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Design of an adaptive pencil lead production RIG

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Abstract:* This paper presents the design of an adaptive pencil lead production device. Pencil lead is made from fine blend of clay, graphite and other additives in appropriate proportion. It is commonly produced by extrusion. The device was designed taking into consideration the necessary design criteria which include stiffness, mass, durability and safety. Hydraulic system was adopted as prime mover because large force is needed to extrude the pencil lead. The determination of capacity of the electric motor, cylinder blind area and ram speed were calculated based on a maximum working pressure of 10 MPa. Structural analysis of critical components was performed to avoid mechanical failure during operation. ANSYS software was used for the analysis.

Index Terms: Adaptive, rig, Extrusion, Hydraulic, Ram speed.

Nomenclature

Symbol Meaning

$Q \text{ or } Q_m$ = $pump\ output/fliud\ flow\ rate$
V_p = $pump\ vol\ displacement$
n_p = $pump\ shaft\ speed$
η_{vol} = $pump\ vol\ efficiency$
η_p = $Pump\ overall\ efficiency$
P_{in} = Power
Pa = Pascal (pressure unit)
V_p= Pump displacement
n_p = $Pump\ shaft\ speed$
A= blind end area – i.e. area of the flat end surface attached to the cylinder rod.
r=radius of the cylinder bore
A_{be} = $cylinder\ blind\ end\ area$
A_r = $Rod\ area$
A_{cr} = $Cylinder\ rod\ end\ area$
F_p = $Push\ force$
P_f = $Fluid\ Pressure$
$F"_p$ = $Pull\ force$
V= cylinder speed
T = tank capacity

I. INTRODUCTION

Pencil is one of the oldest and most widely used writing or drawing implements today, originated in the pre-historic times. Pencils are constructed of a narrow, solid pigment core in a protective casing that prevents the core from being broken and/or marking the user's hand. Most pencil cores are made of graphite powder mixed with a clay binder [1].

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The first pencils were produced manually by pouring the blend of clay and graphite into tubes and allowing it to solidify. The solidified lead is then gently removed from the tubes. This method of production was not economically viable as only few sticks were produced daily Pencils were later produced industrially with sophisticated machineries through direct extrusion. Two systems of extrusion were commonly used which are screw and hydraulic systems. The hydraulic systems are the prime movers in many heavy industries and has these advantages over other systems; they are simple, easy to operate and can be controlled accurately, multiplication and variation of forces, multifunction control, Low-speed torque, Constant force or torque, Low weight to power ratio and can be used where safety is of vital importance [2]. Irrespective of all the aforementioned advantages hydraulic systems have their inherent disadvantages.

The hydraulic system of the pencil lead production device is a closed-loop system which uses feedback. The output of the system is fed back to a comparator by a measuring element. The comparator compares the actual output to the desired output and gives an error signal to the control element. The error is used to change the actual output and bring it closer to the desired value. A simple closed-loop system uses servo valves and an advanced system uses digital electronics [3].

II. MATERIALS AND METHOD

A. Materials

The materials used for the rig construction were carefully selected to meet international standards so as to avoid failure during operation. The bill of quantity and specifications are listed as in Table 1.

Table 1. Bill of quantity and material specification

S/no.	Quantity	Item	Materials
1	12	Main frame	Aisi 1045
2	1	Hydraulic ram	Carbon
3	1	Extrusion	steel
4	1	chamber	
5	2	Compaction	Aisi 1045
6	1	Chamber	carbon
7	1	Dies	steel
8	1	Hydraulic	
9	1	Pump	Stainless
10	1	Hydraulic	steel
11	1	values	
12	1	Hydraulic fluid	
13	1	5Kw electric	ATF
14	1	motor	
15	1	Switch	
16	4	Key	Aisi 1045
17	1	Fan	carbon
		Coupler	steel

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		Bourdon Gauge	Plastic
		Heating coil	
		Pressure Hose	Stainless steel
		Filter	Cupper

B. METHOD

The rig consists of a metal base on which the hydraulic cylinder is mounted, a hydraulic pump connected to an electric motor, which drives the pump. Hydraulic fluid from the tank enters the pump through an inlet hose and is transmitted to the cylinder at high pressure via the outlet pipe. A pressure sensor is mounted on the cylinder to capture and send error message to the safety valves whenever excess pressure builds up in the cylinder. The capacity and sizes of the components were designed based on a maximum working pressure of 100 bar (10MPa).

