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Design and construction of an electric arc welding machine with digital display.

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Abstract

This paper considers the design and construction of an electric arc welding machine from locally made materials. The major components employed in the construction of the electric arc welding machine are the transformer and digital voltmeter. The transformer used is a shell type transformer mounted on the casing bed with bolt and nut. The system was tested with varying numbers of turns and its voltage was recorded. The components were tested using a digital multi-meter (DMM) to ensure proper functioning of component's expected data. Results showed that the arc welding machine transforms low voltage, low amperage primary power into low voltage, high amperage power used for welding at high frequency. This high-frequency transformation helps to reduce the weight and size of the transformer.

Keywords: Arc welding, high amperage voltage, low amperage voltage, transformer, digital display.

1. Introduction

Welding can be defined as the process of joining two or more pieces of metals using electricity or flame to make the art a simple piece. Arc welding is a process that is used to join metal to metal by using electricity to create enough heat to melt metal, and the melted metals when cool result to binding of the metals. It is a type of welding which uses a power supply to create an electric arc between an electrode and the base material, to melt the metals at the welding point. Arc welding processes may be manual, semi-automatic, or fully automated (Asiwe *et al*., 2018).

Arc welding can be carried out using designed machine or equipment that uses welding power supply to create an electric arc between direct current (D.C) or alternating current (A.C), and consumable, and non-consumable electrodes.

The arc welding machine uses an electric power as the input that is supplied through the primary winding and then transferred to the secondary winding by induction. It is used to carry out welding work by connecting through the output terminal to the welding cables. The output of the machine is designed in a manner that it can be varied by adjusting the crank of the machine in a clockwise or anti-clockwise direction, either to increase or decrease the output current depending on the size of the material it is to be used on (Takasaki, 2003).

Arc welding machine provides an electric current of various characteristics to perform its welding functions. The use of such machine is essential for the following:

(i) To convert A.C supply to D.C supply when direct current welding is desired.
(ii) To reduce the high supply voltage to a safe and suitable voltage for welding purposes.
(iii) To provide high current necessary for arc welding drawing a correspondingly high current from the supply mains.
(iv) To provide suitable voltage/current relationships necessary for arc welding at a minimum cost.

Arc welding usually requires high current (over 80 amperes), and it may require above 12,000 amperes in spot welding. It can be used to join pipes in pipelines, power plants at the construction sites, and for home appliances. Furthermore, arc welding is used in shipbuilding, automobile manufacturing, and repair (Xu, 2020).

The major component of the arc welding machine is the transformer. Asiwe *et al*. (2018) investigated the design and construction of an arc welding machine's transformer. The transformer was a single phase having shell type of lamination core and insulated windings of copper coils. They reported that with the help of an angle iron and lamination core, the core loss, iron loss in the machine was reduced to minimum. Asiwe *et al.*, (2018) observed that the scaling factor and the turn factor at terminal A was almost the same indicating that the higher the turns the better the transformer. This feature helps to avoid high current which may cause spark, and also, improve the efficiency of the transformer.

Ibrahim *et al.* (2016) investigated the construction of a welding system which used a low frequency transformer that operated at the utility mains frequency of 50 or 60 Hz with variable current selectors to avoid power quality problem such as voltage, current, and frequency deviation from nominal value in electrical distribution and utilization system. The welding machine was presumed heavy with regards to the construction details of the work done. Ovbiagele *et al.* (2015) designed an inverter circuit arc welding machine to solve the problem of weight and size of conventional arc welding machine. The inverter provided much higher frequency than 50 Hz or 60 Hz for the transformer used in welding. This therefore, reduced the weight, size, and noise level of the transformer used for welding. Furthermore, Evboghai *et al.* (2007) investigated the realization of 3 KVA single phase electric arc welding machine with facilities for charging batteries.

In contrast to existing works, this study presents a novel design and construction of an arc welding machine which transformed low voltage, low amperage primary power to low voltage, high amperage power used for welding at high frequencies with a digital display to show the output voltage. This high-frequency transformation helped to reduce the weight and size of the transformer.

