Two Methods of Approximating Non-linear V-I Arc Characteristics in Electrosurgery

A.D. Rothwell[1], J.R. LaCourse[1], and S.M. Selikowitz[2]
[1] Electrical and Computer Engineering Department, Kingsbury Hall, University of New Hampshire, Durham, NH
[2] Veterans Administration Hospital, White River Junction, Vermont (Department of Urologic Surgery)

ABSTRACT

Although there is limited knowledge of the behavior of high frequency current and voltage of electrical arcs created between the electrode and tissue, electrosurgery has been extensively utilized for many years. In order to gain more insight to the nature of the electrical arcs, V-I characteristics are examined for several input voltages. Functions are approximated, from these non-linear curves, using two methods in order to comprehend the behavior of these parameters. By obtaining a relationship in this manner, one can begin to determine a range of parameters which maybe both safe and effective.

INTRODUCTION

Though electrosurgical instrumentation has been utilized extensively in the medical field for well over fifty years, little is known of the actual electrosurgical behavior of these devices. This ignorance has resulted in electrical hazards, including burns, shock, and involuntary muscle stimulation, which affect patients and surgeons during surgery. Much of these hazards are possibly due to the unknown nature of the high frequency current and voltage of the electrical arc created between the electrode and tissue [1]. Therefore, by examining the characteristics of the output voltage (V) versus the output current (I) of the electrical arc during simulated surgery for several input (sinusoidal) voltages (VI), a relationship of these two parameters may possibly be determined.

Initially, the relationship is examined by separating each curve into two regions, a discharge and nondischarge region. A linear function is fitted using least squares for each region. By taking the inverse of the slope of each equation estimated, the impedance is studied for increasing input voltage. In addition, by treating each curve as a complete relationship, a non-linear least squares approximation is executed which estimates the relationship as a third order polynomial.

By executing two different methods, it is anticipated that a clear correlation between voltage and current for each input voltage will become apparent. Consequently, a foundation can be established for this relationship in which one can begin to develop a range of parameters that are both safe and operative.

MATERIALS AND METHOD

Data are obtained with the simulated electrosurgical unit (ESU) [2]. The ESU is simulated using a Hewlett-Packard 675A sweeping signal generator driving an ENI A-300 RF power amplifier. A transformer is present at the output of the power amplifier which is then coupled to the electrode and to the ground plate. Attached to the electrode is a commercial cutting loop that is typically used in electrosurgery. The ground plate is used in order to direct the current path to ground. This will ensure that arcing will not occur at any point other than at the desired location of the cutting loop. The cutting loop is drawn through the tissue using a DC motor at an adjustable constant speed. In an effort to maintain constant voltage, a row of four light bulbs in parallel with the transformer act as a resistive load.

As a model for the tissue, bologna of a constant thickness is immersed in a bath of glycine. The cutting loop is also submerged in this bath and makes contact with the sample of bologna. A constant frequency of 700 KHz is used which is consistent with the typical radio frequency range used in surgery.

Data are obtained by varying the input (sinusoidal) voltage (VI) and observing the output voltage (V), between the cutting loop and ground, and output current (I) during cutting. The output current (I) through the electrode is measured using a Tektronix AM 503 active current probe amplifier. Both parameters are displayed on one oscilloscope with the current inverted for convenience. These current-voltage curves are determined for seven different input voltages, VI equaling 1000-2200 V peak to peak in steps of 200 V peak to peak. The raw data are in the form of seven photographs, one for each value of VI. An example of this raw data is present in Figure 1.

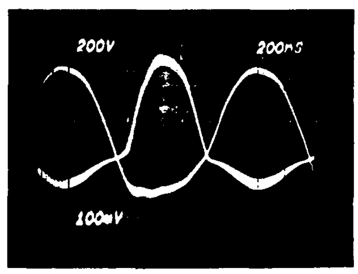

Figure 1: Voltage-current curve for input voltage of 1600 V peak to peak.

RESULTS

Data, extracted from the raw data, are normalized and averaged at fifteen particular locations on each photograph. The V-I arc characteristics are found for each value of VI. An example of this data

CH2997-5/91/0000-0251$01.00©1991 IEEE

is shown in Figure 2.

