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Design and Analysis of Excavator Arm Assembly using Finite Element Method

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Abstract— **The aim of this work is to study the stick and the boom of an excavator & various forces acting on the bucket. The present review provides brief information about the excavator arm mechanism. Excavators are heavy construction equipment consisting of a boom, stick, bucket on the rotating platform known as the house. In this paper it is proposed to study the concept of finite element method and its application to the excavator arm design. Also various calculations are required to do in the areas where the problem occurs in the excavator. For this purpose many different load conditions have been studied numerically on the original excavator in order to estimate a safety factor and the deformability or flexibility of each component. Failure involves cracking of boom, failure in adaptor and dislocation at the bucket end due to the play in pin joint which is mainly because of digging force. In order to suggest the solution to these problems existing in the Excavator arm, it is necessary to do complete study of the Excavator and failures occurring in it.**

Index Terms— **Excavator arm, CAD, FEM, digging, lifting.**

I. INTRODUCTION

Excavators are typical examples of the heavy-duty human-operated hydraulic machine, these machines have manipulator-like structure with four degrees of freedom. The bucket link is in fact movable end-effectors of the manipulator. The main links “boom” and “stick” together with the “swing” serve to control the position of the bucket. Excavators are used for versatile construction operations such as digging, ground leveling, carrying loads, dumping loads, and straight traction. Considerable improvement in the performance of these types of machines can be achieved by computer-assisted control. Only the combination of the boom, stick, and bucket links which form the manipulator arm are studied here. The usual task of a excavator is to free and remove material from its original location and to transfer it to another location by lowering the bucket, digging by dragging the bucket through the soil, then lifting, slewing and dumping the bucket. In moving towards automatic excavation, there is a need for the development of a controller that is robust to uncertainties associated with these operations, for control purposes, kinematic and dynamic models of excavators that assume the hydraulic actuators act as infinitely powerful force sources. Position control with a conventional proportional and derivative controller is used for simulation of the digging process with limited soil interaction. Excavators are, however, subject to a wide variation of soil–tool interaction forces. When digging, the bucket tip motion is effectively force-constrained by the nonlinear constitutive equations of the environment, and by the hydraulic forces. An excavator is a machine for digging, material handling, demolition, general grading and mining. Excavators can be divided into two groups, namely large sized and small sized machines. Untrained operators such as farmers and less skilled engineers frequently operate small sized excavators without a license, although full trained and licensed persons and skilled operators are allowed to operate large sized excavators. The small sized excavators can be used in a small farm. Volvo excavators have been designed, engineered and manufactured with the world’s most advanced systems and technology.

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Fig.1 A typical hydraulic excavator

II. COMPONENTS OF AN EXCAVATOR

The main basic components of an excavator are as follows:
1. The Arm
2. Cylinder Rod
3. The Engine
4. The Swing
5. The Cab
6. The Feet
7. The Boom
8. The Bucket

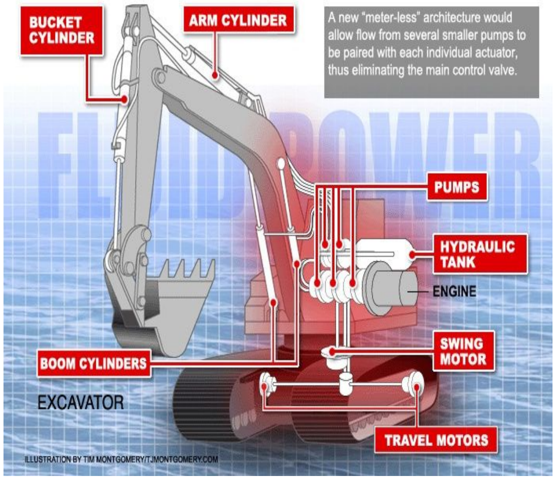

Fig.2 Components of Excavator[3]

III. DEFINING TYPICAL OPERATING CONDITIONS

Operating conditions of a back-digging, single bucket hydraulic excavator mechanism is categorized into four types. To address failure problems in engineering, the paper added a fifth operating condition: rotary braking operating condition. Position characterizations and load computations of these operating conditions are shown below:

Operating condition 1: The cylinder of the working arm retracts completely, the cylinder of the bucket rod has the greatest force arm; the tips of teeth are on the extended line of the line segment passing through the joint of bucket and bucket rods, and the joint of bucket rod and working arm. Under this condition, the load is composed of gravity, tangential force and side force.

Operating condition 2: Cylinders of the working arm and the bucket rod have the greatest force am; the tips of teeth are on the extended line of the line segment passing through the joint of bucket and bucket rod, and the joint of bucket rod and working arm. The load is composed of gravity and tangential force.

Operating condition 3: Cylinders of the working arm and the bucket rod have the greatest force arm; cylinder of the bucket operates at maximum equivalent force arm. The load is composed of gravity and tangential force.

