Developments in Electric Power Supply Configurations for Electrical-Discharge -Machining (EDM)

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Abstract--**The Electric Discharge Machining (EDM) process provides one of the best alternatives, or sometimes the only alternative, to machine a growing number of high-strength and corrosion-and-wear-resistant materials. It is based on the principle of erosion of metals by an interrupted electric spark. The power supply design and configuration requirements for producing the desired "spark" have always been challenge to the researchers and manufacturers. With the evolution of advanced electronics knowledge-base, the EDM power supply configurations have constantly been updated over the years. The present paper reviews the developments in high frequency electric power supply configurations used for the EDM process.**

***Keywords*-- Electric Discharge Machining, pulse generator circuit, power supply, relaxation circuit, resonant converter, transistor switching, thyristor,.**

I. INTRODUCTION

With rapid advancement of technology in the various fields, it is becoming increasingly necessary to use harder and brittle materials with improved accuracy, surface finish, and mechanical, physical and metallurgical properties [1-2]. The conventional methods of machining are providing poor and inadequate means of achieving these objectives. While attempting to find a solution to these problems, many new processes have been developed, namely electroforming, electrolyte machining, electric discharge machining, chemical milling, ultrasonic machining, electro-beam machining, explosive forming, laser machining, etc. Many of these processes use high frequency energy supply and the electric-discharge machining is an important one in this category [3-4]. The process of electric discharge machining (EDM) is now well established and is probably the most versatile of all the electro-machining processes. EDM has made its mark not only by its abilities but also because it is compatible with current workshop practice, modern electronic and software techniques, and current manufacturing philosophy. The basic process coupled with modern control techniques and state of the art power supply configuration permit largely unattended and automated operation.

The spark erosion process or EDM basically consists of the following main components

a) DC source(capable of switching very fast on and off)
b) Dielectric medium (could be synthetic or mineral oil)
c) Workpiece and tool (electrode)
d) Servo system

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The metal removal rate (MRR) and the surface finish depend on the magnitude and duration of discharge[9] .As the current is increased, so does the MRR but the surface finish decreases. As the discharge frequency is increased, the surface finish improves but the electrode wear increases.

There are two types of EDM power supplies:

a) Isoenergetic, which provides constant energy pulses, achieving good surface finish, its drawback is that if the off time is very long, the electrode wear increases, and as the frequency decreases, the MRR diminishes.

b) Isofrequencial, which keeps the discharge frequency constant, ensuring the MRR.

II. THE EDM PROCESS AND POWER SUPPLY

Fig.1 illustrates the schematic layout of the EDM system [1]. The main components are the electric power supply generator, the servo control system, the dielectric medium, the tool and the work-piece.

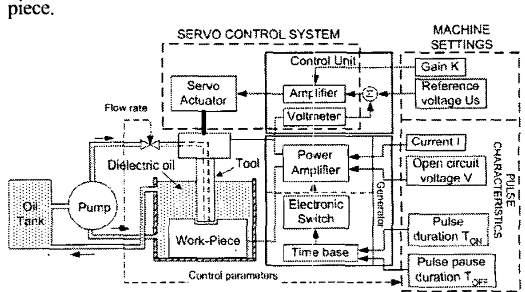

Fig. 1. Schematic layout of basic EDM components

In EDM, material removal is achieved by the thermal action of electric discharges occurring between a tool electrode and the work-piece. The work-piece and the tool are electrically connected to a DC power supply. The work-piece is connected to the positive terminal of the electric source, so that it becomes the anode. The tool is the cathode. A gap in the range of 0.005 to 0.05 mm is maintained between the work-piece and the tool and a suitable dielectric liquid, which is a non-conductor of electricity, is forced through the gap. When a suitable voltage in the range of 50 to 400 volts is applied, the dielectric breaks down and electrons are emitted from the tool (cathode) and the gap is ionized. When more electrons gather in the gap, the resistance drops – causing electric spark to jump between the work-piece surface and the tool. The whole sequence of operation occurs within a few microseconds and is accompanied by a shock wave in the dielectric. The impact of the electrons on the anode causes high transient pressure. The current density in the discharge channel is of the order of 10,000 amp per cm^2, the power density is of the order of 500 MW per cm^3 and the temperature of the spot hit by the electrons is of the order of tens of thousands of ^{0}C. The forces of the electric and magnetic fields caused by the spark produce a tensile force and tear-off particles of molten and softened metal from this spot on the work-piece [1-2].

