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Mini Excavator Design And Analysis

Salih Korucu[1], Ahmet Eren Küçük[2], Gürcan Samtaş[3]
[1]Gazi University, Faculty of Technology, Department of Manufacturing Engineering, Beşevler, Ankara, Türkiye
Skorucu@Gazi.Edu.Tr
[2]Housing Estate Administration (Toki), Central Building, Bilkent Plaza, Çankaya, Ankara, Türkiye
Ahmeterenkucuk@Hotmail.Com
[3]Düzce University, Engineering Faculty, Department of Mechatronics, Beci, Düzce, Türkiye
Grcann@Gmail.Com

Abstract—Excavator is a work machine used in excavation works and also used to break hard objects such as concrete and rock. In rapidly growing industry excavators, on the ground, are expected to have a better performance. Especially during excavation, the excavating force produced by the actuators, undertakes a critical task. Furthermore, the excavating forces developed by the excavators must be larger than the resistance forces of the ground. In this study, it is aimed to manufacture mini excavators, which are not manufactured and assembled in our country and imported from abroad, and to reduce our dependency on the outside in this sector. In line with this goal, this study includes design and analysis of a mini excavator with 10-12 hp engine power and a 175 bar pressure with a working weight of 1000-1500 kg.

Keywords—Excavator; Mini Excavator; Excavator Analysis; Excavator Design; Hydraulic

I. INTRODUCTION

In the first half of the 20th century, cable excavators became dominant in construction yards and mining markets via cables. These are machines that are preferred for digging and loading in the earth processing industry. At that time, there was no alternative option for loading tasks. In the second half of the century, all these changed significantly by the introduction of the hydraulic excavator. Especially after wwii, various producers in italy, france and the united states started to produce the hydraulic excavator as we know it today. The first excavator that was made after the war was invented in 1946 by ray ferwerda, an inventor in cleveland, ohio [1]. Works of design and production on excavators are also evaluated in the scientific sense. One of these studies was conducted by salcudean et al. [2] in the study, they solved the problem of controlling the mini excavator they designed with single-action hydraulic cylinder. They especially monitored the state of excavator arms against the load in the working environment by setting up a closed cycle system. They mathematically modelled the arm of this mini excavator they invented for static and dynamic movement. In their design, they used solenoid control valves for each working element. The process of dynamically modelling excavator is used to determine the behavior of hydraulic cylinders under loads and the elastic deformations of the arms. The study by patel and prajapati [3] used the finite element method to investigate the bucket capacity of a mini digger-loader and the forces that occur during digging. In the study where sae standards were considered, the performance of the mini excavator was assessed using the load values provided in the standards. Traditional methods play an important role in energy savings of hydraulic excavators. However, they generally use to much fuel while working and the biggest factor causing this is their poor exhaust systems. Therefore, they should be designed with new technologies for efficient fuel consumption. Especially nowadays, researchers are developing excavators with hybrid technologies that contain electrical elements. Wang et al. [4] analyzed the performances of semi-hybrid hydraulic excavators with 5 tons of capacity. For this, the compared models that included two different structures of hybrid movement. Likewise, lin et al. [5] worked on recycling energy for hybrid hydraulic excavators. In the study on regaining the potential energy of a hybrid hydraulic excavator, they regained approximately 41% of the total energy. Design and performance assessments of excavators differ based especially on the material that their arms are made of. Other studies on these machines changed the materials that especially the bucket and arms were made of and investigated the behaviors against loads. Solazzi's [6] study used 6061 t6 aluminum alloys instead of alloy steel for their excavator's arms. With this material and under different loading conditions, they investigated the performance of the loading arm and bucket arms for stress, lifting in different distances based on rotation axis, maximum loading conditions, the state of the hydraulic cylinders, and issues that may arise in the excavator due to wear out conditions. Budy et al. [7] studied the control of the excavator process by application of independent valves mounted on the excavator. This approach allows one to avoid the closed control system with a transducer and sensor mounted on the excavator. In the accepted system, there are two systems as a microcomputer and a hydraulic unit (pump and independent valves). System performance is validated by monitoring the sudden changes in the cylinders. They included the experimental results of the study. There are also studies on robotic excavators as opposed to excavators controlled by an operator. Controlling a robotic excavator is difficult due to the following issues: parameter changes in their mechanical structures, various non-linear hydraulic accelerators and imbalances created by ground contact. Lee et al. [8] achieved the control of a heavy-duty robotic excavator by using an integrated sliding surface and time-delay. In their study, they used a 21-ton excavator. Operations were carried out in compliance with the speed settings used by an operator. Gravity and friction forces have a significant role in excavators, which are heavy construction equipment in terms of performance and control. Tafazoli et al. [9] proposed a new approach for unbundled estimation of gravity parameters. In their study, they made a computer-controlled mini excavator perform static experiments in order to estimate gravity parameters. For indirect measurement of junction torques of the hydraulic cylinders, they used loading pins. Today's hydraulic excavators are widely used in construction, mining, digging and forestry. Even if the operator is experienced, attention must be paid on field conditions, soil parameters, soil-machine interaction conditions during the process of digging. Finding the forces between the soil and the machine especially during digging helps design the excavator better. Patel and prajapati [10] conducted research on soil-machine interaction during digging using a mini excavator. The study analyzed soil mechanics, interaction forces between the soil and the machine and various parameters that affect the soil-excavator interaction during the actual process of digging. Tafazoli et al.'s [11] study experimentally demonstrated the control of the resistance they developed for excavators in laboratory conditions. Firstly, they addressed the problem of resistance control for a single hydraulic cylinder and used a method for the analysis of system stability. An excavator is a common form of machines that mechanically control soil movement. This usually requires control by a person. However, recently, equipment producers have started to develop automated machines in an ever-increasing popularity in terms of machine health [12]. Excavators are frequently used like cranes at construction sites with the purpose of carrying equipment. This brings about significant health and safety risks. Edwarda and holt [13] found in their theoretical analysis that excavators are used both formally, and less convincingly, informally as cranes at load anchorages. Dangers of using excavators as cranes (usually at load anchorages and unlinking accessories) may lead to cataleptic failure. A study investigated the risk controls proposed for lifting weights or making them lighter. Ding et al. [14] achieved the control of self-adjusting pressure feedback with pole placement in order to reduce vibration in an excavator with an independently measured fluid-controlled power system. The independently measured control systems for the excavator they used are promising in terms of fluid power technologies as opposed to valve-controlled traditional systems. They used a mini excavator for the experiments in their study. Budny et al. [15] investigated the control of a digging operation by implementing load-independent hydraulic valves. This approach aimed to control the closed cycle system with the help of sensors and transducers mounted on excavators. No sensor cells were mounted on the additional parts of the machine such as the arms. The designed system consisted of two sub-sections as a microcomputer and a hydraulic unit (pump and load-independent valves). In the microcomputer unit, they found a relationship among the digger's velocity vector, inverse kinematics applications and the oil flow for the three cylinders. An excavator's capacity depends on parameters such as the digging force provided by the digger's power, the maximum breakout force provided by the arm cylinder, lifting capacity, progression speed and the maximum slope that it can climb. In their study, sarı and ercan [16] developed a method that allows technical and economic selection of hydraulic systems by using parameters that determine the performance of an excavator. Chang and lee [17] achieved the control of straight-line movement monitoring for a hydraulic excavator system. The control results were applied on the straight-line movements of a 13-ton excavator with a digger speed of 0.5 m/s. These criteria are based on the level of speed where operators do precision work. It is needed to reduce vibrations in the moving arms of mobile machines such as excavators, cranes and forest processing machines [18,19]. Ding et al. [20] achieved self-adjusting pressure feedback control with pole placement and using an independently-measured fluid-controlled power system to reduce vibrations. This study presents the design and analyses of a mini excavator with a weight of 1000-1500 kg, power of 10-12 hp and pressure of 175 bar.

