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Recent Trends on Excavator Component Backhoe: A Review

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Abstract: **Earth moving equipment called excavators are used to excavate hard rocks and soil which are below the natural surface of the ground. Due to different working conditions the various components of excavator like bucket, arm and boom are subjected to high loads. During the excavation operation there are unknown resistance forces offered by the soil which are bear by bucket teeth. Normally, excavators are working under worst working conditions. Due to severe working conditions, excavator parts are subjected to high loads and must work reliably under unpredictable working conditions. Thus, it is necessary for the designers to provide not only an equipment of maximum reliability but also of minimum weight and cost, keeping the design safe, under all loading conditions. The force analysis and strength analysis is important steps in the design of excavator parts. Several studies have been done relating to the Design and optimization of various parts of excavator. FEA and optimization of backhoe excavator attachment, was already carried out by researchers for and which can be helpful for development of new excavator attachment. This paper intends to look for various researches done related to excavators in the past few years. The fields covered under study are finite element analysis, optimization, multibody dynamic analysis and modeling, simulation and control.**

Keywords —Excavator, simulation, modeling, dynamic analysis, multibody system, finite element analysis.

I. INTRODUCTION

The excavators are very popular multi-functional construction and mining machines. It consists of a vehicle body, a swing body and a front digging manipulator, through which digging operation is performed. The digging manipulator arm consists of moving elements- boom, arm and bucket having teethes (Fig.1) which are connected by pin joints [1]. The three in total is named backhoe. The various elements are powered through hydraulic cylinders, which are connected to the excavator. Motion of the elements is by extension and retraction of the hydraulic cylinders which is commanded by the operator. The performance of hydraulic excavator is depending on its front attachment.

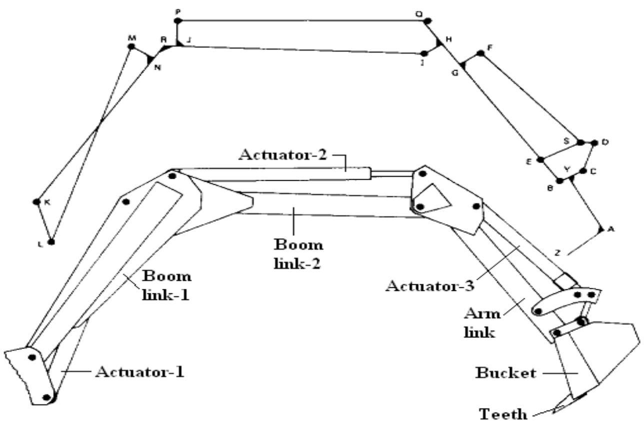

Fig. 1 Structural model of excavator digging arm

II. EVOLUTION AND PROGRESS OF EXACAVATOR

The very first excavator came in existence one and a half decade back which was powered by steam and the arm operation were accomplished using cable. With the development of technology the machine became larger and the moving mechanism also changed gradually. Hydraulic excavator was firstly developed by Carlo and Mario Bruneri in 1948. The first Japanese hydraulic excavator was produced by Hitachi in 1965. From then onwards, hydraulic excavator with its convenient operation performance rapidly replaced traditional mechanical excavator. At that time, hydraulic excavator already had those fundamental work parts: boom, arm, and bucket. It reduced the labor intensity of the workers. However, lag in hydraulic technology and complex operations hindered the development of the hydraulic excavator. Rapid developments of the hydraulic technology in aircraft and machine tool brought the progress of the hydraulic excavator. The volume and transmission system of hydraulic excavator became simpler. Now, the hydraulic excavator has become the main type of machine.

III. STATUS OF RESEARCHES

The developments of backhoe depends on the development of the materials, structures, processes, and the transmission form. The steel pipe frames forming arm, the steam power and the cable transmission of the earlier stage has been

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replaced and the excavator backhoe currently have an advance design. At present, the research of excavator attachment is mainly concentrated in the kinematic analysis, dynamic analysis, structural analysis, trajectory planning and control, fatigue life analysis and structural optimization design at home and abroad.

