderment life & the least magnitude of maintenance and life. Slat conveyor systems withal promotes installing moving sidewalks upon request so the employee can move with the assembled product for a more efficient engenderment. The cull criteria for slat conveyor system is given as following-

- Conveying weight and dimensions.
- Slat material, supports, and variable speed.
- Control & special considerations.

This research paper describes the detail information about the design and optimization of slat conveyor system for the application of tractor assembly line. This conveyor mainly consists of slat, motor, chain, sprockets, shafts, types of bearings, keys, head unit, intermediate unit and, tail unit, etc.

2. PROBLEM STATEMENT

Design and Fabrication of Slat Conveyor System for Tractor Assembly Line. The conveyor should be able to withstand load of 15 tractors including 15 work stations with provision for a trolley on both sides. The speed of conveyor should be variable from 0.8 m/min to 1.4 m/min. For this conveyor design the input parameters are given as following-

- Component to be conveyed - Tractor
- Maximum number of Tractors on a conveyor at a onetime - 15 Nos.
- Total number of stations - 15
- Average weight of 1 tractor - 3000 kg.
- Total length of Conveyor (center to center distance of sprockets) - 72.5 m.
- Station Pitch - 4.83 m.
- Linear variable speed range - 0.8 to 1.4 m/min.
- Average Dimension of Tractor-l*b*h - 3000*2500*2100
- Slat width - 3.5 m.

3. NOMENCLATURE

μ = Coefficient of friction

g = Acceleration due to gravity

λ = Service factor

α = Transmission efficiency

τ_{max} = Permissible shear stress

S_{yt} = Yield strength in tension

S_{ut} = Ultimate tensile strength of material

k_b = Combined shock and fatigue factor due to bending

k_t = Combined shock and fatigue factor due to torsional moment

M_b = Bending moment

M_t = Torsional moment

4. DESIGN CALCULATIONS

4.1 Slat Design

Initially for slat design the required width is given. The selection of material for the slat is very consequential and one of the main decisions in whole project. Because all the weight of all tractors along with its workers and auxiliary equipment is on the slat. If the slat is composed of very light metal, then it will have propensity to buckle due to the load, then whole system will fail. If the very heftily ponderous material is selected, then power required to move the live components will increment. As well as due to this construction, all other power conveying components are made to be vigorous, which will significantly increase the cost of project. By considering the following factors the slat material is selected-

- Strength of material
- Cost of material
- Availability of material
- Fabrication facilities available at plant

By many iterations and considering material properties for long duration of scope, optimum material is opted for.

Selected material – Mild Steel

In order to sustain the weight of all the components to be conveyed on the conveyor, three types of slat design are considered, which are –

1. Normal slat
2. Slat with 'I' section
3. Slat with 'C' section

The final design is selected by performing multiple iterations regarding the constructional details and dimensions of all the components associated with the slat. By considering various factors, optimum slat construction is opted for. The

optimization of slat is very lengthy process and this is described in separate part.

4.2 Power Calculations

1] Mass of 1 tractor- 3000 kg

No. of stations- 15

Mass of all tractors- 45000 kg

2] Mass of 1 slat- 176 kg

No. of slats- 500

Total mass of slats- 88000 kg

3] Mass of chain- 20.4 kg/m

Length of chain- 147.2 m

No. of chains- 2

Total mass of chain- 6005.76 kg

4] Mass of 1 trolley- 600 kg

No. of stations- 15

Total mass of trolleys- 9000 kg

5] No. of workers/station- 6

No. of stations- 15

Total mass of workers- 6300 kg (assuming 70 kg/worker)

Now,

Total mass (M)- 154305.76 kg, μ - 0.05

Total force (F)= $\mu * M * g = 0.05 * 154305.76 * 9.81$

= 75.68697 KN (1)

6] Sliding velocity (V)- 0.02333 m/sec

7] Diameter of sprocket (D)- 0.783 m (2)

Hence,

Rpm (N)= $(V * 60) / (3.14 * D) = (0.0233 * 60) / (3.14 * 0.783)$

= 0.569425 rpm (3)

From (1) & (2)

Torque(T)= $(r * F) = (0.3915 * 75.68697)$

= 29.6287 KNm (4)

Finally,

8] λ - 1.5 (5)

9] α - 0.7 (6)

Power(P)- $(2 * 3.14 * N * T * \lambda) / (60 * \alpha)$

From (3), (4), (5) & (6)

P= $(2 * 3.14 * 0.569425 * 29.6287 * 1.5) / (60 * 0.7)$

Hence,

Power (P)=3.7843 KW

From the catalogue the Helical Geared Foot Mounted Motor is selected having power of 4 KW.

