Design, 3D Modeling and Simulation of Hydraulic Stone Splitting Machine for Processing of Natural and Artificial Stones

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Abstract – *Early, from the beginning of human civilization, up to the present day on, a developed countries having many industries are trying to show their civilization for the rest of the world by building floors and artifacts using stone. In Ethiopia, early at the time of Axum dynasty, peoples of Axum build a great Axum statues from one big stone and now that statues is one of a peculiarities of Ethiopian as historical heritage registered in UNESCO. Human need is constant and continuous, No matter how large the civilization is, the demand of stone increases day to day. Various countries are working hard to improve their lives by many unbelievable buildings, bridges and dams, including Ethiopia. However, the work being done on the rock is still not satisfactory because due to absence of necessary stone processing and splitting machines in construction sites. In order to solve this problem, this paper has been developed with hydraulic Stone Splitter Machine Design. The machine works based on Pascal law principle and it uses devices like Pressure compensator, check valve, four by three way direction control valve, double acting cylinder, pump units, and pressure relief valve. This stone splitter machine is applicable for both natural and artificial stones for the production of cobble stone, kerb stone, tiles and paving stones. The hydraulic circuit design of the system is simulated using fluidsim software with in capacity of five hundred ton. The structural strength, load analyzation, and simulation of the machine is done using Solidworks.*

Key Words*: *Stone, Design, hydraulic, fluidsim, splitter.

1. INTRODUCTION

The species prior homo may have manufactured tools using stone, that Stone Age is contemporaneous with the evolution of the genus homo [1]. According to the age and location of the current evidence, the cradle of the genus is the East African rift valley, especially toward the north in Ethiopia, where it is bordered by grasslands. Starting from about 4 million years ago (mya) a single biome established itself from South Africa through the rift, North Africa, and across Asia to modern China, which is called "transcontinental 'savannahstan'' recently [2]. Starting in the grasslands of the rift, Homo erectus, the predecessor of modern humans, found an ecological niche as a tool-maker and developed a dependence on it, become a "tool equipped savanna dweller" [3].

Now, when people moved to update their livelihoods, they began to use stone for various purposes, counting it as a natural resource. Scientists have consistently stated that stone is the most important resource in the world. History recalls that man used stone to make various sculptures and statues. In Ethiopia, peoples began to improve their life and introduce their civilization to the world by building Axum statue from one stone, the Lalibela stone castle church, and Fsiledes Palace, which symbolize human civilization. However, now men have reached to the extreme high building, which is now over 100 Floors. It is true that stone is the backbone of construction. Therefore, it is necessary to use stone to a building of house or to build a dam and roads. No building will be considered without stone.

In order to use a stone, you must adjust the stone according to the dimensions you want, such as height and width. Mankind has been using artifacts from antiquity, hammer, and metals to shape up stones to the required dimensions still now.

However, the use of hand tools has been found to be costly, hazardous, and time-consuming. It is important to change or replace the traditional method by considering time and newly adverting technologies. To eliminate the prioritized problems of construction environment, a hydraulic system stone splitter was designed. The machine can speed up construction and save time, protect health, and avoid overcrowding. It is suitable for splitting all types of natural and artificial stones, used for the production of large and small materials for mosaic and stone flooring. This machine is characterized by high reliability and efficiency, and it can be integrated in a production line easily. By using this stone splitting machines you could produce a wide range of products like, Cobble stones, Paving stones, Tiles for paving and cladding, wall stones and kerb stones, etc. The machines can be operated automatically and move continuously. Equipped with a separate control cabinet, the electric control part can be operated by a total station and a button box. The start-up and operation is very convenient.

Generally, the machine generate hydraulic power to split the stone down in a spot. Therefore, it is of high speed, good quality, low consumption and so on, which can improve products quality and production efficiency in a high degree.

1.1 General Objective

- To design, 3D modeling and simulation of hydraulic stone splitter machine for processing of natural and artificial stones,

1.2 Specific Objectives

- To provide stone splitting machine which operates hydraulically.
- To eliminate time and labor wastage during stone splitting process.
- To provide efficient way of stone splitting process by minimizing stone wastage during splitting.