Welding machines are usually classified as a constant current (CC) or constant voltage (CV) machine. A constant current (CC) machine varies its output to maintain a steady current while a constant voltage (CC) machine will fluctuate its output current to maintain a set voltage (Theraja, 2008).

2. Materials and Method

The welding of a metal occurs when the control unit and the output subsystem link together through the conductive objective to be welded. In this design, the overall system was partitioned into sub-systems. A computer aided design software known as *Proteus* (ISIS professional) was used to draw the circuit design. The block diagram of the arc welding machine is shown in Figure 1.

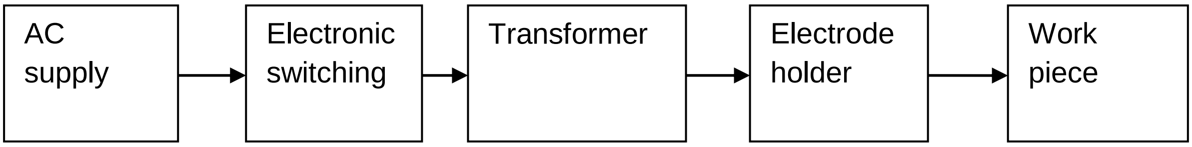


Fig. 1: Block diagram of the proposed arc welding machine

2.1. Components Identification and Description

The components/devices used for the construction of the welding machine are explained below:

2.2. Switch

The switch is used as power ON and OFF for the arc welding machine. The circuit breaker protects the arc welding machine from over-current, and it acts as an isolator. An isolator is a device that can break an electrical circuit, interrupting the current or diverting it from one conductor to another.

2.3. Transformer

The transformer is defined as a static piece of apparatus by means of which electric power in one circuit is transformed into electric power of the same frequency in another circuit. A typical AC transformer is shown in Figure 2.

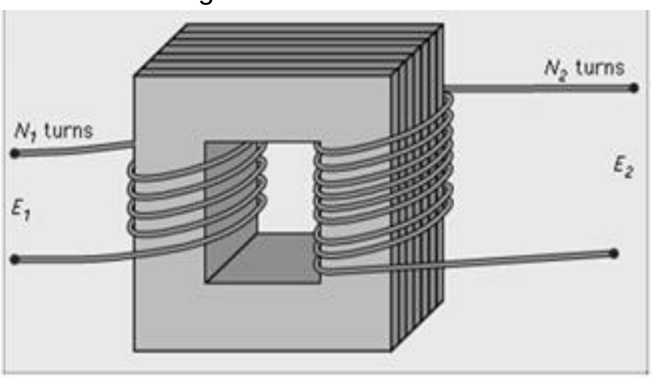


Fig. 2: AC Transformer (Image courtesy en.wikipedia.org)

2.4. Digital Voltmeter

A digital voltmeter is a measurement device that measures the electric potential difference between conductors. A digital voltmeter shows voltage directly as numerals. This meter can determine voltage values to several significant figures. This instrument can measure voltages of either direct or alternating electric current on a scale usually graduated in volts, millivolts (0.001 volts), or kilovolts (1,000 volts). The typical commercial or laboratory standard voltmeter in use today is likely to employ an electromechanical mechanism in which current flowing through turns of wire is translated into a reading of voltage. Other types of voltmeters include the electrostatic voltmeter, which uses electrostatic forces, thus, it is the only voltmeter to measure voltage directly rather than by the effect of current.

2.5. Electrode Holder

An electrode holder is a clamping device used for holding the electrode securely in any position. The welding cable is attached to the holder through the hollow insulated handle. The design of the electrode holder permits quick and easy electrode exchange. Figure 3 shows a typical electrode holder.

Fig.3: Holder

2.6. Fan

The fan serves as the heat regulator because as the welding machine operates, the transformer generates a lot of heat and thus needs to be cooled.

2.7. Metal Oxide Varistor

The metal oxide varistor otherwise, known as the MOV is a voltage-dependent, nonlinear device that provides excellent transient voltage suppression. MOV have a fast response, high stabilization for circuit voltage, excellent voltage ratio, and can serve as surge protector (Teraja, 2008).

