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Optimization of Loader Arm of Wheel Loading Shovel

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Abstract - **The objective is to test the structure (Dump Height, Digging Depth, Loaction and Interference of joints) in optimize design of loader arm with various iteration / Cycles, Pressure mapping of Cylinder and Rams of loader arm with existing / standard bucket and To check the stability of machine for the optimized design. This analysis is conducted using FEA software (ANSYS 15). The analysis is done for various iterations. Maintaining a Factor of safety 2 throughout design analyzing and testing the loader arm at various loads and condition.**
Calculated results are confirmed by experimental measurements or verification is carried out with the help of strain gauging where stress, strain and atmospheric working condition of machine is tested which can be further compared with the with FEA results and theoretical calculations.

Keywords—Dump height, Digging depth, Location and Interference of joint.

I. INTRODUCTION

Introduction To Wheel Loading shovel:
Wheel Loading Shovel is an earth-moving machine equipped with mechanisms to guide its working attachments. It has a loader mechanism in the front, which guides the shovel for loading materials. It is desired to guide this shovel so that it can dig by a certain amount into the ground, lift above ground level to dump on a truck. It also has to reach forward by a certain amount so that it can dump clear of the truck. They can be besides these kinematical challenges, it also has to have as much lifting and breakout force as possible. Loader mechanism is a complex mechanism with 11 linkages and two degrees of freedom. Moreover, there are constraints on the mechanism to be satisfied.
They can be listed as: -

- Dump height
- Digging depth
- Location and interference of joints

A loader is a self-propelled machine, having front-mounted equipment primarily designed for loading operation (bucket use), which loads or excavates through forward motion of the machine. A loader work cycle normally comprises filling, elevating, transporting and discharging material.

- Types of Loaders:-
  a) Crawler loaders
  b) Wheel loaders

They are shown in fig below & each may have the engine located at the front or rear of the machine.

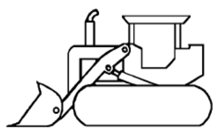


Fig. 1: Crawler loaders

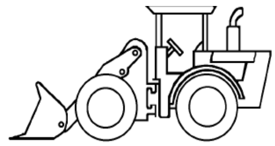
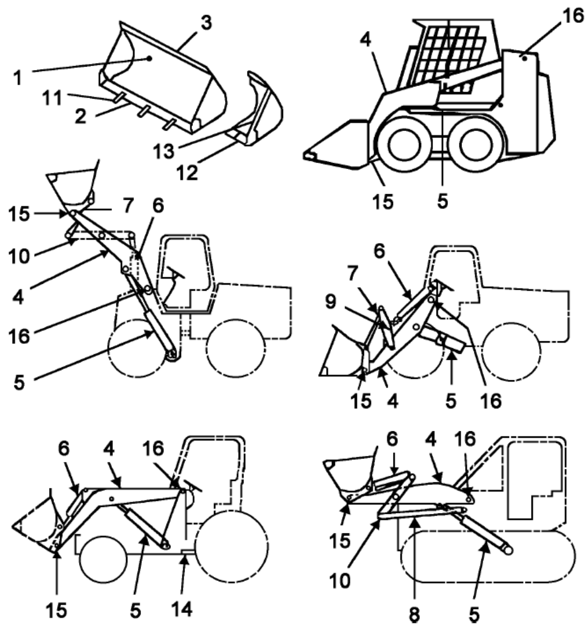


Fig. 2: Wheel loaders

As of today, Wheel loaders are more commonly used and our project comprises modification of this machine.

