Failure Analysis & Redesign of Boom under Static Analysis for Mining Machines

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Abstract- The boom of these machines supports the rotation head and feed mechanism for drilling hole in earth surface. It has been observed that the boom fails due to fracture at extreme level load condition during actual operation of machines. As a consequence several components of other assemblies are subjected to overloading and, therefore, undergo plastic deformation. The principal objective behind boom redesigning is that it should sustain the weight of drill assembly which is approximately 3 ton. In this thesis is presented the failure analysis of the boom assembly and computer simulation of failure considering collapse conditions. Measurements of hardness and micro hardness in the vicinity of the weld have been performed. After FEM analyses and material tests, it is seen that the root cause of the collapse lies in the existing design as also minor welding faults during fabrication. Finite element method analysis of the boom showed stress concentrations exceeding the allowable level and the need to redesign it considering load fluctuations caused by operating environment. The analysis shows that the changing loads adversely affect the load-carrying structure causing its degradation, i.e. the appearance of cracks at stress concentration sites in welded joint areas. The results show that maximum stress is induced at the fracture locations observed during failure examination. Redesigning the boom with increased cross section and improved material property overcomes the boom failure problem observed in the present machines.

Keywords – Boom Analysis, Boom Design, Boom Structure, Open Pit Mining Rig, Surface mining boom

I. INTRODUCTION

The Difficult geological conditions and more intense mining processes taking place today in many building sites lead to a high mechanization level of building works. Because of this, specialized self-propelled drilling machines are constructed, which enable a sufficient progress in the mining works. Among the machines most frequently used in the mining and building sites, there are those directly used in the preliminary works. These are the vehicles used for slabbing, drill rigs and bolt setters. The common feature of those machines is the fact that the working tools are placed on a boom. The boom mounted on self-propelled mining machines should have a sufficient number of degrees of freedom to minimize the time related to changing the location of the machines. Most frequently, this is a straight-line structure ended (in the case of drill rigs and bolt setters) with a rotating head (turnover fixture). It is assembled with feed assembly which is actuated through two hydraulic cylinders as shown below.

Manufacturer of mining equipment and machineries, has observed one particular problem with the boom. It was noted that the boom fails during operation due to fracture and as a consequence several components of other adjoining assemblies undergo plastic deformation. In view of the increased load of drill guide from 2.1 to 3 ton, and also to reduce the overall costs of manufacturing, the company has desired that entire machine be made out of standardized components and machine parts and units for interchangeability reasons. The company desires to design a universal boom which could be mounted on various types of machines. The redesigning of boom, therefore, required identifying the worst loading conditions using simple force analysis. The two cases are:

(1) Maximum tilt angle of drill guide is 22deg when boom is horizontal and

(2) When drill guide is horizontal.

The third typical situation is when force is exerted on the boom when lift cylinder is actuated and also the boom with the mast is a significant load for the structure, its mass should be as smallest as possible. This brings about serious engineering problems stemming from the operation, manufacturing technology, material limitations, etc.

II. PROBLEM IDENTIFICAION

A. Analysis of Existing Model:-

The present boom section is 200 mm x 200 mm built out of 12 mm thickness plates by welding is shown in Figure 2. The design of boom required identifying the worst loading conditions using simple force analysis. The two cases are (1) maximum tilt angle of drill guide is 22deg when boom is horizontal and (2) when drill guide is horizontal. The third typical situation is when force is exerted on the boom when lift cylinder is actuated.

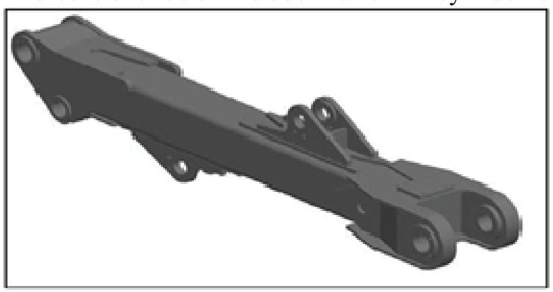

Figure 1. Existing Boom Assembly

Case 1: Boom is in horizontal condition & drill guide at 22deg to vertical
Stress induced in boom = 180.21 N/mm2
Case 2: Boom is in horizontal condition & drill guide in horizontal
Stress induced in boom = 79.87 N/mm2
Stress coming on the boom when lift cylinder is actuated
Stress induced in boom = 168.38 N/mm2
Hence combined stress induced in boom = 348.59 N/mm2

