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Positioning Control of Electrical Discharge Machining Device for Improved Transient Response Performance

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Abstract: Electrical discharge machining (EDM) has experienced steady growth in engineering applications since its emergence. This paper has presented positioning control of electrical discharge machining (EDM) device for improved transient response performance. A model dynamic of a DC servomotor responsible for positioning tool electrode on a workpiece was obtained. The controlled variable is the angular shaft position which was made the output of the process in the model transfer function. A proportional integral and derivative (PID) compensator was designed using robust response time tuning method with interactive, adjustable performance and robustness of the Matlab control tool box. The designed compensator was integrated with the servomotor to form a closed loop control system. Simulations were performed for uncompensated and compensated conditions of the machining process. The results obtained indicated that with the compensator in the loop, the transient response performance of the servo positioning was largely improved.

Keywords: Electrical Discharge Machining, Positioning Control, Transient Response Performance, Compensator

1. Introduction

Electrical discharge machining (EDM) has experienced steady growth in engineering applications since its emergence. Electrical Discharge Machining (EDM), as a machining technique, involves the removing of materials that are electrically conductive with the aid of fast repetitive electric discharges in the presence of dielectric fluid. There are basically two types of EDM that are employed widely in industrial applications –die-sinking EDM and wire EDM. The die-sinking EDM was invented as early as in the 1940's [1] while the wire EDM was invented in the 1970's [2]. The principle of operation is basically the same for both types of EDM; but the setup is different.

The operational principle in the EDM process is such that an electrical potential difference is applied between the tool electrode and a work-piece. The voltage level established between the tool electrode and a work-piece is due to a gap existing between the tool and electrode. The movement of the tool electrode towards the work-piece in the presence of a dielectric fluid –deionised water or oil, acting as an insulator and coolant [3], generates a gap of strong electromagnetic flux as the tool electrode nears the work-piece. As the electrode and work-piece gets closer, the electric field becomes strongest at the point of minimum distance [4]. A spark is generated between the tool electrode and the work-piece arrangement as a result of the breaking down of the insulating effect of the dielectric fluid. The generated spark is between 6000-12000°C depending on the machining condition [5]. It occurs at a small gap between the tool electrode and work-piece known as the spark gap [3]. Material within the spark gap vaporizes and melts. As a result of the heat of the spark, the electromagnetic flux breaks down and thereby leading to the breaking down of the spark, which goes back to the initial conditions again [3].

Today's industry desires a high precision and quality machine process. The servo control system is an essential part of the die-sinking electrical discharge machining (EDM). It automatically maintains the distance or gap spacing between the tool electrode and the work-piece in the proper manner during machine process to guarantee efficient sparking. The design of the servo control system is such that it can effectively work with a wide range of electrodes of several inches to micron sizes [3]. The servo control system guarantees the following during EDM operation: (a) movement of the tool electrode towards the work-piece (b) efficient sparking and retracting of the electrode when inefficient sparking or arcing is noticed (c) stable machine process, because an unstable machine process is capable of damaging machined surface, and also adversely affect the accuracy of the machined product dimension, and lastly (d) adequate gap voltage between the electrode and the work-piece.

2. Related Works

Chung et al [6] examined the mathematical model for the electrical discharge machining (EDM) process by using electromagnetic and circuit theory. The model considered the resistance and capacitance for the electrode gap by electromagnetic theory. The ignition delay time was represented as the RC time constant of the circuit model of die sinking EDM. It stated that the entire control system became nonlinear Lur'e problem during the beginning and middle stage of the machine operation. The final stage it said was a linear process. Strict Positive and real (SPR) condition was applied to EDM control to solve the Lur'e problem of die sinking EDM. A differential- proportional integral and derivative (DPID) controller was proposed at the start and middle stage of the machine process. An adaptive controller was proposed which switch from DPID controller during the nonlinear stage and to a PID controller during the final machine process. They stated that the machining efficiency can be enhanced up to 33% compare to convention PID controller. Olubiwe et al [7] designed a proportional integral and derivative (PID) controller in Matlab/Simulink so as to obtain a servo control system with an improved settling time. The objective of the work was to improve the servomechanism of EDM process. The designed servo control system gave a settling time of 3.52 seconds. Nor Liyana Safura Hashim et al [8] proposed a new design of mechanical structure of work-piece positioning and the controlling model in EDM for machining micro pits on hip implant devices. A design of motor control simulation was performed using DC motor, proportional integral (PI) controller and particle swam optimization (PSO) so as to obtain a better performance of micro machining positioning. PI parameter was tuned with the implemented PSO algorithm that search for optimal value of the controller for ITAE index performance. The simulation showed that the proposed technique reduced overshoot, settling time and steady state error of the system. Andromeda et al [9] designed a proportional integral and derivative (PID) and applied to EDM servo actuator system for maintaining gap. The objective of the work was to obtain a stable, robust and control system. The designed PID was tuned using Differential Evolution (DE) algorithm. The designed controller was simulated in Matlab/Simulink environment. The obtained results from the simulation showed the effectiveness of the DE algorithm on the designed controller for controlling the electrode position.

