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DESIGN AND FABRICATION OF A CENTRIFUGAL CASTING MACHINE

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Abstract

This work focuses on the design and fabrication of a centrifugal casting machine which is based on the principle of centrifugal force. With an engineering design process based on the method developed by G. E. Dieter, draft prototype of centrifugal casting machine with dimension of 550x450x400 mm, 1 HP motor power, pulley and belt mechanism, diameter of 80-160mm, simultaneously with the characteristics of simple casting product, easy manufacture and maintenance, and relatively inexpensive, was fabricated. Mild steel was used to form the mould based on strength, cost and availability. The machine was tested and found to cast polypropylene as was originally intended.

Keywords: mould, centrifugal casting, design, fabrication, shaft.

1.0 Introduction and Literature Review

Casting by definition is the process of producing metal shapes by pouring molten metal into moulds of required form where it is allowed to solidify on cooling. The metal part formed as a result of this operation is called cast. Casting is as old as the Roman Empire. The roman craftsman started the art of casting by making two half mould, wedge them together and carefully pouring molten bronze into the mold cavity. This molten bronze solidifies on cooling and the cast removed from the mold. Within this method, they were able to make swords in large numbers. Casting hence has been a method by which important metal components are made in large quantity. Centrifugal casting consists of producing castings by causing molten metal to solidify in rotating moulds. The speed of the rotation and metal pouring rate vary with the alloy, size and shape being cast.

In general casting processes, it is difficult to form a hollow cast which is a major problem in the procreation of certain machine parts and a setback in the casting industry. The centrifugal casting machine which works with the principle of centrifugal force solves this problem hereby eliminating a major limitation.

Centrifugal casting machine can be used for the production of pipes, cylinder liners, brake drums, flywheels and other axis-symmetric parts, in which molten metal is poured at suitable temperature into rapidly rotating mold to form the cast.

It has been shown that the solidification takes place at faster rate as the thickness of mould increases. This is due to the chilling effect of the mould. The chilling effect on the casting depends on thermal mass of liquid metal and relative movement between the liquid metal and inner surface of the mould. Rapid solidification shows the well distributed fine grains and slow solidification rate shows coarse grain size [1]. It has also been shown that as the rotational speed increases the centrifugal force also increases which creates a strong convection in the liquid pool and this leads to the rapid cooling of the liquid. The rotational speed depends on the material centrifugally cast [2].

The design and development of a centrifugal casting equipment to produce engine pistons with gradient of properties has been presented by researchers [3]. The conception and design of the envisaged equipment includes two main sections: the centrifugal equipment itself and the metallic mould. The design has a problem of high vibration in shaft as there is no intermittent drive used to power to output (mold). Again, research has been carried out to design and fabricate a vertical centrifugal casting machine [4]. They conclude that during rotation of the mould as the casting solidifies from the outside, the inner surface feeds the necessary molten metal to the reminder of the casting as required and the grain structure is created, ready for ejection. Also, [5] carried out work on locking plate of centrifugal casting machine. They have found that during pouring of molten metal into mould, the end where spout is taken out ramains open. While loading, workers need to do fastening the cover plate manually and it requires more time. This results in reduction in productivity.

In 2015, a study was carried out to propose a design of centrifugal casting machine for manufacturing of turbine bearing [6].

The limitation associated with this machine includes its inability to cast regular shapes with definite angles. Such angles include; 45, 90 etc.

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2.0Materials and Methods
The centrifugal casting machine uses an electric motor to drive a shaft carrying the mould at one end. The electric motor produces power which drives the shaft and is transferred with a belt connected from a pulley at the end of the motor to a pulley at the end of the shaft. This enables the shaft to rotate the mould hereby producing the centrifugal force needed.

2.1The Main Frame
The frame of this machine is made up of angle bars joined together having a geometric shape held together by welding. The welding provides very rigid joints and this in turn provides strength and rigidity for the overall machine. The frame is basically the foundation for which the machine is built. The frame houses the electric motor that generates the required power for operating the machine.

2.2Electric Motor and Pulley System
A 1HP electric motor is used to power the machine. A reduction pulley system is used to transmit power and torque to the shaft at reduced speed. The electric motor and the pulley are connected together with a belt.

