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RECONFIGURATION OF AN IMMOVABLE 8 HP LISTER SLIP ENGINE TO A COMPACT MOVABLE GENERATOR

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ABSTRACT

This study was carried out to configure an 8 hp Nisan engine into a portable compact generator using locally sourced materials. In the design and assembly of this engine-generator, the base trolley was fabricated using mild steel H-beams. The base of the trolley was fabricated and formed into the water reservoir as the engine is water cooled. Other components such as the alternator, electric starter, water pump and accessories were mounted on the base trolley. Parameters of some components such as the mass of trolley, the driven pulley diameter, power transmitted by belt and power of pump were determined and the design values were used for the selection of some of these components. Performance test was carried on the reconfigured generator. The results showed that the vibration of the engine was sufficiently mitigated by the four tyres attached to the base of the trolley. The 100-liter water reservoir was sufficient to provide the cooling needs of the engine. Furthermore, it was observed that the desired output of 232 volts was obtained.

1. INTRODUCTION

In the present times, power failures can no longer be addressed by simply lighting a candle or by using torchlights. The issue is not limited to grappling with mere absence of light or a temporary shutdown of domestic electrical appliances. Instead, a power outage now signifies an abrupt termination of connectivity with the rest of the world. In a fast-paced world that is now tightly networked over a virtual space, a disruption in connectivity severely handicaps smooth running of businesses. This translates into hindrances in execution of critical tasks, irreparable damage to an organization's repute, loss of faith among consumers, and eventually, forfeiture of revenues.

An electrical generator is a device that works on the principle of electromagnetic induction to generate electrical energy from a source of mechanical energy, such as a turbine rotated by the force of falling water, a wind turbine, a hand crank, solar energy, an internal combustion engine or any other similar source. Crouse and Anglin (2007) defined an engine as a machine that converts heat energy into mechanical energy. The heat from burning a fuel produces power which moves the vehicle.

An engine-generator is the combination of an electrical generator and an engine (prime mover) mounted together to form a single piece of equipment. In many contexts, the engine is taken for granted and the combined unit is simply called a generator. A diesel generator is the combination of a diesel engine with an electric generator (often an alternator) to generate electrical energy. A diesel compression-ignition engine often is designed to run on fuel oil, but some types are adapted for other liquid fuels or natural gas. The fuel in diesel engines are injected by a spring-loaded injector and the fuel pump is being operated by a cam driven from the engine crankshaft (Eastop and McConkey, 1993).

Portable generators, as the name implies, are not designed for permanent installation. Instead they work with stand-alone applications and are meant to temporarily energize a few critical applications via external cords. These are usually functional for a run time of less than 12 hours, and provide a power output of 500W to 17.5kW. Different models of portable units can be fueled using one or more of specific energy sources like gasoline, diesel, bio-diesel, propane or natural gas. Most portable units are air-cooled and hence ought to be operated in the open for availing maximum air ventilation. Portable units are typically used when backup power requirements are low or only temporary. These serve as handy accessories in residential applications, where they can provide energy for lighting, sump pumps, specific essential appliances like refrigerators and air conditioners, and vital medical equipment. They also find use at construction sites, farms and during camping trips. These units are generally used in trailers where the small power output generated is adequate. Also, being compact and lightweight, these sets can be conveniently stored in the trailer compartment or in the back of a tow vehicle.

Trailer mounted generators or mobile generators, diesel generators are also used for emergencies or backup where either a redundant system is required or no generator is on site. Trailer-mounted generators can be towed to disaster areas where grid power has been temporarily disrupted. Hence this study was carried out to evaluate the possibility of reconfiguring an immovable 8 hp lister slip engine to a compact movable generator.

2. METHODOLOGY

The research methodology covered the approach, methods, materials, assembly procedure and design consideration employed during the course of the research study. These considerations and techniques used in the fabrication of the compact movable generator will serve it purpose in providing an effective and efficient mobility in appropriate terrain for power supply.