II. MINI EXCAVATOR DESIGN

In the design stage of the study, among the catalog values, a rubber pallet that was designed for mini excavators of weight 1000-1500 kg was selected with a standard of 180x72x37 (180: pallet width, 72: pallet gear step and 37: number of links). The selected can endure machines with the weight of up to 3 tons. The other reason for choosing a rubber pallet was the aim to prevent ground deformations that are caused by steel pallets in working environments such as roads, pavements and parks. After the dimensions of the pallet were determined, a chain gear and two ctm1016 cf brzv 100 orbit power engines with brakes were selected. The moving speed of the power engine changes in the range of 2 km/h-1.6 km/h. The displacement volume of the engine was 100 cm3/rev. For the power engine, the study used the maximum pressure of 175 bar, 1120 nm of torque, 40 l/min flow and 65 rpm. For the designed excavator, the fuel tank volume was determined as 17 liters and the hydraulic tank volume was determined as 27 liters. The step interval of the pallet material was chosen as 72 mm, the chain gear that is suitable for the ansi metric standards and the power engine that would actuate the gear were determined, the idler wheel required for the pallet and the design that would add tension with the single-action cylinder connected to the idler wheel were completed, and the subframe was designed. The palled was modelled by drawing a template based on the pallet dimension with the length of 2664 mm (figure 1).

