ELECTRONIC CIRCUIT TECHNIQUES IN ELECTRO-DISCHARGE MACHINING (EDM) EQUIPMENT

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1. Introduction

Electronic pulse power supplies for EDM equipment are considered from the points of view of machining efficiency and electrical efficiency. Secondly, three methods of deriving and processing the feedback signal to instruct the gap control regulator are discussed.

All circuits are evaluated in terms of their potential performance in a production environment.

2. The Instantaneous Effective Spark Gap (i.e.s.).

To facilitate the understanding of various power supply and gap signal processing circuit designs, I have defined the concept of the i.e.s. This is not the shortest distance between the tool electrode and the workpiece electrode, which, in any event in the EDM situation, is an ill-defined quantity. It is an effective distance, valid within the environment of the EDM spark gap, (i.e., a dielectric fluid contaminated with machining detritus), which itself defines the breakdown or pre-sparkover voltage of the spark gap, i.e.

$$V_B = K \times (\text{i.e.s.}) \qquad (1)$$

where K is a constant.

The i.e.s. varies continuously during machining, as a result of the largely random motion of the debris in the dielectric. The maximum value of the i.e.s. is determined by the maximum separation of the electrodes, and the natural contamination of the dielectric. When the electrodes become short circuited, the i.e.s. falls to zero.

3.1. Simplest Arrangement for EDM Pulse Power Supply.

Figure 1 shows a block diagram of the basic functional arrangement. A typical output circuit would use a power transistor with suitable biasing arrangement for the electronic switch. (An alternative arrangement using fast turn-off thyristors is given in Reference 1.) For the lower switching frequencies and higher currents used for roughing in EDM, the transistor can switch 3 - 5A satisfactorily in the saturated mode. For high switching frequencies, it may be necessary to keep the transistor out of saturation; various techniques are available for achieving this. High output currents can be switched simply by paralleling further output stages. It is then desirable to include some emitter resistances to improve current sharing. The arrangement of parallel output switches facilitates a convenient technique to prevent tool and workpiece damage when an abrupt short circuit occurs(2). When the short circuit is sensed, nine out of say ten transistors can be switched out of circuit.

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At least one transistor must remain operational, however, in order that a suitable feedback signal for the gap control regulator may be developed.

The output stage is driven, via buffer stages, by a free-running astable multivibrator, formed by monostables M1 and M2, with S1 in position B. This arrangement is the so-called independent drive system, in that the drive waveform is not dependent on the state of the spark gap. Only under favourable machining conditions can the waveform of Figure 2(c) be maintained. In practice, the waveform of Figure 2(a) is usual, and the corresponding machining rate is reduced. This occurs because the i.e.s. may be too large at the commencement of a potential machining pulse for the available maximum voltage to cause breakdown, and the delay while the i.e.s. reduces, results in a truncated discharge. The operator cannot always adjust the gap control regulator so that a smaller average inter-electrode distance is maintained, (this reduces the range of the i.e.s.), since generally, abrupt short circuiting of the electrodes will occur.

3.2. Increasing the Machining Efficiency.

A problem for the EDM operator is to try to ensure that the selected machining pulse parameters are maintained throughout the job duration: as previously explained, the discharge current duty cycle can vary. However, if the commencement of the discharge is detected electronically, and is then timed, at least the discharge duration can be guaranteed. This system, known as the dependent drive system, shown by the additional circuitry of Figure 1, generally gives a faster machining rate and a well defined surface finish. This becomes clearer if a given i.e.s. variation, is considered, and the corresponding gap voltage waveforms are drawn (Figure 99 of Reference 2). Briefly, it results because there is less waiting time while the i.e.s. becomes small enough for the available maximum voltage to cause breakdown. Relevant waveforms for this system are given in Figure 2(b), and actual photographs from a storage oscilloscope are given in Reference 3. For dependent drive, switch S1 in Figures 1 and 3 should be in position A, when monostable M1 determines the discharge duration, T_{on}, and monostable M2, the minimum gap current 'off' time, $T_{off(min)}$. See also Reference 4.