2. METHODOLOGY

The paper aims to address a practical problems which are happen in construction environment. In construction environment stone is basic material for building floors, roads, dames and so on. To use stone based in our required shape and size is difficult if the construction environments are not well organized by machinery's. In Ethiopia 80%-90% of construction environments are use hammer for splitting stone. This traditional method requires more labor and has a risk in people's health. To address this practical problem, the design of hydraulic stone splitter machine is investigated in this paper. This a hydraulic stone splitting machine are applicable for all kinds of stones, for both natural and artificial stones. It have advantage by reducing number of labor, time minimization, cost effective, risk free, silent operation, and continuous production.

A serious of methods are followed during the design of hydraulic stone splitter machine. The core ones are described as follow.

- Searching that which method of splitting machine can have a good result while splitting natural and artificial stone.
- Checking the material availability for the machine and selecting materials for each components.
- Designing hydraulic circuit for the system and simulating the circuit via fluidsim software
- Modeling the three dimensional physical features of the machine and analyzing the strength of each components via Solidworks

The decisive factor for the development of hydraulic machine is the rule of thumb used and it illustrates that Concrete and rock can hold out against extreme pressures, applied from outside, without being affected. By comparison, their resistance to a force applied internally is relatively low, with the result that they disintegrate easily. This rule of thumb was the decisive factor in the development of hydraulic stone and concrete splitters and their method of operation, based on the wedge principle [4].

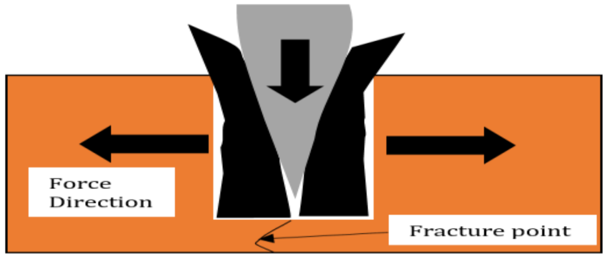

Fig -1: Wedge principle

The wedge principle has long been known, but in former times its application involved driving wooden or metal wedges into the rock with a heavy hammer - arduous, tiring and extremely time-consuming work. The mechanized this process with its hydraulic Stone Splitters, with the result that the wedge principle can now be put to use quickly, simply and, above all, to the utmost effect [4].

3. BASIC COMPONENTS

A. Hydraulic actuator (double acting cylinder)

Hydraulic actuator just do the opposite of pump. They extract energy from the fluid and convert it to mechanical energy to perform useful works. Hydraulic cylinders extend and retract a piston road to provide a push or pull force to drive the external load a long a straight line path.

B. Hydraulic pump

Hydraulic pumps convert mechanical energy from a prime mover (engine or electric motor) into hydraulic (pressure) energy. The pressure energy is used then to operate an actuator. Pumps push on a hydraulic fluid and create flow

C. Check valve

It is a two way valve because it contain two ports. The purpose of check valve is to permit free flow in one direction and prevent any flow in the opposite direction. A poppet is a specially shaped plug element held on to a seat (a surface surrounding the flow path opening inside the valve body) by spring force. A fluid is flows through the valve in the space between the seat and poppet. A light spring holds the poppet in the closed position. The higher pressure, the greater will be the force pushing the poppet against its seat. Pilot operated check valve; this type of check valve always permit free flow in one direction but permit flow in the normally blocked opposite direction only if pilot pressure is applied at the pilot pressure port.

D. Directional control valve (DCV)

Four-Way Valves: Used to control double acting hydraulic cylinders. It can be manual and automatic in this project a push button hydraulic directional control valve is used.

E. Pressure control valve

Simple pressure relief valve, it is normally a closed valve whose function is to limit the pressure to a specified maximum value by diverting pump flow back to the tank.

F. Counter balance valves (pressure compensator)

The purpose of a counterbalance valve is to maintain control of vertical hydraulic cylinder to prevent it from descending due to the weight of its external load.

4. DESIGN OF HYDRAULIC SYSTEM COMPONENTS

Specifications

- Load to be fitted to split stone is 500000kg=500ton.
- Piston travel distance (stroke length) is 250mm=25cm
- Speed of piston rod assembly 20cm/s=0.2m/s
- Working pressure is 600bar=600kg/cm^2
- Type of splitter machine is bridge type.