1. Finite Element Analysis of the Excavator Attachment-

A. V. Pradeep et al, in 2013, [2] aimed of a project to design every component of an excavator, to assemble it and to carry out analysis on the bucket teeth taking different materials and considering the impact load on it. Deformations, Von-Mises stresses and strain energies are compared for the different materials and the optimum material with less weight, high strength and good sustainability were found out. A bucket of less weight and high strength was suggested which gives a saving in material and manufacturing cost. Design and assembly were done in CATIA and meshing and analysis in ANSYS.The analysis was done for three materials, i.e. steel, wrought iron and cast iron and the Von-Mises stresses, deformations and the strain energy for all the three materials were found. Comparisons were made between those three materials and following results were depicted:

Weight (of 1 cu.m)

Steel: 7840 kg.

Cast iron: 7300 kg.

Wrought iron: 7550 kg.

Deformation:

Steel < Wrought Iron < Cast Iron.

Von Mises stresses:

Steel < Wrought Iron < Cast Iron.

Strain energy:

Wrought iron > Steel > Cast Iron.

Since wrought iron is tough, malleable and ductile and can be easily welded, so for the same strength and other advantages wrought iron was suggested as a replacement material. In 2013, Bikash Rai, et al, [3] made an attempt to design and analyze the rotating bucket of the excavator along with the boom and the bucket arm. A focuses on the joint design was made by using the geared motor for angular rotation of the bucket arm. The effect of digging, the motion of the bucket arm, torsional force and bending stresses developed on the joint were also under study. By determining various reaction forces a rotary joint for the arm could be designed, which facilitates the rotation of the arm and can increase the productivity.

Asit Kumar Choudhary and Gian Bhushan [1] carried out finite element analysis of excavator arm by using CAE tools. The tools being used were CATIA, HYPERMESH and RADIOSS LINEAR. The obtained FEA results were compared with the similar work carried out on the CAD model using ABAQUS. In CAE software Pro/E, the three dimensional (3-D) model of arm an excavator was prepared. The finite element analysis (FEA) software ANSYS was used to analyze the stiffness, and strength of excavator design. Meshing and analysis was carried out in Hyper mesh. The results of analysis showed that the strength and stiffness for the arm was sufficient and it was below the critical value and hence the design is safe. The maximum value of principal stress developed in excavator arm for digging operation was 116.4MPa and for dumping operation as 27.15MPa.These values are well below the yield stress for the given loading condition. It was clearly depicted that the stresses produced are within the safe limit. The maximum displacement observed for digging was 3.65mm as well as for dumping 0.8795mm at free end where the bucket was fixed. The values of the Von Mises stresses for digging and dumping were 171.7MPa and 34.75MPa respectively. So the conclusion was that the finite element analysis using computer aided design can be used in force analysis as well as strength analysis, which is an important step in the designing of excavator parts.

2. Optimizing the Structure Design of the Excavator Attachment-

Altaf S. Shaikh, B.M. Shinde, [4] compared the Finite element analysis (FEA) of existing excavator arm with optimized arm for stresses and deflection. Here FEA approach is applied for the optimization. Finite element based optimization of excavator arm was discussed and helped in finding out the most appropriate design of which a prototype is fabricated and tested. The study of various iterations of excavator arm was done and it is found that one of the iteration has sufficient amount of material removed without affecting its strength and finally FEA results was compared with Experimental results. The conclusion of analysis was that the FEM results and experimental results made a comparable study and the validation shows close variance. From comparison of weight of existing model and optimized model, an overall weight reduction of 5% approximately, was achieved. The arm of excavator existing model weight 1082.2 kg while for the Optimized model it was 1034.6 kg (Fig 2).