3.3. Increasing the Electrical Efficiency.

At one time, electrical power consumption was perhaps insignificant in the economics of EDM, but simple considerations show that, with the voltage source and series resistance arrangement of Figure 1, the electrical efficiency is given approximately by:

$$\eta = 25/V_s \times 100\% \qquad (2)$$

and that for $V_s = 80V$, $\eta = 28\%$, i.e. about 70% of the switched power is wasted in gap series elements. This problem results directly from the fact that the physics of the EDM process require the gap to break down at an approximately fixed voltage ~100V, while only 25 - 35V 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 show this to be ~1A), from a 80 - 100V voltage source, and to provide the bulk of the machining current from a current source with a compliance of ~40V. The 1A establishes the arc level voltage, and subsequently allows power flow from the higher power current source. The electrical efficiency of the arrangement can simply be shown to be approximately :

$$\eta = 23/V_c \times 100\% \qquad (3)$$

where Vc is the compliance of the current source, and with $V_c = 40V$, $\eta = 58\%$. Clearly, this represents a most significant power saving. An added advantage of the high electrical efficiency is the corresponding reduction in equipment size. An example is given in Reference 5.

A basic practical design for high electrical and high machining efficiency is shown in Figure 3. Its operation is described in detail in References 2 and 3.

4. Gap Signal Processing Circuitry.

To effectively utilise electrical discharges for machining, an average inter-electrode separation of the order of ~25μm has to be maintained. The corresponding range of the i.e.s. is then suitable for machining with a maximum pre-sparkover voltage ~100V.

Obviously, this inter-electrode separation cannot be sensed with a conventional position transducer, and in practice, either the average value of the gap voltage or current, or their instantaneous values at a suitable point of time, is monitored, processed, and then compared with some reference value, the resulting error signal (if any) being used to instruct the regulator motor to adjust the relative positions of the electrodes. In the following discussions, 'motor' is meant in a general sense, to mean any type of motor or motor and clutch arrangement, including hydraulic, stepping, d.c., etc.

4.1. The Simple Averaging Circuit (AV).

This arrangement, shown in Figure 4, smooths a proportion of the voltage developed across the spark gap. The input to Al is low if the gap is short-circuited, (s/c), requiring electrode separation; an intermediate value, between the s/c and open-circuit, (o/c), thresholds, if machining is stable, (no electrode movement required); and high if the electrodes are o/c, when no discharges or excessively short discharges are occurring. In this case, feed is required.

The circuit has the advantage of simplicity, but suffers from the serious disadvantage of requiring adjustment of the o/c and s/c thresholds whenever the set machining duty cycle is altered. The o/c and s/c thresholds define a 'dead-space' or 'window' in the control band, which is necessary to stabilise the control system.

4.2. The Sample-Hold on Arc Level Detection Circuit (SHA).

This arrangement, shown in Figure 5, largely overcomes the disadvantages of the above circuit, and has a faster response to changing gap conditions. A short time after the commencement of the desired gap current 'on' period, a proportion of the gap voltage is sampled, held on a capacitor and compared with a reference. The arc level voltage remains approximately constant, regardless of the duty cycle of the drive waveform, or the switched current, and a clear differential between o/c, stable machining and s/c conditions can be sensed, even at very low duty cycles. The o/c and s/c thresholds can therefore remain constant for high and low duty cycles, and also for varying switched currents. An associated waveform which is representative of that which would be obtained under good machining conditions is included in Figure 6.

