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Automatic Electrode Feed for Arc Welding

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***Abstract*-This project is a new innovative concept for arc welding purpose. The main aim of this project is to feed the work piece to be welded and also the filler rod automatically with help of lead screw and motor arrangements. The work piece is feed in the x axis and the filler material is feed from the y axis. The main components in this project are motor, lead screw arrangement, proximity sensors. The work piece is feed in the x axis and the electrode is feed from the y axis. The method can be easily applied to any welding system in which the electrode is consumed during the welding process. In this process, a better stability of the arc length, excellent welding performance is obtained**

Keywords- SMAW, slide mode control

I. INTRODUCTION

This project is a new innovative concept for arc welding purpose. The main aim of this project is to feed the work piece to be welded and also the filler rod automatically with help of lead screw and motor arrangements. The work piece is feed in the x axis and the filler material is feed from the y axis. The main components in this project are motor, lead screw arrangement, proximity sensors.

Welding machines are widely used in industry. Of the variety of welding processes, stick-electrode welding, more formally known as arc welding is the most common and is conventionally performed manually. Although wages continue to rise and more manufacturers move to automate their processes to increase productivity, the arc welding still holds a large share of the total welding filler–metal business, largely due to its advantages which include exceptional versatility, low equipment costs, a convenient power source, low maintenance costs, durability, relative simplicity of operation, and ease of setup. The conventional arc welding process is performed manually. The electrode supplies the filler–metal as well as acts as the consumable material in the welding process. It requires a well-trained technician to perform such a consumed electrode welding technique. To develop an automatic welding control system that could replace manual welding, the main challenge is how to control the feed-rate of the electrode, to preserve the stability of the arc during the welding process. This is also the central goal of this study. Welding performance can be improved by appropriate inverter control methods. There have been many control methods proposed, for example the output-current slope control and the pulsed output-current control methods. However, these methods have basically ignored welding problems that occur in the metal transfer procedure itself, which may lead to the welding procedure being performed under non-optimal conditions, and limit the reduction of spatter generation. A more desirable welding performance can be achieved by incorporating an instantaneous output current control, which is based on a metal transfer procedure that uses the feedback current control method. However, its implementation into an actual welding system is complex, since it requires an optimum output currents reference waveform, and the sophisticated adjustment of the gain in the current controller focused on research in the field of gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW). Although SMAW has been so frequently used in industrial welding processes, surprisingly few studies have so far been made in this field. To obtain a stable welding process, it is important to choose appropriate welding parameters, such as the arc current and arc voltage. In a SMAW welding process, a relatively small variation in the arc length, ranging from a few millimeters to a few tens of millimeters, will induce enormous arc voltage fluctuation, which may exceed the maximum

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allowable range of the power source. Therefore, how to stabilize the arc length, avoiding undesirable voltage fluctuation, is a crucial issue in this study. In the past decades, the variable structure control (VSC) strategy which uses a sliding mode control (SMC), has been the main subject of many studies and researches on the control of the DC motor system, due to its many advantages, such as insensitivity to parameter variations, external disturbance rejection, and fast dynamic response. A sliding mode controller is also commonly used with an adaptive algorithm because of its empirically demonstrated robustness properties, as well as its outstanding performance in non-linear dynamic system control. In the conventional SMC technology, without an adaptive algorithm, the upper uncertainty bound needs to be determined and optimized if possible. However, it is very difficult to obtain an optimal upper bound for uncertainties in industrial applications, which may include parameter variation and other disturbances. Thus, generally a large conservative value satisfying the hitting conditions is needed. Here, a sliding mode control, including a simple adaptive algorithm, can be used effectively to estimate favorable small values rather than the conventional sliding mode control. In this paper we derive a mathematical model of the automatic welding system and identify the values of the parameters of the control system. The adaptive algorithm is used to estimate the upper bound of the disturbance, to obtain an appropriate value. The purpose of this paper is to develop an sliding mode controller and automatic electrode feed for arc welding process.