4.3 Chain Selection

There are two chains required for this conveyor. For the main chain initially, we calculated the different types of tension and based on the total tension and required factor of safety the main chain is selected with F type roller & A2 attachment additionally it was checked that whether it is safe or not. Similarly, based on output motor power and output speed of motor the transmission chain is selected.

- 1) Main chain pitch - 300 mm
- 2) Transmission chain pitch - 76.2 mm

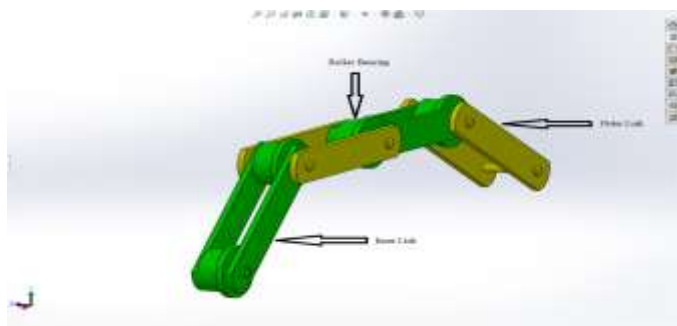


Fig.4.3.1.Solid model of the main chain

4.4 Sprocket Selection

We required two types of sprockets. To design the sprocket, we need theoretical value of torque which should be applied. It is either taken from catalogue or it is calculated from previous designed sprockets-torque relation. Once the torque is defined, we check the value of sprocket diameter which gives us the defined torque value by relation $(T=F*r)$. This is done by relation $v=3.14*D*N/60$. This relation gives us value of N which we can use in power relation. $(P=2*3.14*N*T/60)$

Selected material - Cast iron

- 1) Main sprocket PCD - 784 mm (8T)
- 2) Transmission sprocket PCD -
 - a) Small sprocket PCD - 414.7 mm (17T)
 - b) Large sprocket PCD - 1213.56 mm (50T)



Fig.4.4.1.Solid model of the main sprocket

4.5 Shaft Design

As we required two shafts viz. head shaft and tail shaft. For shafts design the ASME code method is used. According to this code, the τ_{max} is calculated using next two relations

$\tau_{max} = 0.30 S_{yt}$ or $\tau_{max} = 0.18 S_{ut}$ (whichever is minimum) The ASME code is based on maximum shear stress theory of failure and it is given by following equation,

$$\tau_{max} = \frac{16}{\pi d^3} \sqrt{(k_b M_b)^2 + (k_t M_t)^2}$$

From above formula the diameter of shaft is calculated.

Selected material - C45

- 1) Head shaft diameter = 180 mm
- 2) Tail shaft diameter = 120 mm



Fig.4.5.1.Solid model of the head shaft

4.6 Bearing Selection

Based on the shaft diameter the bearings are selected. The type of bearing is selected on the application we required two types of bearings viz. spherical roller bearings and take up bearings. Take-up bearings are a type of mounted bearing primarily utilized for adjusting and maintaining conveyor belt tension. Take-up is the process of adjusting the length of the belt and chain to compensate for stretch, shrinkage, or wear, and to maintain proper tension. The take-up bearing assembly consists of a housing that is mounted to a frame. The bearing is guided along the frame by a slot in the bearing housing or other means. The take-up assembly contains a screw or other mechanism for adjusting its location along the frame. A shaft connects two take-up bearings, one mounted on each side of the assembly. When a conveyor belt or chain needs to be replaced or tightened, the take-up bearing is adjusted via the screw or other mechanism to provide the appropriate amount of tension on the system. The bearings are selected from SKF bearing catalogue.

4.6 Key Design

The key design is depending on the shaft diameter and rotating machine elements like pulleys, gears, sprockets etc.

Selected material – C20

The dimensions of three keys are as following-

- 1) Head shaft key - 120*45*25 mm
- 2) Tail shaft key - 120*32*18 mm
- 3) Motor shaft key - 120*40*22 mm

4.7 Structure Design

The structure generally uses readily available standard sections that are purchased from the steelmaker or steel stockholder and joined together with the application of suitable welding, nut & bolts or other fastening methods. The structural steel is selected because of its innumerable benefits. The solid models of three structural members are shown.



