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Design and Optimization of Lifting Arm of Self Loading Concrete Mixer through Finite Element Analysis

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***Abstract:** This work is mainly focused on the design as well as analysis of lifting arm of self loading concrete mixer through finite element analysis. Shovels are tools used in industry for digging, lifting and moving bulk materials like sand or gravel. These tools have been used for centuries as hand held tools. In the modern age these tools come as part of machines and are adept at carrying out work that humans are incapable of. The present work aims to reduce the weight of the shovel lift arm of a Self-loading concrete mixer with a 2.2 meter cube drum without compromising on the existing functionality of the product. This optimization is done by 3D modelling the existing lift arm assembly and simulating it for impact load. The Finite Element Method (FEM) analysis on the simulation shows the magnitude of stresses at various points which help us modify the design accordingly for optimal reduction in weight. The results are used to make modifications to the existing design after which those designs are tested using the same impact load. The best of the new designs are selected and their superiority is corroborated by a lifting analysis of the arm at its horizontal position. Both the 3D modelling and the analyses have been performed on Cre Parametric 4.0. These modifications in the design help bring down the cost of production and also improves the factor of safety of the arm.*

***Index Terms:** 3D modelling, Finite Element Analysis, Optimization, Weight reduction.*

I. INTRODUCTION

Self-loading Concrete mixers are devices that are used all over the world that can load cement and aggregates such as sand, gravel and water all by themselves into a drum to form concrete. This process of loading is done with the help of a lifting arm assembly which consists of a pair of lift arms hinged to the two ends of a large bucket. The bucket collects the sand and aggregates by ramming into a pile whereas the cement is loaded manually. This mixture is then lifted with the help of hydraulics to be eventually poured into a rotating drum. The lift arms must endure high stresses due to both the impact of bucket ramming into a sand and aggregate pile and the lifting of mixture up to the height from which it is poured into the drum. Creo Parametric 4.0 is used to create a 3D model of the existing assembly as shown in figure 1 and do the finite element analysis on the same. The results help in finding the areas where modifications in the design have to be brought about. The real aim however is to bring about modifications in the design that would reduce the weight of the lift arm assembly without compromising on its functionality and marketability which would eventually lead to a lower cost of production.

Fig 1 Self-Loading concrete mixer

A thorough literature survey was carried out on the existing research works on weight reduction and optimization based on Finite Element Method Analysis. Research on weight reduction of components using FEM analysis has been found to have been extensively used. Article [1] lays down the basic methods by which stiffness can be improved by distinguishing between 3 methods namely: (i) simulation of hanging models, (ii) numerical simulation of soap films, and (iii) structural shape optimization. Author [2] worked on optimizing a Go-kart using Impact Analysis and modified the design of the bush accordingly. He discusses how impact force can be calculated and applied for simulation. Author [3]'s work focussed on optimization of the arm of the wheel loader while maintaining an FOS of 2 after considering the constraints to the mechanism; dump height, digging depth and interference of joints. Author [4] and Author [5] employed the method of changing material used in the drive shaft for weight reduction and Author [4] managed to also show the reduction in fuel consumption after modification of the drive shaft. Author [6] analyzed leaf springs and used an Epoxy composite material for weight reduction and not only improved FOS but fatigue life of the component as well. Author [7] reduced the weight of the universal joint by increasing the fillet radii at various points and reduced the weight of propeller shaft by changing material. Author [8] used FEM analysis to reduce the weight of the lift arm of tractor and reduce stress to 710MPa by increasing the fillet radius from 15mm to 20mm.

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Author [9] reduced thickness at various points on the seat of the amphibious vehicle made of aluminium alloy, based on FEM analysis and managed a weight reduction of 75%. Finally, Author [10]'s work focused on the lifting analysis on the arm assembly of the tractor and gave insights into how the maximum load that can be lifted can be calculated.

From the above literature, it can be understood that numerous methods are employed to optimize and reduce the weight of components like topology modification, change of material or thickness reduction. Although the literature on the topic is vast, studies on optimization of lifting arm of vehicles, especially the concrete mixer weren't completely explored and hence the topic of optimization of the arm of concrete mixers was chosen. The objective of weight reduction of lift arm was achieved using various techniques inspired from the literature available like thickness reduction, increasing fillet radii and material removal from regions of low stress.

II. PROBLEM STATEMENT

The existing arm assembly of the self-loading concrete mixer with 2.2 meter cube drum is found to be too heavy because it is not the correctly down scaled version of the arm assembly with the 4 meter cube drum attached to it. This extra weight of the arm assembly unnecessarily keeps the cost of production high.