2.1. Research Design

A trolley housing the water tank for cooling the engine was fabricated using mild steel H-Beams and plates. It comprised the base, two axles and four tires. A 7.5 kVA alternator which is to be driven by an 8 hp water-cooled lister engine via a belt drive was mounted on the trolley. A water pump was connected to the water tank (reservoir) and engine. The dimensions of the water reservoir pump and belt drive were properly designed and determined. Electric arc welding process was employed in the fabrication of the trolley.

2.2. Selection of Materials

The selection of materials for this study was done after considering several factors such as cost, machinability, availability and reliability. The trolley/tank was made of mild steel H-beams and plates. The pulleys and bolts were made of cast iron and steel respectively. The belt and tires were made of rubber.

2.3. Design and Analysis of the Base Trolley

The design of the base trolley was premised on two important considerations. These were the rigidity of the base and its volume. From the shape of the base which is rectangular, the length and breadth were obtained from the volume using the standard width of the H-beams. From previous designs, a water volume of 100 litres was suitable for the engine.

2.3.1. Determination of the breadth of the base trolley

The breadth of the trolley was selected based on the breadth of the engine. The breadth of the engine was measured to be 450 mm. A clearance of 25 mm was added to both ends. Therefore the breadth of the water tank/reservoir was chosen to be 500 mm ≈ 0.5 m.

2.3.2. Determination of the length of the base trolley

The trolley has a rectangular shape and it is required to support 100 litres of water which is equivalent to 0.1 m^3. The volume of rectangle V_t was determined as follows:
Volume of tank/reservoir,

$$V_t = l \times w \times h \tag{1}$$

where, l = length of tank
w = width of tank
h = height of tank

The H-Beam mild steel used in fabricating the tank has a width of 160 mm ≈ 0.16m. Therefore, the length of the water tank was determined from Equation (1) as follows:

$$0.1 = l \times 0.16 \times 0.5$$

$$l = \frac{0.1}{0.16 \times 0.5}$$

$$l = 1.25 \text{ m} \approx 1250 \text{ mm}$$

A tolerance of 20 mm was added to the length for the purpose of fabrication.

2.3.3. Determination of the mass of the base trolley

In determining the trolley mass, special consideration was given to the calculation of the mass of the metal frame and mass of the metal plate used. Thus:

Mass of Trolley = mass of metal frame + mass of plates (2)

For this design, the following parameters were either obtained from the preliminary design, engine user manual or from standard texts.

Length of trolley =1400 mm ≈ 1.4 m
Length of tank = 1270 mm ≈ 1.27 m
Breadth of trolley = 585 mm ≈ 0.585 m
Breadth of tank = 500 mm ≈ 0.5 m
Height of tank = 160 mm ≈ 0.16 m
Length of axle = 1120 mm ≈ 1.12 m
Diameter of big pulley = 229 mm ≈ 0.229m
Axle to axle distance = 1000 mm ≈ 1 m
Mass of alternator + pulley = 123 kg
Mass of engine + pulley = 285 kg
Mass of water pump = 4 kg

According to the engine user manual, power of engine = 8hp (5.97KW); Speed of engine = 850 rpm and speed of alternator = 1500 rpm.

Mass of H-beam = 15.8 kg/m (Coyote Steel, 2010)
Mass of 6 mm thick mild steel plate = 47.1 kg/m^2 (Coyote Steel, 2010).

2.3.3.1. *Determination of mass of metal frame*

Figure 1 shows the cross-section of the mild steel metal used for the fabrication of the base trolley.

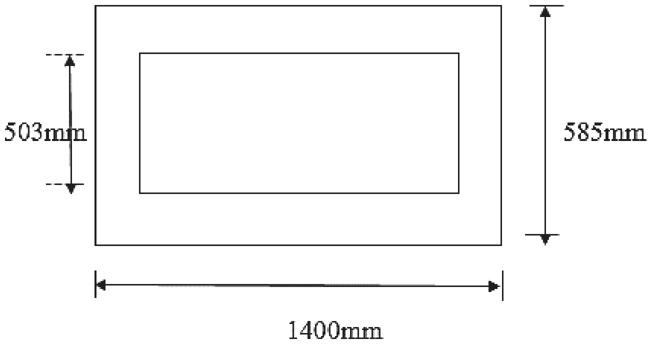

Figure 1: Metal plate cross-section

The mass of frame M_f was determined for the two plates as:

$$M_f = \left[\left(\frac{47.1}{area\ of\ plate \times 2} \right) + \left(\frac{15.8}{length\ of\ plate \times 2} \right) \right]$$

$$M_f = \left[\left(\frac{47.1}{1.4\times0.503\times2}\right)+\left(\frac{15.8}{1.4\times2}\right)\right] = 33.44 + 5.36$$