Fig.3. Wheel Loading Shovel

- Component Nomenclature



1	Bucket	10	Bellcrank
2	Cutting edge	11	Tooth, bucket
3	Spillguard	12	Cutter, corner
4	Lift arm	13	Cutter, side
5	Cylinder, lift	14	Frame, loader (where separate from machine main frame)
6	Cylinder, bucket	15	Pin, bucket hinge
7	Link, bucket	16	Pin, lift arm hinge
8	Link, guide		
9	Lever, bucket		

Fig. 4: Component Nomenclature

II. LITERATURE REVIEW

As of today another application of loaders is emerging with reference to the Indian context.
Producers of raw material such as stones, stone chips (used in road and real estate construction) now sell their produce by truck loads instead of weight or volume. For this purpose once a dumper is heaped it needs to be leveled to remove excess material to ensure that gross amount of material sold does not vary.
Manual leveling is time consuming. It is preferred that loaders after dumping should be able to level the material that too in one pass from one side.
Traditionally loaders have not been designed to achieve this. Our project aims at modifying the current loader to achieve this operation.
The objective of our project was to modify Wheel Loader in order to avoid the lift ram's fouling the side of high level carrier trucks while carrying out dumping/loading operation.
After a visit to the stone quarry in Talegaon during which we interacted with the operators regarding the problems they face with the machine the objective got extended to achieving leveling cum dumping operation on all models of carrier trucks especially TATA 1613 and HYWA which are most commonly in use.
This basically implies that the reach of the loader arm during close to three quarters of extension of the loader arm had to be increased by more than 200mm and hinge position of the lift ram on loader arm adjusted to fall within the wheel base for all positions of the loader arm above horizontal level.
The entire modeling cum simulation process was carried out using 3D modeling software UG NX4.Design is an iterative process and often changes need to be made to incorporate conflicting requirements and manufacturing constraints.
Our approach was completely practical and we performed countless iteration on the loader arm and Parallel-bar linkage mechanism to optimize the design with respect to cycle time, breakout forces and factors of safety. Each possible solution was first modeled and then replaced in the model of the current machine assembly to verify dump angles and fouling conditions etc.

Moreover to ensure safety of design calculations from first principles have been performed to ensured that moments generated by the pay load and machine weight limit the factors of safety such that they exceed the minimum values prescribed by company standards.

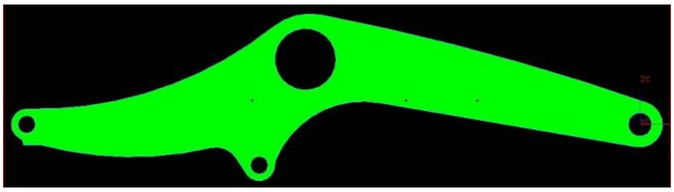
Details While Designing a Loader:
Our approach to this design challenge was completely practical. It was based on observation of machine behaviour and visual derivations while seeing the machine execute its function. Simulating the linkage motion in 3D CAD also played an instrumental role. As a result, a large number of iterations had to be performed to ensure that all criteria were fulfilled and there were no fouling and/or adverse results in the calculations, derived from first principles.
The steps followed for each iteration were as follows:

I. Modelling
II. Assembling the component into current machine i.e. with chassis, bucket and z bar linkage.
III. Motion Simulation & Parameter Verification
IV. Performing Calculations Derived from First Principles

Of these 3 steps the second cannot be captured on paper but the results are well evident.
Keeping the end result in view each iteration comprised of the following:

1. Modifying the loader arm profile by shifting the hinge point of lift ram on the arm by a known approximated distance.
2. Generating various hinge points for loader arm mounting position in chassis.
3. Assembling it into the chassis and also with bucket and linkage.
4. Measuring open and close lift ram lengths by positioning bucket horizontally at the two limiting positions - max height and dig depth respectively.
5. Checking for no fouling/ collision at any position.

During the entire re-modelling process the profile was kept as close as possible to the original to avoid any failure during the analysis as the current arm is proven safe and functioning smoothly.
Note: The entire process has been carried out without altering the chassis at all for ease of manufacturing
Existing Reference:



To achieve the objectives of this project two changes had to be made:

- The hinge point position moved to the right by appropriate distance
- The profile changed to suit leveling which basically involved reducing the included angle of the arm.

Modeling:

This arm could perform all the functions desired like leveling without fouling and dump and roll back achieved at the required angles.

