Design and Stress Analysis of Excavator Arm and Bucket

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Abstract— Earthmoving machines is now a part of industry and construction fields these days. Excavators are the mobile machines that are moved by means of either crawler track or rubber-tired undercarriage. Function of excavator is to dig, dump, swing and elevate material by its mechanisms. Multibody simulation in motion views facilitates system level kinematic and dynamic analysis of whole excavator, making it possible to study the reaction forces and stress variation in every component of system. Dynamic behaviour of loading conditions are required to take account the effect of stress and vibration. In multibody dynamic analysis we are concern with dynamics of multibody interconnected multiple rigid bodies. The objective is to simulate the entire working cycle which consist of digging swinging dumping and swinging back to initial position. Study of stresses developed in various components is very much important in load lifting devices, which cause seal failure and reduction of fatigue life of cylinders. In this paper, a 30-ton hydraulic excavator is used for this particular study. Final outputs desired are the reaction forces at all joints and to evaluate the stresses at all gauge location. Modal analysis of excavator arm lifting mechanism was carried out in ANSYS. Excavator arm of different composite materials can be made out like steel, aluminium, alloy, structural steel etc. Analysis by using ANSYS 14.0 the result obtained that structural steel is preferred as good material for designing of excavator arm.

Keywords: Excavator, Digging, Swing, Dumping, Stress, kinematic, Dynamic, Cad, Cam, Simulation

I. INTRODUCTION

Excavators are mobile machines that are moved by means of either crawler track or rubber-tired undercarriage. Excavator digs, elevates, swings and dumps material by the action of its mechanism, which consists of boom, arm, bucket and hydraulic cylinders. The design of various components of an excavator is complex due to the fact that the reaction forces, displacements and stresses vary with time throughout the full cycle of operation [1]. Conventional methods of design in this case results in overdesigned models since the designer is forced to use a higher factor of safety due to lack of availability of data for full cycle of operation [2]. However, Multi-Body Simulation in Motion View/Motion Solve facilitates system level kinematic and dynamic analysis of the whole excavator, making it possible to study the reaction forces and stress variation in every component of the system throughout the cycle of operation. It helps in predicting the maximum stress at each location during the cycle and thus offers a way to optimize the design [3]. The scope is to simulate a full cycle of operation of a 30-ton excavator using Multi Body simulation capabilities of Altair Motion View/Motion Solve and compare the results with available test data. Pressures of hydraulic cylinders, Strokes of hydraulic cylinders, Bucket load and excavated mass of soil are applied as input. The full cycle of operation consists of three major phases, Digging, Swing and Dumping. By defining the component under study as a flexible body, it is possible to retrieve stress values at gauge locations used in actual testing, which can be used to calculate fatigue life of welds which is of utmost interest to the designer [4]. Furthermore, it is possible to generate load cases for detailed static analysis from the reaction force output [5]. The stress results at gauge locations are compared with both actual testing and static FEA by other commercial software. It is also worth noting that in the current simulation, many assumptions in similar previous simulations are updated [6-7] with actual values from field tests, like bucket tip force. General-purpose multibody dynamics analysis software like MBDyn (Multibody Dynamics) has been developed at Politecnico di Milano. MBDyn enables us to simulate complex mechanical systems such as car suspensions, robots, and wind turbines and study their motions and forces. The movie below shows an example of a robot arm simulation with MBDyn. This is a simple robot arm model for demo. With MBDyn we can construct a multibody system model such as this and study its motions and forces without explicitly formulating complex equations of motion. MBDyn has been developed mainly driven by research. But it has now been matured well enough for industrial use. Although MBDyn does not have its own pre-processor and post-processor at present, its functionalities are solid. In addition to the basic functionalities of multibody dynamics analysis, MBDyn supports many advanced functionalities such as handling of flexible bodies as modal elements, interface with controller design software, and real-time simulation. One distinctive feature of MBDyn is that it is equipped with abundant aero elastic and hydraulic elements due to its roots in aerospace engineering research (especially of rotorcraft and wind energy)