Fig.4.7.1. Head unit



Fig.4.7.2. Tail unit



Fig.4.7.3. Intermediate structure

5. SLAT OPTIMIZATION

After the design of slat, analysis is performed. The main objective of the analysis is to check or verify the endurance of slat. This is done by considering stresses and deformations at extreme points. Analysis is done with the help of FEA method where we choose the mesh size which supports the need for analysis. In our project, we selected 3 types of slat. The selected material is mild steel and it has following mechanical properties.

Mechanical Properties	Mild Steel
Young's Modulus	210 GPa
Poisson's Ratio	0.3
Density	7850 Kg/m ³

Table 5.1. Mechanical properties of mild steel

For all the three slats there is point load of 14.75424 KN and uniformly distributed load of 2.2544 KN. Hence, the total load is 17.10864 KN. The following figure shows the load distribution.



Fig.5.1. Free body diagram

First one was with no section beneath the surface. It has 34.18 MPa stress value. After analyzing, we found out the load on a slat was greater than the permissible load for which the slat was designed and the deformation was quite large.

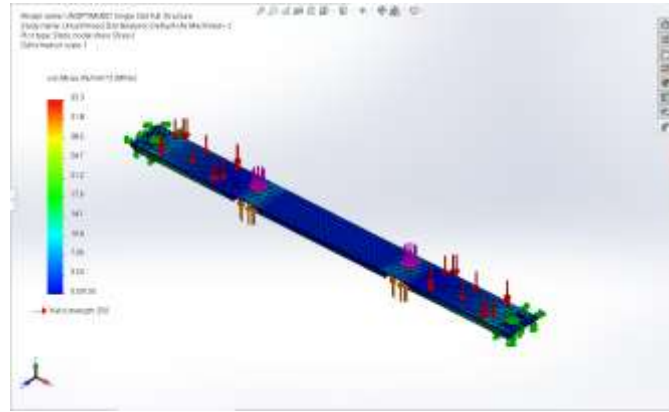


Fig.5.1. Static nodal stress of normal slat (view 1)

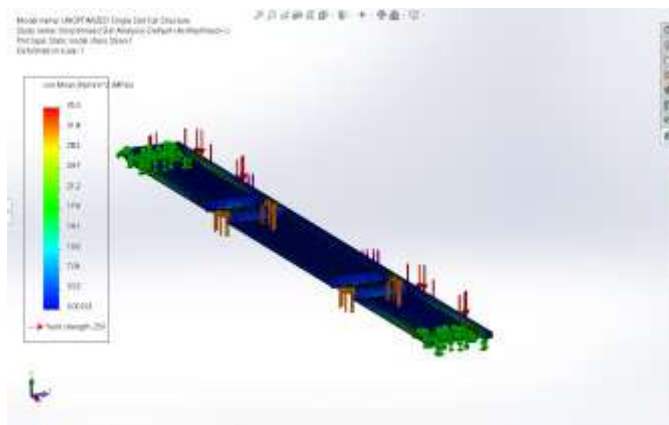


Fig.5.2. Static nodal stress of normal slat (view 2)

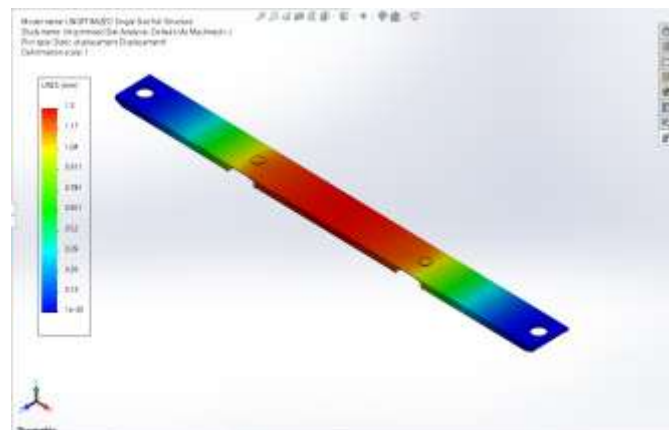


Fig.5.3. Static displacement of normal slat

Second selected design of slat was one with I-section. After analyzing it showed satisfactory results where deformation and stress were in limits which we considered. By analytical values it shows 53.87 MPa. But the main drawback of I section was, we cannot keep it along the slat width as there was arrangement for a trolley which jacks in the hole provided at the end of slats. This truncates the load carrying capacity at the end section of a slat.