II. LITERARY REVIEW

Shielded metal arc welding (SMAW) is an arc welding process with an arc between a covered electrode and the weld pool. The arc is initiated by momentarily touching the electrode to the base metal. The heat of the arc melts the surface of the base metal to form a molten pool. The melted electrode metal is transferred across the arc into the molten pool and becomes the deposited weld metal. The molten pool, sometimes called the weld puddle, must be properly controlled for successful application of the SMAW process. If the current is too high, the depth of penetration will be excessive and the volume of molten weld metal will become uncontrollable. In order to verify the feasibility of the adaptive control system, the process control gains are considered to be uncertain, and the allowed range for this uncertainty is maximized. Adjusting the welding variables, such as the arc current, the arc voltage and manipulating the arc will allow the welder to control the molten metal pool properly (Cary, 1998).

In general, shielded metal arc welding performance can be improved by applying an appropriate inverter control scheme (Zhang et al. 1998). Many control methods have been proposed, including output-current slope control and pulsed output-current control (Verdelho et al. 1998). An improved welding performance can be achieved by incorporating an instantaneous output current control mechanism based on a metal transfer procedure using a feedback current control method (Abdelrahman 1998, Chae and Choe, 1999). However, the practical implementation of this type of control is complex since it requires an optimum reference waveform of output currents and a sophisticated adjustment of the current controller gain.

The SMAW process is a complex one, but the control task is accomplished by applying a fuzzy self-tuning of PID controller that is also nonlinear and whose design does not require any analytical model of the process. In order to improve the performance of PID controller gain tuning for processes with changing dynamic properties, the fuzzy self-tuning of PID controller and adaptive strategies had been proposed. The modality modulating the rate of the electrode feeding mechanism that regulates the arc current to attain the on-line adaptation of the parameter values in the operating conditions of the controlled.

III. SYSTEM MODELING

A schematic drawing of our automatic SMAW control system is shown in Fig. 2.3. It consists of a computer controlled electrode holder driven by a welding robot, a positioning table, and a welding power supply. DC motor 1 drives the welding robot, which serves as an up-and-down electrode feed-rate control mechanism, while DC motor 2 drives the welding robot along the welding path. An adaptive sliding mode arc current controller is used to drive DC motor 1, so that the arc length can be kept stable while the desired current setting value can be obtained. The electrode holder driving mechanism, which consists of a ball screw welding robot driven by DC motor 2, is a first-order velocity dynamic system. It is generally driven by an amplifier, which consists of an inverter and a DC voltage supply. In order to simplify the analysis, we can express the amplifier by a first-order dynamic system. Therefore, the electrode holder driving mechanism can be expressed by.

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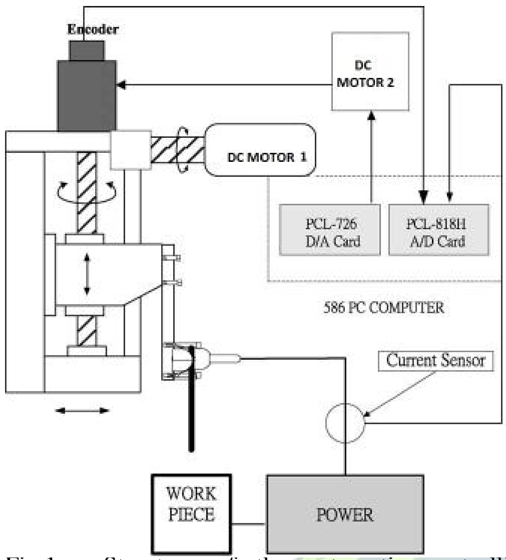

Fig.1. Structure of the automatic controlling system.

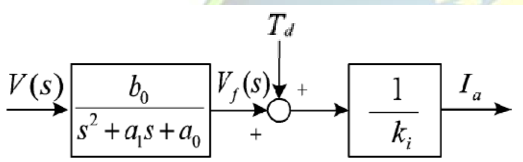

Fig. 2. Block diagram for an open loop transfer function of the welding control process.

a second-order dynamic equation as the follows

$$\frac{V_f(s)}{V(s)} = \frac{b_0}{s^2 + a_1 s + a_0}, \quad (1)$$

where Vf(s) and V(s) denote the electrode feed-rate, and the amplifier voltage, respectively. The purpose of this driving mechanism is to control the electrode feed-rate Vf(s), keeping it equal to the electrode melting-rate Vm and compensating for the melting electrode, by using the AC servomotor as an actuator. The electrode melting-rate Vm, is a function of the arc current Ia and the arc voltage Ua

$$V_m = k_i I_a - k_u U_a$$

ki is the coefficient ratio of the melting-rate to the arc current, and ku is the coefficient ratio of the melting-rate to the arc voltage. In order to maintain a stable arc length, the electrode feed-rate Vf(s) should be equal to the consumption of the electrode or the

