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DESIGN, MODELING AND ANALYSIS OF EXCAVATOR ARM

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ABSTRACT

The present work concentrate on the study of the components of the excavator in order to identify the problems faced while performing the lifting and digging operations and to provide a design solution by using CAD-CAE systems. For light duty construction work, generally mini hydraulic backhoe excavators are used and mostly there are soil surfaces for excavation. So, design of backhoe excavator is critical task in context of digging force developed through actuators during the digging operation. The important criteria for the design to be safe is that, the digging forces developed by actuators must be greater than that of the resistive forces offered by the surface to be excavated. The two important factors considered during designing an excavator arm are productivity and fuel consumption. As the present mechanism used in excavator arm is subjected to torsional and bending stresses during lifting and digging operation respectively, because of which failure occurs frequently at the bucket end of the arm. So, the new mechanism of excavator arm is designed and the Pro-e software is used for making the 3D model of the excavator arm linkage. By using ANSYS workbench software static analysis of each of the excavator arm component is done at existing digging force and also at newly calculated digging force. Also the bucket volume is increased to compensate for the loss in production due to the reduction in digging force.

Keywords: Excavator arm, lifting, digging, actuators, productivity, CAD-CAE systems.

I. INTRODUCTION

An excavator is heavy equipment consisting of an articulated arm (backhoe), bucket and cab mounted on a pivot (a rotating platform, like a Lazy Susan) a top and undercarriage with tracks or wheels. Their design is a natural progression from the steam shovel. Excavators are intended for excavating rocks and soils. Excavators may have a mechanical or hydraulic

drive. Hydraulic excavators are the most important group of excavators. The typical hydraulic excavator of VOLVO is shown in the fig.1.

Fig.1. A typical hydraulic excavator of VOLVO

II. DESIGN OF EXCAVATOR ARM

2.1 Calculation of pin diameter

$F = 10,300\text{N}$, $r = 391\text{mm}$, $L = 315\text{mm}$, $P = 15.69\text{N/mm}^2$, $A = 66836\text{mm}^2$,
Shear stress $= 42\text{N/mm}^2$, Bending stress $= 84\text{N/mm}^2$.

Let, d = diameter of pin

Torque, $T = F \times r = 10300 \times 391 = 4027300\text{N-mm}$, Load, $W = P \times A = 15.69 \times 66836 = 1048656.8\text{N}$

Now, Max. bending moment $= M = WL/4 = (1048656.8 \times 315)/4 = 82581723\text{N-mm}$

Since, pin is subjected to suddenly applied load. Considering $K_m = 1.5$, $K_t = 2$

We know that, equivalent twisting moment

$$T_e = \sqrt{(K_t \times T)^2 + (K_m \times M)^2} = \sqrt{(2 \times 4027300)^2 + (1.5 \times 82581723)^2}$$

$$T_e = 124134176.5\text{ N-mm}$$

But, $T_e = \pi/16 \times d^3 \times \text{shear stress}$

$$124134176.5 = \pi/16 \times d^3 \times 42$$

Therefore, $d = 246.9\text{mm}$

we know that, equivalent bending moment

$$M_e = 1/2[K_m \times M + T_e] = 1/2[1.5 \times 82581723 + 124134176.5]$$

$$M_e = 124003380.5\text{N-mm}$$

But, $M_e = \pi/32 \times d^3 \times \text{bending stress}$

$$124003380.5 = \pi/32 \times d^3 \times 84$$

Therefore, $d = 246.86\text{mm}$

Taking larger of the two values, we have diameter of pin $= d = 246.9\text{mm}$

2.2 Calculation for the total amount of material the bucket can lift

Since, we have considered a light duty construction work. So, calculate for a soil surface.

Density of soil is 1463kg/m^3 .

For existing model,

Volume of bucket, $V = 0.022\text{m}^3$

Total weight of soil, $W = \text{Density} \times \text{Volume} = 1463 \times 0.022 = 32.186\text{ Kg}$

For proposed model,

Calculated volume of bucket, $V = 0.028\text{m}^3$

Total weight of soil, $W = \text{Density} \times \text{Volume} = 1463 \times 0.028 = 40.964\text{ Kg}$

Self weight of bucket $= 17\text{ Kg}$

Now, Total load acting on bucket = Self weight of bucket + Total weight of soil
 $= 17 + 40.964 = 57.964 \text{ Kg}$
 $= 57.964 \times 9.81 = 568.62 \text{ N}$

By using this load, the dynamic analysis will be done.

III. MODELING

3.1 CAD modeling

CAD technology is very important while designing Excavator Mechanism. Following are advantages of CAD technology :

- 1) To increase the productivity of the designer
- 2) To improve the quality of the design

3.2 CAD/CAE softwares for Excavator mechanism design

- PRO/E – For 3D Component Design.
- PRO/Mechanism – For Mechanism

Pro/ENGINEER is a parametric, feature based, solid modeling System. It is the only menu driven higher end software. Pro/ENGINEER provides mechanical engineers with an approach to mechanical design automation based on solid modeling technology and the features such as 3D modeling, parametric design, feature-based modeling, associativity, capturing design intent, combining features into parts, and assembly. The three dimensional model of the assembly of Excavator arm is shown in the fig.2.