$M_f = 38.8$ kg

2.3.3.2. *Determination of mass of the plate*

Figure 2 shows the dimension of the mild steel plate that was used for this study.

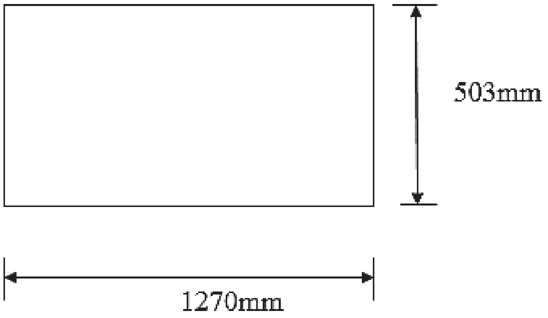

Figure 2: Metal plate dimensions

Mass of Plate $M_p = \frac{47.1}{1.27\times0.503\times2}$

$M_p = 36.87$kg

Using Equation (2), the mass of base trolley, B_t was obtained as follows:

$B_t = M_f + M_p = 38.8 + 36.8$

$B_t = 75.6$ kg

2.3.4 Stress developed in H – beams

The free-body-diagram shown in Figure 3 shows the direction of weight/forces acting on the base trolley. The major weight/forces acting on the base trolley are the alternator, water pump, engine and weight of water in the tank.

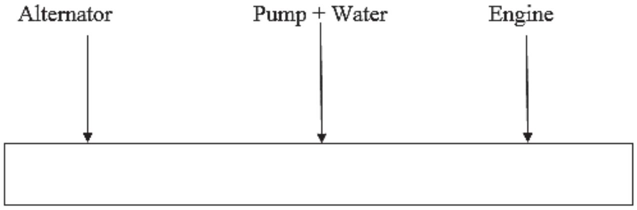

Figure 3: Forces acting on the beam

The stress developed in the H-Beam was calculated according to Khurmi and Gupta (2005), as;

$$\sigma = \frac{F}{A} \tag{3}$$

where, F = total force acting on the H-Beam (N)

A = Area of the entire H-Beam (m^2)

The total forces acting on the H-beam was calculated from the summation of all the masses multiplied by acceleration due to gravity.

F_T = (Mass of alternator with pulley + mass of water pump + mass of water in the base tank + mass of engine with attached pulley) × acceleration due to gravity. (4)

Mass of water in the tank was calculated as follows:

$$M_t = \rho_w \times L \times B \times H \tag{5}$$

where, ρ_w = Density of water = 1000 kg/m^3
L = Length of trolley
B = Breadth of trolley
H = Height of trolley
$M_t = 1000 \times 1.27 \times 0.5 \times 0.16 = 101.6$ kg
$F_T = (123 + 4 + 101.6 + 285) \times 9.81$
$F_T = 513.6 \times 9.81 = 5038.42$ N

The I-section of the beam is shown in Figure 4. The area of the I-section was calculated using Equation (6) (Rajput, 2010):

$$A = A_1 + A_2 + A_3 \tag{6}$$

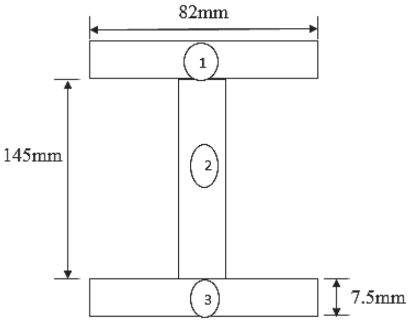

Figure 4: I-cross section of the beam

Sections (1) and (3) are same as shown in Figure 4.

