Improving the Efficiency of Electro Discharge Machining by Dual Voltage Excitation

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Abstract

An Electrical Discharge Machine (EDM) is a vital machine used in manufacture of tools and dies. Its operation is based on discharge of an electrical current across the tool and the work-piece. Due to limitations of the servo control system, the EDM operates with a low efficiency using a high spark voltage. This paper presents a novel technique based on a dual voltage excitation for an EDM. Although this technique was developed primarily to improve the efficiency, it reduces the cost and size of the electronic controller as well.

INTRODUCTION

An Electrical Discharge Machine (EDM) cuts metal by discharging electrical current across a thin gap between the tool electrode and work-piece electrode. Each electrical discharge produces a tiny crater by melting and vaporization, thus eroding the shape of the tool electrode into the work-piece electrode. In EDM, each spark contains a discrete, measured and controllable amount of energy; hence the surface finish of the work can be properly controlled. EDM is widely used in manufacture of tools and dies for casting, forging, stamping, extrusions and molding [2]. The absence of mechanical forces makes it possible to machine fragile parts without distortions.

In EDM, the work-piece and tool are submerged in a dielectric fluid and it flushes out the "chips" generated due to the electrical spark. Figure 1 depicts the schematic diagram of a typical EDM machine. The tool feed mechanism maintains the distance between the tool and the work-piece very accurately. No electrical spark is created when the gap is too large. Usually the spark gap is maintained to its optimum distance by a servo control system. Under the control of the servo control system, the tool is lowered from its rest-position. During this process, tool and work-piece should not touch each other, as it creates a short circuit. Under the short circuit condition, no spark is generated but a heavy current is drawn from the supply. To prevent any short circuit conditions during operation of the servo control system, a sufficient spark gap must be allowed. In practice, a spark voltage (V_{Spark}) of approximately 100 V is required for this purpose. The energy delivered in each spark determines the accuracy of the machining process, and hence the spark current and the spark duration determine the accuracy. The spark current is usually maintained to the required strength by using a current limiting resistor (R) as depicted in Figure 2 [1]. During the spark, the voltage between the spark gap (V_{Gap}) drops to a value as low as 20 V while remaining 80 V is dropped across the current limiting resistor. This makes the EDM very inefficient. For a typical operation condition with a 100 V spark voltage and 20 V spark gap drop, the efficiency of the machine is only 20%. This paper presents a novel technique to improve the efficiency of the EDM using a dual voltage excitation source.

TOOL DYNAMICS

The servo control system that positions the tool is depicted in Figure 3. It consists of a servomotor with a reduction gear or a belt drive, tool holder and tool holder guide. A typical servo control system used in EDM can be modeled as in Figure 3. In this block diagram, the servo controller is represented as a proportional controller with gain K_p. To reduce the effect of friction, a velocity feedback with a gain K_r has been used. The parameter J represents the inertia of the system. The closed loop transfer function of the system is given by

$$\frac{C(s)}{R(s)} = \frac{K_p}{J\,s^2 + K_r s + K_p}$$

Therefore the system is second order with its characteristics equation

$$s^2 + 2\xi\omega_n s + \omega_n^2 = 0$$

where ξ is the damping coefficient and ω_n is the natural frequency of the system. The maximum system overshoot and the corresponding time at which it occurs are given respectively by [3]

$$ov_{\max} = e^{-\frac{\pi\xi}{\sqrt{1-\xi^2}}}$$

and

$$T_{\max} = \frac{\pi}{\omega_n\sqrt{1-\xi^2}}$$

To obtain a fast response time, the servo control system must operate with small damping coefficient, but it creates large overshoots. In practice, $\xi = 0.7$ is selected as the optimum damping coefficient, as it creates only a 5% overshoot [3].