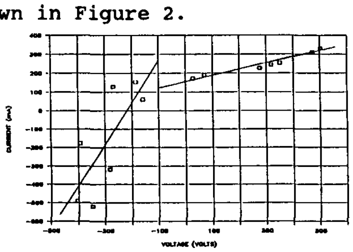

Figure 2: Experimental data (squares) and the two linear approximations for an input voltage of 1600 V peak to peak.

It is evident from these curves that the relationship between the output voltage (V) and the output current (I) is non-linear.

In an effort to estimate this relationship, initially each curve is separated into two regions, a discharge and nondischarge region. For each region, a linear function is approximated using the technique of least squares [3]. An example of this approximation can be seen as two straight lines with the experimental data in Figure 2. In this way, two linear functions are estimated for each input voltage (VI). It is evident from these results that the sets of linear equations approximate the experimental data remarkably well. In addition, by taking the inverse of the slope of each linear function estimated, the impedance is studied for an increasing input voltage (VI) in each region. It is evident from these results that the impedance becomes relatively constant at a certain value of input voltage (VI) in the discharge region. In addition, the impedance increases to a very large value when the input voltage is about 2000 V in the nondischarge region. More research needs to be completed in order to comprehend the full significance of these results.

In order to treat each curve as one entire relationship, a non-linear least squares approximation [3] is executed which estimates the relationship as a third order polynomial. The V-I characteristics for each value of input voltage (VI) are evaluated and are compared to the experimental data. An example of these results is presented in Figure 3. Note that the lines joining the data points to the x axis are due to the plotting program itself and should be ignored.

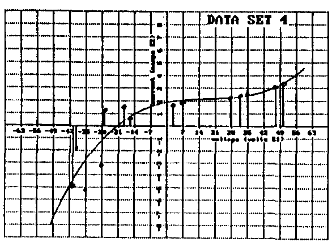

Figure 3: Non-linear third order approximation.

It is evident from these results that the approximated function fails to go through the origin. This offset may be due to the fact that more negative voltage is present compared to positive. This DC offset could possibly be the cause of the electrical hazards. It can be inferred that the offset is due to the difference dielectric compositions of the electrode, the tissue and the gap between the two. Overall, this approach is advantageous for it captures the complete nature of the electrical arc.

By executing these two different methods, one can see a prominent relationship between voltage and current for each input voltage. Consequently, a basis for the relationship is established in which one can begin to develop a range of parameters that are both safe and effective.

CONCLUSION

There are several deductions to be drawn from this work. First, it is evident that the electrosurgerical arc has a well defined V-I characteristic that is highly dependent on the amplitude of the sinusoidal input voltage (VI). Secondly, by dividing the characteristic into two sections, a discharge and a nondischarge region, a linear estimation can be accurately made for each region. With these results, the discharge and the nondischarge behavior of the electrical arc can be estimated. Finally, a non-linear third order polynomial is approximated which may inturn capture the overall behavior of the electrical arc. In addition, it is inferred that the DC offset could be the cause of the electrical hazards experienced by patients and surgeons during surgery. By approximating the V-I arc characteristics, one can begin to determine the realm of parameters which will inflict minimal injury to the patient.

ACKNOWLEDGEMENTS

The simulated electrosurgical unit was built under the Veteran's Administration Merit Review Grant 03-8495. In addition, raw data were taken by two undergraduates, Stephan Kruger and Paresh Suthar, in the summer of 1990. Graphs were executed using the plotting routines of Lotus 1-2-3 and PC Data Master.

REFERENCES

[1] Cook, Albert, M., Webster, John G., Therapeutic Medical Devices, Application and Design, Prentice-Hall, Inc., New Jersey, 1982.

[2]LaCourse, J.R., Gerhard, G.C., Selikowitz, S.M., "Arc Characteristics During Simulated TUR", in Proceedings of the 25th Annual Association for the Advancement of Medical Instrumentation Meeting, 1990.

[3] Parsons, Robert, Statistical Analysis: A Decision-Making Approach, Harper & Row, Publishers, New York, 1974.