$$A_1 = A_3 = L \times b \tag{7}$$
$$= 82\times10^{-3}\times7.5\times10^{-3}$$
$$= 6.15\times10^{-4}\ m^2$$
$$A_2 = L \times b$$
$$= 5\times10^{-3}\times145\times10^{-3}$$
$$= 7.25 \times 10^{-4}\ m^2$$

Substituting the values of A_1, A_2 and A_3 into Equation (6),

$$A = A_1 + A_2 + A_3 = (6.15 + 7.25 + 6.15) \times 10^{-4}$$
$$A = 19.55\times10^{-4}\ m^2$$

Therefore, using Equation (3), the stress developed in the H-beam, $\sigma = \dfrac{5.04\times10^{3}}{19.55\times10^{-4}}$

$$= 2.57\ MN/m^2$$

Since there are two parallel and identical H-beams, each beam will be stressed equally by:

$$\frac{2.57}{2} = 1.29 MN / m^2$$

2.4. Design of Driven Pulley (alternator) Diameter

Figure 5 shows the belt drive of the two pulleys attached to the engine and the alternator. According to Sharma and Aggarwal (2012), the diameter of the driven alternator (smaller) pulley can be determined by:

$$\frac{n_1}{n_2} = \frac{d_2}{d_1} \tag{8}$$

where, n_1 = rotational speed of the smaller (alternator) pulley = 1500 rpm
n_2 = rotational speed of the larger (engine) pulley (rpm) = 850 rpm
d_1 = diameter of the smaller (alternator) pulley (mm)
d_2 = diameter of the larger (engine) pulley = 229 mm,
e = centre distance between larger and smaller pulleys, (mm)

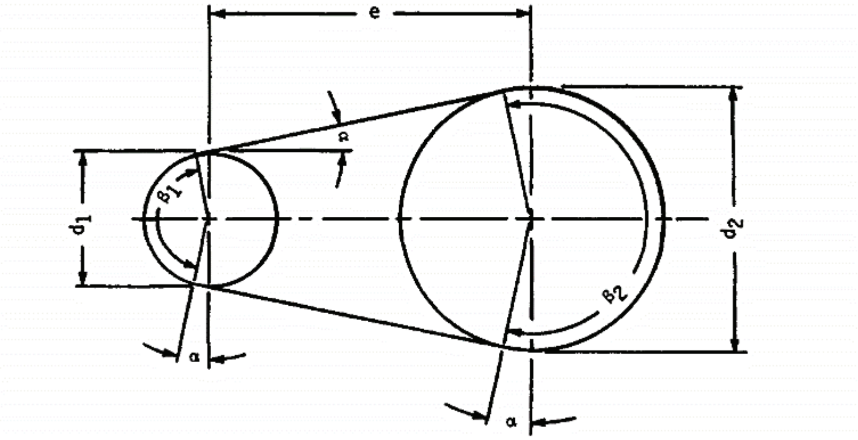

Figure 5: Belt drive

Hence, the diameter of the smaller pulley d_1 is obtained as:

$$d_1 = \frac{n_2 d_2}{n_1} = \frac{229 \times 850}{1500}$$

d_1= 129.77mm ≈ 130 mm

2.5. Belt Design

Belt drive comprises a belt wrapped tightly over two pulleys – the driving and the driven pulleys which are also mounted on the driving and driven shafts respectively (Sharma and Aggarwal, 2012). There are basically four types of belts used for power transmission, these are:

(i) Flat belt
(ii) V-section belt

(iii) Ribbed belt
(iv) Toothed or timing belt

According to Hall et al. (2002), belt design involves the selection of appropriate belt to transmit a required power or the determination of the power that may be transmitted by the belt. Then the power transmitted by the belt,

$$P = (T_1 - T_2)\,v \tag{10}$$

where, T_1 = belt tension on the tight side, (N)
T_2 = belt tension on the loose side, (N)
v = belt velocity, (m/s)