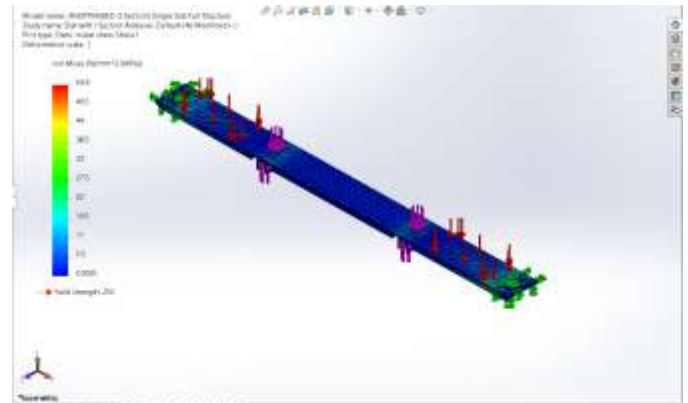


Fig.5.4. Static nodal stress of slat with I-section (view 1)

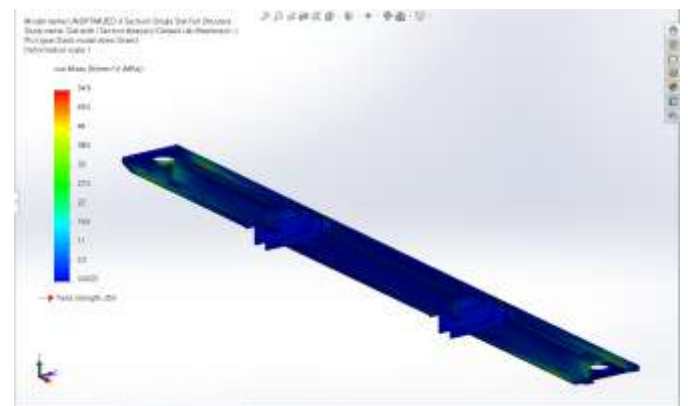


Fig.5.5. Static nodal stress of slat with I-section (view 2)

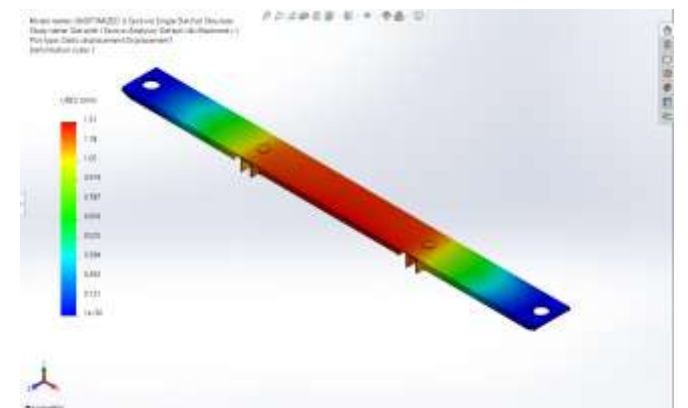


Fig.5.6. Static displacement of I-section slat

Third design is with the C sections on both sides beneath slat surface. It has 72.54 MPa stress value. To avoid the problem with I-section, C-section solves the problem of end section load carrying capacity. It also has more stress carrying value than I-section.

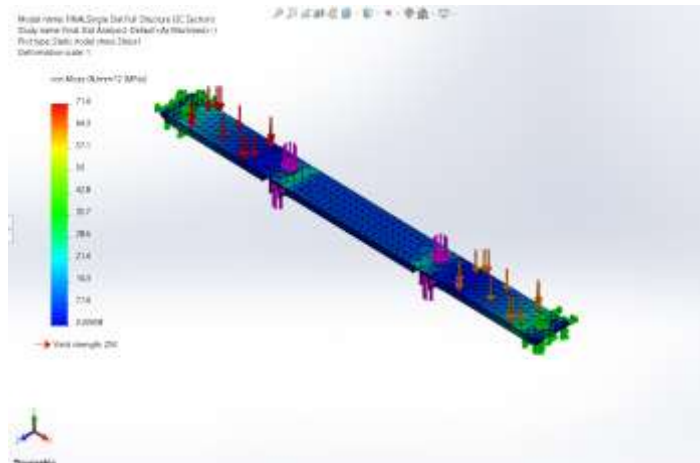


Fig.5.7. Static nodal stress of slat with C-section (view 1)