EDM was developed in Russia in the mid-1940-s and they used the basic resistance-capacitance (RC) power supply which is still used today in many cases where a fine finish is required [3]. The basic components of such a DC operated relaxation circuit are shown in Fig.2 [1]. The capacitor C is charged to the breakdown voltage V which is usually less than the source voltage E. The voltage across the capacitor (and the gap) increases until it is great enough to break down the dielectric and cause a discharge to pass which then ceases when the capacitor is discharged. The capacitor then charges up again through the resistor and the process starts again, the whole system forming a relaxation 'oscillator'. With a small capacitor the discharges are small and occur at a high frequency and give a good surface finish and with a large capacitor the discharges are larger and occur at a lower frequency. The duration of the period of the spark and the subsequent off periods are dependent on the values of R and C as shown in Fig.2.

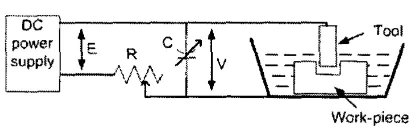

Fig. 2. The basic relaxation circuit

The value of C may be chosen up to 400μF in heavy machines, but it is kept lower in smaller machines. The resistance R must be high enough to prevent arcing between the tool and the work-piece, because the metal removal rate (MRR) due to arcing is much slower than that due to spark. Accuracy and mechanical and metallurgical properties of the work-piece obtained by arcing are also poorer than those obtained by spark-machining. The electric supply units based on relaxation circuit produce high energy sparks at frequencies ranging from about 3,000 to 10,000 sparks per second. The variation in voltage and current with time in the gap circuit is shown in Fig.3.

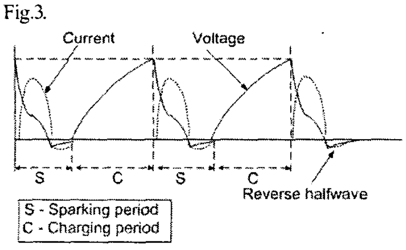

Fig. 3. Voltage and current waveforms for a basic relaxation circuit

III. DEVELOPMENTS IN POWER SUPPLY CONFIGURATIONS

A. Controlled Pulse Generator Power Supply

The RC relaxation circuit based supply is basically cheap and simple but can not provide independent control of the discharge frequency and discharge energy which is essential for maximum efficiency in EDM [3-4]. With the years, the relaxation circuit was widely replaced by the controlled pulse-generator [1, 3]. In a pulse-generator circuit, a separate AC or DC pulse generator is used to produce the high frequency supply to be fed to the work-piece. The following Fig.4 (a) and (b) show two different configurations of the pulse-generator circuit [1].

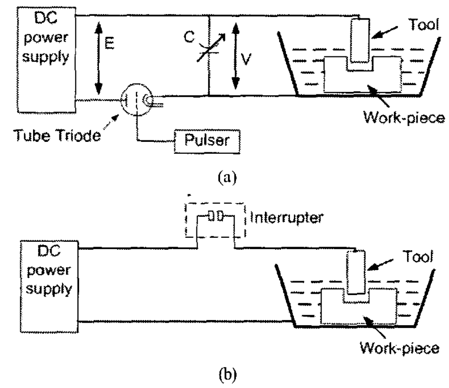

Fig. 4. (a) Pulse generator with a separate pulser; (b) DC interrupter pulse generator

The pulse-circuits are capable of generating pulses at frequencies about ten times those generated by a relaxation circuit. This permits the equipment working on the pulse-circuit to use lower energy sparks for removing metal at the same rate as that by equipment with the relaxation circuit. Therefore, equipment with the relaxation circuit ordinarily uses higher energy sparks to make up for its inherent lower frequencies. This needs a higher voltage across the gap which causes larger over-cut and deeper penetration on the surface of the work-piece. This results in a poorer surface finish. Thus, for equivalent rates of metal removal, equipment with the pulse-circuit will produce better work-piece surface finish with more precision. The energy consumption is also 2-3 times less and the tool wear is reduced by 5 to 20 times [1].

B. Transistor Switching Circuit Power Supply

Probably the most important development in generator design in the 1970's was the transistorized switching circuit (Fig. 5) [3]. The transistor is operated as a high-speed switch to control current from capacitor to the working gap. The voltage across the capacitor is maintained by a DC supply and the transistor base current is controlled by a signal from a low power pulse generator. The pulse-generator is usually of the multi-vibrator type in which the ON and OFF periods of the pulse can be independently adjusted. Although individual transistors may switch only 10 amps to the gap, by arranging them in banks connected in parallel, total outputs of up to 400 amps or more may be obtained [4].