The belt velocity was calculated as follows:

$$v = \frac{\pi d_1 n_1}{60} = \frac{\pi d_2 n_2}{60} \tag{11}$$

$$v = \frac{\pi \times 0.229 \times 850}{60} = 10.19 m/s$$

The belt tension on the tight and loose side was determined from the power transmitted by the belt in Equation (10).

$$P = (T_1 - T_2)\,v$$

$$(T_1 - T_2) = v = \frac{5.97\times 10^3}{10.2} = 585.3 \text{ N}$$

$$T_1 = 585.87 + T_2 \tag{12}$$

The belt tension can be determined using Equation (13) when the width and thickness of the belt are known (Spotts, 2003).

$$\frac{T_1 - mv^2}{T_2 - mv^2} = e^{f\alpha} \tag{13}$$

where, m = mass of 1 m belt, (kg/m)
v = belt velocity, (m/s)
f = coefficient of friction between belt and pulley = 0.32 for a flat belt (Hall et al., 2002),
α = angle of wrap of belt and pulley, (rad)

But, mass of belt is given as:

$$m = \rho \times t \times b \tag{14}$$

where, ρ = belt density, (kg/m^3)
b = belt width, (m)
t = belt thickness, (m)
$m = 970 \times 11\times10^{-3} \times 17\times10^{-3}$
$= 0.181$kg/m

The angle of wrap α for an open belt was computed as follows:

$$\alpha_1 = 180^o - 2\beta \quad (15a)$$

$$\alpha_2 = 180^o - 2\beta \quad (15b)$$

where, α_1 and α_2 are the wrap angles for the loose and tight sides respectively.

$$\text{But } \sin\beta = \frac{d_2 - d_1}{e} \quad (16)$$

However, the centre distance between the two pulleys, e, according to Sharma and Aggarwal (2012) can be determined by the following relationship,

$e \geq 3.5d_2$

where, d_2 is the diameter of the large pulley.

$e \geq 3.5x229$

$e \geq 801.5 \approx 802$ mm.

$$\sin\beta = \frac{0.229 - 0.130}{0.802}$$

$\beta = 7.091^o$

Substituting the value of β, into Equations (15a) and (15b) respectively,

$\alpha_1 = 165.8^o \approx 2.89$ rad, and

$\alpha_2 = 194.2^o \approx 3.39$ rad.

According to Hall et al. (2002), the smaller pulley actually governs the design, hence the angle of wrap of the smaller pulley was used.

Therefore, substituting into Equation (13), we have:

$$\frac{T_1 - (0.181 \times 10.19^2)}{T_2 - (0.181 \times 10.19^2)} = e^{0.32 \times 2.89}$$

$T_1 - 18.794 = 2.52\,(T_2 - 18.794)$

$2.52T_2 - T_1 = 66.154$

(17)

Putting Equation (12) into Equation (17), we have;

$2.52T_2 - (T_2 + 585.87) = 66.154$

$2.52T_2 - T_2 - 585.87 = 66.154$

$1.52T_2 = 66.154 + 585.87$

$\therefore \quad T_2 = 428.96N$

$T_1 = 428.96 + 585.87$

$T_1 = 1014.83N$

The belt tension in the tight side is 1.014 kN and belt tension in the loose side is 428.96N.

Then the power transmitted by the belt using Equation (10), will then be,

$P = (1014.83 - 428.96) \times 10.19$

$P = 5.97$ kW.

From the foregoing, the dimensions given for the belt width and thickness fell within the B-type belt according to Sharma and Aggarwal (2012). Also, the diameter of the large pulley was measured to be 229 mm ≈ 9.01 inches and the nearest standard datum diameter of 8.6

inches was selected. Hence, a belt standard size of 2 B 86 V-belt was selected, where 2 shows the number of grooves and 86 the standard datum diameter of 8.6 inches.

2.6. Determining Power of the Pump

In determining the power of the pump, the flow rate for the traditional method of cooling the stationary engine was first estimated from which the minimum power require to lift water from the tank in Figure 6, to the inlet of the engine was obtained.