Fig.2 Excavator arm assembly

IV. FINITE ELEMENT ANALYSIS

The finite element method (FEM), sometimes referred to as finite element analysis (FEA), is a computational technique used to obtain approximate solutions of boundary value problems in engineering. Simply stated, a boundary value problem is a mathematical problem in which one or more dependent variables must satisfy a differential equation everywhere within a known domain of independent variables and satisfy specific conditions on the boundary of the domain. Boundary value problems are also sometimes called field problems. The field is the domain of interest and most often represents a physical structure.

The field variables are the dependent variables of interest governed by the differential equation. The boundary conditions are the specified values of the field variables (or related variables such as derivatives) on the boundaries of the field. Depending on the type of physical problem being analyzed, the field variables may include physical displacement, temperature, heat flux, and fluid velocity to name only a few.

4.1 Static structural analysis of Excavator arm

The steps involved in static structural analysis are as follows :

- The IGES file of the Excavator arm is imported and geometry is generated.
- The joint connection type used in the Mechanism Design to place a component in an assembly is specified.
- Meshing of the model is done.
- Fixed support is provided to the mechanism.
- The initial digging force of 10300N is applied first and then the newly calculated digging force of 7626N is applied.
- Solution of the problem is done in which the stresses induced due to the force applied is found.

The fig.3 and fig.4 shows the stresses developed due to application of 10300N force and 7626N force respectively.

Fig.3 Maximum Shear Stress at 10300N digging force

Fig.4 Maximum Shear Stress at 7626N digging force

It is seen from the fig.3 and fig.4 that dislocation of pin at the bucket end is occurring at 10300N digging force and when the digging force is reduced to 7626N, the dislocation is eliminated. Also, the digging force 7626N is greater than the resistive force offered by the soil surface which is 4000N. Hence, the design is safe.

4.2 Dynamic analysis of bucket

After the digging operation the bucket will lift the material. So, the total load acting on bucket will be the sum of self weight of bucket and total weight of material in the bucket. The load acting on bucket while working is 568.62 N. Hence, the dynamic analysis of bucket is done by applying a load of 570 N. The steps involved in dynamic analysis are as follows :

- Defining the geometry of bucket.
- Meshing of the geometry is done. The component is divided into 2147 elements having 4457 nodes.

- Providing fixed support at one end of the bucket.
- Applying force on the bucket.
- Solution involves determination of the stresses occurred due to the application of load and also finding out the total deformation.

The fig.5, fig.6, and fig.7 shows equivalent (Von-Mises) stress, Maximum Shear stress and total deformation respectively which are developed because of the 570N force applied.

Fig.5 Equivalent (Von-Mises) Stress

Fig.6 Maximum Shear Stress

Fig.7 Total Deformation

V. RESULTS AND DISCUSSIONS

The static structural analysis of the excavator arm is done and the maximum shear stress developed in the model is shown. Also, the dynamic analysis of the bucket is done when the Excavator is working. The stresses developed and deformation occurred is also shown in the models of the bucket. The graphs of various stresses and deformation is drawn with respect to the time interval and are shown in the fig.8, fig.9 and fig.10 respectively.

Fig.8 Graph showing equivalent (Von-Mises) stress

Fig.9 Graph showing maximum shear stress

Fig.10 Graph showing total deformation

The comparison of the proposed model with the existing model is shown in the table 1.

Description	Existing model	Proposed model
Arm length	650 mm	723 mm
Boom length	1400 mm	1347 mm
Overall height	2150 mm	1996 mm
Bucket capacity	0.22 m ³	0.28 m ³
	32.186 Kg	40.964 kg
Digging force	10300 N	7626 N
Max. Shear Stress	6975.7 Pa	5164.7 Pa
Total Deformation	2.8178 e ⁻⁰⁰⁵ m	2.0863 e ⁻⁰⁰⁵ m

Table 1. Comparison of Proposed model with the Existing model

Thus, it can be seen from the results that the digging force can be reduced by doing some changes in the geometry of the Excavator arm. From the table 1, it can be seen that the arm length is increased in the proposed model, and the length of boom and overall height of the structure is slightly reduced.

VI. CONCLUSION

Design of the excavator arm has been modified and analysis of the design is also done. From the analysis results, it is proved that the design is safe for the calculated digging force. During designing of excavator arm, the important factors taken into account are productivity and fuel consumption. Since, dislocation of the pin at bucket end and the cracking at the adapter end is eliminated by reducing the digging force. But reduction in digging force directly affects the productivity. So, the bucket capacity is increased to compensate for the loss in production due to the reduction in digging force. Also, fuel consumption is less due to the reduction in digging force. Finally, the results of the proposed model is compared with the existing model.

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