2.3 The Shaft and the Mould
The power transmitted through the reduction pulley system to the shaft is then transmitted to the mould producing the centrifugal force required to produce the desired shape to be cast. The shaft and the mould rotate at the same speed in a counter clock-wise direction.

3.0Design Analysis

3.1 Design for electric motor
1HP = 1800rpm having 6.91A and 120V
Using a 20µF capacitor to reduce the speed
$N_1 = 1800 \times 4/5 = 11440$rpm

3.2 Determination of the speed of driven pulley
The speed of the driven pulley is given as:
$N_2 = N_1d_2/d_1$ (1)
N_2 is the speed of the driven pulley (RPM)
N_1 is the speed of the motor pulley (RPM) = 1440RPM d_1 is the sheave diameter of the motor pulley (mm) = 80mm d_2 is the sheave diameter of the driven pulley (mm) = 160mm The speed of the driven pulley, N_2, is gotten to be 720RPM

3.3Design for bearing
$L_{10} = [\{C/P\}^e \times 10^6]/60N$ (2)
C = dynamic capacity (dN or lbs) = 20700N = 2070dN
P = Equivalent bearing load (N or lbs) N = Rotating speed in rpm = 720rpm
e = 3.0 for ball bearing, 10/3 for roller bearing Weight of shaft = 0.5kg
converting rpm to m/s = 7.2m/s
P = 19.44N
L_{10} = 27947213.18 days = 76778.0582 years

3.4Belt design and selection

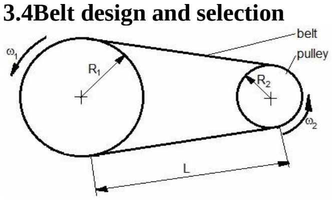


Fig. 1: Belt Design

b = 12mm, t =8mm w/c = 106 d_1 = 80mm, d_2 = 160mm
Density of belt, $\rho = 1250kg/m^3$, Power of belt, P = 746watts
Rotational speed of driver, N_1 = 1440rpm, S_s = 3.0mpa,
μ =0.25, Groove angle of pulley, $30^0 = 2\beta$
Length of belt, $L = 2C + [\pi(d_1 + d_2)]/2 + [(d_1 + d_2)^2]/4C$ (3)
C = center distance between the two pulleys (mm)
$C = \max [3d_1/2] + [d_2/2]$ (4)

C = 200mm
Using a center distance of 250mm
Length of belt, L = 883.39mm

Tension on tight side of belt, T_1
$T_1 = btS_s = 0.012 \times 0.008 \times 3 \times 10^6$ (5)
T_1 = 288N
Angle of wrap
$\theta_1 = 180 - 2\alpha$: $\theta_2 = 180 + 2\alpha$ (6)

$\sin\alpha = [d_2 - d_1]/2C = 0.16$ (7)
$\alpha = \sin^{-1}(0.16) = 9.2^o$ $\theta_1 = 180 - 2\alpha = 161.6^o$ $\theta_2 = 180 + 2\alpha = 198.4^o$
Tension on slack side of belt, T_2
$2.3\log(T_1/T_2) = \mu\theta \text{cosec}\beta$ (8)
$2.3\log(T_1/T_2) = 0.25 \times 161.6 \times \pi/180 \text{ cosec } (15)$
$T_1/T_2 = \ln\{[0.25 \times 161.6 \times \pi \times \text{cosec}(15)] / [2.3 \times 180]\}$
$T_2 = 13.6N$
Power transmitted through the belt
$P = (T_1 - T_2) V$ (9)
Where $V = \pi D_1 N_1/60$ (10)
P = 1655.14watts
Number of belts = (746/1655.14) = 0.45belts = 1 belt
3.5Determination of the belt speed

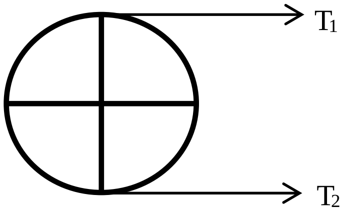


Fig. 2a
The speed of the belt is determined by the relation:
$V = \pi d_1 N_2/1000$ (11)
Where V = speed of the belt
The speed of the belt is gotten to be 180.95 m/min