1. Design principles and mathematical modeling

In actual extrusion practices, it has been difficult estimating the following factors:

i. The coefficient of friction and its variation throughout all work piece-die contacting surfaces.

ii. The flow stress of the material under the actual conditions of temperature and strain rate.

iii. The work involved in inhomogeneous deformation

Consequently, a simple empirical formula has been developed in the form of (1).

$$\alpha = f(E_r, \sigma_f, F_f, F_f') \tag{1}$$

For indirect extrusion analysis,

$$A_o = \frac{\pi D_o^2}{4} \tag{2}$$

$$A_f = \frac{\pi D_f^2}{4} \tag{3}$$

$$r_x = \frac{A_o}{A_f} \tag{4}$$

Pressure required,

$$p = \bar{Y}_f \ln r_x \tag{5}$$

With friction,

$$\varepsilon_x = a + b \ln r_x \tag{6a}$$

Where a = 0.8; b increases with the die angle, ranging between 1.2 to 1.5 (6b)

For indirect extrusion,

$$p = \bar{Y}_f \varepsilon_x \tag{7}$$

For direct extrusion, there is additional pressure to overcome friction at the container wall. Hence,

$$p_f = \bar{Y}_f \frac{2L}{D_o} \tag{8}$$

$$p_f \frac{\pi D_o^2}{4} = \mu p_c \pi D_o L \tag{9}$$

$$p = \bar{Y}_f \left(\varepsilon_x + \frac{2L}{D_o}\right) \tag{10}$$

The shear yield strength,

$$\bar{Y}_s = \frac{Y_f}{2} \tag{11}$$

The ram force,

$$F = pA_o \tag{12}$$

The power required,

$$P = Fv \tag{13}$$

For extrusion dies and press,

$$K_x = 0.98 + 0.02\left(\frac{C_x}{C_c}\right)^{2.25} \tag{14}$$

So, for indirect extrusion dies,

$$p = K_x \bar{Y}_f \varepsilon_x \tag{15}$$

And for direct extrusion dies,

$$p = K_x \bar{Y}_f \left(\varepsilon_x + \frac{2L}{D}\right) \tag{16}$$

The hydraulic cylinder blind end area can be determined from (17),

$$A_{be} = \pi r^2 \tag{17a}$$

$$A_{be} - A_r = A_{cr} \tag{17b}$$

While the cylinder output force can be determination from the relations

$$F_p = A_{be} \times P_f \tag{18a}$$

$$F''_p = (A_{be} - A_r) \times F_p \tag{18b}$$

And the output flow of the hydraulic pump is given by [5] as,

$$Q_m = V_p\, n_p\, \eta_{vol}/1000 \tag{19a}$$

$\eta_p = Pump\ overall\ efficiency\ (0.85 - 0.95)$ (19b)

The mechanical efficiency of a gear can be as high as 90% and can generate a pressure of 40 bar – 100bar (4MPa-10MPa) [4]. Capacity of the system's electric motor may be determined from the relation,

$$P_{in} = P_a\,(V_p\, n_p\,)/600000\eta_p \tag{20}$$

Fluid flowing into a double acting hydraulic cylinder causes either an extension or retraction of the cylinder rod depending on which end the fluid enters. The rate of extension or retraction is proportional to the flow rate into the cylinder [6]. The ram speed is given by the relation,

$$V = \frac{231\ x\ 3.785Q}{60\ x\ Net\ Cyl\ area} \tag{21}$$

2. Determination of Oil Reservoir Size

The tank also known as the reservoir has multiple function of storing hydraulic fluid, it also accommodates fluid volumes change provide access of topping-up the fluid, removed entrained air from fluid and removes solid contaminants in the fluid by settlement. Tank size calculation varies depending on the design of piping and mounting system [4]. Hunt, [4], also recommends a tank size of 3-5 times pump output flow per minutes plus 20% of this volume as air space above the fluid. This recommendation is represented in the expression of (22).

$$T = 1.2(5Q) = 6Q \tag{22}$$

3. Fabrication of Production Rig

The rig was fabricated at the engineering department of John Ray Industries Nnewi, Nigeria. Component parts were sourced locally from Onitsha and Nnewi respectively. Figure 1 is the hydraulic circuit of the

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production rig, while Figure 2 depicts the assembly drawing of the machine element.