Operating condition 4: Cylinder of the working arm retracts completely, the tips of teeth are on the extended line of the line segment passing through the joint of bucket and bucket rod, and the joint of bucket rod and working arm; the three points are all on the plumb line. The load is composed of gravity, tangential force and side force.

Operating condition 5: Cylinder of the bucket rod retracts completely; cylinder of the working arm ensures that the working arm and bucket rod operate at a position furthest away from the axis of rotation. Cylinder of the bucket extends to its maximum length, enabling the bucket to take up loads. The load is composed of gravity and inertial braking moment[8].

IV. LOAD CONDITIONS

For the purpose of increasing the productivity of excavator many different load conditions have been studied numerically on the original excavator in order to estimate a safety factor and the deformability or flexibility of each component. These parameters have been used in order to design a new arm. Five different load conditions have been checked in order to establish the stress conditions in each component of the excavator arm.

The first load condition concerns the levelling operation which allow to start the bucket at the maximum and minimum distance from the axle of rotation. The distance of the bucket from the surface does not change in this roto-translation (Fig. 4).

(a) (b)

Fig.3 First load condition: (a) initial position and (b) final position.

The second and third load conditions are similar. The second concerns the lifting operation with the maximum load at the minimum distance from the axle of rotation. The third load condition concerns the lifting operation at the maximum distance from the axle of rotation(Fig.5).

Fig.4 Second and third load conditions: lifting at the maxima and minima distance from axle of rotation.

The fourth load condition is a usual operation which concerns the levelling in the orthogonal direction as regards to the axle of the arm. This load condition is more important in order to evaluate the torsional behaviour of the components(Fig.6).

Fig.5 Fourth load condition[11].

The last load condition examined is an exceptional condition. In this case the force applied to each component of the excavator arm is the maximum force generated by the hydraulic cylinders both in tension and both in compression.

V. FINITE ELEMENT METHOD (FEM)

FEM is a computational approach that allows manufacturers to virtually test products and systems under different conditions such as changes in temperature and stress. The finite element method (FEM), also known as finite element analysis (FEA), is a numerical technique that has become an essential component for the design of products and engineering systems, as well as for the analysis of a broad variety of physical problems. As it is suggested in its name, finite element discretizes a continuum problem into a number of finite elements. Generally, design geometry is complex and the discretization allows for a consistent treatment of such complex geometries and boundary conditions. The engineer might find situations on which the creation of a prototype is not possible. Virtual engineering and in particular the finite element method (FEM) help in the development process by allowing the engineer to create an extensive variety of scenarios for a specific model[15]. Certain steps in formulating a finite element analysis of a physical problem are common to all such analyses, whether structural, heat transfer, fluid flow, or some other problem. These steps are embodied in commercial finite element software packages (some are mentioned in the following paragraphs) and are implicitly incorporated in this text, although we do not necessarily refer to the steps explicitly. The steps are described as follows :

A. PREPROCESSING

The preprocessing step is, quite generally, described as defining the model and includes :
Define the geometric domain of the problem.
Define the element type(s) to be used.
Define the material properties of the elements.
Define the geometric properties of the elements (length, area, and the like).
Define the element connectivities (mesh the model).
Define the physical constraints (boundary conditions).
Define the loadings.

The preprocessing (model definition) step is critical. A perfectly computed finite element solution is of absolutely no value if it corresponds to the wrong problem.

B. SOLUTION

During the solution phase, finite element software assembles the governing algebraic equations in matrix form and computes the unknown values of the primary field variable(s). The computed values are then used by back substitution to compute additional, derived variables, such as reaction forces, element stresses, and heat flow. As it is not uncommon for a finite element model to be represented by tens of thousands of equations, special solution techniques are used to reduce data storage requirements and computation time. For static, linear problems, a wave front solver, based on Gauss elimination, is commonly used.

C. POSTPROCESSING

Analysis and evaluation of the solution results is referred to as postprocessing. Postprocessor software contains sophisticated routines used for sorting, printing, and plotting selected results from a finite element solution. Examples of operations that can be accomplished include:
Sort element stresses in order of magnitude.
Check equilibrium.
Calculate factors of safety.
Plot deformed structural shape.
Animate dynamic model behavior.
Produce color-coded temperature plots. [9]

CONCLUSION

The paper investigates a detailed study of the excavator arm assembly which includes study of different components of excavator, different operating and loading conditions of an excavator and a study of different steps involved in a finite element methd.The existence of commercial software packages has allowed engineers and analysts to narrow the development process in either products or systems since the past few decades. Virtual engineering and finite element method (FEM) provides detail analysis of a conceptual design. These tools allows us to determine forces and stresses that are developed in critical points. This help us to determine modifications for the purpose of meeting the established criterion of the design.

This study will help in providing a remedial solution for the different problems occurring in excavator arm assembly.

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