4.1 Design of piston

- **Determination of piston diameter**

The piston area and diameter is given by:

$$A_{pr} = \frac{F_{pr}}{P_{pr}} \quad (1)$$

$$A_{pr} = \frac{\pi D_{pr}{}^2}{4} \quad (2)$$

$$D_{pr} = \left(\frac{4A_{pr}}{\pi}\right)^{0.5} \quad (3)$$

- **Determination of piston rod diameter**

Assume:

- Factor of safety for rod S=3
- Free buckling length S_k = 21 cm
- Elasticity module E=2.1*10^6 (for steel)

Buckling load for piston rod given by:

$$K = \frac{\pi^2 EJ}{SK^2} \quad (4)$$

Where: $k = S * F$ (5)

From eqn. 4.

$$J = \frac{SK^2 * K}{E\pi^2} \quad (6)$$

Piston rod diameter is given by:

$$d^4 = \frac{J * 64}{\pi} \quad (7)$$

- Then, the actual working pressure for extending

$$P_{ext} = \frac{force}{Area\ of\ piston} \quad (8)$$

Area of piston is given by:

$$A_p = \frac{\pi d^2}{4} \quad (9)$$

- Actual working pressure for retraction

$$P_{ret} = \frac{force}{Apr - Ap} \quad (10)$$

4.2 Capacity of pump determination

- **Determination of pump displacement**

Assume:

- n_{vol}= 0.85
- Internal gear type pumps revolution are generally limited at 4000rpm.
- Maximum velocity on the cylinder v=0.2m/s.
- Maximum rotational speed np= 4000/60=66.6 rev/s.

Pump output flow rate is given by:

$$Q = A * V \quad (11)$$

$$Q = Dp * np * Nvol \quad (12)$$

From eqn. 11. And eqn. 12

$$Dp = \frac{A * P}{np * nvol} \quad (13)$$

- Determination of pump output flow rate from eqn.11

$$Q = A * V$$

4.3 Determination of electric motor power

$$P_{pr} = \frac{QP_{pr}}{nvol * nhm} \quad (14)$$

Where: $Nvol = 0.85$ and $Nhm = 0.95$

4.4 Determination of cylinder parameters

- **Determination of cylinder tubes thickness and cylinder diameters**

Thickness of cylinder is determined by thin wall container formula:

$$S_o = \frac{da * P * S}{200 * Gyield} \quad (15)$$

Where: $da = 1.7 * di$ (16)

$S = 2$ (17)

$di = 325$ (18)

$Gyield = 23daN/mm2$ (19)

- Cylinder diameter is given by:

$$da = di + 2so \quad (20)$$

4.5 Determination of cylinder base thickness

$$S_o = \frac{da * P * S}{100 * Gyield} \quad (21)$$

4.6 Determination of all input and output flow rate at the cylinder

Coefficient of cylinder and output flowrate is given by:

$$X = \frac{D^2}{D^2 - d^2} \quad (22)$$

$$qout = \frac{qin}{X} \quad (23)$$

4.7 Determination of hoses and tubes inner diameter

Separate hose and tubes are used for cylinder

Flow velocity should be chosen if working pressure=600bar, the pressing flow velocity Vpr=8m/s.

Generally suction flow velocity =1.5m/s and return line flow velocity = 2m/s

$$d^2 = \frac{21 * q}{V} \quad (24)$$

$$d_{rt} = \frac{21 * q}{V_{rt}} \quad (25)$$

$$d_{pr} = \frac{21 * q}{V_{pr}} \quad (26)$$

4.8 Determination of oil tank capacity

In real life tank capacity is chosen by 3-5 times bigger than the flow [5].

Oil cooling is very important for all hydraulic system so more oil using is better for the cooling oil tank capacity

$$Capacity = 996 * 3 = 2988 lt. \quad (27)$$

5. SIMULATION OF HYDRAULIC SYSTEM CIRCUIT

The hydraulic circuit simulation illustrates the overall fluid flow phenomena of the system. The simulation of hydraulic circuit of this machine is done using fluidsim softwear. The circuit simulation has been performed for 500ton of force.

This hydraulic circuit helpes us to well understand working of the machine. It indicates the flow lines of fluid, when and how it could be highly pressurized, and cylinder condition while extending and retracting.

When the piston rod is back to botom dade center due to pressurized, fluid that position is called as fully retracted position, and while at top dade center, fully extend position.

The directional control valve (DCV) is the main part for hydraulic system and it is core part for hydraulic stone splitting machine. When the machine starts work the DCV stays at the center position and this position is called bypass position and this position does't permit the pressurized fluid to flow throgh the system. When the DCV stays at this position the pressurized fluid comes back to tank and the simulation of the system while at this position is shown in the below Fig -2.