Table 1. Stress induced in boom analytically of existing design

Loading condition	Stresses induced in boom analytically(N/mm^2)
Case 1: Boom is in horizontal condition & drill guide at 22deg to vertical	**180.21**
Case 2: Boom is in horizontal condition & drill guide in horizontal	**79.87**
Maximum stress coming on the boom when lift cylinder is actuated	**168.38**
Combined stress induced in boom	**348.59**

Considering that yield stress for rolled steel section FE410W = 245 Mpa and the allowable stress as per IS:800 -1984, Steel Handbook = 24.5 Kg/mm2=245 N/mm2 , it is found that the total stress induced in the boom is more than the permissible yield stress of the material under static load conditions and without considering any factor of safety. Hence, it is recommended to use higher strength material or modify boom cross section for safe functioning

III. THEOROTICAL APPROACH

The possible approaches that have been considered to overcome the overloading issue include redesigning of the boom by changing the material or the section modulus or both. It is recommended to use higher strength material FE510WC next grade of existing material FE410WA. Section modulus can be improved by changing cross section of the boom by welding additional plates of thickness 12 mm on the outer periphery of the existing design. This would increase moment of inertia and enable sustaining increased load for safe functioning.

The original boom tube size – 200 mm x 200 mm x12 mm thickness has been retained. New plates have been welded upon as shown in Figure 4.1. The weight of feed beam and boom assembly now, as estimated, is 3105 Kg (30460.05 N) and 750 Kg (6916.05 N) respectively. Section modulus (Z) for boom is evaluated next.

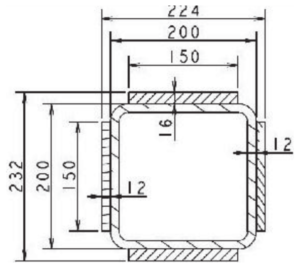

Figure 2. Cross section of proposed Boom

Case 1: Boom is in horizontal condition & drill guide at 22deg to vertical
Stress induced in boom = 109.971N/mm^2
Case 2: Boom is in horizontal condition & drill guide in horizontal
Stress induced in boom = 71.25 N/mm^2
Stress coming on the boom when lift cylinder is actuated
Stress induced in boom = 168.38 Nmm^2

Hence combined stress induced=278.351N/mm^2

Now, yield stress for rolled steel section FE510W = 377Mpa.
Allowable stress IS:800 - 1984, Steel handbook =37.7 Kg/mm2=377 N/mm^2
The total stress induced in the boom is less than the permissible yield stress of the material only for static load conditions. Hence the design is safe with factor of safety of 1.35.

Table 2. Stress induced in boom analytically in proposed design

Loading condition	Stresses induced in boom analytically(N/mm^2)
Case 1: Boom is in horizontal condition & drill guide at 22deg to vertical	**109.971**
Case 2: Boom is in horizontal condition & drill guide in horizontal	**71.25**
Maximum stress coming on the boom when lift cylinder is actuated	**168.38**
Combined stress induced in boom	**278.351**

IV .SOFTWARE ANALYSIS

In this analysis mesh generation is auto mesh generation with element size is 10. This element size is used f or all the body of boom. Hex-dominant method is used for all the parts of boom. Results obtained are shown in table 3

Table 3. Mesh Result using ANSYS

Details of "Mesh"	
Defaults	
Physics Preference	Mechanical
Relevance	0
Advanced	
Relevance Center	Fine
Element Size	10. mm
Shape Checking	Standard Mechanical
Solid Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Initial Size Seed	Active Assembly
Smoothing	High
Transition	Fast
Statistics	
Nodes	385447
Elements	140102

The results obtained are as follows:

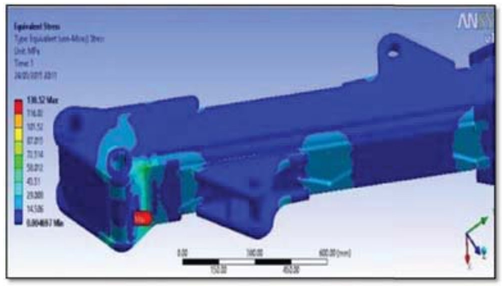

Figure 3. Max stresses induced in case 1

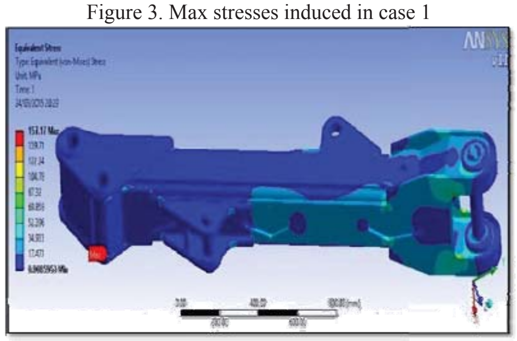

Figure 4. Max stresses induced in case 3

From the figure, it can be observed that maximum stress zone occurs at the pin. Therefore, stress value is important in predicting failure. Maxi mum principle stress obtained from FE analysis is 130.52Mpa for Case 1 and 157.17 Mpa for Case 3 as shown above. This stress value obtained which is less than allowable stress.

Table 4. Result comparison for Analytical and Ansys results

Varying parameter	Stresses in boom (N/mm^2)	Stresses in boom (N/mm^2) by ANSYS
Case 1:	109.971	130.52
Case 2:	71.25	-
Stress when lift cylinder is actuated	162.64	157.17
Combine stress induced in the boom	278.351	287.69

V. EXPRIMENTAL ANALYSIS

FE analysis on base model was carried out as explained earlier. To check resemblance of simulation result strain gauge test was performed on base model. Test for Redesign of Boom for vertical and Horizontal Condition as follows.

The boom was design under static loading condition and it was tested under actual loading condition. This report will describe the performed measurements and the measurement technique used during the stress and strain measurements of the boom on the Rock drills models. The aim of the measurements was to provide the stress levels and dynamic behavior of the boom system for Drill rig in order to provide data for a FEM model check.

The measurements were performed at the test area at plant. The measurements were made with four different types of measurement probes:

- Strain gauges for direct stress and strain measurements in the boom
- Dynamic pressure transducers in all major hydraulic cylinders in order to calculate the forces action on the boom system
- Wire transducers for measurement of the position of the different moving parts during the operation.
- Accelerometers for measurement of vibrations action of the different parts and calculation of inertia forces.

In the tests, performed in the test area of plant, the rig was operated in well-defined ways, called time sequences, in order to be representative to all expected situations for a rig on a customer site. This means the rig was operated in drilling, positioning and several tramming maneuvers, i.e. on varying ground conditions and with the boom and feed in different positions.

IV.CONCLUSION

At the end of extensive literature survey and FEM analysis and testing the following conclusions have been reached.

- Study of the existing boom and its failures was the most important step to begin the analysis.
- Finite element analysis of boom gives the behavior of material or part on application of load.
- Analytical solution with aid of FEA result matches well within a range of testing results.
- It is observed that the total stress induced in the boom is less than the permissible yield stress of the material only for static load conditions, that is equivalent (Von-Mises) Stress Maximum in vicinity of pin is 278.351 Mpa which is less than the permissible yield stress of boom material 377 Mpa, which shows that our design is safe by considering distortion energy (Von-Mises) theory.
- Higher value of stress was a prime reason for failure of base model.
- The boom designed in this work shall be useful as a standard assembly for all surface drilling machines manufactured by various OEMs and would ease maintenance. Cost of manufacture of the basic machines is expected to be lowered.

With reference to this thesis; in future; it is useful for cost reduction point of view for any parts of drilling rig in consideration of procedure and respective technical specification of respective parts. It is also applicable for other rig model for internal reference purpose.

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