Med. & Biol. Eng. & Comput., 1983, 21, 654–656

Technical note

True r.m.s. volt/ammeters for surgical diathermy measurements during an operation

Keywords—*Diathermy measurements, Surgical diathermy*

1 Introduction

THE RISK of skin burns and the disturbance of electromedical equipment by high frequency currents are two important problems linked with the use of surgical diathermy in the operating room. In order to examine the risk of such incidents it is necessary to measure the high frequency voltages and currents *in situ* at the patient and the equipment.

The conditions of measurement are special, both because of the particular procedures followed in an operating room, and the special effects of the high frequencies used (0·5–5 MHz). The effective measurement time is only a few seconds, often at long intervals apart. The values fluctuate widely during the brief time the diathermy unit is active. Attempting to change the instrument measuring range during this period is often of little use; therefore a set-up which measures three or four voltages and currents simultaneously is very useful. The accuracy requirements are not critical, it is sufficient to know the current or voltage with a precision of ±25%. Because of the high frequencies used and the self-inductance of the leads, the values will be dependent on the exact position of the measuring points. In addition it is not always possible to have access to a preferred measuring point during an operation. Care must be taken to ensure that the measuring instruments introduce as small additional capacitance and inductance as possible. Instruments should therefore be small and independent of the mains supply.

The risk of skin burns is related to the high frequency power and the measuring instruments must respond to the true r.m.s. value. The crest factor may be > 10 and the peak potential several thousand volts. In contrast, the disturbance of electromedical equipment probably depends more on the peak value than the r.m.s. value. Peak measurement methods will not be dealt with here.

2 Measuring principles

Generally, high frequency true r.m.s. electronic voltmeters cannot be used in all cases. The maximum full scale crest factor they can tolerate is usually around 5–10 and this is not sufficient for spark gap and modern high crest factor generators. Clip-on current probes like the Hewlett Packard model 1110 are very convenient but our experience is that a current probe connected to an electronic voltmeter picks up so much noise from high crest factor generators that a reading is obtained just by approaching the probe to the high frequency current-carrying lead. On the other hand a current probe and an electronic voltmeter constitute a very efficient single value measuring instrument with low crest factor generators.

For general application the usual approach has been to use thermocouple instruments (DOBBIE, 1969). They fulfil many of the necessary requirements already mentioned. They are small and simple and do not depend on electronic amplifiers so vulnerable to high crest factor, high frequency signals. However, they have two distinct disadvantages:

the scale has a square-law characteristic, the dynamic range is therefore limited, usually with no reading below 20% of full scale value

they are rapidly destroyed at small overloads.

Two simple constructions will be described which largely overcome these problems.

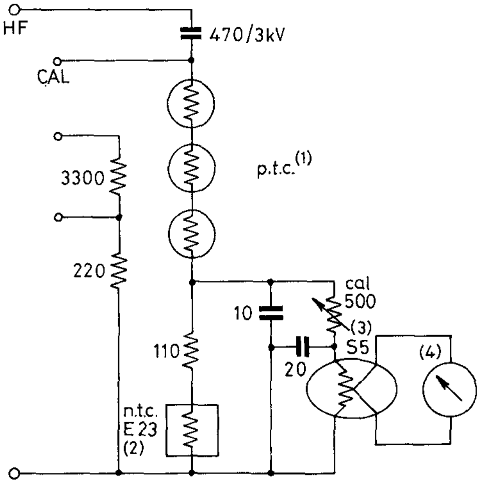

Fig. 1 *Voltmeter circuit. Values in ohm and pF.* (1) *bare lamp bulbs* 110 *V*/20 *mA.* (2) *ITT, vacuum thermistor.* (3) *thermocouple, max input* 2·5 *mA plus permissible overload* 250%, *made by Best Prod. Felixstowe, Suffolk.* (4) *moving coil instrument, full scale* 13 *mV,* $R_i = 10\,\Omega$

3 Voltmeter

A combination of positive temperature coefficient (p.t.c.) resistors in series and a negative temperature coefficient (n.t.c.) resistor in parallel with the thermocouple is used to retain the true r.m.s. response while changing the scale characteristic, extending the dynamic range and protecting the thermocouple. Small 110 V/20 mA lamps were chosen as p.t.c. resistors. They increase their resistance approximately 10-fold from cold to the nominal burning condition. A full scale of 24 mA for the thermocouple–n.t.c. resistor combination has been chosen, so that the lamps also act as a fuse. Fig. 1 shows the circuit diagram and Fig. 2 the