3.6Design of the Shaft

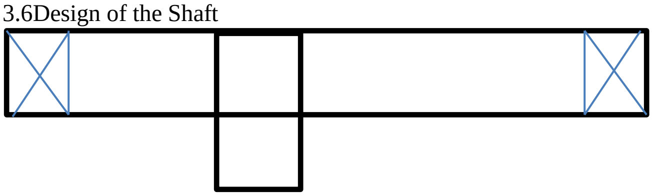


Fig. 2b

Mass of driver pulley = 0.5kg
Mass of driven pulley = 1.0kg
Diameter of driver pulley = 0.08m
Diameter of driven pulley = 0.16m
Length of shaft = 0.7m
Allowable stress, $S_s = 40MN/m^2$

For vertical load;

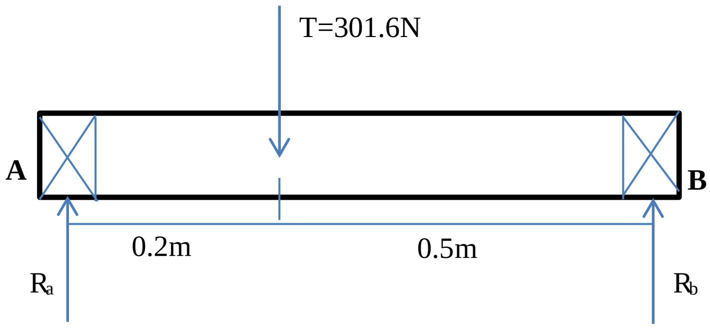


Fig. 3:
$T_1 = 288N$, $T_2 = 13.6N$

$T_1 + T_2 = 301.6N = T$
$D^3 = [16/\pi S_s]x\sqrt{[(K_bM_b)^2 + (K_tM_t)^2]}$ (12)
$M_t = (T_1 - T_2)\ R = (288 – 13.6) \times 0.105$
$M_t = 28.812Nm$
$\Sigma x = 0; \Sigma y = 0; \Sigma M = 0$
$R_a + R_b = 301.6$
Taking moments about A
$\Sigma M_a = (301.6 \times 0.2) – (0.7 \times R_b) = 0$
$R_b = 86.17N$
$R_a = 301.6 – 86.17 = 215.43N$

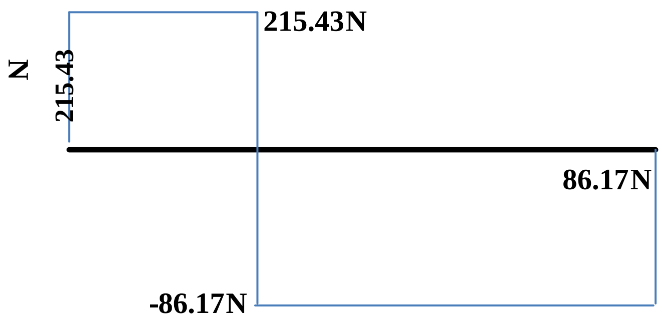


Fig. 4: Shear Force Diagram

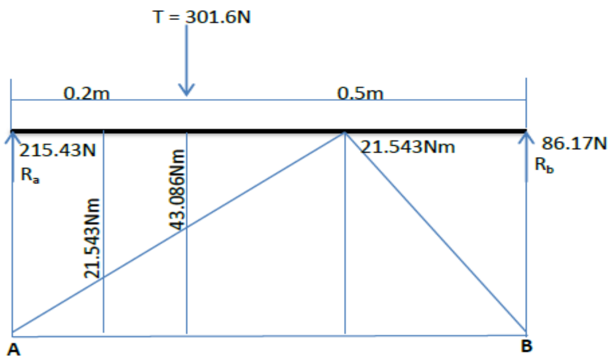
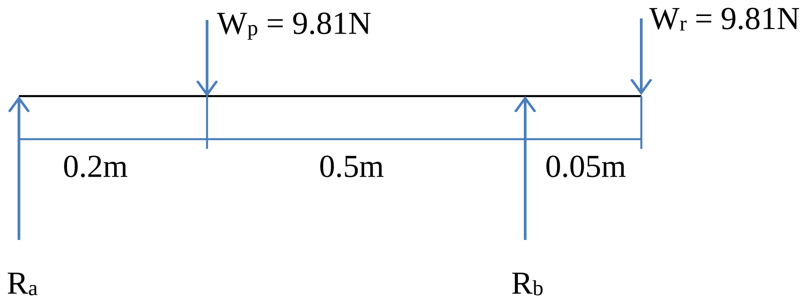