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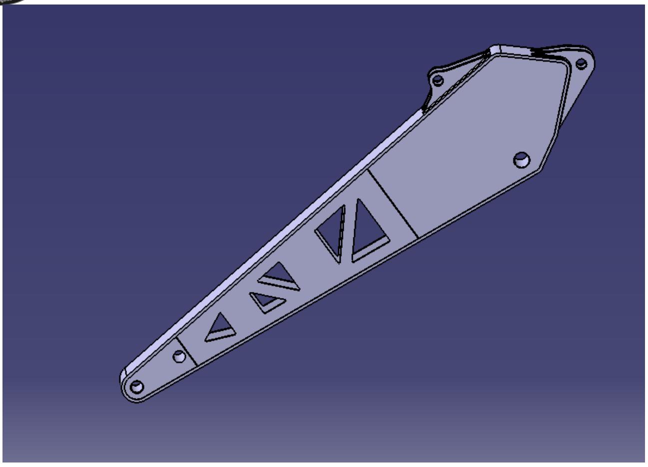

Fig.2: CAD model of Optimized arm

Dharmendra Kumar and Rahul, [5] reviewed the work on FEA and optimization of excavator. Finite Element Analysis (FEA) was suggested as the most appropriate technique in strength calculations of the structures working under known load and boundary conditions. Computer aided drawing model of the parts to be analyzed must be set prior to the FEA. It is also promising to reduce the weight of the mechanism by performing optimization in FEA. The paper provides the platform for proceeding for the Modeling, FEA and optimization of backhoe excavator attachment, which was already carried out by other researchers for their related applications and it can be very helpful for development of any material handling equipment and new excavator attachment. To carry out the modeling and Finite Element analysis of an excavator, many software has been used by researchers like Space claim, PRO-ENGINEER, ADAMS, NASTRAN, CATIA, ANSYS, Hypermesh, Abaqus, I-deas, Soldiworks etc. It becomes very easy to identify the weak components by doing the strength analysis of excavator attachment. OPTIBOOM software utilized by Cevdet Can Uzer, in 2008 generates a Computer aided design model using a meshing tool. The model can be discretized and then a finite element analysis is performed. A Grid-enabled analysis with self-developed codes provides easy access to computational and database capabilities to improve the engineering system based on stress, strain, deformation (FEM) results. Topology optimization gives the better results by changing the initial topology. Space claim and Ansys is a powerful tool for optimization. Better lighter and cheaper designs can be obtained by using FEM and optimization techniques and corrections are possible before prototyping. Yitao Zhu [15] submitted his dissertation based on Sensitivity Analysis of Multibody Systems in 2014.

3. Multibody Dynamic Analysis of the Excavator Attachment-

Nikolay Pavlov, Evgeni Sokolov, Mihail Dodov, and Stoyan Stoyanov, in 2017, [6] created a multibody dynamic model of a compact wheel loader. The model includes the sprung and the un-sprung masses of the tractor and the mass of the bucket. Results for the natural frequencies and the accelerations of the dynamic system were obtained. The dynamic model was verified by comparing the calculated results with the ground test results. The conclusion was that the developed multibody model makes it possible to study the vibration of sprung and un-sprung masses, as well as the vibration of the loader boom. The model allows to study the vibrations at different stiffness and damping ratios of the boom suspension. The results obtained may be used for estimation of dynamic properties related to wheel loader vibration, ride comfort and road holding. The specially designed front loader allows for the realization of different stiffness ratios of the boom suspension. The front-end loader has been made and a ground test was conducted, which shows good comparability with the results from the numerical simulations.