$V_f(s) \cong V_m.$ melting-rate Vm, i.e Based on the assumption that the electrode feed-rate Vf(s) is equal to the electrode melting-rate Vm for a specific electrode feed-rate, therefore, the electrode feed-rate Vf(s) can be expressed as follows

$$V_f(s) = k_i I_a(s) - k_u U_a. \quad (2)$$

(2) However, if we rearrange Eq. (2), the arc current can be expressed as follows

$$I_a(s) = \frac{V_f(s)}{k_i} + T_d, \quad (3)$$

where $T_d = (k_u/k_i)U_a$.:

For a long arc length SMAW welding process, the arc current Ia(s) affects the electrode feed-rate Vf(s) more than the arc voltage Ua. If the arc voltage Ua is considered as a disturbance to simplify the SMAW control system, we can obtain a simple relationship between Vf(s) and Ia(s). It is expressed as follows:

$$\frac{I_a(s)}{V_f(s)} = \frac{1}{k_i}. \quad (4)$$

By combining Eq. (4) with Eq. (1), the transfer function of the SMAW process G(s), a second-order dynamic equation, is formed and can be expressed as follows:

$$G(s) = \frac{b_0}{k_i(s^2 + a_1 s + a_0)}. \quad (5)$$

It can be expressed by a block diagram in Fig. 3.4

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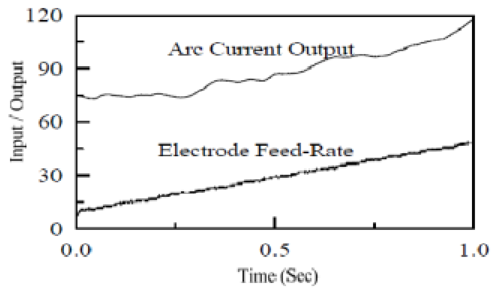

Fig. 3. The relationship between Arc current v/s electrode feed-rate

Figure 2.5, is obtained from the experiment shows that the rate of arc welding output current is approximate and proportional, but not linear relationship to the electrode feed-rate , for a long SMAW process

$$G(s) = \frac{10,113,702.6}{s^2 + 462.6s + 87,860}.$$

For a long arc length welding process, the welding current affects the electrode feed-rate more than the arc voltage does. Thus, we could consider the arc voltage as a disturbance of SMAW process.

A. SYSTEM IDENTIFICATIONS

$$\frac{V_f(s)}{V(s)} = \frac{3,469,000}{s^2 + 462.6s + 87,860},$$

Mathematical modeling describes the dynamic behavior of a system based on physical laws. This helps us to realize the characteristics of the system theoretically. However, in an actual system, the values of many parameters cannot be precisely obtained. An identification technique can be used to determine such values by analyzing the experimental input and output data. To identify the transfer function characterized in Eq. (1), which represents the electrode feed-rate mechanism, sine waves which are obtained directly from a computer software program with sweep frequencies ranging from 1 to 50 Hz and peak-to-peak amplitude of 2 V are selected as the input signals. The output signals are the velocity of the electrode feed-rate mechanism driven by DC motor 1 The sampling time of the system identification process is 0.001 s. The input and output data are recorded and an ARX model in the 'Matlab IDENTIFICATION Tool Box' is used to estimate the best-fit values of the welding control system parameters. Therefore, the nominal mathematical model of the SMAW controlling system represented by Eq. (1) can be expressed as follows:

(6)

The second part of the system identification is to determine the relationship between the arc current and the electrode feed-rate. The experimental results show that the

rate of the arc current output increases if the electrode feed rate increases slightly. This trend is well

$$\dot{e}_1 = e_2, \quad \dot{e}_2 = a_0(r - e_1) - a_1 e_2 - cu + \bar{e},$$

approximated in Eq. (4), using a proportional constant, i.e., ki, with a value

ranging from 0.3 to 0.4. If we combine the results of the two parts of the identification process, and take the constant kiZ 0.343 as the nominal value, then the nominal mathematical model of the SMAW controlling system is:

(7)

It is clear that the transfer function in Eq. (7) is a second order nominal transfer function with the poles located on the left half of the s-plane. The DC gain of the SMAW control

system transfer function is 115. This means that the nominal current output will be 115 A if we apply 1 V as input to the system.