Figure 6: Flow rate estimation

The power of pump was determined from Equation (17) as follows.

$$P = \frac{QHg\rho_{H_2O}}{\zeta} \tag{17}$$

Where: Q = the volumetric flow rate, (m^3/s)
H = head (mm) = 500mm
g = acceleration due to gravity, (m^2/s)
ρ_{H_2O} = density of water
ζ = pump efficiency

But, volumetric flow rate, $Q = C_d \times a \times \sqrt{2gh}$ (18)

Where: C_d = Discharge coefficient at the bottom of the hopper for water = 0.98
a = Orifice area
g = gravitational acceleration
h = Elevation of tank

From Figure 6, the diameter of the orifice d and height of hopper h are 40mm and 900mm respectively. Then the area of the orifice will be,

$$a = \frac{\pi d^2}{4} \tag{19}$$

$$= a = \frac{\pi 0.04^2}{4}$$

$$a = 1.257 \times 10^{-3}\ m^2$$

$$Q = 0.98 \times 1.257 \times 10^{-3} \times \sqrt{2 \times 9.81 \times 0.9}$$

$$Q = 5.176 \times 10^{-3}\ m^3/s$$

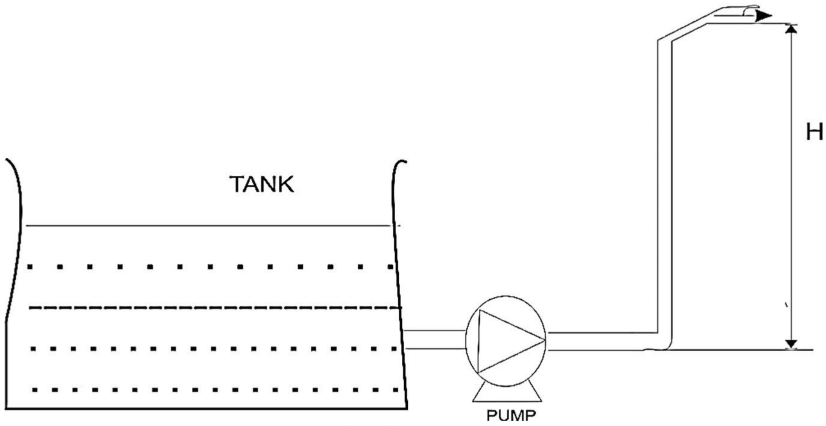

Figure 7: Water reservoir with pump

For a water pump of 85% efficiency, the power of the pump using Equation (17),

$$P = \frac{5.176\times10^{-3}\times0.5\times9.81\times1000}{0.85}$$

$$= 29.07 \text{ W}$$

$$\approx 0.03\text{kW}$$

3. FABRICATION AND ASSEMBLY OF THE GENERATOR

The trolley was constructed by arranging H-beams to form a rectangle with dimensions 1400 mm x 585 mm x 160 mm. A 6mm thick plate was cut out to seal the top of the rectangular framework appropriately. A hole with a diameter of 40 mm was drilled on the center of the plate. This was to allow for water inlet. Four 16mm holes were drilled on both ends of the plate and threaded. This served as openings for the alternator and engine to be bolted to the trolley. The underside of the frame was covered with 2 mm mild steel pan. The sealed rectangular frame formed the water tank for cooling the engine. An H-beam of length 440 mm was cut and a hole of diameter 40mm drilled on it. Two axles measuring 1120 mm in length were positioned 200 mm from both ends of the tank and welded to its underside. Four vehicle tyres of size 175/65R14 were fastened to the hub of the axle with the aid of bolts to absorb the vibration of the engine and to provide portability to the generator. The water tank had two holes drilled at a different elevation to serve as supply and return ducts to the tank. The alternator was mounted on the trolley with the spindle pointing towards the right side of the trolley and the engine also mounted on the trolley with steel bolt. Cast iron pulleys with diameters 127 mm and 230 mm were fitted to the spindles of the alternator and engine respectively. Standard belt size of 2B86 V-belts that was selected was used to connect both pulleys. Kick starter was mounted close to the flywheel on the trolley so as to engage the flywheel when switched on. Figure 8 shows the third angle orthographic projection of the reconfigured engine.

