MODELLING AND ANALYSIS OF EXCAVSATOR ARM - A REVIEW

[1]B. Raghu, [2]B. Rajesh, [3]CH. Swathi, [4]D. Rishikesh, [5]G. Abdul Kadir

[1]Assistant Professor, [2, 3, 4, 5]Student

[1]Department of Mechanical Engineering
[1]Guru Nanak Institute of Technology, Ibrahimpatnam, Telangana, India

Abstract: The Hydraulic excavator machines are heavy duty earth movers consisting of a boom, arm and bucket. It works on principle of hydraulic fluid with hydraulic cylinder and hydraulic motors. The Hydraulic excavator arm operation require coordinated movement of boom, arm and bucket. 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 main objective of this paper is to perform design and analysis Excavator Arm for the calculated Force. The CATIA software is used for making the 3D model of the excavatorss arm linkage. By using ANSYS workbench software analysis of the excavator arm is done at existing digging force and lifting force. Excavator bucket is very crucial element of hydraulic excavator. The whole loads of excavated materials have been carried out by this element. As the present mechanism used in excavator arm is subjected to deformation and bending stresses during lifting and digging operation respectively, because of which failure occurs frequently at the bucket end of the arm.

Keywords: **Excavator arm, lifting force, Digging force, CATIA, ANSYS 19.0.**

1. INTRODUCTION

Excavator is a heavy construction equipment consisting of a boom, dipper (or stick), bucket and cab on a rotating platform known as the "house". The house sits at top of undercarriage with tracks or wheels. All movement and functions of a hydraulic excavator are accomplished through the use of hydraulic fluids, with hydraulic cylinders and hydraulic motors. Due to the linear actuation of hydraulic cylinders, their mode of operation is fundamentally different from cable-operated excavators which use winches and steel ropes to accomplish the movements.

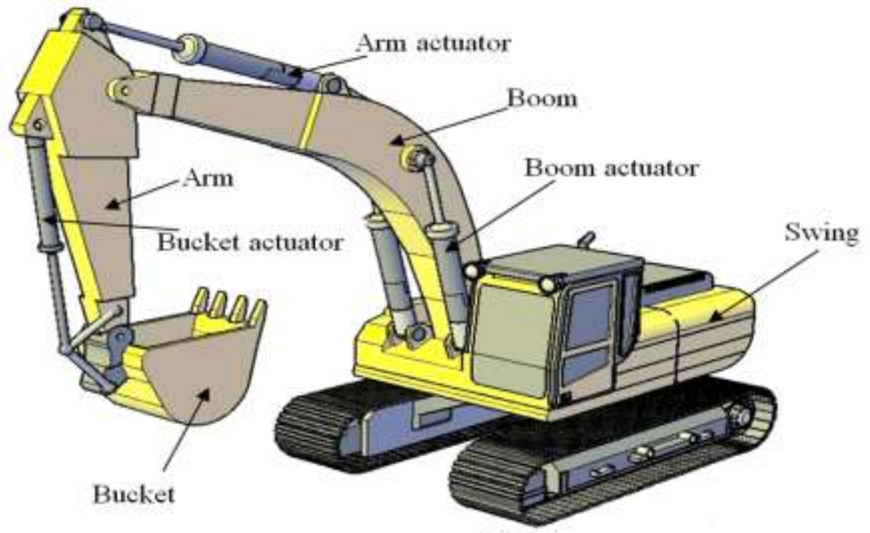

Fig1. Hydraulic excavator with parts.

The fundamental mechanism of an excavator consists of the undercarriage that includes the tracks, track frame, blade and the final drive. The final drive has a hydraulic motor and gears that provide drive to the tracks. The operator's cabin, engine, counterweights, hydraulic and fuel tanks are attached to the undercarriage, enabling the excavator to swing 360° without any hindrance.

The main function of the excavator engine is to drive the hydraulic pumps that provide oil at a high pressure to the slew motor, rams, track motors, and several accessories. An arm is attached to the boom end that imparts the force for digging into the ground and other operations. A bucket is fixed at the arm end for carrying the soil and for required operation. Hydraulic cylinders apply forces to boom, arm and therefore the bucket to actuate the mechanism.