2.8. Measuring Equipment Used

Digital clamp meter: The digital clamp meter is an electrical device having two jaws which open to allow clamping around an electrical conductor. This allows properties of the electric current in the conductor to be measured without having to make physical contact with it or to disconnect it for insertion through the probe.

Micrometre screw gauge: It is used to measure the diameter of the copper conductor. It is a device incorporating a calibrated screw, widely used for precise measurement of components in machining.

2.9. Construction of an electric arc welding machine

The major components employed in the construction of the electric arc welding machine are the transformer, and the digital voltmeter. The transformer used in this case is a shell type transformer mounted on the casing bed with bolt and nut. Other parts like the electrode holder, earth lead etc., are as well connected.

2.9.1. Transformer

A burnt transformer with a suitable size and low cost was purchased. The existing coils were removed and thrown away. Then, a new transformer coil of 4.88 mm was purchased and used in rewinding the transformer secondary side, and then the primary side was wound with a coil of 3.65 mm with an appropriate number of turns capable of welding on a plastic core. Figure 4 shows the basic construction of the transformer of an arc welding machine.

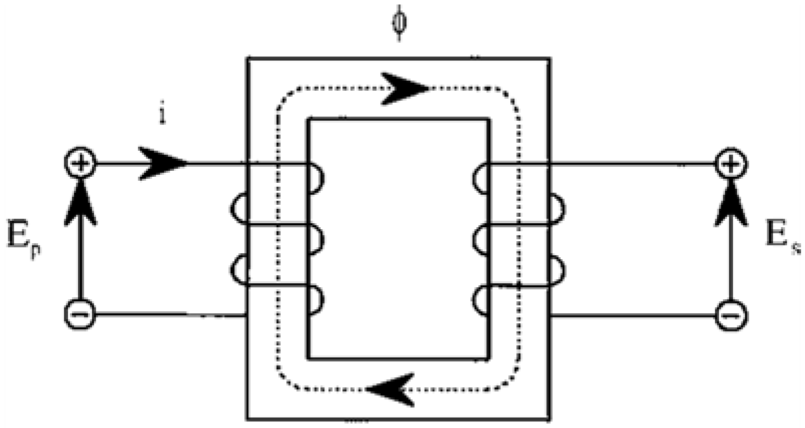


Fig.4: Transformer and its primary and secondary winding (Asiwe *et al*., 2018).

2.9.2. Core

The hole in the center of the coil is known as the *core* while each loop of wire is called the *turns*. The core provides the magnetic path to channel the flux; it consists of thin strips of high-grade steel called *laminations* which are electrically separated by a thin coating of insulating material. The lamination strips are stacked with the windings built separately and assembled around the core sections.

There are two basic types of core construction used in power transformers: core form and shell form.

2.9.2.1. Core-Form Construction: There is a single path for the magnetic circuit. Figure 5 below shows a schematic diagram of a single-phase core with the arrows showing the magnetic path. For single -phase applications, the windings are typically divided into both core legs. Windings are constructed separate from the core and placed on their respective core legs during core assembly (Howard, 2005).

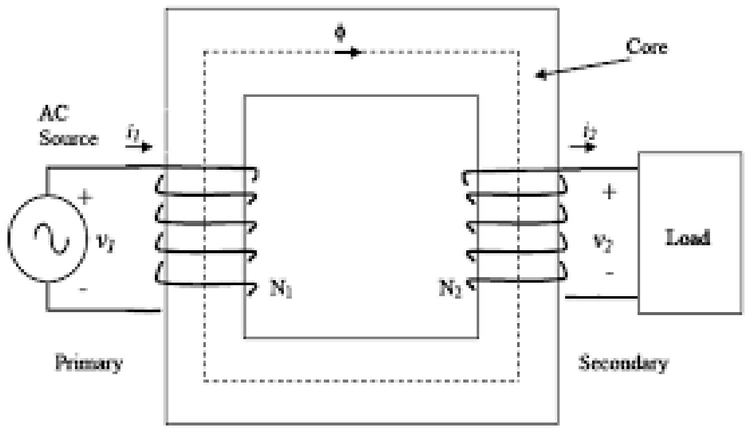


Fig.5: Schematics of a single-phase core-form construction (Theraja, 2008).