Fig. 5: Bending moment diagram
From A to B
$A = 215.43 \times 0.1 = 21.543Nm$
$= 215.43 \times 0.2 = 43.086Nm$
$= 215.43 \times (0.2 + 0.25) = 96.9435Nm$
$T = 301.6 \times 0.25 = 75.4Nm$
$= 96.9435 – 75.4 = 21.5435Nm$
$A = 215.43 \times 0.7 = 150.8Nm$
$T = 301.6 \times 0.5 = 150.8Nm$
Maximum bending moment for vertical load, $M_{BV} = 21.5435Nm$
For horizontal load;
Weight of rotating disc, $W_r = 1.0 \times 9.81 = 9.81N$

Volume of cylindrical part of disc, $V = \pi r^2 h = \pi \times 0.04^2 \times 0.15$

$V = 7.5398 \times 10^{-4}\ m^3$



Weight of driven pulley, $W_p = 1.0 \text{ x } 9.81 = 9.81N$

Fig. 6

$R_a + R_b = 9.81 + 9.81 = 19.62N$
Taking moments about A
$\Sigma M_a = (9.81 \text{ x } 0.2) – (R_b \text{ x } 0.7) + (9.81 \text{ x } 0.75) = 0$
$R_b = 19.6 – 13.3135 = 6.3065N$

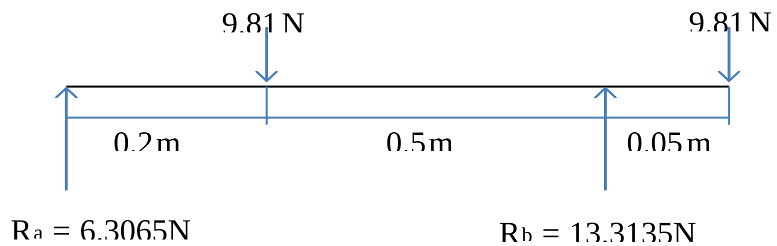


Fig. 7

For 0<x<0.2m

$M_x = 6.3065X$
$X = 0, M_x = 0$
$X = 0.2, M_x = -1.2613Nm$

For 0.2<x<0.7m

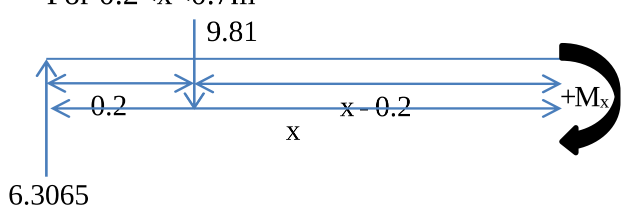
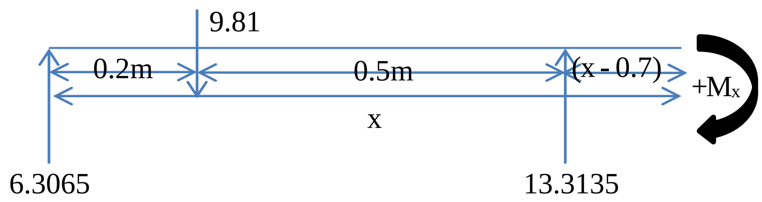