Assembly:

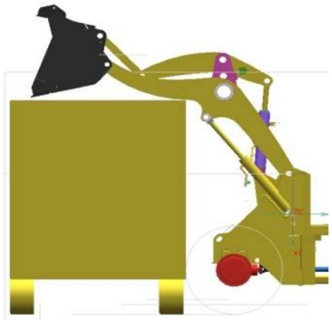


Fig.2. Unloading Position

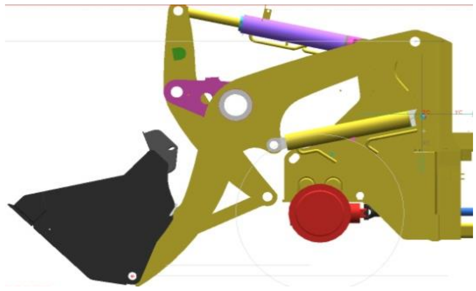


Fig.3. Digging Position

Material Properties:

Material: 5000/0103
International Standard: - EN 10025 S355JR
Description: - Low-alloy structural steel (standard bend radii)
Min Yield (N/mm^2):- 355-345
Min UTS (N/mm^2):- 630-490
Max C %:- 0.24
Max Mn %:- 1.60
Max Si % - 0.55
Max P % - 0.035
Max S % - 0.045
Other: - 0.009 Max.

III. DESIGN CALCULATION

This force is applied at the lip of the bucket. The max load is calculated considering the force generated from the bucket cylinder.

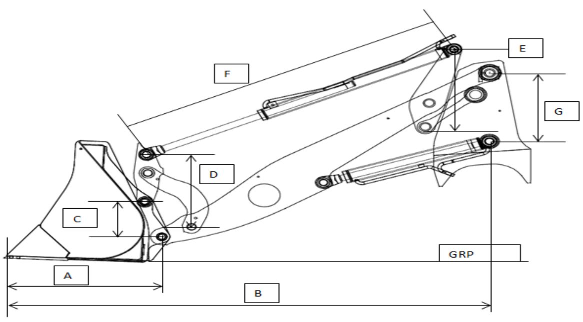


Fig.4. Attachment Configurations**:** Bucket will plated on GRP and parallel to ground

Position Dimension:-
A: - 1260 mm
B:- 3474.65 mm
C:- 416.6 mm
D:- 671.6 mm
E:- 660.180 mm
F:- 1385.230 mm
G:- 565.210 mm

Max. Hydraulic Pressure of the cylinder:-

P = 250 bar
= 25 Mpa or N/mm^2
= 2.55 Kg/mm^2

Ram Eff. = 1

Bucket cylinder:

Cylinder	Ram
Bbu = 180 mm (Diametr)	Bbu = 80 mm (Diameter)
Bbu_r = 90 mm (Radius)	Bbu_r = 40 mm (Radius)
Force = п*Bbu_r^2*P	Force = п*(Bbu_r^2- Bbu_r^2)*P
= 635850 .51376 kg	= 52013.2518 kg
= 635850 N	= 5120250 N

Arm cylinder:

Cylinder	Ram
Bbu = 160 mm (Diametr)	Bbu = 80 mm (Diameter)
Bbu_r = 80 mm (Radius)	Bbu_r = 40 mm (Radius
Force = п*Bbu_r^2*P	Force = п*(Bbu_r^2- Bbu_r^2)*P
= 51213.04791 kg	= 38409.7859k
= 502400 N	= 376800 N

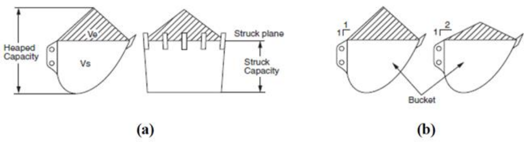
Maximum Breakout force Generated by BUCKET Cylinder

Fbru = (Bucket force * E)/D* (C/A) = 21081.89 Kg
= 206.81 KN (21081.89*9.81/1000)
= 172 KN (83%)

Maximum Breakout force Generated by LOADER ARM Cylinder

Fbru = (Arm force * G)/B = 8330.66 Kg
= 81.72 KN (8330.66*9.81/1000)

Bucket Capacity :



Bucket struck and heaped capacities

Fig.5.