In this paper, a robust compensator will be developed to control the gap between the tool electrode and the work-piece. The objective of the research is that the designed controller will ensure stable, robust and optimal performance of servo control system of the EDM machining process by improving the overall transient response performance of the servo positioning system. This will ensure an improved transient response of the DC servo control motor. A typical diagram showing the essential components of an EDM system is shown in Figure 1.

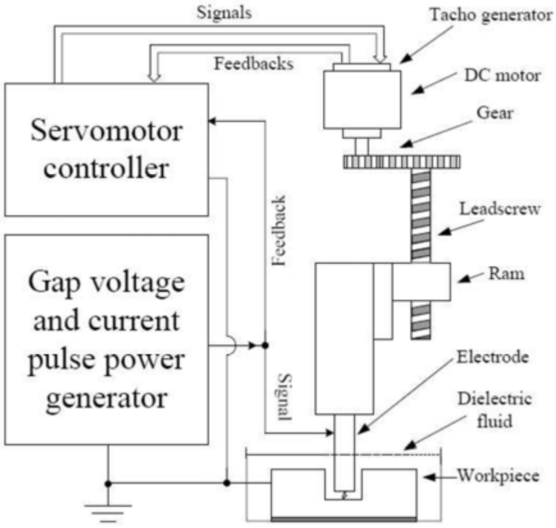

Figure 1. *Essential Components of an EDM system [9].*

3. Method

It is desired in this section to obtain a mathematical model of a typical EDM servomotor. A robust proportional integral and derivative (PID) compensator is designed and integrated with EDM servomotor dynamics so as to improve the transient response performance of the system.

3.1. Mathematical Model of Servo Positioning System

The servo positioning system aids the advancement of the electrode into the workpiece with the machining process in progress. It does this by sensing the spacing and thereby controlling the EDM process so as to maintain and provide appropriate spark gap for a good machining operation. A typical EDM servomotor diagram presented in [10] is used in this context

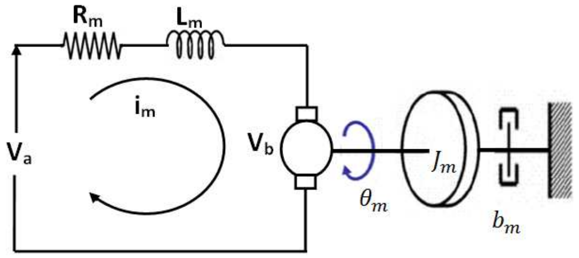

Figure 2. *A typical servomotor representation of an EDM process [10].*

Figure 2 is s DC servomotor such that two main components, the electrical and the mechanical components determine its performance. The electrical components consist of resistance, inductance, input voltage and the back electromotive force. The mechanical component determines the mechanical rotational movement at the servomotor shaft. The mechanical components consist of the motor's shaft, inertia of the motor or load inertia and damping. Given that the input voltage is applied to the armature circuit, an armature –controlled d. c. motor. Transfer functions are developed assuming the field current $i_f(t)$ is constant.

Applying Kirchoff's voltage law to the armature circuit of Figure 2 gives:

$$V_a(t) = R_m i_m(t) + L_m \frac{di_m(t)}{dt} + V_b(t) = u(t) \tag{1}$$

The angular speed of the shaft and the angular positioning output of the shaft are related as:

$$\omega(t) = \frac{d\theta_m(t)}{dt} \tag{2}$$

When the motor is driving a load, a back electromotive force (e. m. f) voltage will be developed in the armature circuit to resist the applied voltage. The back e. m. f voltage is linearly proportional to the angular velocity of the motor shaft. It is given as:

$$V_b(t) = k_m \frac{d\theta_m}{dt}(t) \tag{3}$$

Substituting Eq. (3) into Eq. (1) yields:

$$u(t) = R_m i_m(t) + L_m \frac{di_m(t)}{dt} + k_m \frac{d\theta_m}{dt}(t) \tag{4}$$