The spark gap between the tool and the work-piece is directly proportional to the applied voltage between the tool and the work-piece. Usually, the dielectric fluids used in EDM have dielectric strengths in the order of 20 *kV/m* and hence the spark gap is approximately given by 0.05 $\mu m/V$. With a 5% overshoot in the servo control system and initial tool position of 0.1 *mm* above the work-piece, a 5μm spark gap is required to prevent any short circuit conditions being developed during the tool movement. In order to maintain a 5μm spark gap, 100 *V* spark voltage is required. As the voltage drop across the gap during the spark (i.e. V_{Gap}) is as low as 20 *V*, and 80 *V* drop is developed across the current limiting resistor, the system operates with a low efficiency in the order of 20%. It is now clear that direct system efficiency improvement needs reduction in the spark voltage V_{Spark}. Any reduction in spark gap voltage is associated with a reduction in the spark gap and hence reduction in system overshoot is required. For example, a 25 *V* spark voltage may increase the efficiency of the system to 80%, but it reduces the spark gap to 1 *μm*. Positioning the tool to maintain a 1 *μm* spark gap from the original tool position of 0.1 *mm* above the work-piece allows only a 1% overshoot. When the system damping is increased to reduce the system overshoot to 1%, the system operates slower. Hence any attempt to improve the system efficiency by reducing the spark voltage is not successful as it slows down the tool positioning speed.

DUAL VOLTAGE EXCITAION TECHINIQUE

A careful examination of the spark generation process, tool positioning process and spark maintenance process reveals the following facts:

a) A high voltage is required to generate the spark with a high tool positioning speed.

b) A low voltage is sufficient to maintain the spark once the spark is generated without any effect on the tool positioning speed.

These two facts can be easily met with a dual voltage excitation as depicted in Figure 4. It contains a high voltage source (V_h) to generate the spark and a low voltage source (V_l) to maintain the spark. Two resistors in combination with a diode are used to improve the efficiency. The high voltage path resistance (R_h) is very high to prevent excessive power dissipation. The low voltage path resistance (R_l) is selected according to the spark current, and it is fairly low as the low voltage supply is in the order of 25 *V*. One can now note that with a 20 *V* spark gap voltage drop, only 5 *V* is dropped across the current limiting resistor R_l and hence the system efficiency is now as high as 80%.

The dual voltage excitation not only improves the system efficiency, but also reduces the cost of the system as well. The power dissipation on the current limiting resistor for an 80 *V* drop at 50 *A* current is 4 *kW*. Hence the single source excitation requires high wattage resistors and a good cooling system must be employed. Usually an array of 300 *W* resistors is used in practice and the cost of a single 300 *W* resistor is approximately Rs. 5000/=. To meet the required 4 *kW* capacity, the cost of the current limiting resistor array alone is around Rs.70,000/=.

On the other hand, power dissipation on the current limiting resistor with a 5 *V* drop at 50 *A* current is only 250 *W*. The wattage rating of the current limiting resistors is reduced by a factor of 16. Hence it reduces the cooling requirements as well. This low power dissipation current limiting resistor can be constructed by using a 50 *W* resistor array. The cost of a 50 *W* resistor is around Rs. 400/=, and hence the cost of the current limiting resistor array is now only Rs. 2000/=. The cost of the current limiting resistor is reduced by a factor of 35.

Furthermore, the dual voltage excitation reduces the capacity of the power transformer. In order to draw a 50 A current from a 100 V supply, at least 5000 VA transformer is required. For the dual voltage excitation system supplying 50 A from a 25 V supply, only 1250 VA transformer is required.

The reduction in the power rating of the current limiting resistors, cooling requirements and transformer capacity not only reduces the size of the electronic controller but the cost of the system is also reduced by a significant factor. Figure 5 show a photograph of an EDM system developed by the author using the dual voltage excitation technique described in this paper. This system has been used in the field successfully for more than a year to manufacture moulds for the plastic industry.

CONCLUSION

A dual voltage excitation technique for improving the efficiency of the EDM was presented in this paper. Although the primary aim was to improve the efficiency, the new technique reduces the cost and size of the system due to reduction in the power rating of the current limiting resistors. The new technique has been field tested in manufacture of plastic moulds and shows good performance.