B. CONTROL METHODSAND SIMULATION RESULTS

Since we assume that the arc voltage Ua is a disturbance, the mathematical model obtained should be a nominal model with some uncertainties. Therefore, we cannot design a sufficiently precise current controller for the welding process by using conventional control methods. In the preparation of sliding mode control, the state-space representation of the Eq. (7) that includes the disturbance Td, is expressed as follows

$$\dot{x} = Ax + Bu \quad y = Cx + T_d,$$

$$x \in R^2 \qquad (8)$$

where is the state vector, y is the scalar output

$$A = \begin{bmatrix} 0 & 1 \\ -a_0 & -a_1 \end{bmatrix}, B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

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variable, u is the scalar control input,

or a regulation problem, the error e(t) is defined as

$$C=[c\quad 0],\ a_1=426.2,\ a_0=87{,}860,\ \text{and}\ c=10{,}113{,}702.6.$$

$$e(t)=e_1=r-y(t),$$

where r denotes the reference command input and y is the arc current which is the only measurable variable. Substituting the error e(t) into Eq. (6), the error dynamic equation is obtained as follows

where $\bar{e}=-a_0T_{\mathrm{d}}-a_1\dot{T}_{\mathrm{d}}-\ddot{T}_{\mathrm{d}}$ and is bounded. Define the sliding surface

$$s(t)=\dot{e}(t)+\lambda e(t). \qquad (10)$$

Then, a sliding mode arc current controller that satisfies the hitting condition

$$\lim_{t->0} s\dot{s}<0$$

can be obtained as follows

$$u=\frac{1}{c}[u_{\mathrm{eq}}+\bar{\beta}\mathrm{sgn}(s(t))], \qquad (11)$$

where $u_{\mathrm{eq}}=a_0(r-e)+(a_1-\lambda)\dot{e}$ is the equivalent control, and sgn(.) is a sign function defined as

$$\mathrm{sgn}(s(t))=\begin{cases}+1, & \text{if } s(t)>0\\ -1, & \text{if } s(t)<0\end{cases},$$

and β is the upper bound of the disturbance, i.e. |ê|< β. The sliding mode controller in Eq. (11) can satisfy the hitting condition only if |ê|< β and the sliding mode occurs; therefore, the welding control system in Eq. (8) is expected to be stable. Parameter β in Eq. (11) needs to be determined. In order to meet the hitting condition, parameter β must be greater than the upper bound of the system disturbance ê. However, it is difficult to estimate the system disturbance that may exist in a welding system. That is, we cannot precisely realize the upper bound |ê| in Eq. (9) in advance. Therefore, we develop an adaptive law for the sliding mode controller, so that the upper bound of the disturbance can be accurately estimated.

C. ADAPTIVE SLIDING MODE ARC CURRENT CONTROLLER

To estimate the upper bound |ê|, we can introduce an estimator

$$\tilde{\beta}(t)=\hat{\beta}(t)-\bar{\beta}, \qquad (12)$$

where β (t) is an estimate of β.

Then, we choose a Lyapunov function candidate

$$V(s(t),\alpha\tilde{\beta}^2(t))=\frac{1}{2}[s^2(t)+\alpha\tilde{\beta}^2(t)]. \qquad (13)$$

Taking the derivative of the Lyapunov function in Eq. (13) and replacing the parameter β of the sliding mode controller in Eq. (11) with

$$\dot{V}=s(t)\dot{s}(t)+\alpha\tilde{\beta}(t)\dot{\tilde{\beta}}(t)$$

$$=s(t)[-\hat{\beta}\mathrm{sgn}(s(t))+\bar{e}]+\alpha(\hat{\beta}(t)-\bar{\beta})\dot{\hat{\beta}}(t). \qquad (14)$$