2. LITERATURE REVIEW

Bilal Pirmahamad Shaikh and et.al in their paper they taken the maximum digging force condition as the boundary condition and loading condition to carry out static finite element analysis for different excavator bucket tooth. They have found that the Stresses below yield strength obey Hook's law, so deformation in elastic limits. From results it can be seen that stresses are till below safe stress/ allowable stress value so more material can be removed. They have found in the results that the tiger and twin tiger teeth stresses are above safe stresses [1].

B. Govinda Reddy and et.al in their paper they have done the analytical and Ansys results percentage error. The stress at the Tip of teeth of an Excavator bucket is calculated 86.39 MPA and stress due to shearing of rivet is calculated 187.67 MPA by analytically. The stress at the tip of the teeth is calculated 112.98 MPA and stress due to shearing of rivet 157.47 is calculated. Percentage error between analytical result and Ansys result are 13.69 % and 6.72 %. From the above results they have suggested that the bucket used for the excavation purpose should be properly checked for its application on the basis of the soil strata [2].

Takashi YAMAGUCHI and et.al in their paper they reports on the results of performing experimental measurements of the motion of a hydraulic excavator operated by a human operator and analyzing the data obtained by the measurements in order to achieve autonomous control of excavating and loading work by hydraulic excavators based on the skill of experienced operators. the ground materials that are the object of the excavation and loading work by a hydraulic excavator have non-uniform properties, so it is difficult to know the properties in the entire work range before performing the work [3].

Sharan gouda A Biradar and et.al in their paper they have calculated the forces acting on the excavator bucket teeth according to the standard SAE J1179 as 60 KN and also the bucket capacity is calculated according to the standard SAE J296 as 0.75 m3. The stress at the tip of teeth of an excavator bucket is calculated. As per the analysis results, they have suggested that the bucket used for the excavation purpose should be properly checked for its application on the basis of the soil strata [4].

Dharmesh h. Prajapati and et.al in their paper they have concluded that the capacity of bucket has been increased up to 300 kg from 150 kg. they have modified design and increased capacity also by adding two more teeth to full feel the functional requirements. They have checked the design of excavator bucket under different loads. They have increased the volumetric capacity as well as reduce the total deformation of modified bucket [5].

Altaf S. Shaikh and et.al in their paper, the forces on the excavator are calculated and the forces flowing to excavator arm are determined. The analysed part shows there is a scope for optimization. The optimizations of the excavator parts is carried out by different iterations and finally the optimized results are obtained. Excavator arm is fabricated and experimentally tested. The FEM results and experimental results are made a comparable study and the validation shows close variance. From comparison of weight of existing model and optimized model it is seen that Overall weight reduction of 5% approximately has been achieved [6].

Sachin B. Bende and et.al in their paper they have modified the Design of the excavator arm and analysis of the design. From the analysis results, they have proved that the design is safe for the calculated digging force. During designing of excavator arm, they have taken the important factors into account they 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 are compared with the existing model [7].

A. V. Pradeep and et.al in their paper they have designed excavator bucket and analysis is done for three materials, i.e. steel, wrought iron and cast iron. They have found out the von-misses stresses, deformation and the strain energy for all the three materials. They have made the comparisons among them. Steel and wrought iron has lesser stresses developed when compared to cast iron. Form the results they have concluded that the steel can be replaced with wrought iron [8].

P. Govinda Raju and et.al in their paper, the static structural analysis of the arm and bucket is done and the maximum shear stress and deformation developed in the model is shown. From their study the total weight of the arm is reduced by 50%. The capacity of the bucket is also increased [9].

G.Ramesh and et.al in their paper topology optimization approach is presented to create an innovative design of an excavator Lower Arm. Final comparison in terms of weight and component performance illustrates that structural optimization techniques are effective to produce higher quality products at a lower cost. The Lower Arm has further undergone weight reduction using the material selection through the usage of ALTAIR RADIOSS SOFTWARE. 9.28% of weight is reduced from the base model and it is stiffer [10].