Acknowledgement

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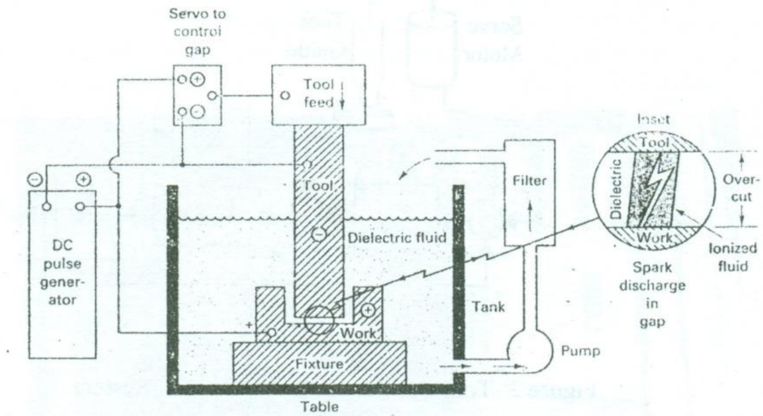

Figure 1: Schematic Diagram of a Typical EDM

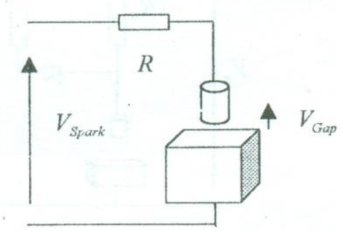

Figure 2: Electrical Circuit of a Typical EDM

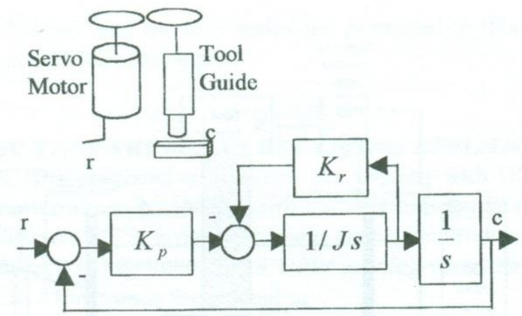

Figure 3: Tool Positioning Servo Control System

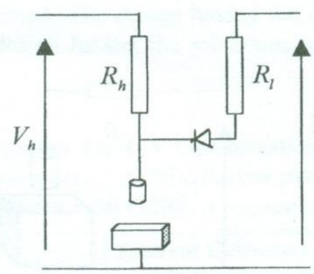

Figure 4: Dual Voltage Excitation Scheme

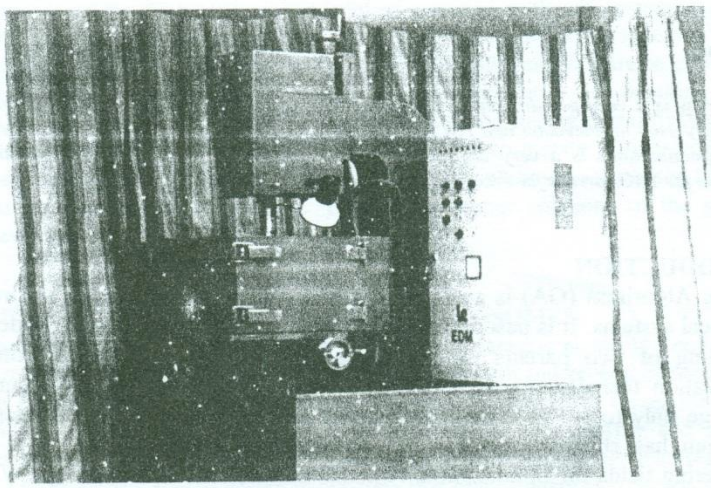

Figure 5: Photograph of the EDM based on Dual Voltage Excitation