FEED MOTION SYSTEM FOR AN EDM DRILLING MACHINE

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Abstract: Machining small holes in conductive materials, by electrical discharges, needs special designed machines, due to specific characteristics of the tool electrode as well as of the process. An important part of the machines consists from the feed motion system, which performs the feed rate of a wire or a bar with a small diameter, with various speed, determined by various machining condition. In consequence, a stable working of the feed motion system is very important and this requirement is tracked by the author in theoretical as well as in experimental ways.

Keywords: EDM, feed motion, controller, stability, micro holes

1. INTRODUCTION

Electrical Discharge Machining (EDM) of small holes, having diameter between 0.1 and 1 mm, offers in many cases an efficient alternative versus mechanical machining, restricted by the work piece material hardness and reduced stiffness of the tool. This fact determined the development of various EDM machines and technologies for machining small holes for nozzles, filters etc., example being the RAYCON SH101 type machine [1], destined to drill nozzles used in Diesel engines. This machine uses an electro hydraulic actuator for feed motion of the tool electrode which consists of a virtually endless wire made from tungsten, brass or cooper. Due to the weak performances of this actuator, in order to update the machine, was developed an electromechanical feed motion system with a DC micro motor, intended for replacing the existing system. For this new feed motion system was carried out a study and experimental works regarding its stability and technological performances.

2. EXPERIMENTAL ARRANGEMENT

To analyze the characteristics of the motion system, was used the mechanical part of a machine for micro holes drilling by EDM [2], on which are disposed a RC type pulse generator and the studied feed motion system.

The main features of the pulse generator are:
- open voltage: \( U_0 = 100 \ldots 400 \text{ V} \);
- energy of pulses: \( w_i = 0.03 \ldots 110 \text{ mJ} \);
- discharges frequency: 0.33 \ldots 240 \text{ kHz}.

The structure of the feed motion system is shown in the figure 1.

![Fig.1. Structure of the feed system](image)

The dynamics of the feed motion system was established upon a study of the stability based on the block diagram, shown in figure 2.

![Fig.2. Block diagram of the feed system](image)

Transfer functions of each block was determined from particular characteristics, as follows:

1. controller: \( Y_R(s) = \frac{U_M(s)}{\Delta U(s)} \)  \( (1) \)

Regarding its electrical diagram (figure 3), can see:

\[ Y_R(s) = k \]  \( (2) \)

where: \( k \) is the amplification factor.
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\[ k = \frac{r^4 \cdot (r1 + r2)}{r1 \cdot r2} \approx 10 \]  
\( (3) \)

Fig.3. Electrical diagram of the controller

2. DC motor:

\[ Y_m(s) = \frac{n_m(s)}{U_m(s)} = \frac{k_{UM} / k_D}{1 + T_m \cdot s + T_e \cdot T_m \cdot s^2} \approx \frac{k_{UM} / k_D}{1 + T_m \cdot s} \]  
\( (4) \)

The used DC motor type CM 12V has the following characteristics:
Rated voltage: \( U_n = 12 \text{ V} \); Rated speed: \( n_n = 3000 \text{ [rev.min}^{-1}] \); Coil resistance: \( R_s = 2.7 \Omega \); Coil inductance: \( L = 4.1 \text{ mH} \); Torque/amper: \( k_T = 8.1 \cdot 10^{-3} \text{ Nm / A} \); Viscous torque constant: \( k_D = 10^{-3} \text{ [Nm / (rev min}^{-1}]) \); Constant of time: mechanical: \( T_m = 12 \cdot 10^{-3} \text{ s} \); electromagnetic: \( T_e = L / R_s = 1.5 \cdot 10^{-3} \text{ s} \). Replacing \( k_{UM} = k_T / R_s \) and neglecting \( T_m \cdot T_e \) (<< \( T_m \)), results:

\[ Y_M(s) = \frac{3}{1 + 12 \cdot 10^{-3} \cdot s} \]  
\( (5) \)

3. Gearbox:

\[ Y_{LC}(s) = \frac{v_s}{n_m} = i \cdot \pi \cdot \frac{D}{60} \]  
\( (6) \)

where: \( i = 1 / 400 \) is the reduction ratio of the gearbox and \( D = 8 \cdot 10^{-3} \text{ [m]} \) is the diameter of the friction roller.

