A SOLID STATE PULSED COAGULATING DIATHERMY INSTRUMENT [1]

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The spark gap diathermy introduced by Cushing and Bovie in 1928[1] won ready acceptance throughout the surgical world, and has come to play an essential role in haemostasis in all branches of surgery. The fact that present day instruments are basically unchanged from the original design attests to the soundness of that design for achieving its intended purpose. However the advance in electronic technology, particularly in the field of semiconductors, has prompted a reconsideration of the design of coagulating diathermy instruments.

THE INSTRUMENT

An instrument has been designed and built to provide square wave pulses through an isolating transformer. The circuit is shown in Fig. 1, and is simple, inexpensive, and reliable. The power supply is conventional, with full wave rectification from either tap of the transformer providing +20 or +40 volts D.C. selected by switch S_2, which functions as a coarse power control. The large value of capacitance is used to provide the high peak energy required. During initial investigations a variable transformer was placed in the primary circuit to provide adjustable voltages. The pulse repetition frequency is fixed by the unijunction transistor relaxation oscillator, Q_1. The frequency is determined by R_1 and C_1, shown for a frequency of 250 Hz which may be varied by changing R_1 and/or C_1. The unijunction transistor provides a stable frequency over a wide temperature and voltage range. Triggering of the monostable multivibrator is through control switch (foot pedal), S_3, which passes the 2 volt pulse from Q_1. By placing the control switch at this low current-low voltage point in the circuit all danger to the operator is obviated.

The monostable multivibrator, Q_2 and Q_3, determines the pulse width and drives the output stage, Q_4 and Q_5. The pulse width is determined by R_2, R_3 and C_2 and is adjustable from approximately 20 to 80 microseconds. This adjustment is used as a fine power control.

Output is through a 1:10 step-up pulse transformer which provides a high degree of electrical isolation and the requisite pulse amplitude. Series resistor R_4 limits the output current and protects the circuit against the overload which would otherwise occur when the output is shorted. Vibration in the output transformer produces an audible note, providing a useful indication that the instrument is operating.

The forceps for bipolar coagulation were made by separating the blades of a pair of Gerald forceps at their junction, then rejoining them with a sheet of ½ mm. nylon interposed, using two nylon nuts and bolts. One wire was then attached to each blade, and polyolefin tubing shrunk over the whole junction.

The whole instrument fits in a cabinet 4X5X6 inches overall.

RESULTS

The bipolar configuration has been utilized for the diathermy forceps in this initial phase of development of the instrument, as the power required is much lower than with unipolar coagulation.[2,5]

The ability to obtain haemostasis and coagulate tissue with this instrument has been tested in living tissue of anaesthetized cats and rats. Particular attention has been paid to haemostasis in brain. The effects were compared with "ordinary" coagulation with a Bovie unit and were considered satisfactory only if coagulation was at least as good as with that instrument.

Each of the parameters of voltage, pulse width, and repetition rate was varied in turn.

On hundred and fifty volts was the minimum voltage at which coagulation would occur, but it was inconveniently slow at this level. Two hundred volts provided efficient and steady coagulation of brain, small and large (up to 3 mm.) arteries and veins, and small "bites" of muscle. Four hundred volts provided good haemostasis in large "bites" of muscle and was satisfactory for coagulation on the surface of the brain but was less satisfactory for coagulation of vessels than was 200 volts. The reason for this is that at 200 volts "white coagulation" occurred, but at 400 volts "fulguration" -- sparking causing charring and burning -- was the predominant effect. These different types of coagulation have been discussed recently by Mitchell and Lumb.[6,7] The voltages specified are the open circuit voltages (measured with a Tektronix 532 oscilloscope with type D differential plug-in amplifier) across the ~~forceps~~ transformer output. The voltage drops, during coagulation, by an amount dependent upon the impedance of the tissue and the value of the series load resistance. Tissue impedance is of the order of 200 ohms, but varies with the type of tissue, size of the "bite," and stage of coagulation. Figure 2 shows the voltage waveform appearing across tissue during coagulation.

The repetition rate was varied in the range from 100 HZ to 20 KHz.

At each repetition rate the pulse width was varied in the range 1 μsec. to 80 μsec. The stimulating effect was found to be equally marked at any repetition rate or pulse width, and approximately the same as with a Bovie instrument. Our initial premise was that the duty cycle (the ratio of pulse width to pulse spacing) would be the most important factor with regard to these parameters, but this was found not to be true. Rather, each parameter manifested a separate and largely independent effect.