First received 1st March and in final form 26th November 1982

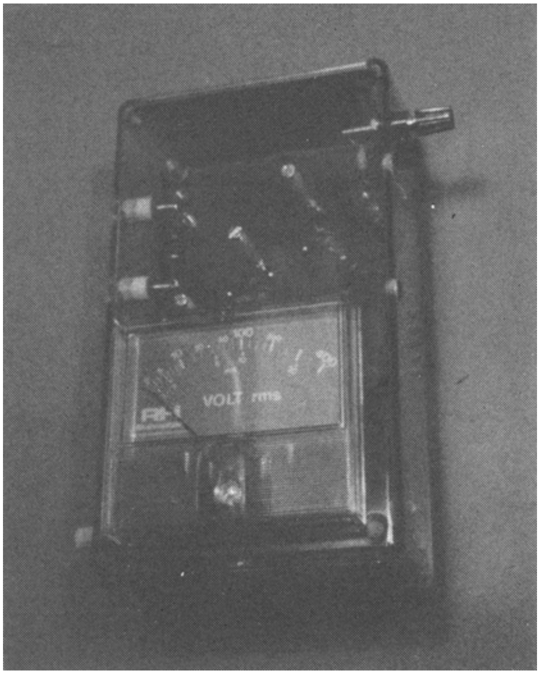

Fig. 2 *The voltmeter*

instrument. From the scale shown in Fig. 2 it can be seen that the p.t.c./n.t.c. resistor combination more than cancels the square-law characteristic. The scale is quasilogarithmic and expands in the most interesting range of patient safety measurements (10–100 V). Because of the high frequencies and potentials the lamp holders were omitted and the lamp metal threads were also removed. The bare lamp bulbs were soldered directly into the circuit. The capacitance of the lamp holders with ordinary lamps was approximately 4 pF, measured with the filiment cut off. This corresponds with a capacitive reactance of about $40\,\mathrm{k\Omega}$ at 1 MHz, which would increase the reading by about 10% with the lamps burning at nominal voltage. With the bare lamp bulbs the capacitance is reduced to about 0·4 pF, this moves the frequency of 10% increased reading to 10 MHz. To cancel this increase the two capacitors shown in Fig. 1 were inserted. They overcompensate at smaller potentials where the lamp resistance is lower. At readings around 10 V the reading is 10% down at approximately 4 MHz. The frequency response was checked both with a signal generator and different diathermy units. The light from all three filaments was controlled and was of equal intensity, and the glow corresponding with a certain reading was equal, both with the d.c. and high frequency current. This was the case with the 2·5 MHz signal from the cut generator and the spark gap coagulation generator of an old Wappler model C 263. With the coagulation generator the readings were completely false without the aforementioned capacitors. This is in agreement with the results of Dobbie (1969) who found considerable amplitudes from a spark gap generator at frequencies above 10 MHz. With the Wappler coagulation generator, which has a crest factor > 10, it was also checked that the three lamps in series were able to withstand the no-load maximum peak voltage, approximately 5000 V. The response time of the meter is determined by the time constants of the p.t.c./n.t.c. resistors and the thermocouple/moving coil instrument. These time constants are not equal and somewhat dependent on the current level, but the total system is always overdamped with a period of between 2 and 3·5 s to reach 90% of true reading. The r.m.s. value is defined as the square root of the *average* value of the squares of the instantaneous values, the meter time constant determines the lowest frequency for which this averaging is effective. Because the meter has d.c. response it will have (as all thermocouple instruments) a frequency band for which the reading is wrong, in our case the band 0·02–1 Hz. The lowest modulation frequency used in commercially available diathermy units is 50 Hz, this therefore introduces no noticable error. On the other hand too short a measuring time and fluctuating amplitudes may introduce obvious errors. It must also be taken into consideration that the input resistance of the meter is dependent on the r.m.s. level, from about $2{\cdot}2\,\mathrm{k\Omega}$ at 0 V to $16{\cdot}7\,\mathrm{k\Omega}$ at 400 V.

A safety capacitor in series with the input terminal is important to prevent rectified l.f. currents passing via the voltmeter. Be aware of the danger to the patient if a voltmeter with low d.c. or l.f. impedance is connected across the output terminals of a surgical diathermy unit! A direct terminal which should not be used during an operation is provided for calibration and l.f./d.c. measurements. The meter should be calibrated once a year, for example, with a Hewlett Packard meter calibrator model 6920B, at d.c. or 50 Hz. Owing to the p.t.c./n.t.c. resistors the meter has a negative temperature coefficient which is level-dependent but less than 3% per °C. Calibration should therefore be carried out close to the expected operating room temperature.

Two additional non-inductive resistors were incorporated in the instrument. They can momentarily be connected in parallel with the input. From the voltage drop a rough estimate of the source impedance can be obtained.

The overall accuracy of the instrument is dependent on many factors. Because of the semilogarithmic scale it is better to relate the accuracy to the reading than to the full scale valve. In the range 5–400 V an overall accuracy of ±20% of reading is feasible.

4 Ammeter

It is difficult to obtain the same degree of protection and increased dynamic range in an ammeter design without a considerable increase in voltage load. Only the effect of parallel n.t.c. resistors has therefore been utilised at some sacrifice of dynamic range. Instead of p.t.c. lamp resistors an ordinary fuse is incorporated to protect the thermocouple.