A Purushotham & Mr. J.Anjeneyulu [7], did analytical Research work in multi-body dynamics and applied Kane's Method (originally called Lagrange form of d'Alembert's principle) on the Robotic Dynamics for developing dynamical equations of motion and then prepare a solution scheme for space Robotics arms. The method was implemented on 2R Space Robotic Arm with Mat Lab Code. The limitations and difficulties that are aroused in arm dynamics were eliminated with this novel Approach. The conclusion was that Kane's method is a powerful technique in robot dynamics. It offers the advantages of both the Newton-Euler and Lagrange methods. For implementing Kane's method, a dynamics software package (MATLAB) had been used. The generalized procedure of Kane's method to develop equations of motion and perform simulations was also explained. A dynamic models using lagrangian method to R-R Robotic Arms was build. It was also concluded that the developed Kane's model is very useful in Robotics when its complexity is increased.

Jun-Yong Park, Wan-Suk Yoo, Heui-Won Kim, [8] used ADAM, a multibody dynamic code, to develop 3-D model of a hydraulic excavator and simulated it assuming flexible multibody. A hydraulic excavator consists of 16 bodies with 3 revolute joints, 4 translational joints, 8 universal joints, 6 spherical joints and a fixed joint.

Dynamic analysis of mini excavator using Lagrange-Euler approach have been proposed using a dynamic model which determines the required joint torques for given set of trajectory points, joint angle vector, joint speed vector, joint acceleration vector. The proposed dynamic model may be used for the autonomous controlling problem of the backhoe excavator [9, 16, and 17].

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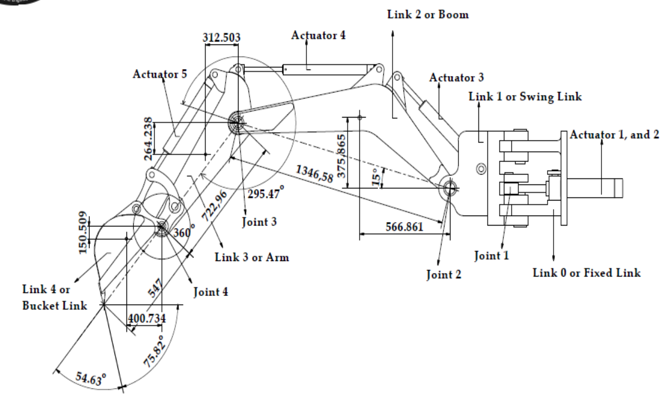

Fig. 3: Schematic view of a backhoe excavator attachment.

4. Modelling, Simulations and Control of the Excavator Attachment-

Onesmus Muvengei, John Kihiu [10], prepared a model of the interaction of hydraulic and mechanical dynamics, the inter-actuator and inter-link interactions in an excavator using bond graphs and then simulated it on a MATLAB/SIMULINK environment. Bond graph method was chosen as the modeling method because it is a domain-independent graphical method of representing the dynamics of physical systems. The method being relatively new has not been thoroughly applied to model the dynamics of nonlinear systems such as excavators. A complete bond graph dynamic model of the excavator was obtained by coupling the mechanical and hydraulic models using appropriate Manipulator Jacobians which were treated as Modulated Transformer Elements. The causal bond graph model of the excavator was expanded into block diagrams and simulated on MATLAB/SIMULINK to determine the transient and steady state responses of the system. From the responses obtained, the model developed was found to capture the inter-component interactions and also the interaction between the hydraulic and mechanical dynamics. Therefore, the model developed could be used for design purpose. Forward dynamic simulations was run to determine the open loop transient and steady state responses of the excavator. The bond graph model developed was found to capture the interactive dynamics, that is, inter actuator interactions, inter-link interactions and interaction of the hydraulic and mechanical dynamics. The excitation caused by suddenly stopping the bucket link during simulation, was felt in the response curves of the other links and also of the hydraulic system. So it was concluded that the dynamic model developed in this work can be applied in designing appropriate control laws for the manipulator motions. S. Vechet and J. Krejsa, [18] modelled the Hydraulic arm using MATLAB SimHydraulics in 2009.