2.9.2.2. Shell-Form Construction: The core provides multiple paths for the magnetic circuit. Figure 6 below is a schematic diagram of a single-phase shell-form core with the two magnetic paths illustrated. The core is typically stacked directly around the windings which are usually ‘‘pancake’’-type windings, although some applications are such that the core and windings are assembled similarly to core form. Due to advantages in short-circuit and transient-voltage performance, shell forms tend to be used more frequently in the largest transformers, where conditions can be more severe (Howard, 2005).

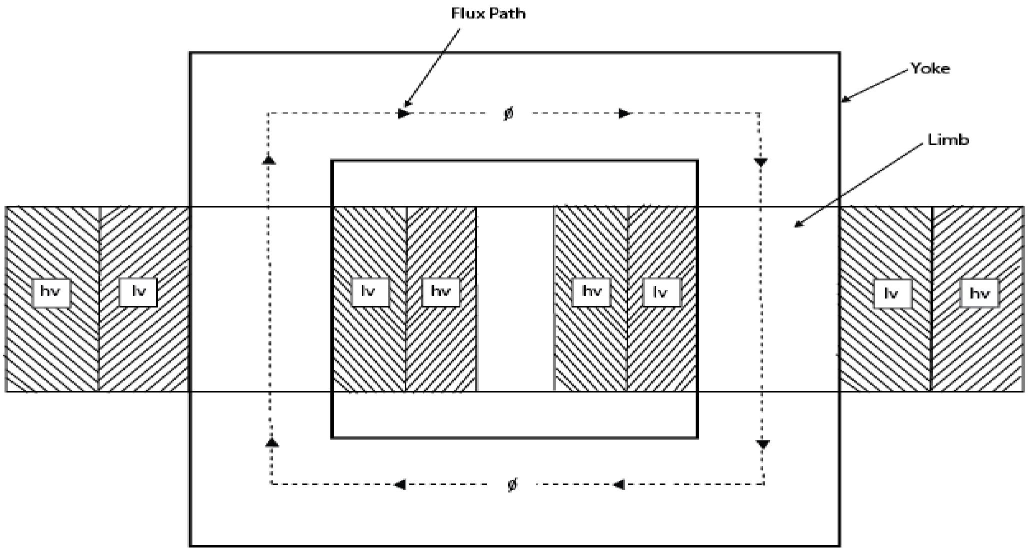


Fig. 6: Schematics of a single-phase shell-form construction (Theraja, 2008)

2.9.3. Windings

The wire or conductor which constitutes the coil is called the winding**.** The wires are insulated with enamel with a diameter of 0.5mm thus there is no problem of partial contact (i.e. when current passes between the wire turns). The winding is often wound around a coil form made of plastic to hold it in place (Howard, 2005). The ends of the wire are brought out and attached to an external circuit. Windings may have additional electrical connections along their length, these are called *taps*. A transformer winding which has a single tap in the center of its length is called a center tapped transformer.

The windings consist of the current carrying conductors wound around the sections of the core and these must be properly insulated, supported and cooled to withstand operations and test conditions. Copper and Aluminum are the primary materials used as conductors in power transformer windings, but preference is given to copper over aluminum in this work due to the following reasons:

i. Copper has higher mechanical strength
ii. Copper has higher conductance capacity than aluminum.

The type of winding used in this construction is known as the pancake winding because the conductors are wound around a rectangular form with the widest face of the conductor oriented horizontally.

In the construction of the transformer, the number of turns on the primary side is more than that of the secondary side to aid smooth welding thus this design has the primary turns to be 215 turns, and the secondary to be 92 turns (with center taps at 75 and 50). The transformer coil was wounded around the plastic former and then placed in the lamination forming a shell-type transformer. The calculations involved in rewinding the transformer are explained below, using the ideal transformer equation (Thereja, 2008).

$$Ep/Np = \quad Ep/Np \qquad (1)$$

$$Ep/Es = \quad Np/Ns \qquad (2)$$

Equation (1) is the transformer law.