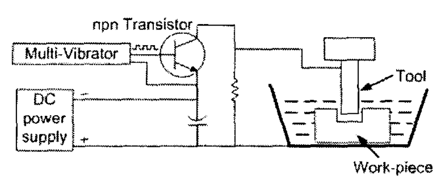

Fig. 5. Typical Transistor switching circuit power supply

The output current available can be controlled in steps by switching a number of output transistors in parallel. The higher voltage power supplies are particularly useful for working at short pulse times, to provide a good surface finish [4].

C. Relaxation Circuit with "Free-Wheel" Diode

The complete schematic of a relaxation generator with 'Free-Wheel' diode for EDM is shown in Fig. 6.

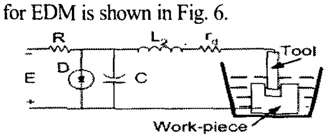

Fig. 6. Schematic of simple relaxation generator with free-wheel diode

L_2 is the discharge side inductance and r_d is the total resistance in the discharge branch. L_2 consists of the inevitable lead inductance, the self-inductance in the discharge capacitor and any other stray inductance in the discharge path. The resistance of the discharge wires and the spark-gap during discharge constitute r_d. In such a relaxation generator, the discharge period (approximately equal to $2\pi\sqrt{(L_2C)}$) is usually small compared to the charging time constant RC. In practical machines, the supply voltage lies between 60 to 300 volts and C is between 0.1 to 100 μF. For this range of C and V even with the usually small values of L_2, the discharge current is oscillatory and the voltage across the capacitor goes negative. The value of this negative voltage influences considerably the amount of power transferred to the discharge capacitor. Without the diode across the capacitor, the discharge current is in the form of an exponentially decaying sinusoid (Fig. 7). The presence of the diode alters the discharge circuit conditions. After the diode conducts, the circuit is no longer an LCR circuit but a simple IR circuit. The diode conducts when the voltage across the capacitor tries to reverse through zero. Thus, the diode does not allow the discharge current to reverse in the spark-gap, resulting in a unipolar current pulse. This result in better utilization of power [5] and reduced tool wear [6].

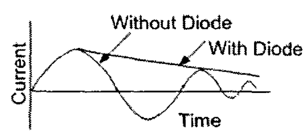

Fig. 7. Discharge circuit current

D. Thyristorised EDM Power Supply

The next step in EDM power supply development was towards replacing the transistor with thyristor as the switching element [7]. A thyristor generally have a greater current capacity than the transistor. Also the thyristorised EDM generator does not need many switching elements in parallel as in the case of the conventional transistorized EDM generator. Furthermore, the withstanding voltage of a thyristor usually being higher than that of a transistor, the thyristorised generator permits a relatively high power supply voltage, resulted in attaining a stable automatic control for the feeding of the tool electrode.

1) Thyristorised EDM Power Supply of Capacitive Type

A thyristorised EDM generator proposed by [7] in Fig. 8 is basically a RLCL relaxation generator designed to repeat charging and discharging of a capacitor. The improved generator can steadily repeat a pulse discharge with a high duty factor, resulting in increased removal rate of the work-piece. In addition, the wave form of the transient arc discharge produced by the generator is uniform and unpolarised, which indicates that surface roughness on the finished work-piece becomes uniform and the wear of the tool electrode is reduced due to the polarity effect.

No additional commutating devices are required in the proposed circuit shown in Fig. 8. PG is a trigger pulse generator for the thyristor Th, consisting of a UJT relaxation oscillator. L_0 in the figure is a reactor for prolonging the pulse duration, of which the resistance is expressed by r_0. L_1 is a commutating reactor for the thyristor T_h, and r_1 is its resistance.

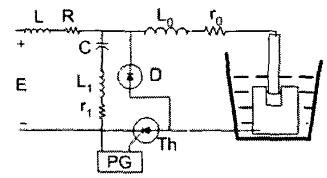

Fig. 8. Thyristorised EDM generator of capacitive type

When the thyristor Th is turned ON by a signal from PG, the transient arc occurs followed by breakdown of the insulation in the gap. As a consequence, the terminal voltage on the capacitor C is reduced rapidly and reaches nearly zero. At this moment, the rectifier D starts to clamp for the capacitor C and the thyristor Th commutates due to the resonance incurred in the circuit C-L_1-Th-D. Thus, the gap is eventually isolated from the power supply, but the arc in the gap still continues because the electromagnetic energy stored in the reactor L_0 is released into the gap. The arc current decreases with time constant L_0/r_0 until the arc extinguishes.