Vh = Heaped Capacity = Sum of struck capacity plus volume of excess material heaped on the bucket at 1:1 or at 1:2 angle of repose

Vs = Struck Capacity = Volume capacity of the bucket after it has been struck at the strike plane

Wf = Inside width front, measured at cutting edge or side protectors

Wr = Inside width rear, measured at narrowest part in the back of the bucket.

PArea = Side profile area of bucket, bounded by the inside contour and the strike plane of the bucket

$$V_s = P_{Area}\left(\frac{(W_f+W_r)}{2}\right)$$

P_{Area} (mm^3) = 300
W_f (mm) = 15
W_r(mm) = 12

Vs(mm^3) = 4050

Ve = Excess material capacity heaped either at 1:1 or at 1:2 angle of repose

V_e for angle of repose 1:2

$$V_e = \left(\frac{L_B W_f^{\,2}}{8} - \frac{W_f^{\,3}}{24}\right)$$

Lb (mm) = 250.6
Wf (mm) = 175
Ve (mm^3) = 736020.8333
Heaped Capacity (Vh) mm3 = Vs + Ve = 740070.8333mm^3

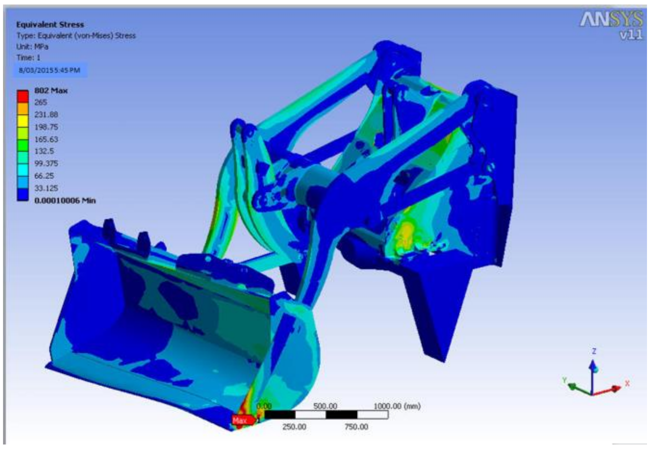
Comparision:

To sum up the changes made in the machine we have drawn a set of comparisons as shown below:

1. The loader arm profile changed drastically in terms of length and included angle.

Overall length increased by 200mm.

IV. FINITE ELEMENT ANALYSIS

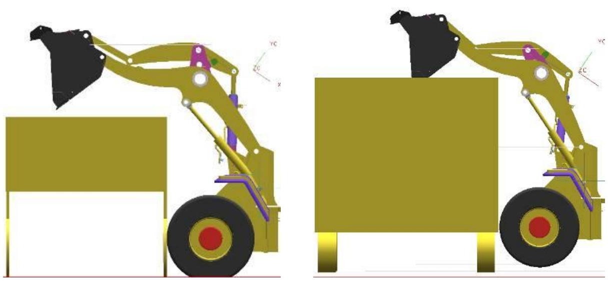


V. CONCLUSION

The new design besides having solved the leveling problem has some more advantages. Though the machine weight shall increase due to usage of longer loader arms, the calculations were satisfactory and the factors of safety within limits.

To conclude we shall list advantages of the new machine:

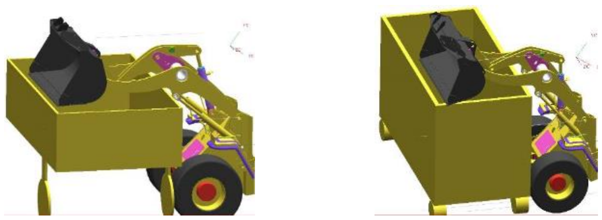
1. Piston out of Danger while dumping for all lorry sizes.



Tata 1613 Wagon   Tata HYWA

Fig.8. Piston out of Danger while dumping for all lorry

2. Levelling in a single pass for all Lorries



Tata 1613 Tata HYWA

Fig.9. Levelling in a single pass for all Lorries

VI. ACKNOWLEDGEMENT

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