Equation (4) can be expressed in Laplace form as:

$$R_m I_m(s) + L_m s I_m(s) + k_m s\theta_m(s) = U(s) \tag{5}$$

The rotational elements of the servomotor representing the mechanical part of the servomotor are represented as:

$$T(t) = J_m \frac{d^2\theta_m(t)}{dt^2} + b_m \frac{d\theta_m(t)}{dt} \tag{6}$$

The motor torque can be is represented as:

$$T(t) = k_m i_m(t) \tag{7}$$

Substituting Eq. (7) into Eq. (6) and expressing the resulting equation in Laplace transform gives:

$$k_m I_m(s) = Js^2\theta_m(s) + b_m s\theta_m(s) \tag{8}$$

The elimination of I_m from Eq. (5) and Eq. (8) yields the transfer function for servo positioning as:

$$G(s) = \frac{\theta_m(s)}{U(s)} = \frac{k_m}{s\left[(Js + b_m)(R_m + L_m s) + k_m^2\right]} \tag{9}$$

Equation (9) is the transfer function of servo positioning of the EDM which is the ratio of the servo position to the applied voltage input to the system. This is the transfer function from $V_a(t) = u(t)$ to θ_m of the armature controlled DC servomotor. Equation (9) can be further expressed as:

$$\frac{\theta_m(s)}{U(s)} = \frac{k_m}{s\left[Js^2 L_m + s(JR_m + b_m L_m) + (b_m R_m + k_m^2)\right]} \tag{10}$$

Table 1 is a representation of the parameters used and their symbols.

Table 1. *Servomotor parameters and symbols.*

Parameter	Symbol
Armature resistance	R_m
Armature inductance	L_m
Applied or input voltage	V_a
Back e. m. f	V_b
Shaft inertia	J_m
Damping	b_m
Angular position of the motor shaft output	θ_m
Angular speed of the shaft	ω
Motor torque	T
Armature current of the motor	i_m
Motor torque constant	k_m

The values of the parameters of a typical Die-Sinking EDM are obtained from previous work [11] and used in this context. $R_m = 4.0\Omega$, $J_m = 3.22\times10^{-6}\text{Kgm}^2$, $b_m = 3.508\times10^{-6}\text{Nm}^{-1}\text{rads}^{-1}$ $k_m = 0.027\text{Vrad}^{-1}\text{s}^{-1}$, $L_m = 2.75\times10^{-6}\text{H}$. Substituting these values into Eq. (10) yields:

$$G_p = \frac{0.027}{s\left[8.86\times10^{-12}s^2 + 1.29\times10^{-5}s + 7.43\times10^{-4}\right]} \tag{11}$$

Equation (11) is the transfer function of the servo position control of a Die-sinking EDM process. It contains the complete details of the positioning process. This is done to take care of the approximate model mainly used in literature.

3.2. PID Compensator Design

In order to design the compensator implemented in this context, a robust response time tuning method was employed with an interactive (adjustable performance and robustness) design mode using the MATLAB single input single output (SISO) control tool. The bandwidth used for the tuning purpose is 29.3rad/s. Bode tuning was employed. The designed proportional integral and derivative (PID) compensator is presented in Eq. (12) and the block diagram of the implemented servo positioning system for an EDM process is shown in Figure 3. The Bode plot obtained from the tuning procedure used in designing the PID compensator is shown in Figure 4. The feedback mechanism is a unit gain sensor.