Fig.8

$\Sigma M_{xx}= 0$

$(6.3065x) – [9.81 (x – 0.2)] + M_x = 0$ $M_x = 3.5035x + 1.962$ x = 0.2

$M_x = 2.6627Nm$
x = 0.7

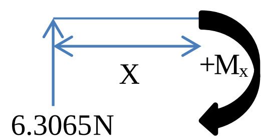


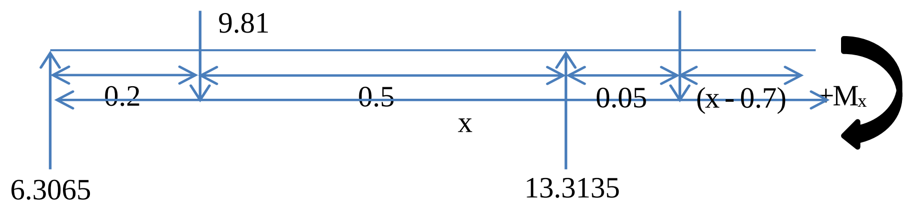
M_x = 4.41445Nm

Fig. 9

$\sum M_A = 0$

$(6.3065x) - [(9.81 \text{ x } (0.5 + x - 0.7)] + 13.3135(x - 0.7) = 0$
$= 9.81x - 7.35745$
For x = 0.7





M_x = -0.49045Nm

Fig. 10

$\sum M_A = 0$

$(6.3065x) - 9.81[0.55 + (x - 0.75)] + 13.3135[0.05 + (x - 0.75)] - 9.81(x - 0.75)$
$M_x = 0x + 0 = 0$
M_{BH} = 4.41445Nm

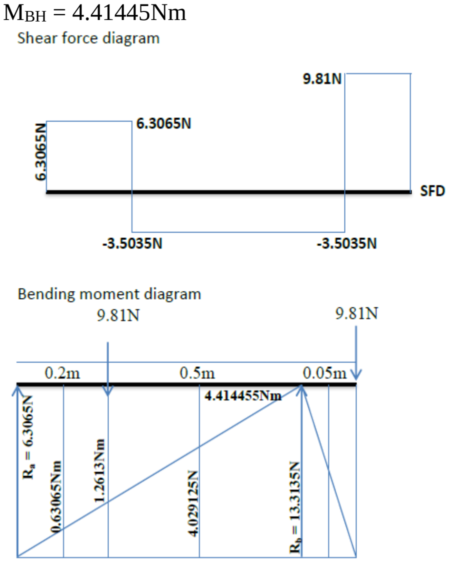


Fig. 11: Shearing force and bending moment diagram

MB = √[MBV2 + MBH2]
M_B = 21.99Nm = 22Nm
For diameter of shaft
$D^3 = [16/\pi S_s] x \sqrt{[(K_b M_b)^2 + (K_t M_t)^2]}$
M_t = 28.812Nm; K_b = 2.0 K_t = 2.0 D = 0.02097m
= 20.97mm

3.7Determination of the Centrifugal Force on the machine:

$$F = M \times r \times \omega^2 \quad (13)$$

Where:
F = Centrifugal force of the machine (N) M = total mass of the rotating disc (Kg)
r = Radius of the rotating disc (m)
ω = angular velocity of the rotating disc (rad/sec) M = 1kg; r = 0.04m;
$\omega = 2\pi N_2/60$ = 75.39rad/sec
The centrifugal force, F, is determined to be 227.39N

3.8Determination of the Torque generated by the machine

The torque of the machine is determined by:

$$T = F \times rd \quad (14)$$

Where:
F = centrifugal force on the machine (N) r_d = radius of the disc (m)
The torque is determined to be 9.095Nm

3.9Determination of the required Power by the machine

The required power by the centrifugal machine is determined by the relation:

$$P = \frac{2\pi T N_2}{60} \quad (15)$$

Where:
P = the required power (W) = 685.792Watts = 0.685KW

4.0Cost analysis

The cost of the manufactured machine is estimated based on the materials used, labour and overhead cost. High priority is placed on cost minimization in the course of the design of the machine. The choice of locally available materials in the construction is aimed at making the machine affordable for small scale industries. The cost of production is N117,000.

4.1 Performance evaluation

To test the machine, a plastic material having the same volume as that of the mould was melted and poured into the mould while it's rotating and allowed to solidify while rotating. A low density fluid was used to lubricate the internal surface of the mould to prevent the cast material from sticking to the mould upon solidification.