For the short circuit in the generator, a preventive measure is shown in the Fig.9, where the terminals of the power source of PG are connected to the gap. If the gap is electrically shorted by the derbies or the overfeeding of the tool electrode, the voltage of the power source of PG immediately drops down to zero and the trigger pulse cannot be supplied to the gap of T_h. Consequently, the operation of the generator stops and damage to the work piece caused by the short circuit current is successfully avoided. When the short circuit occurs, the tool electrode is raised up from the work piece by the servomechanism of the tool electrode until the short circuit is broken off. In this case, since the power should be applied for operating PG, it is necessary to insert

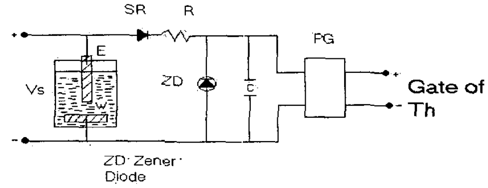

Fig. .9. Preventive Measure for short circuit the resistor of several kilo ohms in parallel with T_h in the above preventive measure.

An experiment on the copper tool electrode vs the hardened steel workpiece was carried out under the reverse polarity ie.the tool electrode was held positive and the workpiece negative. A thyristor with the turn off time of 15μs was used for The Fig. 10. shows the effect of inductance of L_0 on the removal rate for the workpiece M and the relative electrode wear γ in weight.

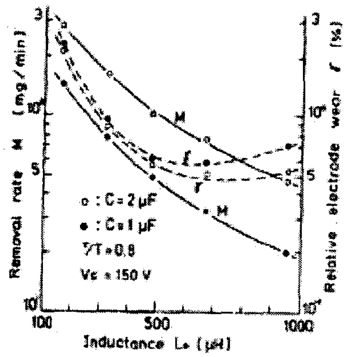

Fig. 10. Effect of induction L_0 on the removal rate for the workpiece M and the relative electrode wear γ in weight [7]

2) Thyristorised EDM Power Supply of Inductive Type

The power supply proposed by [7] in Fig 9 uses a thyristor Th in the inductive relaxation generator, where charging and discharging of the capacitor C in Fig. 8 is replaced by that of the reactor L_0. In Fig. 9, the turn-off device for the thyristor Th is composed of C, R and L.

When a transient arc is fired at the gap by turning on Th, both the inductance L_0 and the capacitor C are charged by the current from the power source. As soon as the terminal voltage across C reaches nearly the power source voltage E, the diode D starts to act and two closed loop of C-E-L_1-D and L_0-gap-D are composed. An oscillating current flows through Th as a consequence of resonance in the circuit of capacitance C and inductance L_t. Thus, Th commutates and the gap is eventually isolated from the power supply.

On the other hand, the arc in the gap still continues because the electromagnetic energy stored in the reactor L_0 is released into the gap, and the electrostatic energy stored in the capacitor C is discharged through R and L. The arc discharges with time constant of L_0/r_0 until the arc extinguishes.

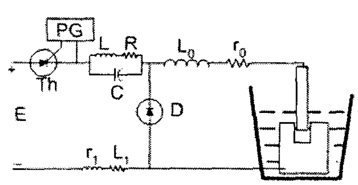

Fig. 11. Thyristorised EDM generator of inductive type

The effect of the inductance L_0 on the removal rate for the workpiece M and then relative electrode wear γ in weight is shown in Fig. 12.

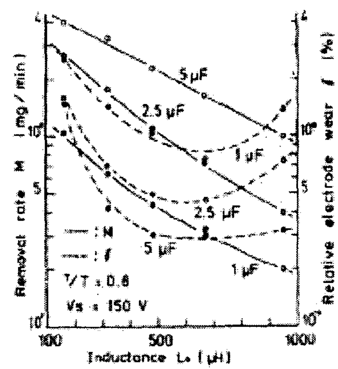

Fig. 12 Effect of the inductance L_0 on the removal rate for the workpiece M and the relative electrode wear γ in weight [7].