$$C = 0.34811 \times \frac{(1+0.0062s)(1+2.3s)}{s(1+0.0052s)} \tag{12}$$

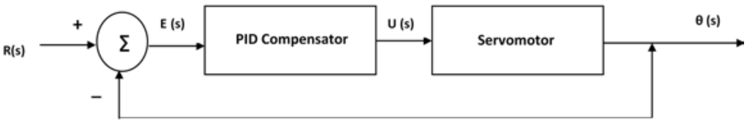

Figure 3. *Block diagram of a servo positioning EDM process.*

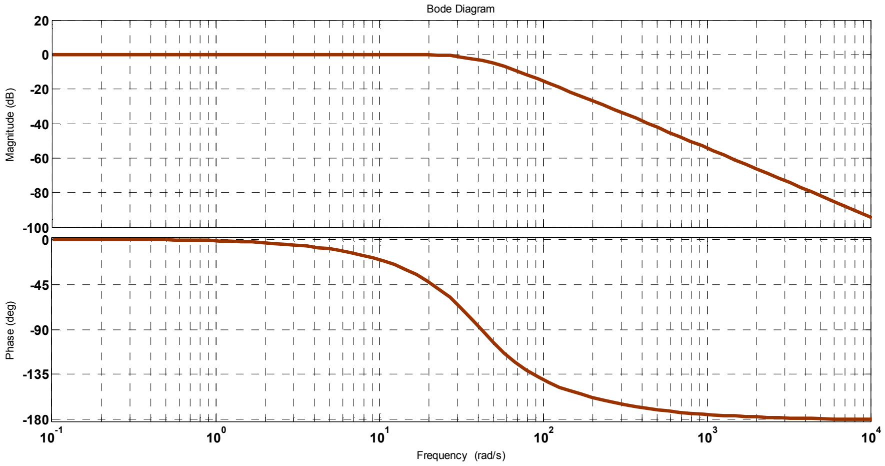

Figure 4. *Bode plot for the process response.*

The Bode plot shows that with the implement compensator on the forward path and a feedback mechanism, a stable positioning is achieved by the servomotor. In general, the system is stable.

4. Simulation Results

4.1. Simulation Results

Simulation results are performed using MATLAB software. The graphical plots obtained are shown in Figures 5, 6, 7 and 8.