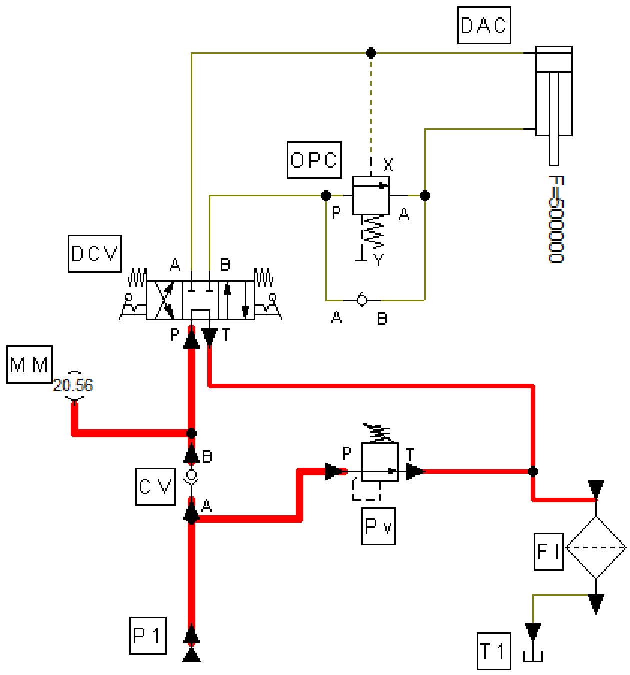

Fig -2: Simulation hydraulic cicuit while the directional control valve is in bypass position

When directional control valve (DCV) actuated to extending position the pressurized fluid directly pass throgh the check valve(CV) and DCV; and it actuates the cylinder to extend and split the stone. The below Fig -3 and Fig -4 illustrates the circuit while extending and fully extend respectively.