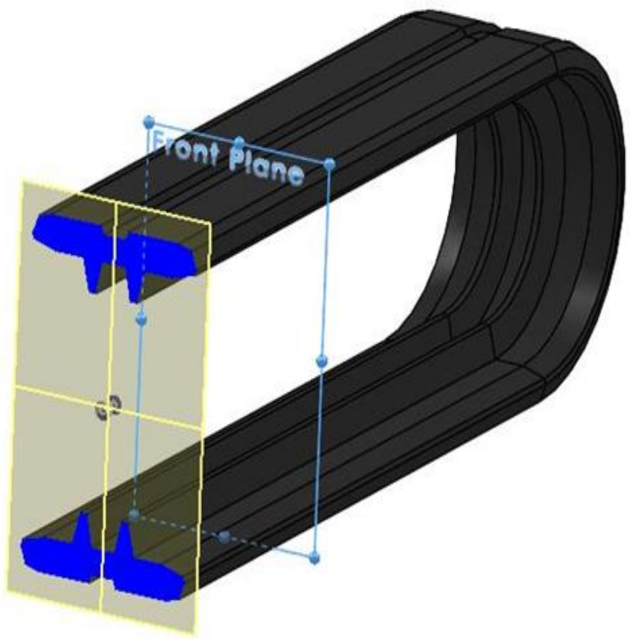

Figure 1. The Pallet Modelled and Cross-Sectioned Based on the Catalog Dimensions

In the construction machine whose pallet design was completed, the idler wheel, pallet-stretching cylinder, power engine, idler rollers and pallet chain gear were designed to form the drive train of the machine. The power engine that was calculated based on the machine's weight and the desired progression speed was modelled, again, based on the catalog dimensions, and placed on the subframe design. While calculating the torque value for the power engine, it was aimed that the machine would be able to climb land with a slope of 45 degrees. As a result of the calculations, the pallet's chain gear was designed by considering meeting the maximum torque value obtained from the power engine, the chain gear step length of 72 mm, and the diameter value in the pallet's template. Here, the gear tooth bottom diameter and the diameter of the idler wheel were held the same to make the bottom and the top of the pallet to work in parallel to the ground (figure 2).

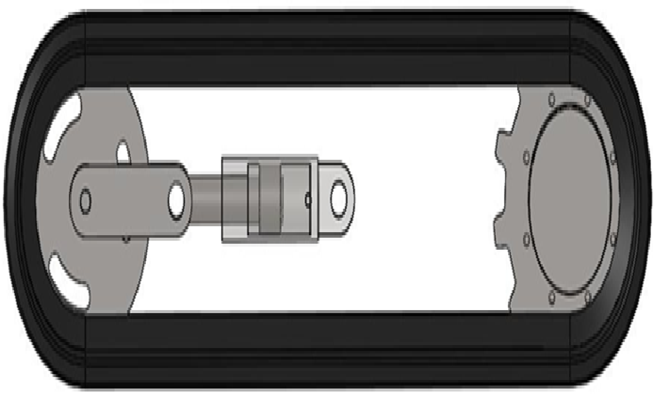

Figure 2. Pallet Chain Gear Model

The drive train design was completed by seeing that the parts worked in harmony with each other after considering the pallet template and the other parts, designing the idler wheel and the idler rollers. In the machine that was designed with consideration that indoor repairs and building demolishment are among the significant usage areas of mini excavators, the end to end distance between the two pallets were designed as 892 mm and it was made possible for the machine to pass through building entrances. Selection of the central gear that will allow the machine to rotate 360 degrees on its axis was made by considering the axial and moment forces the subframe would be exposed to, and additionally, a model was formed based on the catalog dimensions and placed on the subframe design (figure 3).

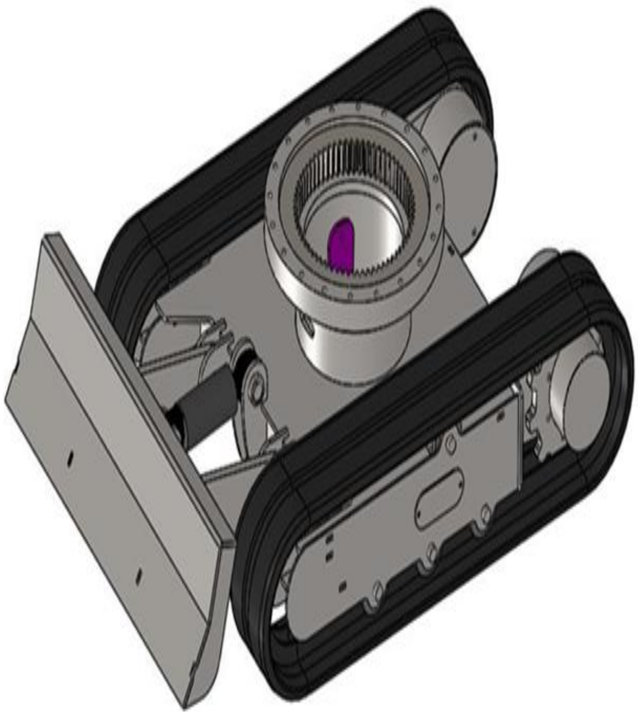

Figure 3. Design of the Drive Train

The subframe design was completed by designing a dozer blade which, as opposed to the case in heavy-tonnage construction machines, plays the role of rear weight, establishes balance by preventing the machine from falling forward during digging and has the function of plowing at the same time, and calculating hydraulic cylinder power and stroke length (figure 3). As the second step for the design of the machine whose subframe design was completed, upper frame sheet metal plate design was carried out. The most important parts of the machine are the parts like the diesel engine, hydraulic pump, hydraulic cooler, fuel and oil tanks, swing hydraulic motor, hydraulic valves, joystick and controls which are located in the upper frame that was initiated for design by considering the central gear dimensions that connect the upper frame and the subframe (figure 4).