III. VALUE ANALYSIS

The manufacturer makes two variants of the self-loading concrete mixer; one of which has a drum of 4 meter cube volume while the other one has a drum of 2.2 meter cube volume. It is found that the weight of the arm assembly for the self-loading concrete mixer with drum of capacity 4 meter cube is 230Kg while the existing arm assembly of the 2.2 meter cube version is found to have a mass of 173.5Kg. Since, the lifting arm assembly of the self-loading concrete mixer having the 4 meter cube drum has been found to be adequate, there is scope for reducing the weight of the self-loading concrete mixer with the 2.2 meter cube drum.

The weight of the existing arm assembly of the vehicle with 2.2 meter cube drum can therefore be reduced by a factor of ***2.2/4=0.55*** which means that the mass of the existing machine can be reduced to a minimum of 2***30Kg*0.55=126.5Kg.***

IV. DESIGN OF LIFE ARM ASSEMBLY

All the required parts are individually 3D modelled using the engineering drawings of the existing arm assembly. 3D model of the existing lifting arm assembly is created by modelling all the constituent parts separately and assembling them together. The arm that is currently used has a thickness of 32mm and the mass of the assembly as a whole is 173.548Kg.

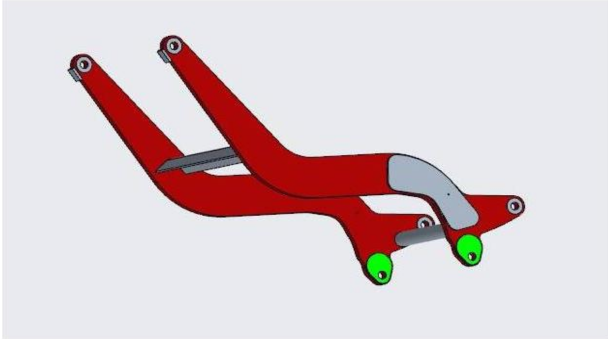


Fig 2-Design of Lift arm assembly

The existing 3D model of the bucket is assembled to the above model shown in figure 2 model for a realistic application of impact load.

4.1 Impact Analysis

Machine operators are usually careful while reversing the machine to load it with sand and aggregates and are known to not exceed the speed of 8Km/hr .Hence, force is calculated for a speed of 8Km/hr. The Impact Force is calculated using equation 1.

F=Impact force

D=Distance travelled by bucket before stopping=0.5m

M=Mass of the self-loading mixer=11300Kg

V=Velocity of self-loading mixer=8*(5/18) m/s

$$F*D = 1/2*M*v^{(2)} \quad (1)$$

F=55,802N

This calculated Impact force is applied along the bottom edge of the bucket (1100mm) up to a height (Digging depth) of 16mm to the models that were created on Creo Parametric.The hinges are fixed as shown in purple in figure 2 to see the effect of stress on the model.

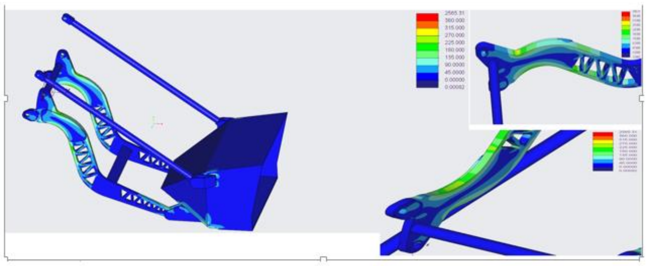


Fig 3-The auto meshed existing lifting arm assembly

The mesh is auto-generated depending on the requirement of the analysis as shown in figure 3. Each cube of mesh can go up to a minimum edge length of 0.5mm