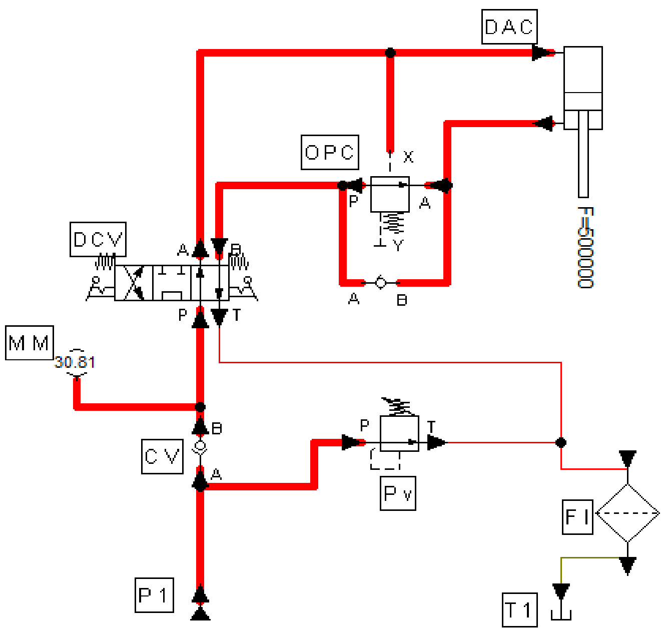

Fig -3: Simulation of hydraulic circuit while cylinder extending to split stone

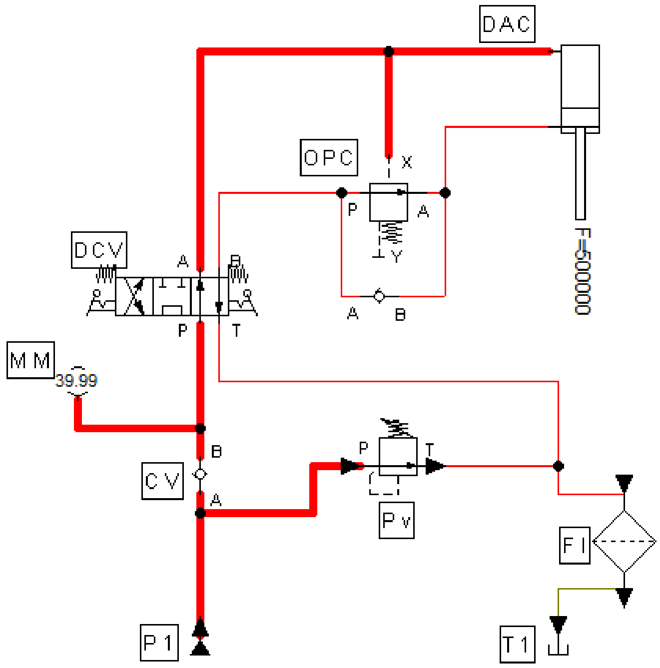

Fig -4: Simulation of hydraulic circuit while cylinder at fully extend position

The below Fig -5 and Fig -6 illustrates the simulation of hydraulic stone splitting machine, hydraulic circuit while the cylinder retracts and fully retract to its original home position respectively and this is done when the DCV is at position 1. The overall stone splitting process is controlled by directional control valve. 3 postion 4 way DCV is used in this machine.

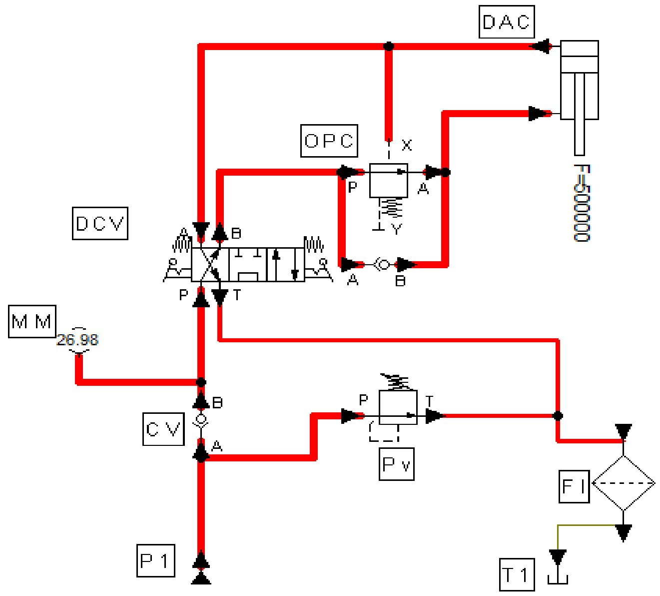

Fig -5: Simulation of hydraulic circuit while cylinder retract to home position

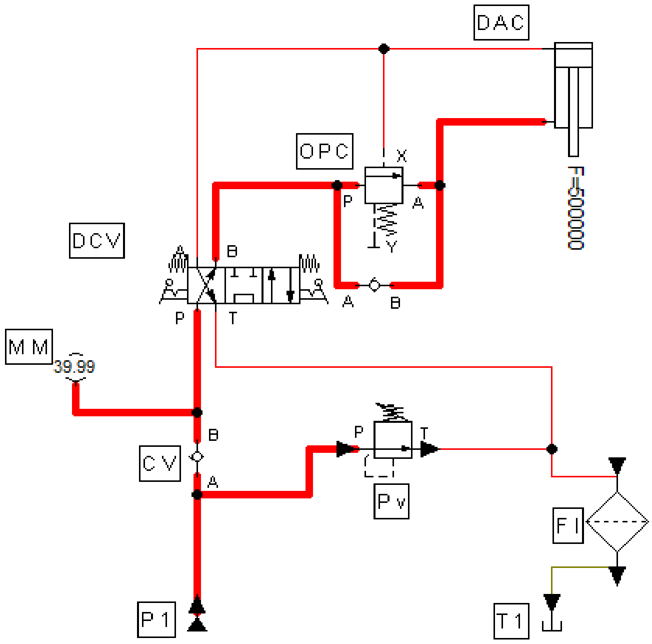

Fig -6: Simulation of hydraulic circuit while cylinder is at fully retract postion