E. High Efficiency Power Supply [8]

At earlier times, electrical power consumption was perhaps insignificant in the economics of EDM, but simple considerations show that, with the voltage source and series resistance arrangement as shown in Fig. 2, the electrical efficiency at the gap is given approximately by:

$$\eta = \frac{25}{E} \times 100\% \quad (1)$$

and that for E = 80V, η = 28%, i.e. about 70% of the switched power is wasted in the gap series elements. This problem results directly from the fact that the physics of EDM process require the gap to break down at an approximately fixed voltage of around 100 V, while only 25 to 35 V is developed across it for the bulk of the discharge duration.

The solution is simply to supply a small part of the machining current (experiments have shown that this is around 1A) from an 80 – 100V voltage source and to provide the bulk of the machining current from a current source of around 40V. The 1A source at higher voltage establishes the arc level voltage, and subsequently allows power flow from the higher power current source at lower voltage. The electrical efficiency of such an arrangement can be found out to be

$$\eta = \frac{23}{Vp} \times 100\% \quad (2)$$

where V_p is the voltage of the high-power, low voltage power source, and with V_p=40V, η = 58%. Clearly, this represents a most significant power saving. The basic circuit for achieving high electrical efficiency is shown in Fig. 13.

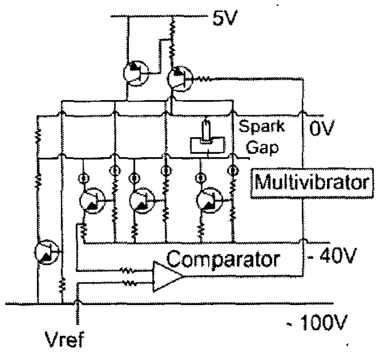

Fig. 13. Circuit diagram of high efficiency supply

F. LCC Resonant Converter

Modern day EDM equipments use LCC resonant converter based power supply source [9-10]. The system (Fig. 14) is a DC to DC LCC resonant converter whose switching frequency is tuned at the natural frequency where the converter tends to act as a current source. In this way, two effects are achieved:

1) the necessary over-voltage, first to ionize the dielectric and then to establish the electric arc is generated and
2) a constant current is supplied during the erosion of the work-piece, providing the circuit with inherent protection under short circuit conditions.

The output voltage is intended to be adjusted by an external system that controls the arc distance.

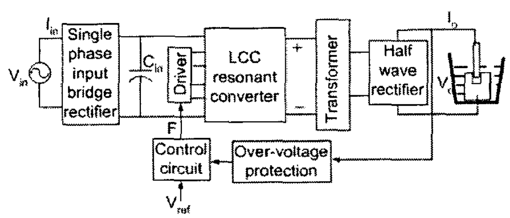

Fig. 14. Basic block diagram of the EDM power supply using a LCC resonant converter

The full bridge has been chosen because of it's capability of converting high power. As the continuous change in the gap distance may lead to load changes from open to short circuit conditions, the resonant inverter is designed as a current source to provide the system with inherent protection under short circuit condition. The open circuit fault must be limited by an over voltage protection.

Fig. 15 [10] shows an improved version of the LCC resonant converter with the added benefits of:

1) inherent protect ion under short circuit
2) a simple linear controller results in a highly robust feedback control under load changes and the transistor turning off at zero voltage is guaranteed at any load value.

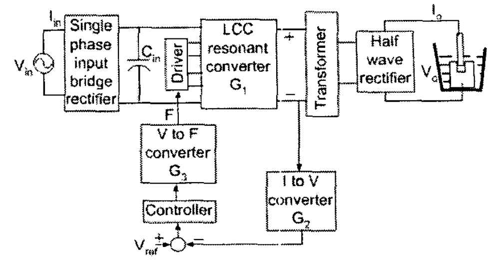

Fig. 15. Basic block diagram of the current controlled EDM power supply system using a LCC resonant inverter

IV. CONCLUSION

Electric Discharge Machining has become one of the most effective methods of machining hard and brittle materials. For proper machining, high MRR, and good surface finish it is essential to have a highly developed power supply system capable of producing the required quality and form of discharges. Controlled amount of energy during the discharge process is essential to ensure high quality and perfection in machining. Starting from the basic R-C relaxation circuit, the main aim is to produce high energy sparks at frequencies ranging from about 3,000 to 10,000 sparks per second. In later years, transistorized and thyristorised controlled pulse generator circuits have been introduced to achieve complete and independent control of pulse duration and pulse energy. The efficiency of such power supply configurations have recently been largely augmented by incorporation of high speed electronic switching and control components such as resonant converters. Latest research is aimed towards incorporating microprocessor/PC based optimization and control schemes for EDM power supply configurations.

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