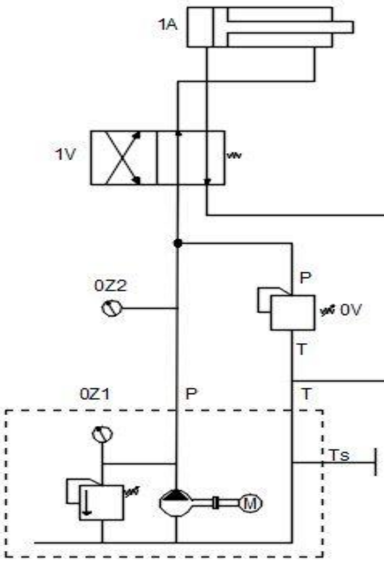


Fig 1. Hydraulic circuit

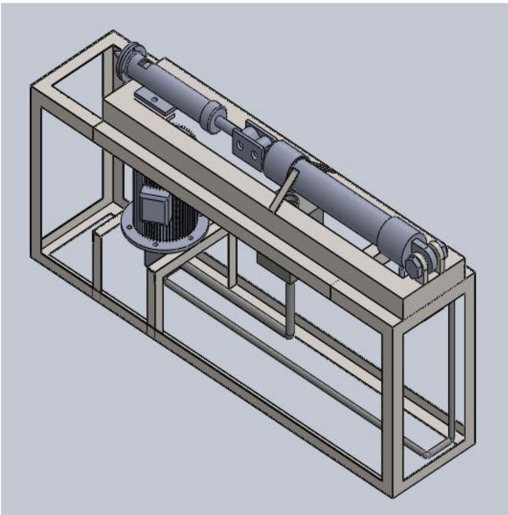
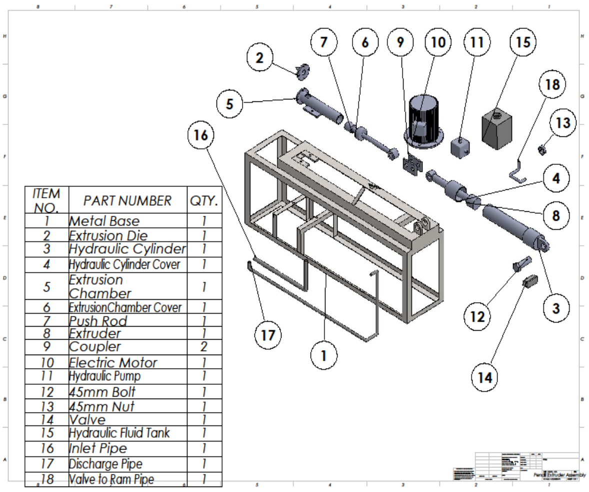


Fig 2. Solid model of Rig



ITEM NO.	PART NUMBER	QTY.
1	Metal Base	1
2	Extrusion Die	1
3	Hydraulic Cylinder	1
4	Hydraulic Cylinder Cover	1
5	Extrusion Chamber	1
6	ExtrusionChamber Cover	1
7	Push Rod	1
8	Extruder	1
9	Coupler	2
10	Electric Motor	1
11	Hydraulic Pump	1
12	45mm Bolt	1
13	45mm Nut	1
14	Valve	1
15	Hydraulic Fluid Tank	1
16	Inlet Pipe	1
17	Discharge Pipe	1
18	Valve to Ram Pipe	1

Fig 3. Assembly drawing of Rig

Fig 4. Photograph of Rig

III. RESULTS AND DISCUSSION

Hydraulic pump is a device that converts mechanical energy such as rotation of motor to fluid energy. An external gear pump was selected for this machine due to its efficiency, light weight and low cost. Volumetric displacement is $25cm^3$/rev. Selection of the electric motor was based on the ability of the motor to supply sufficient torque to drive the hydraulic pump, which in turn generates enough fluid pressure to operate the plunger. The capacity of the electric motor was determined as in (20) on assumption that the pump efficiency is 90% [6].The cylinder rod end area was calculated from (17). Double acting hydraulic cylinder is most commonly used in hydraulic system [7].

Fluid flowing into a double acting hydraulic cylinder causes either an extension or retraction of the cylinder rod depending on which end the fluid enters. The rate of extension or retraction is proportional to the flow rate into the cylinder [6]. The speed is determined by (21)

A. Structural Analysis

The structural analysis of the various components of the machine was made using finite element software. Fig 5 shows a refined mesh image of the metal base. Positions and spread of the nodes and elements of the device can be clearly seen. Closeness of the nodes and increased number of elements facilitate stress analysis of the metal base.

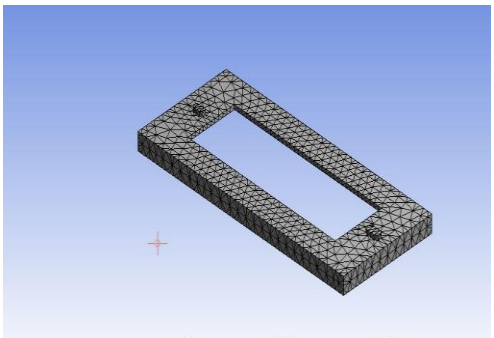


Fig 5. Refined mesh image of the base

Fig 6 shows the equivalent Von Mises stress. The equivalent stress value of 18.211 MPa is greater than the applied stress of 6.0MPa generated by the hydraulic system. This implies that the frame will not fail when maximum pressure is applied by ram on the frame. The location where the pressure seems to affect the base is at the extreme where the hydraulic cylinder fixed end is mounted.