Roshan V. Marode and et.al in their paper, the backhoe-loader bucket have been analyzed with the maximum loads and boundary conditions using FEM. Analyses have been carried out for the maximum hydraulic cylinder forces. Symmetrical boundary conditions have been examined along with the fatigue life. The theoretical life cycle of any component in ANSYS is considered as 106 and in the present study the estimated life cycle is 0 for very small region. This can further be improved by changing the shape of the feature. It is also observed that the life of the component reduces considerably as it undergoes fatigue loading [11].

Nitin S. Patil and et.al in their paper all the iterations have been carried out the final iteration shows the better results. Therefore they have been concluded that it would be a better replacement for the conventional model. After the optimization the total weight reduction of approximately 120 kg is achieved in turn it would increase to the performance of the boom and hence the cost reduction. As the yield strength of the material is 1000MPa, the stresses are within limit and hence the design is safe (3.45 factor of safety) [12].

R M Dhawale and et.al in their paper the mini hydraulic backhoe excavator attachment is developed to perform excavation task for light duty construction work. Based on static force analysis finite element analysis is carried out for individual parts as well as the whole assembly of the backhoe excavator with and without consideration of welding. It is clearly depicted that the stresses produced in the parts of the backhoe excavator attachment are within the safe limit of the material stresses for the case of with and without consideration of welding [13].

Janmit Raj and et.al in their paper the FEA of excavator boom was done in various operating states, simulating actual working conditions in software. The studies shown that mostly higher stress concentration occur at bottom plate of the boom near boom cylinder connecting seat. The forces at each hinge point were calculated mathematically [14].

Sujit Lomate and et.al this paper basically focused on an Analysis and Optimization of Excavator Bucket. The results were supported with an experimental validation for verifying the actual distortion and FEA results. Following are concluding remarks based on the analysis performed on bucket model & Bucket validation at ARAI. Model of Bucket is analysed under 4 different loading conditions to find out the bucket distortion, and bucket distortion is compared with regular bucket. It is observed that the stresses in 1.8 cum design when analyzed for 1/3 offset and for full offset are lesser than 1.9 cum Current production bucket [15].

Chinta Ranjeet Kumar and et.al in their paper the main changes in the model are done by adding rectangular ribs, round ribs and half sphere ribs to the inner surface of the bucket and also EN19 Steel material was replaced with AISI1059 Carbon Steel for better results. Static and buckling analysis on the excavator bucket is done. By observing the analysis results, the stress values for half sphere ribs are less than other three models. When, they compare the results for materials, the stress value is less for AISI 1059 Carbon steel and also its weight is less compared with EN19 Steel [16].

Swapnil S. Nishane and et.al in their paper By modelling and analysis of backhoe excavator bucket they have been observed that, the values of von-mises or equivalent stresses for existing and optimized bucket become less difference, but the area of stress in optimized backhoe excavator bucket is reduced as compared to existing one. Also, the value of deformation and stress intensity optimized HORDOX-400 excavator bucket becomes 2.138mm & 201MPa respectively, are less as compared to other materials. The life of existing bucket material is of 22760 min cycles. but by analyzing and comparing with different materials, they have been found that the life of optimized HORDOX-400 excavator bucket 66102 min. which is better than existing & optimized – 500 material [17].

Khedkar Y and et.al in their paper Analytical soil-tool interaction models are utilized to calculate resistive forces exerted during digging operations. The digging force is higher than the resistive force so the bucket design is proficient for digging. From the graphs, it's clear that resistive force is increasing as the tool depth below the soil, bucket width and rack angle so it's necessary to select optimum value of bucket width and rack angle while designing bucket. With the static force analysis, we come to know about forces acting at joints of the bucket for each angle of lift and digging [18].

Y Madhu Maheswara Reddy and et.al in their paper by modelling and analysis of backhoe excavator bucket tooth it has been observed that,the values of von-misses or equivalent stresses for existing and optimized bucket become less difference, but the area of stress in optimized backhoe excavator bucket tooth is reduced as compared to existing one[19].