Figure 4. Design of the Upper Frame

While designing the excavator, the hydraulic cylinders that were needed were determined based on the bucket breakout force needed during the process of digging. A dozer blade cylinder was chosen with an outer cylinder diameter of 75 mm, piston diameter of 63 mm, piston arm mill diameter of 40 mm and stroke length of 55 mm. A boom-arm cylinder was chosen with an outer cylinder diameter of 75 mm, piston diameter of 63 mm, piston arm mill diameter of 40 mm and stroke length of 380 mm. A bucket-arm cylinder was chosen with an outer cylinder diameter of 75 mm, piston diameter of 63 mm, piston arm mill diameter of 40 mm and stroke length of 285 mm. A boom-frame cylinder was chosen with an outer cylinder diameter of 75 mm, piston diameter of 63 mm, piston arm mill diameter of 40 mm and stroke length of 316 mm. A boom-right-left cylinder was chosen with an outer cylinder diameter of 75 mm, piston diameter of 63 mm, piston arm mill diameter of 40 mm and stroke length of 200 mm. Two pallet-stretching cylinders were chosen an outer cylinder diameter of 70 mm, piston diameter of 60 mm, piston arm mill diameter of 40 mm and stroke length of 75 mm. In addition to the hydraulic cylinders, for the two power engines in the subframe and the swing movement that allows the machine to rotate 360 degrees on its axis, we chose a casappa lvp 30 axial-piston hydraulic pump with a displacement rate of 28.8 cm3/rev that would run the system on the flow and pressure values needed by the orbit bmr-200 hydraulic engine with a displacement rate of 200.9 ml/rev. For the hydraulic pump, the study used a pressure of 125 bar, revolution rate of 2050 rpm, displacement rate of 22 cm3/rev, power value of 7.4 kw and torque value of 44 nm. The study used a kubota d722-e3b 3-cylinder liquid-cooled diesel engine with a maximum revolution rate of 3600 rpm and engine power of 14.9 kw. The design used 2050 rpm and 7.4 kw power. As the battery for the diesel engine, a 390 a sae battery with a voltage of 12v and capacity of 42ah was selected. Suction line hose diameter was 1 / 1/4 inches, return line hose diameter was 1 inch, the diameter of the pressure line of the valve block from the pump was ½ inches and the diameter of the working line from the valve block to the receiver was 3/8 inches. The model walvoil full flow sharing dpx050 bsp was used as the valve block of the system. This valve block consists of 9 sections. It contains 6 electrical proportional valves (one for the swing motor, on for the dozer blade cylinder, one for the boom-arm cylinder, one for the bucket-arm cylinder, one for the boom-frame cylinder and one for the boom-right-left cylinder) and 3 hydraulic signal-controlled proportional valves (one for crusher pedal control and two for the right and left control pedals of the power engines).

In the next stage, for the mini excavator whose upper frame design was completed, the design process continued with the arm, boom and bucket, which would carry out the digging operation. While designing the digging parts of the machine, the digging power of the bucked and the arm piece was considered. The boom, arm and bucket were designed such that during digging, if the operation of breaking will be made with the bucket the maximum breakout force would be about 950 kg, and if the operation will be made with the arm piece, it would be about 500 kg-f. As counterweight parts that are mounted on the rear side of the machine in high tonnage construction machines have limited usage in mini excavators due to lack of space, in order for the center of gravity of the machine to be in positions that would allow balanced operation in the maximum forces from the digging parts of the machine, the arm, boom and bucket designs were adjusted accordingly. The designed excavator has the feature of carrying out the digging process without the need for the swing movement by rotating the boom piece towards right and left with the help of a link and a hydraulic cylinder. With this feature, it is possible for the designed excavator to carry out digging operations in working spaces with little room for maneuvering. The boom is able to rotate towards right or left by 73 degrees without the need for the swing movement with the help of a hydraulic cylinder. The dimensions of the parts that were readily purchased in the design process (diesel engine, hydraulic pump, swing rotation hydraulic engine, valve block, hydraulic cooler, radiator, battery, seat and joystick) were taken from the catalog values. The starting point of the design was the subframe. As the starting point in the subframe, the rubber pallet was taken as the basis. The parts of the mini excavator designed and installed in the computer environment were connected in harmony with each other (figure 5).