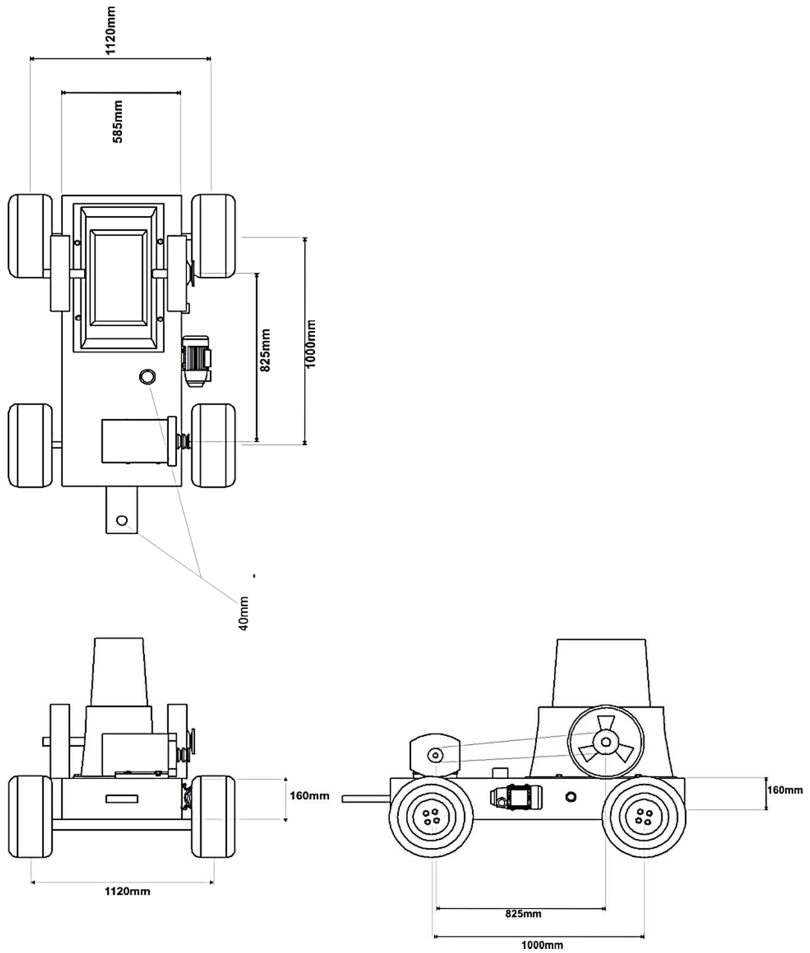

Figure 8: Third angle projection of the engine-generator

4. PERFORMANCE TESTS

The assembled generator was subjected to idle run, to ensure that the whole assembly was rigid and functioning as a single unit. It was run for about one hour and twenty minutes and the belts and pulleys were examined for slack, tears and cracks.

4.1. No load Test

The machine was subjected to a no load test, during which the machine was visually inspected while in operation for intense vibration, and the output voltage was measured at the terminals of the alternator by means of a voltmeter. The voltage across the terminals of the alternator was measured to be 232 volts and the vibration was seen to be sufficiently controlled by the four tires attached to the axles of the trolley. From the tests, it was observed that the assembly performed satisfactorily. It was also observed that at varying load, the mean torque changed in order to balance the excitation speed to produce a steady flow of current. The voltage as read over the terminal brushes of the automatic voltage regulator had a range of 218-250 volts, a relative constant frequency of 60 hertz and the desired power output (8hp). The vibration of the generator was also sufficiently controlled by the four tyres attached to the axles of the trolley. The newly designed and fabricated compatible generator has a great flexibility over the stationary mounted ones. There is a remarkable breakthrough in the ease of movement well over the general immovable ones.

5. CONCLUSION

In this study, a hitherto immovable Lister generator (that is usually mounted on a fixed concrete base) has successfully been reconfigured into a compact movable Lister generator.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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