4.2 Results: Existing model

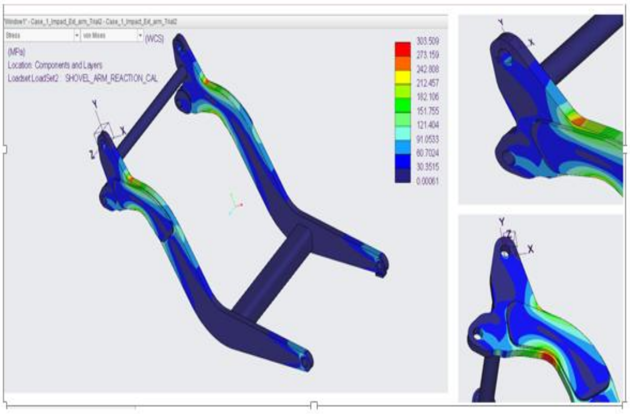


Fig4 -Results of Von-Mises stress analysis for the existing model

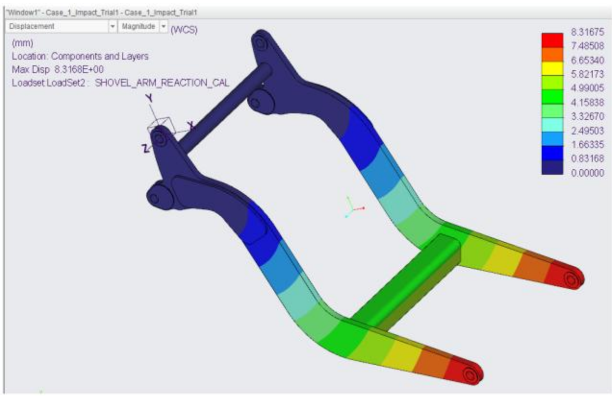


Fig 5-Results of deflection for the existing model

The results obtained are:

- The maximum Von-Mises stress amounts to 303.509MPa as shown in figure 4
- The maximum deflection is 7.512mm as shown in figure 5
- Factor of safety is calculated to be 1.1367

After this analysis, the stress is found to be particularly high in the curved cross-section of the model as shown in figure 4 and the deflection is within the safe limits as shown in figure 5.
From this, it is understood that the elastic section modulus has to be improved at the curved cross-section and material removal has to take place from the low stress regions shown by the different shades of blue.

4.3 Design Optimization

The results of the analysis on the existing model, give an idea of where design modifications can be brought about. The stress at any point on the arm must not exceed 345MPa (Yield strength of S355Jr grade steel) and preferably, must be lower than the maximum stress for the existing arm
The deflection must not exceed 11mm since the arm has a clearance of 11mm from the ground.
Due to the availability of metal sheets of thickness 28mm with the vendor, the thickness of each arm, if reduced, can only be reduced to 28mm.This step brings down the weight to 153.83Kg.
After this step, elastic section modulus at the curved section is improved by adding material at the portion with a radius of 208mm as shown in figure 6 to tackle the problem of high stress at the curved cross-section.
This slightly increases the weight of the assembly to 156.7258Kg

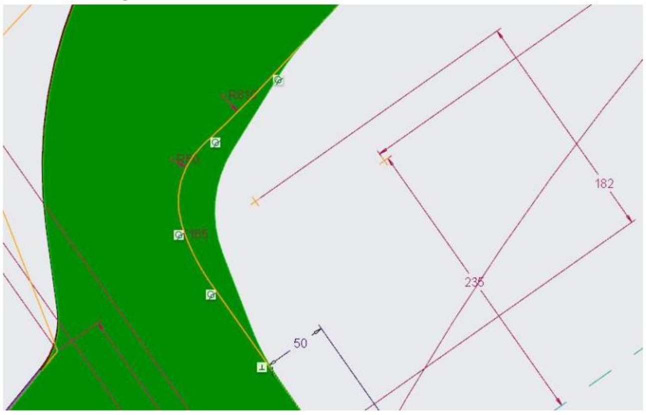
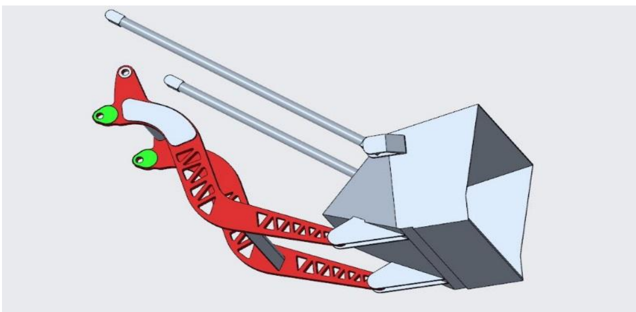


Fig 6-Design modification after addition of material to the curved cross-section

Finally, material is removed from the purple coloured section shown in the initial finite element analysis. This area has a Von-Mises stress lower than 30MPa which is far below the yield strength of 345Mpa.
A fence like pattern is conceived where triangular cavities are made along the safe region in an alternating fashion. Since, a space on the arm is required for welding another component, it is not possible to have a continuous set of cavities. This leads to two separate sets of triangular cavities on both sides of the space.
The cavities have a spacing of roughly 20mm.The upper triangular cavities have a base length of about 34 mm except for the lowest triangle in the set which has a base of 68mm. Each triangle on the upper half of the arm is given a 6 mm fillet radius at the apex and 10 mm fillet radii at the other 2 vertices. The set of triangles below the welding space have a base of 54mm which gradually reduces to 25 mm for the lowest cavity and has an apex fillet radius of 2 mm and the other vertices have a radii of 5mm.