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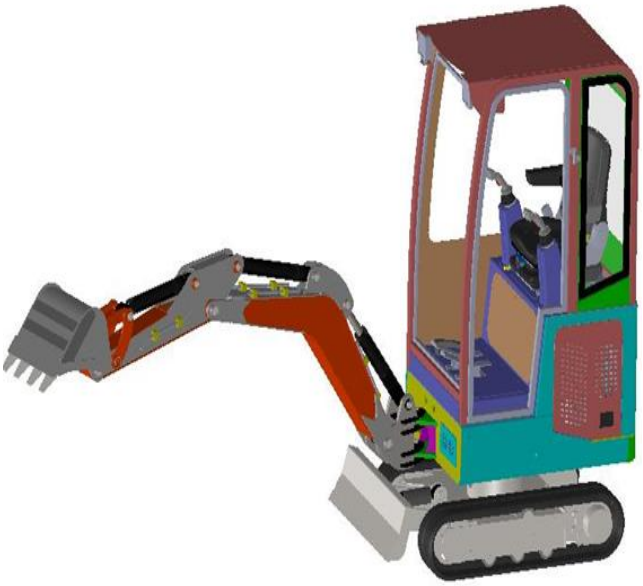

Figure 5. The Designed Mini Excavator

Analyses were carried out on this model using the method of finite analysis, the endurance of the machine to the forces that it would encounter were examined before production.

III. MINI EXCAVATOR ANALYSIS

The rubber pallet, power engine, chain gear and idler wheel single-action cylinder parts which were chosen based on their catalog dimension were obtained, subframe design was conducted and analyses were carried out before production. The analyses were carried out using the finite element method, and the final design of the subframe was completed. After determining the capacities and dimensions of all the parts to be used in the subframe, finally, the design of the sheet metal plate was made for these parts to work in harmony with each other and with the needed durability. In the subframe, as the material for sheet metal, bearings and mills, the study used st-37 and 4140 tempered steel, which are easily accessible in the metal industry. Before the finite elements analysis, all sheet metal materials were assigned as st-37 steel in the materials library of the analysis software. Similarly, all bearing and mill materials were assigned as 4140 tempered steel again in the materials library of the analysis software. After all parts were assigned materials, the weight of the subframe was found by the software as 360 kg, and the center of gravity was found at a 11.72-mm distance from the central gear.

A. Subframe finite elements analysis

After material assignment, forces that the parts would endure were applied on them, the deformations on the material were examined and the necessary revisions were made on the frame. The power engines were selected by designing the machine in a way that would allow it to climb a 45-degree slope and reach a speed of 2 km/h on flat terrain. As a result of calculation, the selected power engine was assigned a torque value of about 900 nm, and the analyses were made accordingly. Calculations were made for the central gear and pinion that allow mini excavators to rotate 360 degrees on their axis, a swing hydraulic motor that would allow 9 rounds of rotation per minute with 380 nm of torque was selected as a result of the calculations, and the analyses were made accordingly. Cylinder selection was made by calculating the bucket breakout force of the machine as approximately 950 kg-f and its arm breakout force as approximately 500 kg-f during digging. These forces were considered in the analyses on the digging parts of the machine, and the arm, boom and bucket materials were given their final pre-production form. Before the analysis, in order to be sure that we represented the subframe correctly in terms of geometry and behavior, the correct mesh size was selected by finite elements convergence analysis. Using the stress values as a result of the applied mesh, the mesh size was reduced gradually, and the correct mesh size for the subframe was determined based on the concept of convergence.

The maximum stress value was 841 n/mm2 for a mesh size of 20 mm, 805 n/mm2 for a mesh size of 30 mm, 857 n/mm2 for a mesh size of 40 mm, 839 n/mm2 for a mesh size of 50 mm, and 762 n/mm2 for a mesh size of 60 mm. As the stress value changed less in comparison to the stress values in other mesh size when the mesh size is set as 50 mm and 40 mm, it was found that the mesh size of 40 mm was the most suitable size for the part (figure 6).

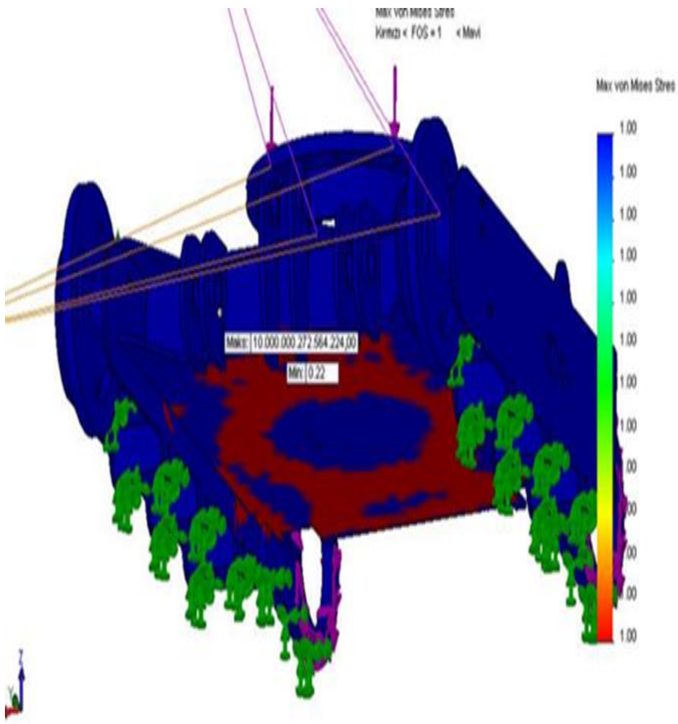

Figure 6. Subframe Analysis (Bottom Part)