6. MODELING AND ANALYSIS

6.1 Modeling

Modeling is the pre process of manufacturing engineering, with out modeling nothing is manufactured perfectly or acurately as a design consideration. The 3D-Model represents the physical fuetures of the machine well-nigh and its used to determine the effects of loading while splitting stones in the machine. Solidworks are used to simulate, calculate the overallweight, surface area, and inertial property of the machine and its shown in the below Fig -7 and Fig -8 respectively.

```
Mass properties of Assem11
    Configuration: Default
    Coordinate system: -- default --

Mass = 1062883.67 grams

Volume = 216499219.39 cubic millimeters

Surface area = 12456355.29  square millimeters

Center of mass: ( millimeters )
     X = 241.86
     Y = 119.30
     Z = 557.53

Principal axes of inertia and principal moments of inertia: ( grams *  square millimeters )
Taken at the center of mass.
      Ix = ( 0.03, -0.34,  0.94)      Px = 205764952455.23
      Iy = ( 0.16, -0.93, -0.34)      Py = 256864503404.15
      Iz = ( 0.99,  0.17,  0.02)      Pz = 316064632859.97

Moments of inertia: ( grams *  square millimeters )
Taken at the center of mass and aligned with the output coordinate system.
     Lxx = 314320841617.22      Lxy = -10344420188.40      Lxz = 290014540.65
     Lyx = -10344420188.40      Lyy = 252576562197.94      Lyz = -16596861975.14
     Lzx = 290014540.65         Lzy = -16596861975.14      Lzz = 211796684904.20

Moments of inertia: ( grams *  square millimeters )
Taken at the output coordinate system.
     Ixx = 659829843880.52      Ixy = 20323102510.92       Ixz = 143612690792.28
     Iyx = 20323102510.92       Iyy = 645133466466.13      Iyz = 54096812339.72
     Izx = 143612690792.28      Izy = 54096812339.72       Izz = 289097997164.20
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Fig –7: Mass, surface area, and inertial property of the machine calculated using Solidworks

Fig- 8: 3D- Model of stone splitter machine

6.2 Structural analysis

The frame, base, and hydraulic cylinder are an important parts of hydraulic stone splitting machines. The overall loads of the parts are mounted on the frame; such as weight of cylinder, base, piston rod, cutting edge, and stone while splitting. The frame must be rigid enough to with stand with the given loading and the strength of frame is analyzed using Solidworks simulation and result is shown in the below Fig -9 and Fig -10 respectively.

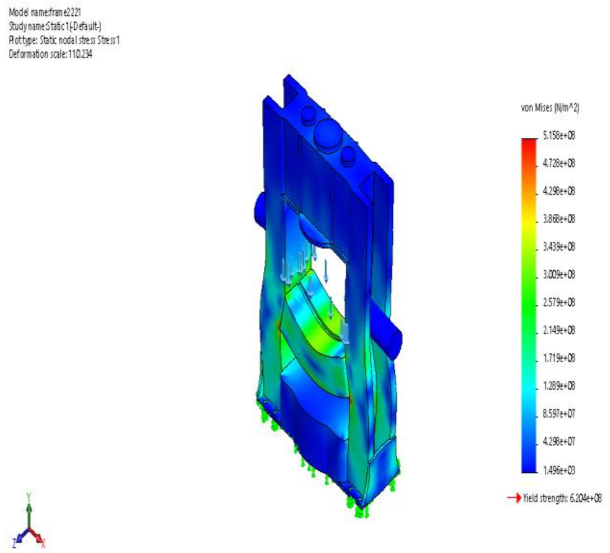

Fig -9: Von-mises stress simulation for frame

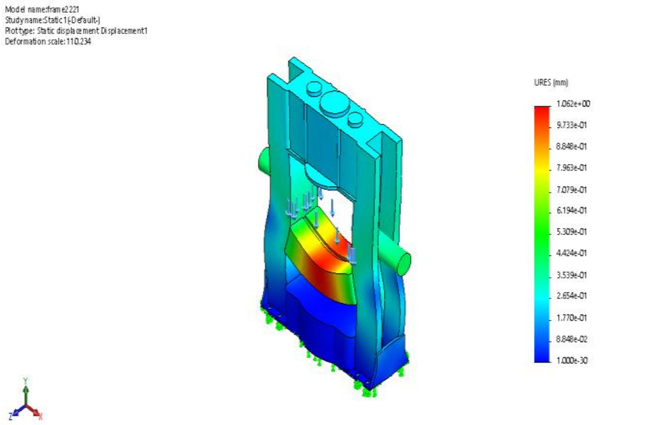

Fig – 10: Resultant displacement for frame

The hydraulic cylinder piston rod is the main parts for hydraulic stone splitting machine and it has high loading while splitting stone and it also analyzed using Solidworks simulation and its result is shown in the below Fig –11 and Fig –12 respectively.