Fig 7-Modified arm fully assembled after bringing about



the necessary changes

The non-uniformity in the dimensions are due to the fact that the arm is curved and the sides of the arm converge at the bottom. The fully assembled model is shown in figure 7. The design modification reduces the weight of the assembly by 21.056 % to 137.21Kg.The model is then simulated for the Impact load.

4.4 Results: New model

Fig 8-Results of stress on new model

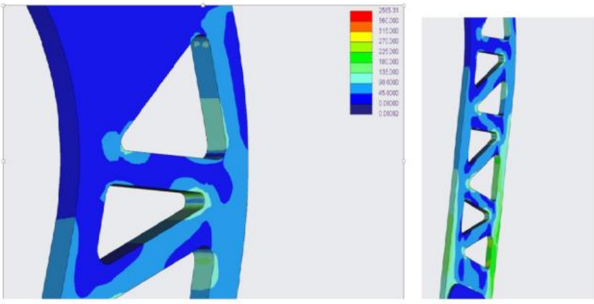


Fig 9-Improvement in stress on the inside of the triangular cavity after increasing the fillet radii

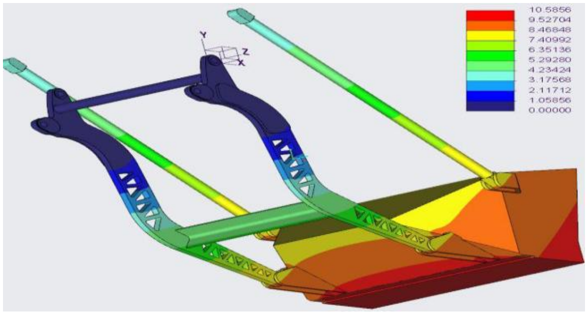


Fig 10-Results of deflection on the new model

The resulting assembly is lighter than the existing assembly by 36.338Kg

- The mass is reduced by 21.056%
- The maximum Von-Mises stress is 288MPa
- The maximum deflection is 9.527mm
- FOS is 1.197

Following this step, the weight of the assembly has been reduced by a whopping 36.338Kg and the maximum stress has subsided to an unprecedented 288MPa as shown in figure 8.The stress on the inside of the triangular cavity has been reduced to 205MPa as shown by figure 9 and the deflection just managed to be within 0.5mm of the limit as shown by figure 10.

V. LIFTING ANALYSIS

After the bucket rams into a pile of sand and aggregates, it is lifted from that point to its highest position before it is poured into the drum. The Lifting analysis is only a precautionary step in the optimization since the arm endures maximum stress only during Impact.

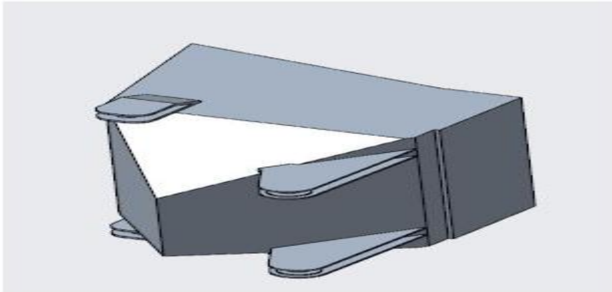


Fig 11- 3D Model of Bucket

A cuboidal dummy is modelled as shown in figure 12 for the bucket for the easy application of load since the existing bucket has a complex shape as shown in figure 11 which creates a confusion about where exactly the load acts. The length, breadth and height of the dummy are 1100, 100 and 110 mm respectively. The same 2 hinges are fixed as was done for the Impact analysis.