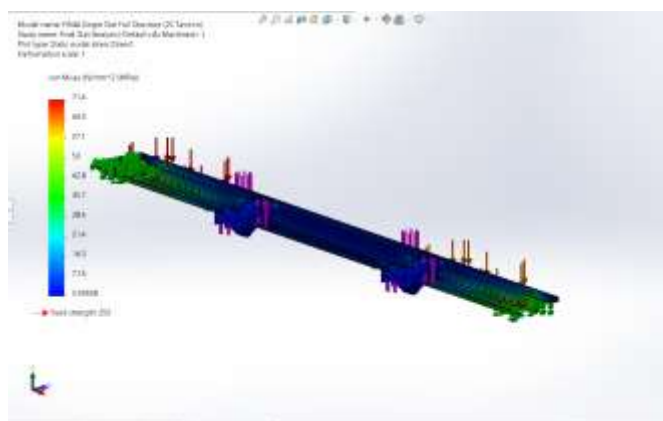


Fig.5.8. Static nodal stress of slat with C-section (view 2)

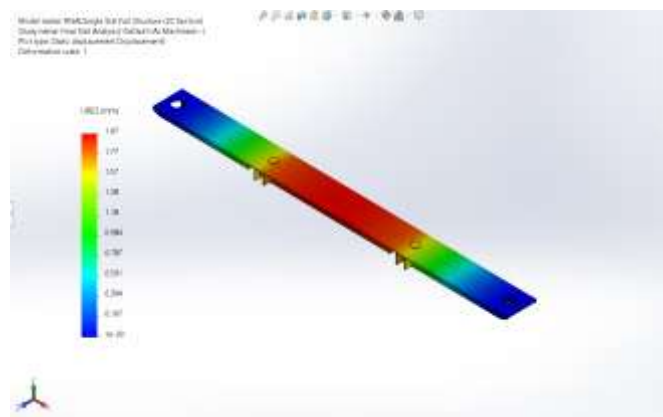


Fig.5.9. Static displacement of C-section slat

For optimization of slat, the length of slat is divided into three parts such that at each end the maximum force is applied which can be transferred to support sections. The basic design of slat also requires support elements in order to reduce deformation. After analyzing we found that the minimum deformation is achieved by providing I-sections beneath a slat than no support provided. But this serves half the purpose as we need hole at ends of slat which connects external trolleys. To solve both requirements we can use C-sections at both sides instead of I-sections. This allows us to drill hole at an end of slat. Extra plates are designed at the end of slat sections. By this we optimized the slat design.

6. RESULT AND CONCLUSION

We have completed all the design calculations including power calculations, chain selection, sprocket selection, shaft design etc. For optimization of the slat stresses (von Mises) obtained from FEA method are as following-

Section	Analytical method	FEA method
Normal slat	34.1832 MPa	35.3 MPa
I-section slat	53.8722 MPa	54.9 MPa
C-section slat	72.5412 MPa	71.4 MPa

Table 6.1. Comparison of von Mises stresses

These results are approximately homogeneous with analytical solutions. Apart from this the various stresses calculated as following-

Section	Normal stress along X axis	Normal stress along Y axis	Principal stresses
Normal Slat	11.9 MPa	8.08 MPa	11.9 MPa
I-section slat	23.1 MPa	44.2 MPa	45.2 MPa
C-section slat	46 MPa	36 MPa	46.1 MPa

Section	Shear stress	Von Mises stress
Normal slat	8.92 MPa	35.3 MPa
I-section slat	23.9 MPa	54.9 MPa
C-section salt	34 MPa	71.4 MPa

Table 6.2. Comparison of different stresses

Also, we have calculated the deformations are as following-

Section	Analytical method	FEA method
Normal slat	0.034 mm	1.3 mm
I-section slat	0.206mm	1.31 mm
C-section slat	0.278 mm	1.97 mm

Table 6.3. Comparison of deformations

The load at maximum deformation are as following,

Section	Load	Deformation
Normal Slat	882.9 N	1.3 mm
I-section slat	765.18 N	1.31 mm
C-section slat	706.32 N	1.97 mm

Table 6.4. Load at maximum deformation

Hence, from the above results we have selected the slat with the C-section as it can sustain more stress than the other two. Withal, it has many advantages than the other two slats as discussed above. This completes the both components of our project. The speed of the conveyor can be controlled by utilizing Variable Frequency Drive (VFD) as this was one of the requisites in the design. This is a type of motor controller that drives an electric motor by varying the frequency and voltage supplied. The slat conveyor system can additionally be more automated by utilising various sensors. To make this system safer and more foolproof the shear pin can be designed. The solid modelling and analysis are done by utilising solidworks software. The whole assembly of this system is as shown below.



Fig. 6.1. Solid model of whole assembly

7. REFERENCES

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