After the mesh value suitable for the subframe was determined, finite elements analysis was conducted; however, the minimum safety coefficient was 0.22 as seen in figure 6, and there was a need to make revisions in the subframe sheet metal parts.

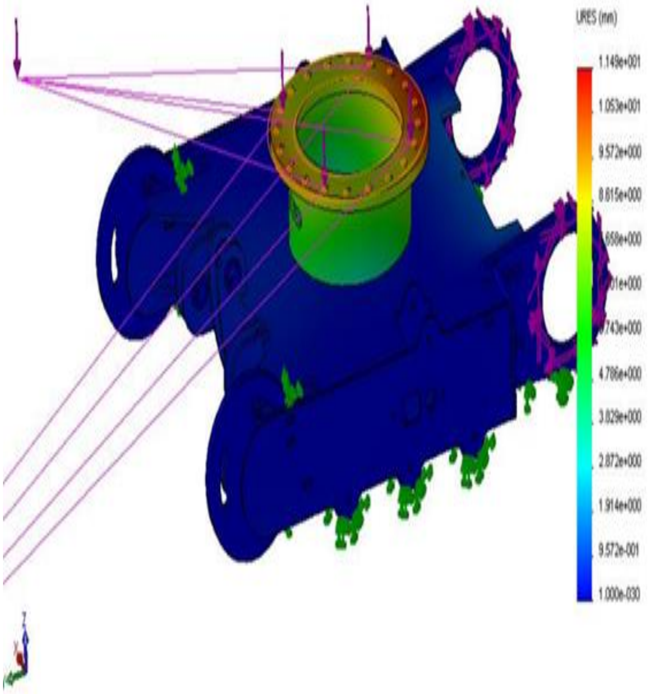

Figure 7. Subframe Analysis (top part)

Maximum displacement of the top part of the subframe was calculated as 11.4 mm. As a result of the analysis, it was determined that the material was week as the safety coefficients were lower than 1 in the regions shown in red in the measurements taken from various points on the frame (figure 7). In order to strengthen the red zones with safety coefficients lower than 1 in the bottom part of the subframe, the previously 6-mm thickness of the bottom sheet metal was increased to 8 mm. Moreover, sheet metal support pieces were added to the joint places between the bottom sheet and the side sheets, and the subframe was provided with toughness. As a result of the analysis of the subframe, when the test was repeated after making the necessary revisions, it was found that the maximum displacement in the part was 0.61 mm. As a result of applying forces after the increased sheet metal thicknesses and added materials, it was seen that the safety coefficients of the subframe had a minimum of 3.4. The design was forced to rotate based on the torque value of the hydraulic motor with the central gear in the center of the design, and it was found that the factor of safety was approximately 4.5, and the maximum displacement was 0.004. After the torque applied on the bearing sheet metal on which the power engine was connected, it was seen that the bearing sheet metal had a displacement of approximately 0.012 mm and a minimum safety coefficient of 6.84 (figure 8).