4.3. Pre-Sparkover Level Hold Circuit (PSLH).

When machining with stable electrode materials, and under generally good machining conditions, as discussed earlier, the regulator can be adjusted to control a smaller average inter-electrode distance, and the majority of the potential machining pulses will be fired at the gap for the whole of their intended duration, and with the minimum 'off' time, with both the independently driven and the dependent generators. Under these conditions, it can be seen from Figure 6 that neither the AV circuit nor the SHA circuit produces a signal proportional to the reduction of the i.e.s. as the s/c condition is approached; they only indicate this condition, in the case of the AV circuit, sometime after it has occurred, or in the case of the SHA circuit, immediately after it has occurred. This results directly from the fact that, under these near ideal conditions, the feedback signal is effectively derived from the arc level voltage only, which does not vary significantly with the i.e.s. If a PSLH circuit is used however, the approach to the s/c condition is clearly indicated, and the regulator motor can be suitable instructed, possibly avoiding a s/c. Perhaps more important in EDM practice is the ability of this circuit to signal the approach of the o/c condition, i.e. to indicate when feed is required. (In practice, the majority of the loss of machining time will result from feed delays.)

However, under less favourable machining conditions, when the smaller average inter-electrode distance would result in short circuiting, even if a higher maximum pre-sparkover voltage were made available with a view to controlling a larger average inter-electrode distance, the AV and SHA circuits could not take advantage of this, and a considerable proportion of the job time would be wasted at the o/c condition. By contrast, the PSLH circuit could still provide superior performance, if the regulator is adjusted to hold a pre-sparkover voltage of 100V, with say a maximum of 120V availability. In this case, the corresponding controlled average inter-electrode distance would be large enough to facilitate effective flushing, etc. The loss of machining tolerance and re-distribution of the arc energy between the electrodes associated with this small increase of voltage would appear to be negligible.

5. Conclusions.

The high machining efficiency generator, (dependent drive), is now widely used, and manufacturers claim that improved machining rates and well defined surface finishes result. The simple theoretical considerations presented here confirm this in general, but under good machining conditions, there is little to chose between the dependent and independent systems.

High electrical efficiency supplies do not appear to be widely used at present, but the continuing upwards trend in electricity prices will make them more attractive.

The AV and SHA gap signal processing circuits are in common use, and their respective advantages and disadvantages detailed here have been demonstrated in practice. To the author's knowledge, a sufficiently well controlled series of experiments to confirm the theoretical advantages of the PSLH circuit has not yet been performed.

References.

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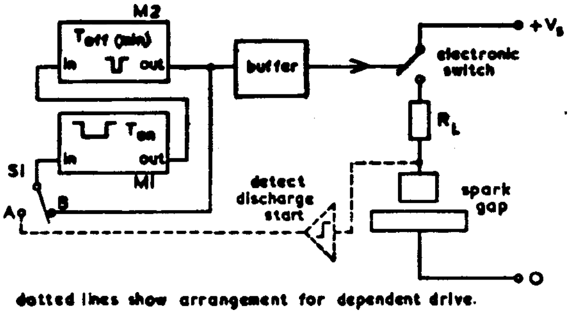

Fig.1. Basic block diagram of EDM supply (dotted lines show arrangement for dependent drive)