\[ Y_{LC}(s) = k_{LC} = 1.05 \cdot 10^{-6} \text{ [mm s}^{-1} / \text{ rev min}^{-1}] \]  
\( (7) \)

4. Work space:

\[ Y_{SL}(s) = \frac{U(s)}{V(s)} \]  
\( (8) \)

To establish the transfer function of the gap, we consider the modifying its depth \( dg \) in de time interval \( dt \), due to the feed velocity \( v \):

\[ dg = -v \cdot dt \]  
\( (9) \)

When the gap has a depth about the optimal value, between this one and the average voltage \( U \) is a linear correlation \( [2] \):

\[ dg = k_{SL} \cdot dU = -v \cdot dt \]  
\( (10) \)

respectively:

\[ k_{SL} = -k_{U}(s) \cdot s = -v(s) \]  
\( (11) \)

The correlation \( g = f(U) \), experimental established and shown in figure 4, allow to calculate the gap constant:

\[ k_{SL} = \frac{dg}{dU} = \frac{d}{dU}(-0.5088 + 0.05604 \cdot U) = \]  
\( = 0.05604 \text{ [µm/V]} \)  
\( (12) \)

respectively:

\[ k_{SL} = 5.6 \cdot 10^{-8} \text{ [m/V]} \]  
\( (13) \)

Finally:

\[ Y_{SL}(s) = \frac{1}{5.6 \cdot 10^{-8}} \cdot \frac{1}{s} \]  
\( (14) \)

Fig.4. Correlation between gap depth and average voltage on the gap

5. Gap sensor, with consists from an integrating voltage divider, included in the controller (r5, r6, C3) and having the transfer function:

\[ Y_{β}(s) = \frac{U_{β}(s)}{U(s)} = \frac{1/k_{β}}{1 + 1/k_{β} \cdot T_{β} \cdot s} \]  
\( (15) \)

where:

\[ k_{β} = 1 + \frac{r_1}{r_2} = 40 \quad ; \quad T_{β} = r_1 \cdot C_3 = 1.1 \cdot 10^{-3} \text{ [s]} \]

\[ Y_{β} = \frac{0.025}{1 + 2.5 \cdot 10^{-5} \cdot s} \]  
\( (16) \)

The transfer function for the closed loop control circuit (see figure 2) is:

\[ Y(s) = \frac{Y_{d}(s)}{1 + Y_{d}(s) \cdot Y_{β}(s)} \]  
\( (17) \)

where:

\[ Y_{d}(s) = Y_{R}(s) \cdot Y_{M}(s) \cdot Y_{LC}(s) \cdot Y_{SL}(s) \]

is the open loop circuit transfer function.
\[ Y_0(s) = Y_R(s) \cdot Y_M(s) \cdot Y_{LC}(s) \cdot Y_{SL}(s) \cdot Y_\beta(s) = \frac{k}{s \cdot (1+T_m \cdot s) \cdot (1+1/k_\beta \cdot T_\beta \cdot s)} \]  

(18)

Respectively:

\[ Y_0(j\omega) = \frac{k}{j\omega \cdot (1+j\omega \cdot T_m) \cdot (1+j\omega \cdot k_\beta)} \]  

(19)

\[ Y_0(j\omega) = \frac{k}{A+jB} \]  

(20)

\[ A = 1 - \omega^2 \cdot (T_m + T_\beta/k_\beta) \]  

(21)

\[ B = \omega \cdot (1 - \frac{1}{k_\beta} \cdot T_\beta \cdot T_m \cdot \omega^2) \]  

(22)

\[ Y_0(j\omega) = P(\omega) + jQ(\omega) = \frac{-k \cdot A}{A^2 + B^2} + j \frac{k \cdot B}{A^2 + B^2} \]  

(23)

Hodograph of the \(Y_0(j\omega)\) function is presented in figure 5. According to the Nyquist stability criterion, we can see that the analyzed system are stable for the adopted value of parameters. In order to increase the reserve of the stability, the amplification factor can be reduced from 10 to 5 or 3, by replacing the r4 resistor in controller with an 500 k\(\Omega\) potentiometer.

**Fig.5. Hodograph of the \(Y_0(j\omega)\) function**

3. CONCLUSIONS.

Technological performances of the feed motion system, determined by experiment are shown in figure 6.

**Fig.6. Drilling speed versus average gap voltage**

**REFERENCES**