E_p = applied primary voltage,

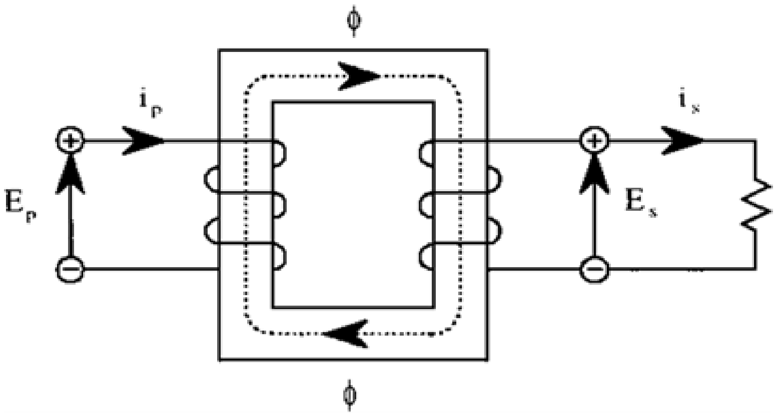
E_s = induced secondary voltage,

N_p = number of primary turns,

N_s = number or secondary turns.

Since the induced voltage in the primary coil equals the applied voltage, and since the induced volts per turn is the same for both primary and secondary, the ratio $\boldsymbol{Np/Ns}$ is called the transformer turns ratio.

When a load resistance is connected to the secondary coil, secondary voltage causes current in the secondary to flow in a direction that always tends to cancel flux in the core. This tendency to cancel the flux reduces the induced voltages in both the primary and secondary coils. With a reduction in the induced voltage in the primary, the applied voltage across the primary winding increases the primary current to restore the flux to its original value. Equilibrium is established when the total magnetomotive force (MMF) is just sufficient to induce a voltage equal to the voltage applied across the primary coil. This is equal to the magnetizing MMF. Figure 7 shows the transformer winding with load connected to the secondary.



Fig,7: Transformer winding with load connected to the secondary (Theraja, 2008).

$$MMF_{pry} + MMF_{sec} = MMF_{magnetizing} \qquad (3)$$

With substantial currents flowing in both the primary and secondary winding under load, the magnetizing MMF is negligible compared to the primary MMF and secondary MMF.

$$MMF_p + MMF_s = 0 \qquad (4)$$

$$(N_p \times i_p) + (N_s \times i_s) = 0 \qquad (5)$$

$$N_p I_p + N_s I_s = 0$$

$$N_p I_p = -N_s I_s$$

$$\frac{i_p}{i_s} = \frac{-N_s}{N_p} \qquad (6)$$

The minus sign in equation (6) indicates that the currents in the primary and secondary windings are in opposite directions with respect to producing a magnetic flux in the core. While this is true, the minus sign can be dropped in order to express the ratio of primary current to secondary current.

$$\frac{i_p}{i_s} = \frac{N_s}{N_p} \quad (7)$$

Equation (7) is the second transformer law.
By multiplying equation (1) by equation (7)

$$\frac{E_p}{E_s} \times \frac{i_p}{i_s} = \frac{N_p}{N_s} \times \frac{N_s}{N_p} = 1 \quad (8)$$

$$(E \times i)_p = (E \times i)_s$$

$$\frac{i_p}{i_s} = \frac{E_s}{E_p} \quad (9)$$

Equation (9) indicate that the instantaneous power supplied to the primary coil from the applied voltage equals the instantaneous power supplied to the secondary coil to the load, (i.e. P_{in}=P_{out}). The transformer laws are true irrespective of the phase angles of the currents.