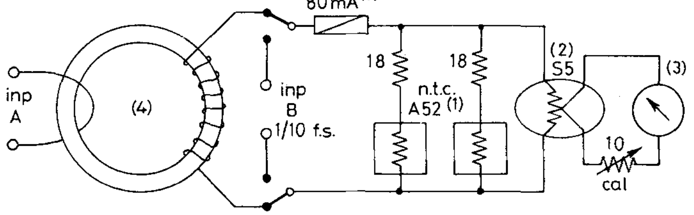

Fig. 3 *Ammeter circuit. Values in ohm.* (1) *ITT, vacuum thermistors.* (2) *same thermocouple as used in voltmeter.* (3) *same as in voltmeter.* (4) *Siemens B64290-A0040-X830.* (5) *fuse, slow-blow medium type for minimum voltage drop*

Fig. 3 shows the circuit and Fig. 4 the instrument. The input can be chosen either directly from the input terminals (full scale 120 mA) or from a ferrite ring core (full scale 1200 mA). The ring has an inside diameter of 42 mm and is used as the core of a current transformer with 10 turns on the secondary winding. The lead with the unknown current is put through the ring one or more times. The highest sensitivity with one turn is 20 mA and the sensitivity is proportional to the number of primary turns. The primary potential difference (voltage load) is about 0·2 V r.m.s. at full scale with one primary turn, in the direct input mode it is about 2 V.

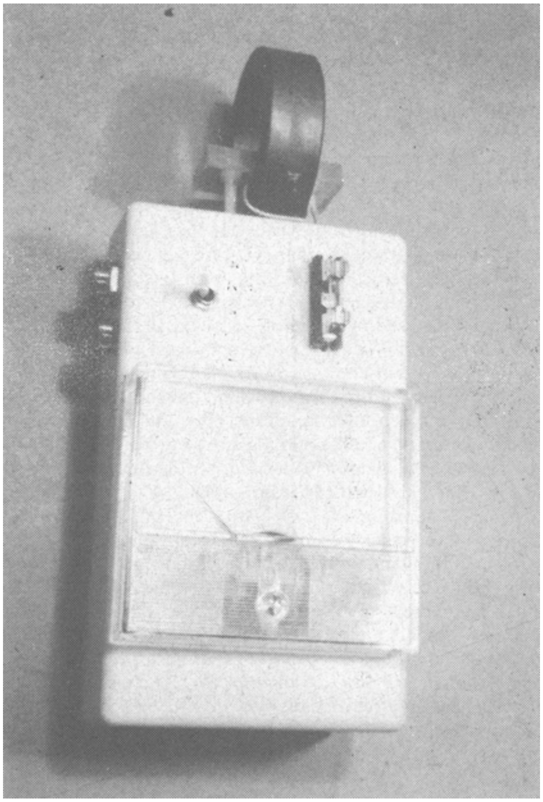

Fig. 4 *The ammeter*

At low levels the meter is overdamped with a period of about 2 s to reach 90% of true reading. At high levels the meter is underdamped, with a period of 3–4 s to reach 90% of true reading (from above). The meter cannot be used in the frequency range 0·01–1 Hz in the direct input mode. With the transformer the low frequency limit (−10%) is about 0·1 MHz and the upper limit above 5 MHz. The meter is calibrated in the direct input mode at d.c. or 50 Hz. The overall accuracy is similar to that of the voltmeter.

5 Typical results and conclusion

Laboratory measurements and those taken during an operation have shown that the instrument can be used with all kinds of diathermy units. Results in operating rooms have shown that the patient potentials and the currents in the patient leads may vary within wide limits. It is rare to find potentials <5 V between the operating table and the patient, or currents in patient leads <5 mA. Particularly when the potential or current is derived from sites near the operating field the levels are high. Often the patient potential with respect to the operating table is in the range 20–40 V, and the current in the e.c.g. leads 20–50 mA. This is in accordance with model experiments (GRIMNES, 1978) and earlier measurements made during an operation (DOBBIE, 1969). It can therefore be concluded that it is not possible to operate within absolutely safe limits because the high frequency currents are never zero in patient leads during activation. They are at a certain distance from the burn region according to the actual area of contact, current duration and current magnitude. This is why it is important to measure and assess these parameters, especially when some well introduced procedure is changed.

S. GRIMNES

Department of Biomedical Engineering
Rikoshospitalet
Oslo
Norway

References

DOBBIE, A. K. (1969) The electrical aspects of surgical diathermy. *Biomed. Eng.*, **4**, 206–216.

GRIMNES, S. (1978) Analysis of the choke-earthed surgical diathermy circuit. *Med. & Biol. Eng. & Comput.*, **16**, 451–453.