R. Jaison and et.al in their paper a detachable backhoe and loader components are designed to be fitted on a agricultural tractor to lift a load of 2000N and 6000N respectively. This attachment can be removed once its work is completed and the tractor can be used for other purposes like ploughing, carrying loads etc. This backhoe is preferred for trenching and digging in the fields where the trenching process will be carried out often and to carry waste from fields through the loader [20].

Dhanpal Nin his paper Analytical soil-tool interaction models are utilized to calculate resistive forces exerted during digging operations. The digging force is higher than the resistive force so the bucket design is proficient for digging. From the graphs, it's clear that resistive force is increasing as the tool depth below the soil, bucket width and rack angle so it's necessary to select optimum value of bucket width and rack angle while designing bucket. With the static force analysis, we come to know about forces acting at joints of the bucket for each angle of lift and dig [21].

P Mahesh Babu and et.al in their paper the digger arm is developed to perform excavation task for light duty construction work. Based on static force and dynamic force loads, finite element analysis is carried out for digger arm. It is clearly depicted that the stresses produced in the component of the digger arm are within the safe limit of the material stresses for the case of static and dynamic load conditions. It is also clearly depicted that the fatigue life cycle of the digger arm is more by 42.6% for modified digger arm compared to original digger arm. Based on results they have conclude that optimization can help to reduce the initial cost of the digger arm as well as to improve the functionality and life cycle as the digger arm operates in worst working conditions. The optimization also helps to avoid frequent failure of digger arm which may cause the entire system become idle and lead to a commercial loss to the owner [22].

Rahul Mishra and et.al in their paper the capacity of bucket has been calculated according to SAEJ296. The bucket specification is the most superior when compared to all other standard model. The breakout force is calculated by SAEJ1179. The SAE provide the breakout and digging force. For max. breakout force condition but for autonomous application it is important to understand. Which are improved bucket geometry for more efficient digging and loading of material. And heavy-duty robust construction for increased strength and durability [23].

J Subba Raju and et.al in their paper Working range in one of the important characteristics of backhoe mechanism. To estimate the working range, a forward kinematical modal and its computer algorithm was developed. Working range computed from computer algorithm was validated with virtual and physical prototype of BEML designed excavator. Results were consistent and proved to be right. This paper emphasizes the significance of structural parameters of backhoe, sequence of design and design validation procedures. This work lays foundation for analyzing the backhoe from stability and digging forces point of view Also, developing a customised tool in MSC Adams, which adapts the concept of mathematical modelling and its computer algorithm, will reduce the design efforts [24].

Zhigui Ren and et.al in their paper, the accurate calculation of the theoretical digging force shows many applications: not only in the optimal design of the excavator and the evaluation of the excavator's digging performance, but also in trajectory planning and control automation. In TDFCM model the normal resistance and resistance moment are simplified and ignored. Based on the resistance characteristics, the LDF model is established in this paper, simultaneously taking the tangential force, normal force, and the bending moment into consideration. Taking the digging resistance by testing for a 35t hydraulic excavator with backhoe attachment as the standard, this research compares the calculation results of the TDFCM model with those of the LDF model proposed in their paper [25].

Suraj R. Jiddewar and et.al in their paper In order to eliminate the problem of dislocation due to the play in pin at the bucket end of the excavator arm, the analysis of the problem occurring is done to find out the reasons behind the failure of excavator arm. While performing various operations, excavator arm is subjected to various stresses because of the force acting on it. Due to this all the parts of excavator arm gets deformed and when deformation exceeds a certain limit failure takes place. During working a large amount of vibration is always occurs in an excavator arm assembly and the frequency of this vibration is always changing at different moments during operation [26].

Prof. C. K. Motka and et.al in their paper Stresses are well within the allowable stress for the entire area. There is a stress concentration at the point where the max force is applied, which can be neglected. The total deformation at the bucket teeth point is 5.5292 mm which is negligible. By increasing pin diameter at critical loading points strength of the assembly is increased. By changing the material of the components of backhoe and by trial and error method in ANSYS results are obtained [27].