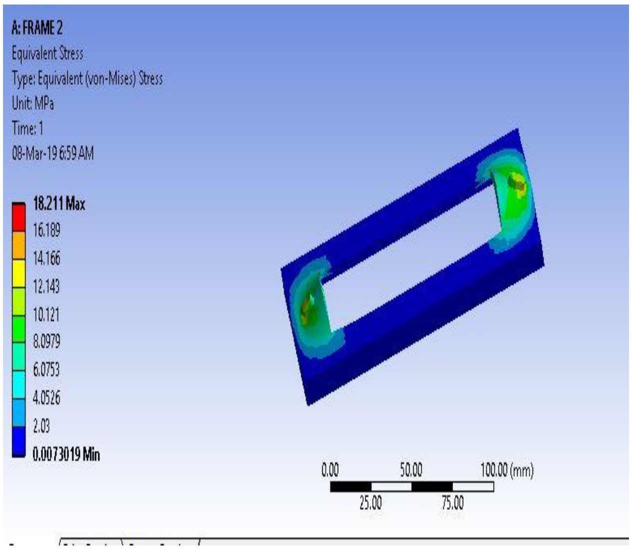


Fig 6. Equivalent von Mises stress image of base

Fig.7 shows the total deformation of frame structure. The maximum total deformation is 0.3722mm for an applied external pressure of 10MPa. This deformation could be considered negligible with respect to the size of the frame.

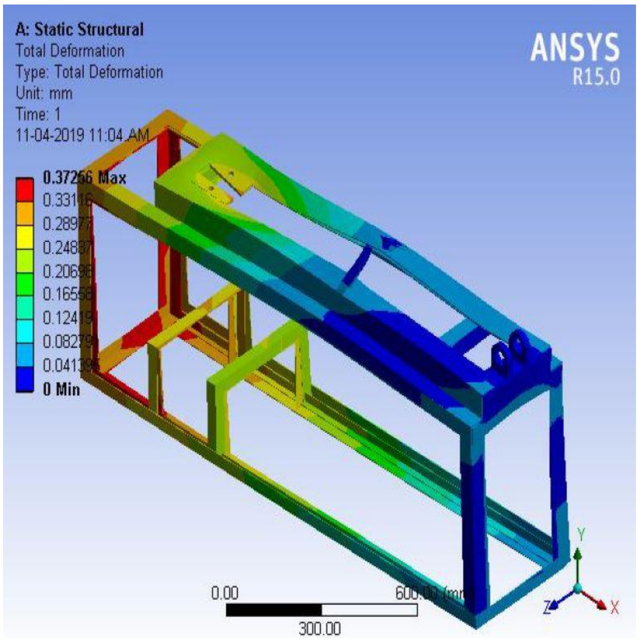


Fig 7. Total deformation image of frame structure

Fig 8 shows the equivalent (von Mises) stress of the structure. The stress value is 80.41 MPa which is far above the maximum applied stress of 6.0 MPa. With this, the structure will withstand the tensile stress it is subjected to. Failure by shear is completely eliminated.

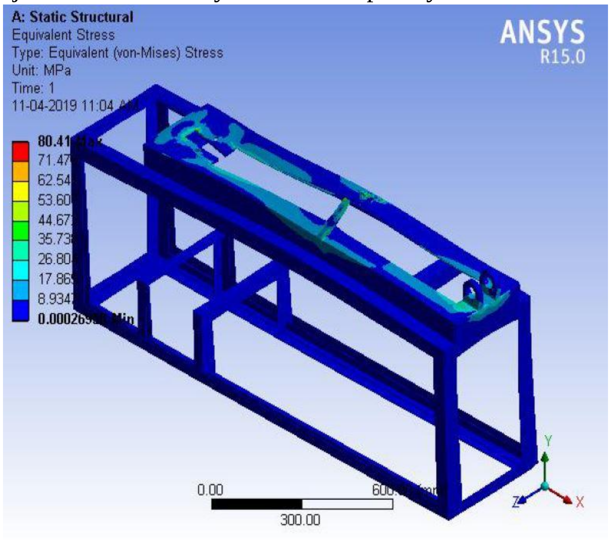


Fig 8. The equivalent (von Mises) stress of the rig structure

IV. CONCLUSION

The adaptive pencil lead rig was designed and constructed. Experimental analysis show that the 5hp 3phase electric motor driving the hydraulic pump at 1500 rpm, with fluid discharge rate of 20 L/min generated sufficient pressure to extrude the blend of clay and graphite for pencil lead production. Structural analysis results show that the rig can withstand the maximum applied pressure without mechanical failure.

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