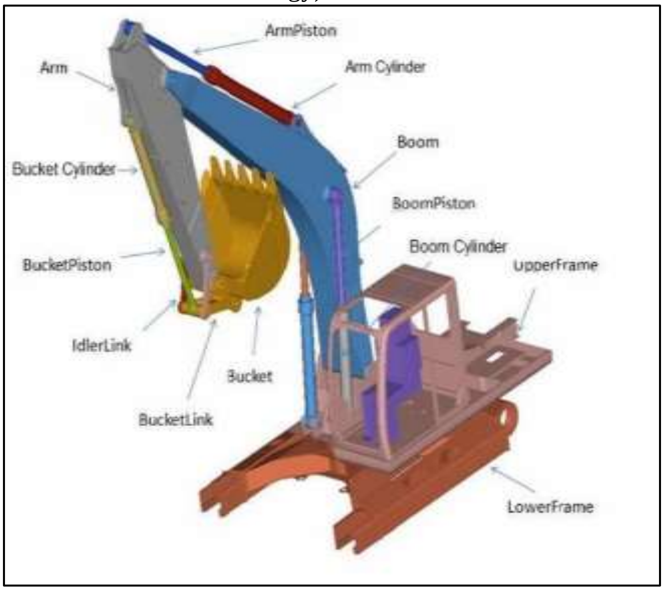

Fig. 1: various component of excavator

II. PROBLEM IDENTIFICATION

The working cycle of an excavator consists of digging, swinging, dumping and swinging back to the initial position. The objective is to simulate the entire cycle of operation. A 30-ton hydraulic excavator is used for this particular study. Final output desired are the reaction forces at all joints and to evaluate the stresses at all gauge locations.

- 3D Geometry or mesh data of every link to be modeled in the assembly.
- Mesh data of parts to be analyzed for stress (flexible body).
- Pressure on cylinder side and piston side of all cylinders during cycle of operation.
- Stroke of all cylinders during cycle of operation.
- Swing motor rotational speed during cycle of operation.

III. METHODOLOGY

An excavator consists of many links and joints, the analyst has to segregate the mechanism into different links and decide what kind of joints these links are connected with. The procedure to set up the problem is explained as follows. All the links of the mechanism are imported and assembled with appropriate joints in Creo Parametric. The lower frame is grounded. Both geometry and mesh files can be imported for rigid body simulation, but in case of flexible bodies, mesh files are required.

Cylinder pressures are converted into forces and applied at respective bodies.

{Considering the Structural Steel as engineering material.}:

1) Earth moving equipment having displacement 5 mm in x, y, z directions considering the structural steel as an engineering material. Considering bucket load capacity of 23500 kg.
2) Earth moving equipment having displacement 5 mm in x, y, z directions considering the structural steel as an engineering material. Considering bucket load capacity of 28000 kg.
3) Earth moving equipment having displacement 5 mm in x, y, z directions considering the structural steel as an engineering material. Considering bucket load capacity of 36000 kg.

LiuGong Excavator model no. 922D(HD) have following specifications: -

Engine	Cummins QSB 7
Gross Power	166 hp @ 2050 rpm
Max. Digging Depth	5,875mm
Bucket Capacity	$0.73m^3 – 1.2m^3$
Operating Weight	22,000 kg
Track Length	4456 mm (LC)

Table 1: Equipment Specifications

Earth moving equipment having displacement 5 mm in x, y, z directions considering the structural steel as an engineering material. Considering bucket load capacity of 23500 kg.

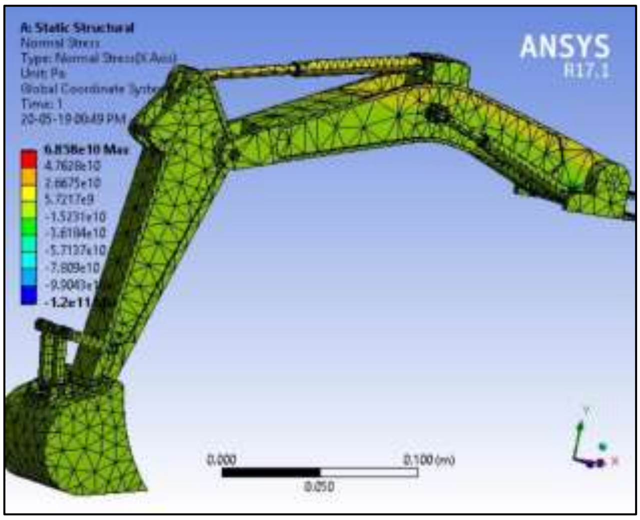

Fig. 2: meshing of excavator arm

Earth moving equipment having displacement 5 mm in x, y, z directions considering the structural steel as an engineering material. Considering bucket load capacity of 28000 kg.