Amol B. Bhosale and et.al in their paper the work is carried out on the boom component of the hydraulic excavator. The linear static analysis is done to find out the linear static characteristics of the boom component. From those static characteristics, the structural weight optimization is carried out. Then boundary conditions are applied on existing model and on 4 cases considered for weight optimization using varying thickness of boom plates. The maximum value of stress is considered in each case and weight optimization is done with factor of safety as 1.5.Structural weight optimization gave the total weight reduction of 715 kg (36.4%). Comparison in results of the Von Mises stresses obtained by numerically and analytically is very less and total variation in result is of only 1.12% which shows that the result of structural weight optimization performed numerically is accurate and acceptable [28].

Ahmet Erklig and et.al The backhoe-loader back and front arm have been analyzed with the maximum loads and boundary conditions using FEM. Analyses have been carried out for the maximum hydraulic cylinder forces. Symmetrical and unsymmetrical boundary conditions have been examined. With respect to analyses results, the backhoe-loader arms need an improvement to increase its strength. Two different improvements have been performed for arms. After improvements, safety factor is increased to 1.98 from 1.59 for back arm. Strength of the back arm has been increased by 24.5%. For front arm, safety factor has been increased to 2.18 from 1.94 at the symmetrical loading while loader cylinder is active [29].

Bhavesh Kumar P. Patel and et.al in their paper The FEA and optimization is versatile tool for designing the backhoe attachment in hydraulic excavator. By conducting FEA it is very easy to identify weak components through strength analysis of excavator attachment and corrections are possible in early stage of design. Topology optimization may give better results by changing the initial topology. Genetic algorithm (GA) and neural network is a powerful tool for optimization. Better lighter and cheaper designs can be obtained by using Finite Element Method and optimization techniques [30].

Y Madhu Maheswara Reddy and et.al in their paper by modelling and analysis of backhoe excavator bucket tooth it has been observed that, although, the values of von-misses or equivalent stresses for existing and optimized bucket become less difference. the value of deformation and stress intensity optimized by using material HSS, therefore the values of the HSS is become 5.9645x10-6 M and 23.58MPain static structural analysis, 6.36x10-6 M and48.0 MPa in couple field analysis respectively, are less as compared to other materials. Failure of excavator bucket tooth is due to abrasive wear and impact loading [31].

Qingying Qiu and et.al in their paper A new design parameter setting method based on the combination of the lengths and angles between hinge joints is successfully applied to the description of the hydraulic excavator working device, which can improve the effectiveness of sample points. It is impractical for all of the design variables to be merely expressed by length in conventional methods because so many conflicts would occur after sampling. Compared with the original methods, this method takes full advantage of basic trigonometric functions, ensuring that all sample points are valid. Multiple surrogate models are then adapted to comparatively study the optimal design of the hydraulic excavator working device [32].

Sumar Hadi and et.al in their paper design and analyze a Trapezoidal bucket excavator by using ANSYS R15.0. Maximum strain that display in a fixed position of top the bucket. Maximum deformation will occur at the end of the tooth to the entire body. They recommended that buckets used for excavation purposes should be checked properly for their application based on soil. Also, geometry is one of the parameters and effects of deformation during the lifetime a bucket [33].

Vishwajeet A. Patil and et.al in their paper the excavator bucket is developed to perform excavation task for light duty construction work. The bucket and arm digging forces are found out by calculations. By using different material properties and based on static force loads, finite element analysis is carried out for excavator bucket. Using stress values the fatigue life is carried out which gives the cycle time life converted to hrs. Also but using online e-fatigue calculator results are validated. By using the result the stress points are carried out and the optimized bucket model is created [34].