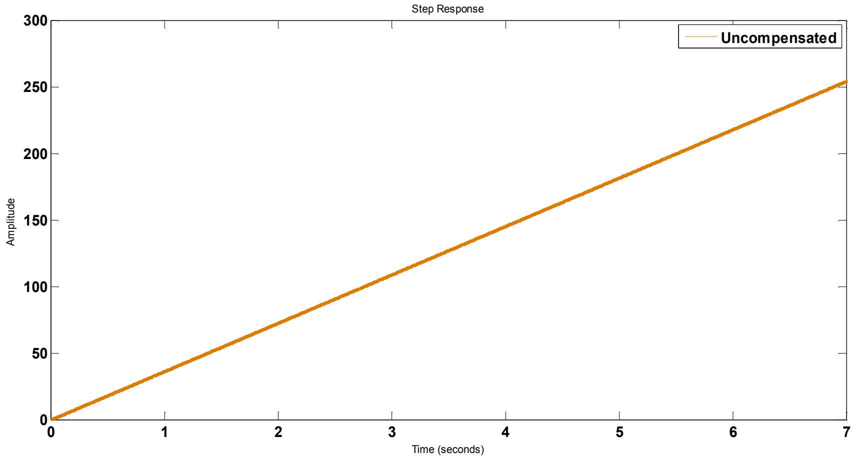

Figure 5. *Step response plot of uncompensated process.*

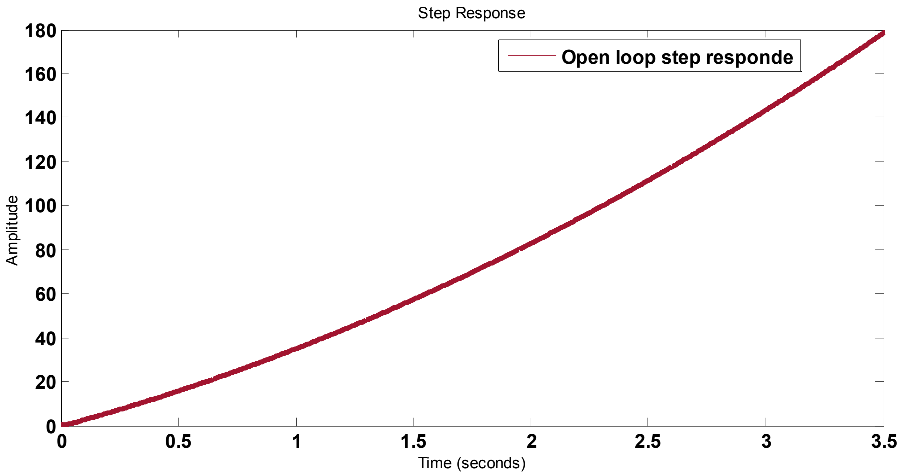

Figure 6. *Open loop plot of compensated system.*

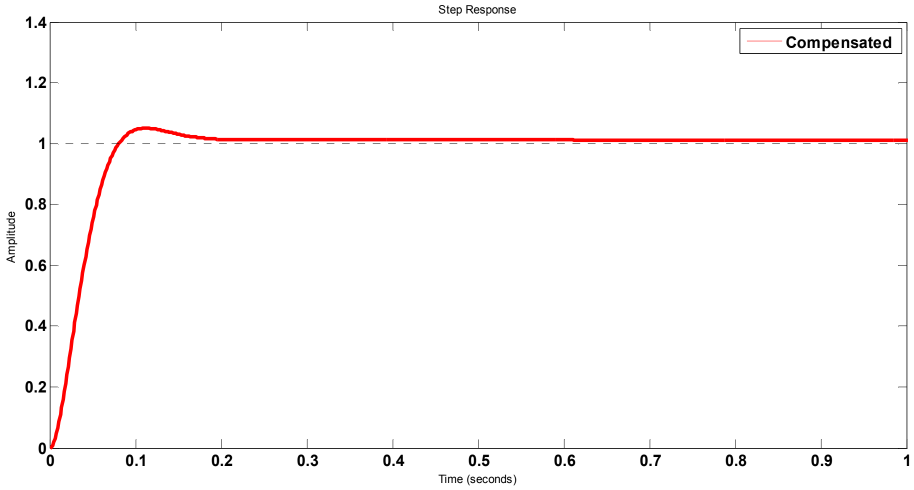

Figure 7. *Step response plot of compensated feedback system.*

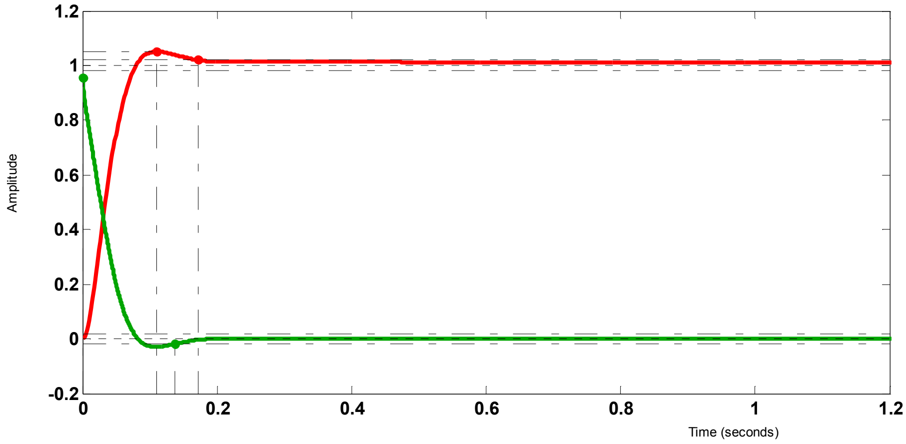

Figure 8. *Response plot of output and control input against unit step input.*

4.2. Discussion

Simulations are performed for two separate cases as to when no compensator is in the control loop and when it is part of the control system. Figure 5 is the simulation of servo positioning system with no PID compensator. The simulation result shows that the transient response time of the process grows linearly without settling. This response time is undesirable and will affect the positioning performance handling required for effective machining process. The open loop plot of the compensated system is presented in Figure 6.

It can been seen that the step response of the system grows exponentially. In Figure 7, the designed compensator is integrated with the servo positioning dynamics to form a closed loop control system. The simulation result shows that the designed compensator largely improved the transient response performance of the positioning process with overshoot of 5.06%, settling time of 0.173s, rise time of 0.0526s and zero steady state error. Figure 8 shows the simulation plot comparison of the output response and the control input signal with respect to the step input. The plot shows that the control input signal perfectly improved the response performance of the servomotor.

5. Conclusion

This paper has presented positioning control of electrical discharge machining (EDM) device for improved transient response performance. A model dynamic of a typical DC servomotor responsible for positioning an electrode onto a workpiece is obtained and an adjustable and robust PID compensator is developed using MATLAB software. The model of the plant is well detailed. This is done so as to provide comprehensive and accurate model. The compensator is integrated with the plant model to form a closed loop control system. The result obtained shows that transient response performance of the system is largely improved.

Further work is aimed at designing an intelligent controller and implementing it with experimental data obtained from industry.

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