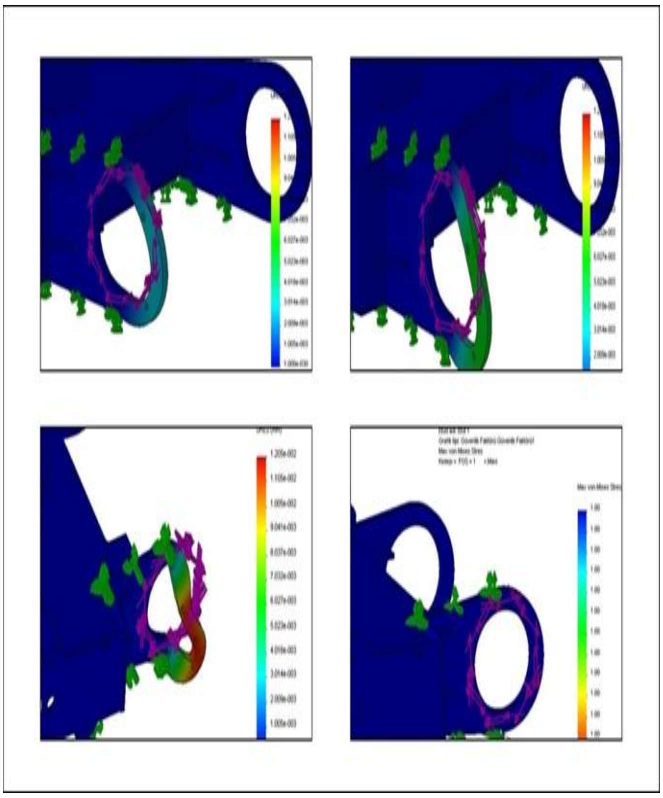

Figure 8. Subframe Plowing End Analyses

Later on, forces that it would endure during digging were applied on the dozer blade which would play the role of supporting the mini excavator in addition to plowing, and analyses were carried out (figure 8). The subframe was applied the forces that it would be exposed to in operational conditions, and the behaviors of the parts against these forces were examined. Revisions were made for the zones on the subframe with safety coefficients of lower than 1, the analyses on the subframe were completed, and it was made ready for production.

B. Upper frame finite elements analyses

Like the case in the analysis of the subframe of the excavator, during the analysis of the upper frame, the parts that would not affect the results of finite elements analysis were removed from the setup and the analysis of the upper frame was simplified. Before applying forces on the upper frame, the model was made ready by assigning st-37 to steel plates and 4140 tempered steel to mills and bearing parts as materials. Finite elements analysis was carried out by applying the forces that the upper frame would endure, the maximum breakout force of the digging bucket part, the arm-boom-bucket weight and the weight of the upper frame on the frame. The minimum safety coefficient was found as 3.34. Based on the measurements taken from different points on the model, the model was found durable against the forces applied onto it.

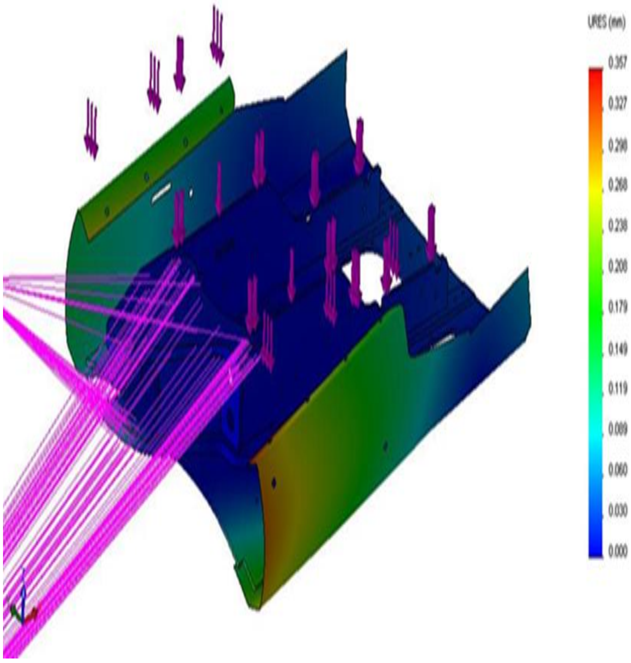

Figure 9. Upper frame analysis

As a result of the forces applied on the model, the maximum displacement was found as 0.3 mm. When the forces applied by the bucket on the upper frame during the sweeping movement in digging operations by the bucket, the minimum safety coefficient was found as 1.2 and the maximum displacement was found as 0.36 mm. Consequently, when the maximum forces that the upper frame may be exposed to were examined via the finite elements analysis, it was observed that the upper frame showed sufficient durability against forces in its pre-production stage, and it was determined that the design was ready for production.

C. Arm, boom and bucket finite elements analyses

In the finite elements analysis of the mini excavator, the forces that would be imposed on the digging mechanism (arm, boom and bucket) of the machine were implemented on the model in the design environment, and the behavior of these parts during operation were examined. As in the cases of subframe and upper frame analyses, the parts that would not affect the result of finite elements analyses were removed and the analysis model was simplified. After simplification, materials were assigned to the arm, boom and bucket parts. Again, st-37 was assigned to the metal sheet parts and 4140 tempered steel was assigned to the mills and bearings. The bucket part was designed to endure a maximum of 950-1000 kg-f breakout force during digging, and forces were applied to the digging mechanism based on this design. Our analysis model was obtained by calculation and application of the suitable mesh size for the parts that constituted the digging mechanism via convergence analysis. As a result of the analyses, the minimum safety coefficient in the model was calculated as 1.02.

As a result of the stresses applied, the maximum displacement of the digging mechanism was calculated as 3.3 mm. The stresses created on the digging mechanism by the bucket during sweeping operations with the side of the bucked while digging were investigated on the model. When the model was examined as a result of the applied stresses, the minimum safety coefficient was found to be 1.37, and the maximum displacement was found to be 4.7 mm (figure 10).