Rosen Mitrev, Radoslav Gruychev and Petr Pobegailo [11], devoted their work to CAD/CAE investigation of the mechanical system of large mining excavator with Tri power system. The investigation was performed in Autodesk Inventor environment and its dynamical simulator. A 3D model of the excavator working equipment was developed and used for investigation of the geometrical, force, kinematical and dynamical parameters of the mechanical system. Also investigation of these parameters for an operating cycle of the excavator was performed. The used CAD/CAE approach was found suitable for performing geometrical, force, direct and inverse kinematical and dynamical analysis of the working equipment mechanical system. By simulation it was possible to investigate the change of parameters during operating cycle and optimize its duration. Though the used CAD/CAE system had no built-in tools for optimization of the mechanical system parameters, optimization would be performed by trial and error method.

Yu Du, Michael C. Dorneich and Brian L. Steward [12], in 2016, investigated how machine operator expertise, strategies and decision-making can be integrated into operator models that simulate authentic human behavior in construction machine operations. Physical prototype tests of construction machines require significant time and cost. However, computer-based simulation is often limited by the fidelity in which human operators are modeled. A greater understanding of how highly skilled operators obtain high machine performance and productivity can inform machine development and advance construction automation technology. Operator interviews were conducted to build a framework of tasks, strategies, and cues commonly used while controlling an excavator through repeating work cycles. A closed loop simulation demonstrated that an operator model could simulate the trenching work cycle with multiple operator strategies and adapt to different vehicle and work site settings. A Virtual Operator Model that captures human expert behaviors can be used to assess vehicle characteristics and efficiency and inform the design of automation systems. Hence, an approach or methodology for virtual operator model development was developed, resulting in the capability to simulate the function, response, and characteristics of operator behavior to simulate vehicle control inputs for an excavator trenching operation. This capability enables simulation of virtual machine prototypes for performance analysis including fuel efficiency, productivity, and component loading. Virtual operator models enable closed-loop, whole system evaluations of new design features early in the design process. The approach developed combined human factors methods with dynamical system modeling techniques to capture and model operator expertise in a virtual operator model that can be used in closed loop vehicle simulation. The model was designed to capture the behavior and performance of a human operator and represent the operator in a virtual operator model that simulates authentic human behavior for a well-defined construction machine operation. The approach can be generalized to off-road vehicle simulation,

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and the virtual operator modeling approach can inform the machine automation design. The use of fuzzy logic allows multiple states to be active simultaneously and thus it can be used to represent operations that include task overlap. Fuzzy logic also uses human-like reasoning rules to perceive information, and mimics the perception process of a human operator. The model generates the human operator control inputs to execute a work cycle of an excavator trenching operation. The simulation results in a work cycle that is generated by executing a series of tasks in the way a human operator would – perceiving the state of the machine, deciding when to transition from one task to the next, and controlling the machine to move the bucket through the tasks.

IV. Conclusion

Since the evolution of an excavator, many changes and modifications have been made to improve the performance of this machine. An attempt is made through this paper to find out the recent research activities carried out for an excavator in the field of multibody dynamics, finite element analysis etc. It has been concluded that:

(1) Using FEM the researchers had attempted to find out the portion of the excavator in which the stress was more and hence suggested for the change in design.

(2) Through optimization technique [13], the overall weight of the excavator was tried to be reduced by 2 to 20 kg.

(3) Multibody dynamics is the newly applied technology and method through which the whole structure is assumed as a single body and hence the stress and strain and also other results reach to more accuracy.

(4) Finally, the recent technology and soft wares like MATLAB etc. used for modelling and simulation helps to find better results.

It is also an attempt to find out various technologies, methods and soft wares used to improve the design of excavator. Many more researches are also have been done in other fields like contact analysis, kinematics etc. are not included in this paper. The development trends of excavator attachment mainly comprise to improve the excavator's reliability and efficiency and to reduce production costs. Technologies are applied and different materials are analyzed to improve efficiency and save energy. The efficiency of the excavator can be improved by Bionics which is a discipline with the obvious characteristics of interdisciplinary science and technology. It provides new ideas, new original management and new methods for the science and technology innovation.

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