Besides, we consider the following adaptive algorithm for estimating the upper bound of |ê|, and start with setting

$$\dot{\hat{\beta}}(t)=\frac{1}{\alpha}|s(t)|, \qquad (15)$$

where a denotes an adaptive gain to be determined and α<0. By replacing in Eq. (11) with β, the sliding mode controller in Eq. (11) becomes

$$u=\frac{1}{c}[u_{\mathrm{eq}}+\hat{\beta}\mathrm{sgn}(s)]. \qquad (16)$$

The derivative of the Lyapunov function in Eq. (14) then become

$$\dot{V}=-\hat{\beta}|s|+\bar{e}s+\hat{\beta}|s|-\bar{\beta}|s|=-|s|(\bar{\beta}-|\bar{e}|)\leq 0.$$

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(17)

Now, the adaptive sliding mode arc current controller described in Eq. (16), coupled with the adaptive algorithm formulated in Eq. (15), makes the welding control system as in Eq. (8) asymptotically convergent to the switching surface s(t)=0. Eq. (17) implies that $V \le 0$ only if $|\hat{e}| < \beta$ holds, i.e. the hitting condition is satisfied. This results in a desirable stable welding control system. In general, the arc current controller described in Eq. (16) is, with a sign function, a high gain bang–bang control. Undesirable high-frequency oscillation may be excited in the control action, due to implementation delays, noise or other practical issues. Such oscillations may excite high frequency dynamics neglected in the modeling which could damage the actuator (the servomotor). This is commonly known as chattering. To avoid this chattering phenomenon, the sign function in Eq. (16) is replaced by a saturation function proposed and modified by Slotine. The sliding mode controller with the saturation function is modified as follows

$$u = u_{eq} + \frac{\hat{\beta}}{c}\,\mathrm{sat}(s/\phi),$$

where

$$\mathrm{sat}(y) = \begin{cases} y, & |y| \le 1 \\ \mathrm{sgn}(y), & |y| > 1 \end{cases}.$$

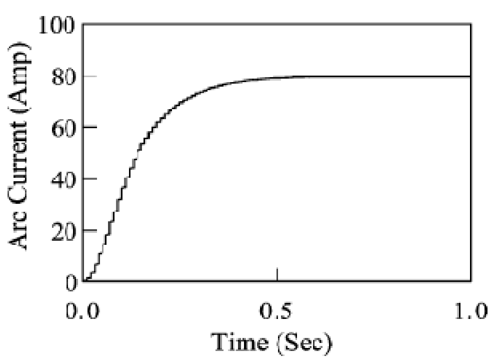

Fig. 4. Simulation of an adaptive sliding mode controller using 80 A as the reference command input

The saturation function basically defines a boundary across the sliding surface s(t) with the width Ø. This boundary layer will smoothen the sign function and remove the chattering. Desirable results will then be obtained, despite of the existence of the disturbance ê(t). Generally, the adaptive law in Eq. (15) is usually used to estimate the parameter value of the constant β. The adaptive gain a significantly influences the convergent rate of the adjustable parameter β experimentally. Since the adaptive law makes the derivative of the Lyapunov function in Eq. (14) negative-semi definite, the overall welding control system is globally stable for any positive a. Furthermore, a positive adaptive gain can be chosen to optimize the performance for the closed loop system in some sense. In our presented example, choosing an arbitrary constant a is enough to guarantee the stability of the welding control system. A time-varying adaptive gain, of course, can be considered. However, according to the step response analysis, Tung and Lo proposed a modified rule to adjust fuzzy reasoning rules based on the error and error derivative. Based on this concept, we can modify the adaptive gain a resembling in the same manner as by replacing e and ê with s and ṡ. The adaptive gain α is modified as follows

$$\alpha(t+1) = \alpha(t) - f[s\cdot\dot{s}],$$

where

$$f[s\cdot\dot{s}] = \begin{cases} 1, & s\cdot\dot{s} > 1 \\ s\cdot\dot{s}, & -1 < s\cdot\dot{s} < 1 \\ -1, & s\cdot\dot{s} < -1 \end{cases}. \quad (19)$$

Fig. 5.