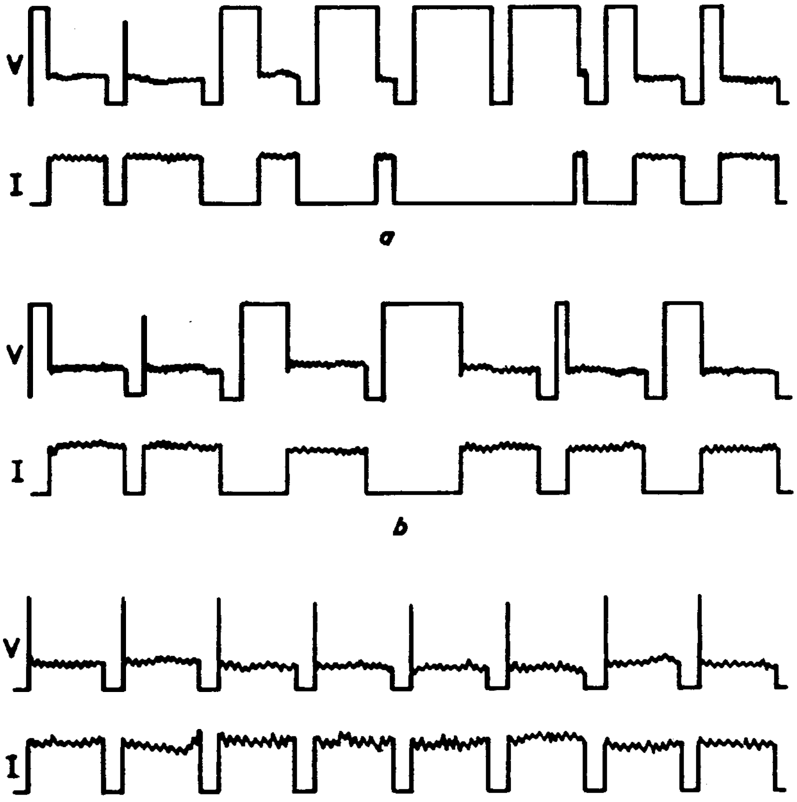

Fig. 2. (a) Typical gap voltage and current waveforms for independently driven supply