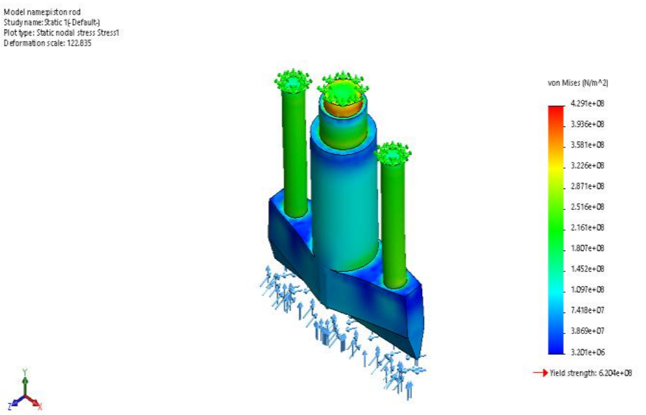

Fig -11: Von-mises stress simulation for piston rod

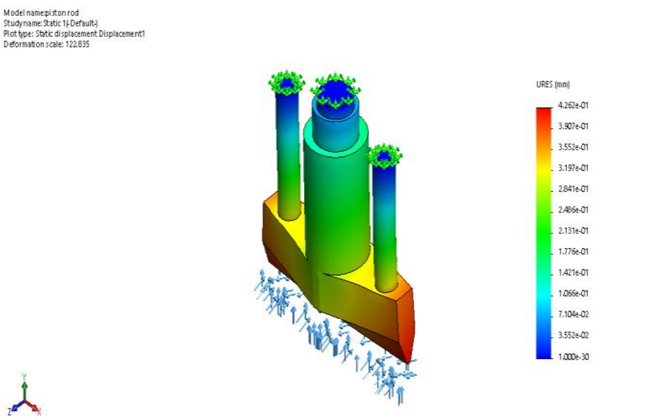

Fig -12: Resultant displacement for piston rod

7. RESULT AND DISCUSSION

Table-1: Result of Hydraulic Circuit Design

Description	Designation	Result
Design of piston	Apr	833.3cm²
	D_{pr}	352.7mm
	K	1500000kg.
	J	31.916cm⁴
	d	85mm
Pump design	Q	0.0166m³/s
	D_p	2.932*10⁻⁴m³/rev
Electric motor	P_{pr}	121kw

Table -2: Result of Cylinder and Tube Design

Description	Designation	Result
Cylinder base thickness	S_o	144mm
	D_a	613mm
Cylinder base thickness	S_o	319mm
Hoses and tubes inner diameter	d_{rt}	12.26mm
	d_{pr}	51mm
Tank capacity	L	2988lt.
Actual working pressure	P_{ret}	631.6bar
	P_{ext}	588bar

The above tables show the design result of hydraulic stone splitting machine. Table -1, it illustrates the calculated results which are obtained while determining the parameters of piston, pump, and electric motor. Based on the results the devices are selected for stone splitting machine. The table which illustrates the results of calculation it is conducted while designing cylinder base thickness, hose and tubes inner diameter, tank capacity, and actual working pressures for extending and retracting the cylinder of the system; and it is shown in the above table -2. The design of stone splitting machine for processing of natural and artificial stone is necessary and play a major role for construction environment by replacing traditional ways of stone splitting method using hand tools like hammer, and by providing efficient and time minimization method.

The machine is designed within 500ton capacity and it is applicable for only natural and artificial stones like Cobble stones, Paving stones, Tiles for paving and cladding, Wall stones and Kerb stones, etc.

8. CONCLUSION

When people moved to update their livelihoods the demand to use stone is also increased with each foot steeps of people. The tool hammer, which are used for construction environment to split stone to the required dimension still now and this method are tedious, time consuming, and have a risk in persons health. To eliminate this prioritized problem a hydraulic stone splitting machine is designed. This machine have enormous splitting force up to 500ton and its structure is designed to split stones with in volume of 500mm*250mm*250mm. The machine is applicable for production of cobble stone, tiles for paving and cladding, wall stones and kerb stones, etc. It has precious work, vibration free, risk free, cost efficient, dust free, and near silent operation. For the future scope, it can be advanced with technologies like; loading and unloading mechanisms, increasing number of cylinders for clamping the stone, and using sensors for controlling the power consumption.

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BIOGRAPHIES

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