Proper conductor for primary/secondary winding can be selected from the standard wire gauge table.
To determine the secondary voltage;

$N_s = 92 \quad (no\ of\ turns\ in\ the\ secondary\ side)$
$N_p = 215 \quad (no\ of\ turns\ in\ the\ primary\ side)$
$E_s = ? \quad (secondary\ voltage)$
$E_p = 220\,V \quad (primary\ voltage)$

$$\frac{E_p}{N_p} = \frac{E_s}{N_s} \quad (10)$$

$$Es = \frac{92 \times 220}{215} = 94.12V$$

To determine the flux of the transformer, consider the use of the electromotive force (emf) equation (Theraja, 2008).

$$E = 4.44FN\Phi_m; \quad (11)$$

where E = V_p= emf per turn
F = frequency = 50Hz
Φ = maximum flux
N = no of primary turns

$$\Phi_m = \frac{220}{4.44 \times 50 \times 215}$$

$$\Phi_m = 0.00461$$

$$\Phi_m = 4.61Wb$$

To calculate the transformer power rating for a single phase transformer:

$$\text{Power rating} \quad (KVA) = \frac{V \times I}{1000}, \quad (12)$$

where V = voltage and I = current.

$using\ equation\ (12)$

$$KVA = \frac{58 \times 22}{1000} = 1.276$$

$$= 1KVA$$

2.9.4. Casing

The casing or housing for the designed unit is very important. The unit is designed to be very handy. Therefore, the material to be used must be light, durable and strong. For this design, steel was used for the casing. The steel was made in the form of a cuboid and a handle is attached to it, this make the unit to be portable and very easy to handle.

The dimensions are as follows:

Length = 40cm
Breadth = 27 cm
Height = 27cm

Perforations were made on both sides of the casing to provide an avenue for air to circulate properly in the unit and for the heat generated to be dissipated. Screws were used to hold the casing together.

Four important factors were considered in making the casing and which are:

a. Use of steel**:** A corrosive material has to be used for the casing.
b. Consideration for air vent: The need for adequate and appropriate ventilation in order to reduce the amount of heat dissipated by the transformer when in use necessitated the need to have vent holes on the metal case.
c. Outlets for components: Space has to be drilled on the case for switches, earth wire, voltmeter display etc.
d. Drilled holes on the base and sides of the casing: This is necessary for the screws i.e. for screwing the transformer to the base.
The arc welding machine with casing is shown in Figure 8 while the arc welding machine showing the digital display is shown in Figure 9. In addition, Figure 10 shows the arc welding machine casing with the handle while Figure 11 shows the arc welding machine indicating the switches.

Fig 8: Arc welding machine with casing

Fig 9: Arc welding machine showing the digital display

Fig 10: Arc welding machine casing with the handle. Fig 11:Arc welding machine showing the switches.

3. Result and Discussions

The electric arc welding machine constructed was tested for durability, efficiency, and effectiveness with a view to ascertain if there was a need to modify the design. The system was tested with varying numbers of turns and the voltage was recorded. The components were tested using a digital multi-meter (DMM) to ensure proper functioning of components expected data.

3.1. Test Plan and Test Data

This section details the overall system testing of the integrated design of the voltage measurement device. The testing and integration are carried out to ensure that the design function properly as expected thereby, enabling intending users to appreciate the implementation, and as well as the approach used in the design and integration of the various modules of the research work. This involved checks made to ensure that all the various units and subsystems function adequately. Also, there has to be a good interface between the input/output unit subsystems. When the totality of the modules was integrated together, the system was created and all modules and sections responded as specified in the design.

3.2. System Test

During the test, it was observed that the electrode holds the workpiece when trying to start an arc for welding. The various tests conducted were recorded and highlighted in Table 1 and Table 2, respectively.

Table 1: System test under no-load:

No of turns N_p	N_s	Voltage (V)	Current (A)	Resistance (Ω)
215	92	78	15	1.4
215	86	67	22	1.1
215	50	49	35	0.9

Table 2: System test on load

No of turns N_p	N_s	Voltage (V)	Current (A)	Resistance (Ω)
215	92	58	22	1.4
215	86	45	29	1.1
215	50	33	39	0.9

4. Conclusion

The Arc welding machine designed in this work transformed low voltage, low amperage primary power into the low voltage, high amperage power used for welding at high frequencies. This high-frequency transformation helped to reduce the weight and size of the transformer. Furthermore, it was also observed that the voltage and the current of the welding machine increased and decreased, respectively, as the number of turns of the secondary increased.

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