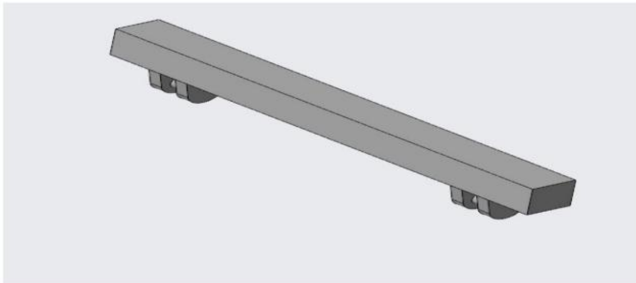


Fig 12- Dummy model of Bucket

5.1 Calculation of Lifting Force

The lifting force calculation as described below:
F=Weight of the sand + Weight of bucket
(This is calculated using Equation 2)
d=Density of sand=1922Kg/m^(3)
M=Mass of bucket=200Kg
V=Volume of bucket=415/1000m^(3)
g=Gravity=9.81m/s^(2)

$$F = d * v * g + m * g \qquad (2)$$

F= 9,785~10,000 N

FOS = Yield Strength/ Apparent strength (3)
Yield Strength - 345Mpa
The factor of safety is calculated using equation 3

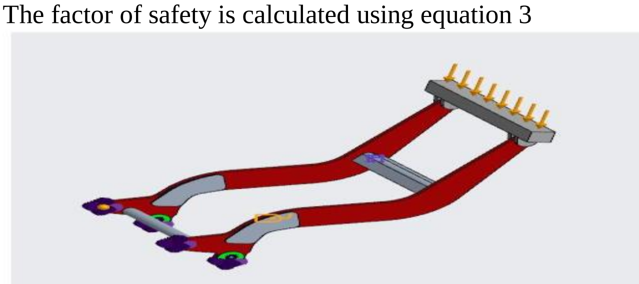


Fig 13- Load application of lift analysis

Load is applied on the surface of the dummy model and this load is referenced to remain vertical to the ground as shown in figure 13. The mesh is auto-generated as per the requirement of the analysis.

The model is analyzed for stress and displacement at the horizontal position of lifting since this is the position at which bending stress is maximum at the hinges.

5.2 Results: Modified Lifting assembly at 90 degrees (horizontal)

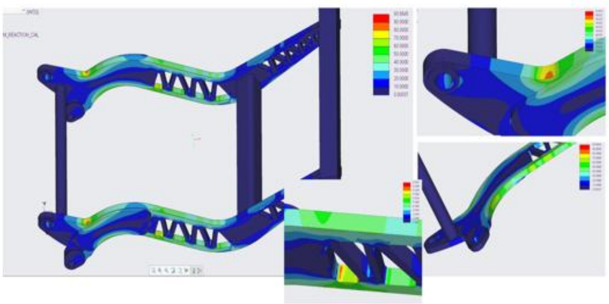


Fig 14-Results of stress at the horizontal position on case 8

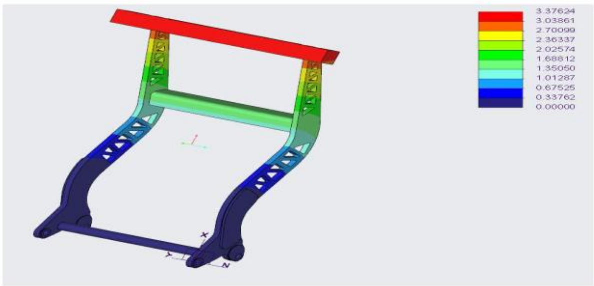


Fig 15-Results of deflection at the horizontal position on case 8

The model attains the following satisfactory results for this case:

- The maximum Von-Mises stress is 93.2978MPa as shown in figure 14
- The maximum displacement is 3.376mm as shown in figure 15
- Factor of safety is calculated to be 3.697.

5.3 Calculation of reduction in cost of production

- Market price of S355Jr steel=Rs.100/Kg
- Material saved in the new design= 36.338Kg
- Average Number of machines manufactured in a month= 25
- Total cost saved per annum on production of new model *=36.338*100*25*12=Rs.10,90,140*

VI. CONCLUSION

The proposed design and analysis will be useful to reduce weight of the shovel lift arm of a self-loading concrete mixer without compromising on the existing functionality of the product.

Table 1-Summary of results of Impact analysis

MODEL Name	Weight Kg	Wt reduc Kg	% Wt red _	Stress Mpa	FOS _	Deflection mm
Existing	173.548	_		303.509	1.1367	7.51
New	137.21	36.338	20.938	288	1.197	9.527

From the results, it is observed that the weight is reduced by 21.056% and the FOS increased from 1.13 to 1.197. The reduction in weight helps reduce the cost of production. Therefore, the implementation of the new model would result in an annual savings of Rs.10, 90, 140. A further reduction in mass of about 11Kg is possible according to the theoretical value analysis but this could not be done owing to the fact that the bucket used on the arm is neither optimized nor down scaled. This shows that the quest for an overall optimization can be continued from here.

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