Repetition rate affected mainly the quality of the coagulum, high rates (500 Hz and higher) causing stickiness with consequent adherence of tissues and tearing on withdrawal of the forceps. Lower repetition rates (250 Hz and lower) provided cleaner haemostasis and coagulation, and for this reason a fixed repetition rate of 250 Hz has been adopted in the present design.

Pulse width affected the rate of coagulation virtually independently of repetition rate. Pulses of between 40 and 80 μsec. were practical values, the shorter time being appropriate for very small vessels, the longer time for bigger vessels. Eighty μsec. was the widest pulse obtainable at 200V with the output transformer used. This widened to a maximum of 100 μsec. as the waveform degraded under load (Fig. 2). Even wider pulses still would probably be necessary if monopolar coagulation were to be performed in this way.

Pulse width variation was utilized as the method of power control since this provided a smooth gradation of power without variation in quality. Change in quality of coagulation (as stated above) was provided by switching the voltage level.

Instantaneous power was calculated by measuring the voltage drop across the series load resistor with the oscilloscope and from this, instantaneous current during coagulation was calculated. This varied with conditions, but was approximately 1 amp. Thus the total instantaneous power at 200 volts was 200 watts (half of this being dissipated in the series load). The average output power however was approximately 4 watts, because no current flowed during the intervals between pulses.

Grounding of the instrument is to the negative side of the power supply. (Grounding either side of the output would seriously impair bipolar coagulation.)

The EKG was monitored during coagulation, and no interference with the trace occurred, even when pectoral muscles were coagulated. To test for radio and T.V. interference, the instrument was operated adjacent to, and from the same power point, as a domestic television receiver and domestic AM radio. There was no effect on either receiver.

DISCUSSION

The operating parameters of the present instrument help to clarify the mode of action of spark gap machines. These latter instruments produce a damped train of waves which we have observed (on a Bovie instrument under typical neurosurgical conditions) to have a fundamental frequency of about 3 MHz, a peak to peak maximum voltage of about 1200, a duration (for the train) of about 5 μsec. and a repetition rate of 120 Hz.

(The repetition rate with a 50 Hz main supply would be 100 Hz.)

Most previous authors[1,3,4,6,7] have pointed out the importance of the damped waveform for achieving good coagulation, but have not always emphasized that the duty cycle is extremely low.

The present instrument also produces short pulses of high energy with a low (250 Hz) repetition rate, but with a very different waveform. The coagulation obtained in this way appears to be in every way similar to that obtained with spark gap machines and we therefore feel justified in concluding that the actual waveform is less important than the mode of energy input, which is brief high energy pulses separated by relatively long inactive periods. With this type of energy input, an extremely rapid rise in temperature would occur at the forceps tips at the time of the pulse, the relatively long quiescent interval would permit heat transport mechanisms (conduction and blood perfusion) to maintain adequate cooling of even very closely adjacent tissue.

The peak power in the pulses of the present instrument is 200 watts, but with a 2% maximum duty cycle, the total average power is only 4 watts. This is considerably less than spark gap instruments, reflecting a higher efficiency of the present circuitry. However, the power output of this instrument in its present form is inadequate for monopolar coagulation, which requires at least 5 times more power than the bipolar configuration.[5]

The elimination of the spark gap removes the fire danger from the instrument itself, but as sparking will still occur at the forceps tips, this danger can never be totally eliminated.

The absence of interference with other electronic devices is a valuable asset of this instrument. Spark gap instruments generate energy in a broad frequency band up to 5 MHz[7] and high voltages exist throughout the circuit, permitting radiation from internal and external leads, and reflection into the power lines. In this instrument the high voltage (200 to 400) appears only in the secondary of the output transformer which is very well isolated from ground and the mains supply.

The main reason for lack of EKG interference is, however, the use of the bipolar configuration, as there are thus no currents flowing through the body towards a remote indifferent electrode.

SUMMARY

A solid state pulsed coagulating diathermy instrument is described. The operating parameters of this instrument have been investigated for bipolar coagulation.

The advantages of this instrument over spark gap instruments are lower power requirement, smaller physical size, lessened fire danger and elimination of EKG interference (when used with the bipolar configuration).

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CAPTIONS FOR FIGURES

Fig. 1. The circuit of the instrument in its present form.

Fig. 2. The waveform appearing across tissue during coagulation. The grid represents 1 cm. squares on the face of a Tektronix 532 oscilloscope, using a type D plug-in unit, with differential input.

a. A single pulse. Calibration: vertical 10V/cm. Horizontal 50 μsec./cm.

b. Three separate pulses. Calibration: vertical 10V/cm. Horizontal 1 msec./cm.