4.2 Discussion

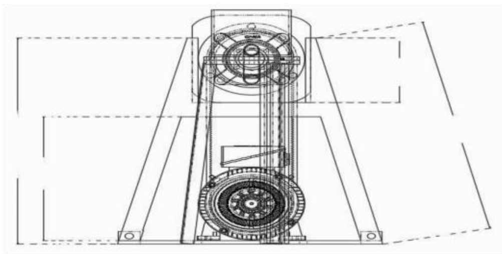
The centrifugal casting machine as designed and manufactured is effective in its function. From the test of the machine, it is seen that at a speed of 720RPM the cast material solidifies faster within a time limit of 4 - 5 minutes depending on the condition of the environment. From the design calculations, it was confirmed that the machine will perform the desired task with optimum efficiency.

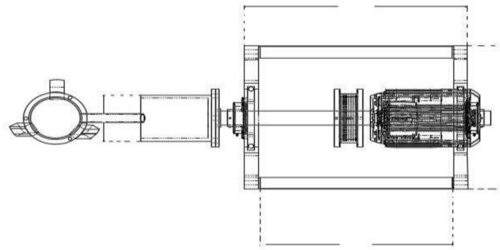
5.0Conclusion

It is gratifying to know that it has been proven that this machine performs its function satisfactorily. It is pertinent to add here that some of the materials used for this fabrication may not be adjudged as the best in the market but were selected based on the constraint of cost.

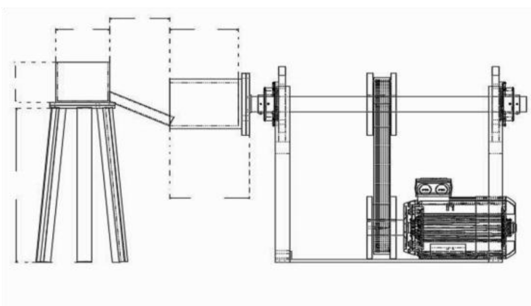
Finally it is expected that with the low cost of this machine, every small scale industry can comfortably afford this machine to carry out the desired function.

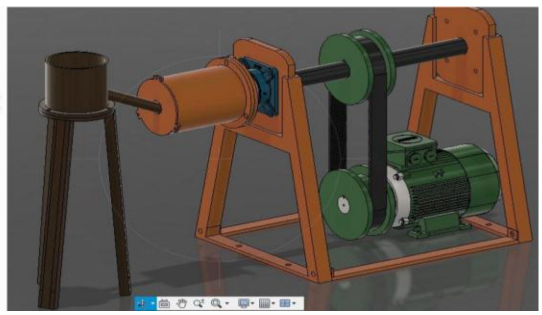
Drawings



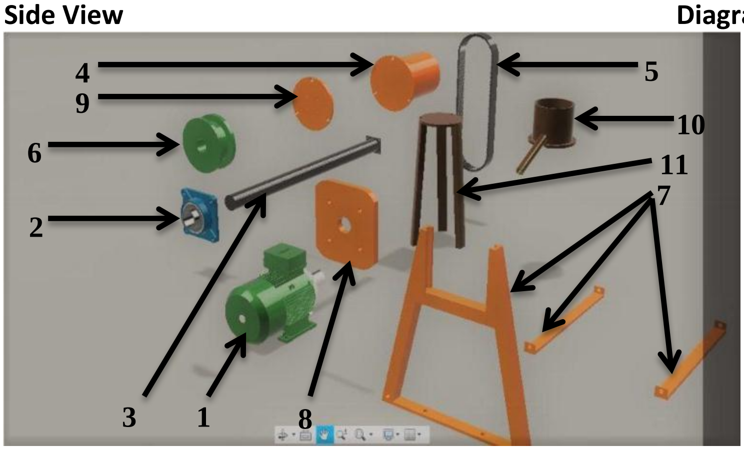


Front View **Top View**





Side View **Diagram of the Machine**



Exploded view of the machine

1. Electric motor
2. Bearing
3. Shaft
4. Mould
5. Belt
6. Pulley
7. Angle bar
8. Bearing plate
9. Mould end seal plate
10. Funnel for Cast material
11. Funnel stand

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