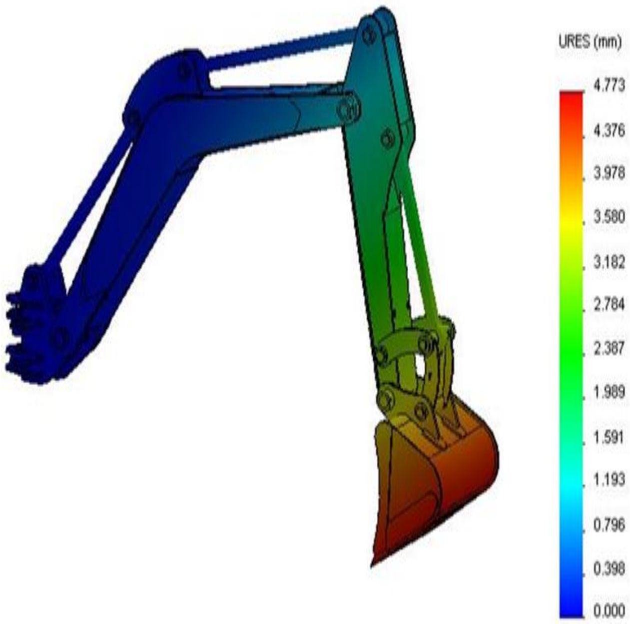

Figure 10. Stresses imposed on the model

Based on the finite elements analysis of the arm, boom and bucket pieces, it was observed that the digging mechanism had sufficient durability, and it was ready for production.

IV. RESULTS AND DISCUSSION

This study presented the design of a mini excavator with a weight of 1000-1500 kg, power of 10-12 hp and pressure of 175 bar, as well as the analysis of the design. The study consisted of three stages as: designing the mini excavator and drawing it in three dimensions in the computer environment, installment of the machine in the design environment, and conducting analyses. The results of the study may be listed as the following;

- The study designed a mini excavator with a weight of 1000-1500 kg, power of 10-12 hp and pressure of 175 bar.

- A rubber pallet with a standard of 180x72x37 (180: pallet width, 72: pallet gear step and 37: number of links) was chosen for the design.
- Two ctm1016 cf brzv 100 orbit power engines with brakes were selected. The speed of the power engine changed in the range of 2 km/h-1.6 km/h. The displacement volume of the engine was 100 cm3/rev. For the power engine, the maximum values of 175 bar pressure, 1120 nm torque, 40 l/min flow and 65 rpm revolution rate were used. A chain gear that was suitable for the ansi metric standards and 72 mm of step length was selected.
- A casappa lvp 30 axial-piston hydraulic pump with a displacement rate of 28.8 cm3/rev was selected by calculating the flow and pressure values needed by the orbit bmr-200 hydraulic engine with a displacement rate of 200.9 ml/rev. For the hydraulic pump, the study used a pressure of 125 bar, revolution rate of 2050 rpm, displacement rate of 22 cm3/rev, power value of 7.4 kw and torque value of 44 nm.
- A kubota d722-e3b 3-cylinder liquid-cooled diesel engine with a maximum revolution rate of 3600 rpm and engine power of 14.9 kw was selected in the study. The design used 2050 rpm and 7.4 kw power. As the battery for the diesel engine, the design included a 390 a sae battery with a voltage of 12v and capacity of 42ah.
- Suction line hose diameter was 1 / 1/4 inches, return line hose diameter was 1 inch, the diameter of the pressure line of the valve block from the pump was ½ inches and the diameter of the working line from the valve block to the receiver was 3/8 inches.
- The boom, arm and bucket were designed such that during digging, if the operation of breaking will be made with the bucket the maximum breakout force would be about 950 kg, and if the operation will be made with the arm piece, it would be about 500 kg-f.
- The machine is able to rotate towards right or left by 73 degrees without the need for the swing movement with the help of the link and a hydraulic cylinder.
- As the material for sheet metal, bearings and mills in the subframe, the study used st-37 and 4140 tempered steel, which are easily accessible in the metal industry.
- The power engines were selected so that the machine would be able to climb a slope of 45 degrees and reach a speed of 2 km/h on flat terrain. As a result of calculations, the torque value of the selected power engine was chosen as about 900 nm and the analyses were run accordingly.
- As the minimum safety coefficient was found as 0.22 in the analyses, there was a need for revision in the subframe parts.
- In order to strengthen the red zones in the bottom of the subframe with safety coefficients lower than 1, the previously 6-mm thickness of the sheet metals was increased to 8 mm.
- The minimum safety coefficient in the upper frame was obtained as 3.34. The measurements taken from different points on the model showed that the model was durable against the forces applied.
- The bucket piece was designed to be exposed to a maximum breakout force of 950-1000 kg-f during the digging operations of the mini excavator, and forces were applied on the digging mechanism accordingly.
- As a result of the finite elements analysis on the arm, boom and bucket parts, it was observed that the digging mechanism had sufficient durability and it was ready for production.

In a future study, the necessary analyses will be made on the excavator designed and analyzed here, and the excavator will be produced.

V. ACKNOWLEDGMENT

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