Kishore Krishna M and et.al in their paper the offset boom attachment is developed to perform excavation task for light duty construction work like trenches and pipe laying work. Based on static force analysis finite element analysis is carried out for individual parts. The analysis results indicate that the stresses produced in the parts of the attachment are very less equal to limiting (safe) stress of the parts material. The total deformation is also found to be negligible when compared to thickness of the attachment part. In future, there is a scope to perform the structural optimization of the boom attachment for weight reduction. Optimization can help to reduce the initial cost of the attachment as well as to improve the functionality in context of controlling of the excavation operation. Using a swing set cylinder with trunnion mounting can be used [35].

Anthony Kpegele Le-ol and et.al in their paper the backhoe arm of the backhoe loader has been analysed using FEM and the results obtained showed that the volume capacity of the bucket can be improved while decreasing the breaking force of the bucket and curling force of the arm. It has been further shown that this increase in the bucket capacity leads to an increase in the number of teeth of the backhoe as opposed to the number used in conventional backhoe loaders. It proves that the breaking force used by conventional backhoe loaders by the backhoe arms can be reduced greatly without sacrificing the functionality of the equipment and this leads to power and cost conservation. This implies that a decrease in the breaking force does not lead to increased deformation of the bucket [36].

Fahim Mahmud Khan and et.al in their paper the modification of the arm is possible from different perspectives as seen in this paper. The thickness of different components of the arm can play a vital role in the modification which has been discussed in details. The results found from the displacement and von-misses stress using different materials have been used to decide whether the designs are safe or not [37].

Manisha P. Tupkar and et.al in their paper the stress at the Tip of teeth of an Excavator bucket is calculated 96. 39 MPA and stress due to shearing of rivet is calculated 157.67 MPA by analytically. The stress at the tip of the teeth is calculated 112.98 MPA and stress due to shearing of rivet 167.42 is calculated. Percentage error between analytical result and Ansys result are 14.69 % and 5.82 %. They suggested that the bucket used for the excavation purpose should be properly checked for its application on the basis of the soil strata [38].

Hemanth Kumar BL and et.al in their paper The Deformation and Stress plot for the Backhoe Boom are obtained from the analysis results. The stresses are less than the fatigue strength of the material. The design of Backhoe Boom assembly is safe [39].

K. Guna Sekhar and et.al in their paper, the stress at the Tip of teeth of an Excavator bucket is calculated 96.39 MPA and stress due to shearing of rivet is calculated 157.67 MPA by analytically. The stress at the tip of the teeth is calculated 112.98 MPA and stress due to shearing of rivet 167.42 is calculated. Percentage error between analytical result and Ansys result are 14.69 % and 5.82 %. As per the above analysis, they suggested that the bucket used for the excavation purpose should be properly checked for its application on the basis of the soil strata. And considering the failure of the tooth and rivet due the impact loading [40].

Bikash Rai and et.al in their paper they show that by determining various reaction forces a rotary joint can be designed for the excavator arm, which facilitate the rotation of the arm and increase the productivity. This is very important to analyze all the forces during designing process, selection of material, power of motor. The excavation could be carried out in different position of the bucket [41].

Bhavesh Kumar Patel and et. al in their paper the capacity of the bucket has been calculated according to the standard SAEJ296 and comes out to be $0.028m^{3.}$ this bucket specification is the most superior when compared to all the other standard mini hydraulic excavator models. The breakout force calculation is done by standard SAE J1179 and comes to be 7626 N. The static force analysis performed by considering the maximum breakout force configuration and can be used as the boundary conditions [42].

3. METHODOLOGY

Generation of the 3D model consists of the mathematical and computer modelling. Based on the application we have gone through the mathematical calculations and obtained the geometrical parameters for the 3D model of Excavator arm. After generation of the 3D model the analysis is gone through the Ansys 16.0.

4. CONCLUSION

Hydraulic Excavator is the most commonly used machinery in the construction and for the other operations, From the literature review there are many optimisations of excavator components. We want to design an excavator arm by taking the force and load in to consideration. The digging force, lifting force and maximum load are given as the boundary conditions for analysis. We have calculated the forces acting on the excavator bucket teeth according to the standard SAE J1179 and also the bucket capacity is calculated according to the standard SAE J296.

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