Fig. 3: results of analysis of excavator arm without vibration

Earth moving equipment having displacement 5 mm in x, y, z directions considering the structural steel as an engineering material. Considering bucket load capacity of 36000 kg.

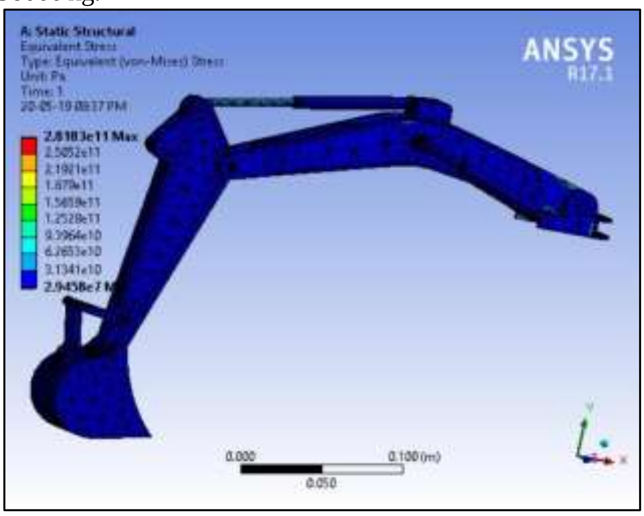

Fig. 4: results of analysis of excavator arm with vibration

IV. Result and Discussion

LiuGong Excavator 922D(HD) is considered

The model of Excavator arm and bucket is made in Creo Parametric 2.0 and for analysis purpose of the bucket, IGES file is imported in ANSYS Workbench 17.1 and then the model is analyzed further and various solutions were calculated (Von misses stress, Normal stress).

After analysis of "LiuGong Excavator 922D(HD)" the main focus of the analysis is to increase bucket loading capacity with change in design if pin of the bucket. Hence, the following results are obtained: -

1) Excavator base having displacement of 5mm in x, y, z directions. And when the bucket loading is 23500 kg then the pin of the bucket is safe because the factor of safety provided by the company.
2) Excavator base having displacement of 5mm in x, y, z directions. And when the bucket loading is increased by 4500 kg which means, now the operating weight is 28000 kg then the pin of the bucket breaks because of the excessive stress on the pin. Which means our design will fail if the bucket loading is more then it's safe limits.
3) Now in this scenario we increased the thickness of the pin of bucket, which results in the more weight carrying capacity of the Excavator bucket. We have increased the operating weight to 36000 kg and the Excavator is able to easily with stands that loading without breaking of the pin.

V. Conclusion

CAD model of the excavator is generated in Cero Parametric 2.0 and this model is imported to ANSYS Workbench 17.1 for processing work. An Amount of load 352 KN is applied along the circumference of the excavator's bucket made of STRUCTURAL STEEL, and base have displacement of 5mm in x, y, z directions.

Following are the conclusions from the results obtained:

1) Since von-misses stresses are less than the ultimate strength, talking deflections into account, Structural Steel is preferred as good material for designing of excavator.
2) Excavator bucket pin of different composite material can be made out like steel, aluminium alloy, magnesium alloy. titanium alloy, forged steel wheel or the combination of the different materials, to increase the load carrying capacity of the bucket

STRESS	VIBRATION	LOAD (kg)	RESULT
Normal stress	5mm	23500	Pin safe
Normal stress	5mm	28000	Pin fail
Equivalent stress(von-mises stress)	5mm	36000	Pin safe

Table 2: quantitative outcome

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