The simulation results for this automatic SMAW control system with an adaptive sliding mode controller are shown in Fig.2.6; an 80 A step input is the reference command. Fig. 2.7 shows the sliding surface corresponding to the result

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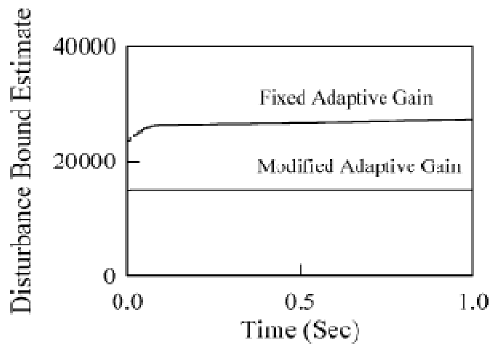

Fig. 5. Estimate β of the upper bound of the disturbance

in Fig. 2.3 Fig. 2.5 shows a diagram of the estimate of the upper bound of the uncertainties. There are two curves in this figure and the initial value of the disturbance upper bound estimator β is set to 15,000. Its value influences the response of the arc current simulation result. The top curve's value is obtained by using a fixed adaptive gain a with a value of 0.01. It is larger than the one on the bottom such that the welding control system can obtain a faster response on the simulation process. On the contrary, the bottom curve that is obtained by using a modified adaptive gain a with initial value of 0.01 converges to constant value in a very short time.

D. DESIGN OF EQUIPMENT

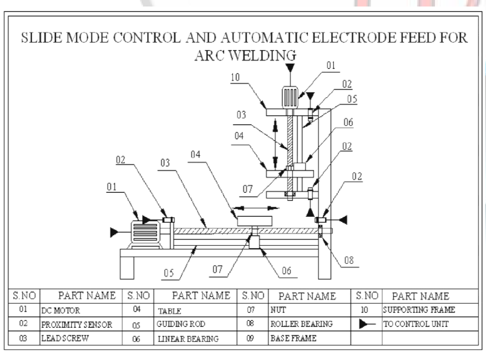

Fig. 6. First drawing of slide mode control and automatic electrode feed for arc welding

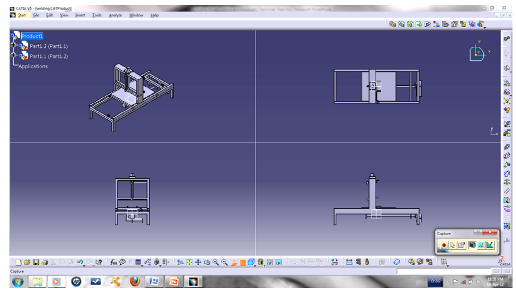

Fig. 7. Catia drawing of slide mode control and automatic electrode feed for arc welding (multi view)

E. RESULT AND DISCUSSION

The lead screw is connected with motors shaft. Table is mounted with help of nut arrangement. Guide way guides the table in a definite path. When the motor is switched on the lead screw rotates hence it is attached with the motor shaft. When the lead screw rotates the table moves front and back as per the motor rotation. Nut arrangement is welded to the table. The guiding rod is placed below the lead screw with linear bearing arrangement hence it moves the table linearly and does not rotate. The same arrangement is made for the y axis movement and filler material is made to feed in the y axis. Four sensors are used for limiting the movement of the both tables.

At first the a drawing of the machine is created as mentioned in figure 4.1 and 4.2 after that Catia modeling is done as mentioned in figure 4.2, 4.3 4.4, 4.5, 4.6, 4.7. After Catia modeling a real model is made as shown in figure 7.1 and for controlling the model a circuit board is made as shown in figure 7.2

A low cost automatic arc welding equipment is made as shown figures 7.1 and 7.2. First diagram represents the slide mode control and automatic electrode feed for arc welding model and figure 7.3 represents the working of the slide mode control and automatic electrode for arc welding. A circuit board is connected to AC power supply and is connected to the model. This simple model can be applied to any arc welding process which uses consumable electrode for welding. Here I have selected shielded metal arc welding for the purpose because of its simplicity, easy to use and its importance in global arc welding business.

The overall dimensions of the machine are length-1000mm, width-400mm, height- 550mm, Maximum width of work piece that can be accommodated is 100mm, Maximum length of weld is 300mm.

Fig. 8. Slide mode control and automatic electrode feed for arc welding

Fig. 9. Working of Slide mode control and automatic electrode feed for arc welding

CONCLUSION

In this project, an automatic SMAW system is developed for an alternating current power supply. The slide mode control and automatic electrode feed for arc welding is a compact low cost machine. The electrode and work piece feed is done automatically using DC motor and lead screw arrangements. The movement of electrode and work piece is restricted by sensors. The slide mode control and automatic electrode for arc welding cannot only replace manual operations, but can also effectively perform shielded metal arc welding.

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