(b) typical gap voltage and current waveforms for dependent drive

(c) ideal gap voltage and current waveforms

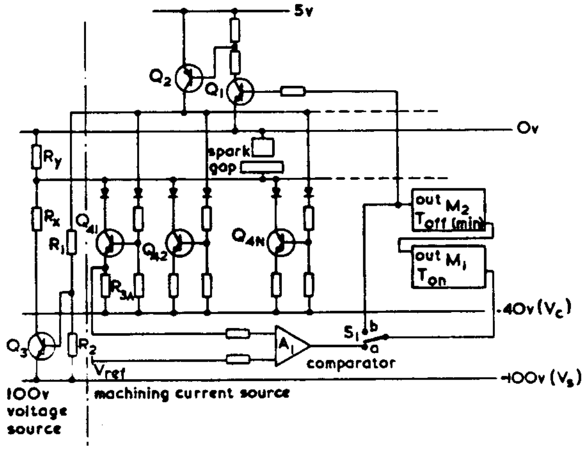

Fig. 3. Circuit diagram of high-efficiency supply

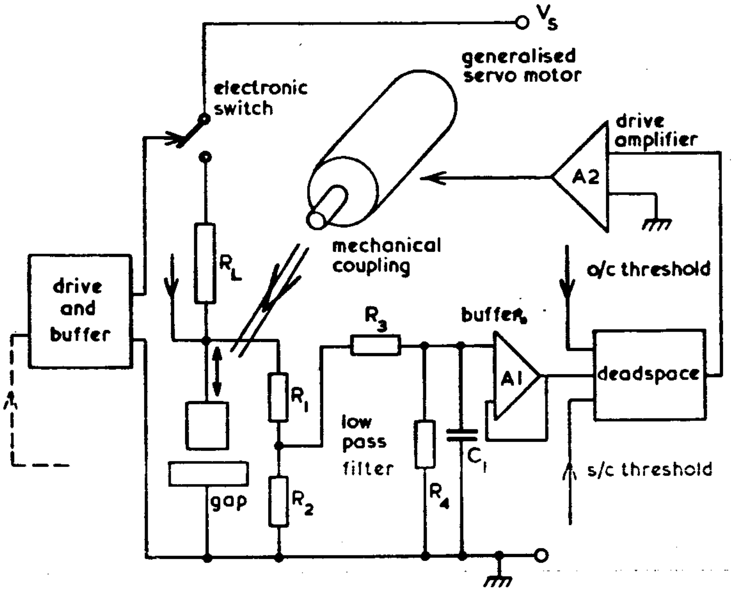

Fig. 4. Gap voltage averaging circuit

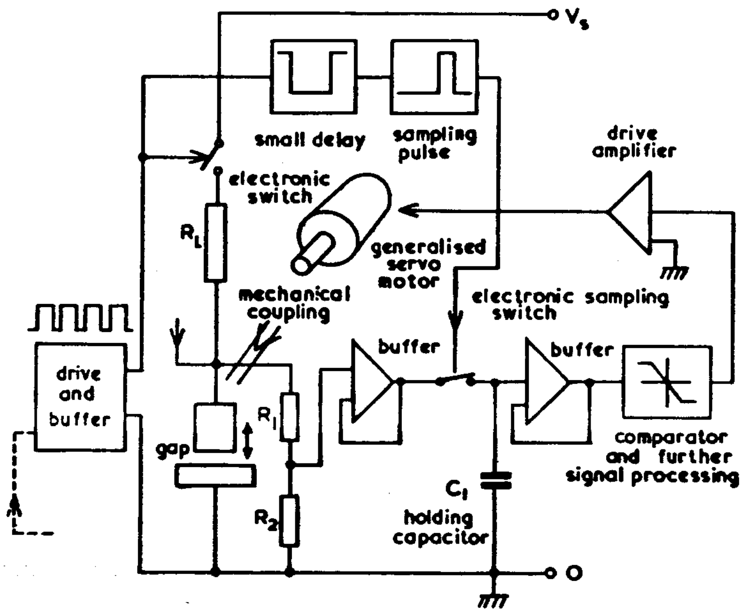

Fig. 5. Sample-and-hold on arc level detection circuit

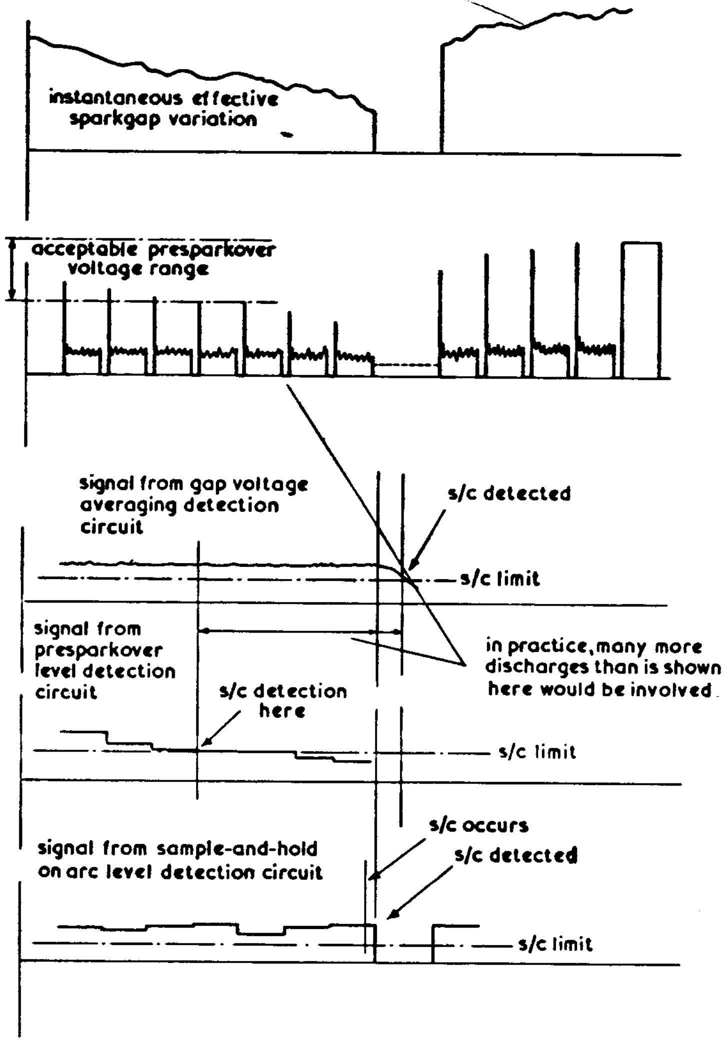

Fig. 6. Comparison of performance of gap signal processing circuit at approach to short circuit condition