ELECTROMUSCULAR INCAPACITATING DEVICES

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Abstract: An electromuscular incapacitating device (EMD) temporarily incapacitates combative individuals so they can be apprehended with minimal harm to themselves, bystanders, or law enforcement agents. Many newpaper articles [1] have suggested that EMDs can kill those apprehended. A peer reviewed study on anesthetized swine reports that there is a large safety factor that prevents EMDs from killing [2]. Biomedical engineers, with knowledge of the effects of electricity on the body can provide information to clarify this conflict.

Introduction

An electromuscular incapacitating device (EMD) presents law enforcement with another less-lethal option for subduing violent individuals who pose a threat to themselves and others. More commonly known as stun guns, or as a Taser®, they deliver a high voltage electric charge that disrupts the nervous system, causing the suspect to lose control and fall to the ground. Less lethal weapons are designed to temporarily incapacitate, confuse, delay, or restrain an adversary in a variety of situations.

Methods

It is useful to understand the operation of EMDs. All generate voltages of about 50 kV, currents of about 2 to 15 A, pulse durations of about 10 to 50 μs, repetition rates of about 20 pulses/s, for about 5 s, and can ionize an air gap to form an arc about 50 mm long. Early EMDs, called stun guns, required close contact with the person, and since the electrodes are about 50 mm apart, only affected a small target area. Later EMDs used a compressed gas propellant to fire barbed darts with trailing insulated wires about 7 m long at an 8° angle so the darts would stick on clothing or the skin a distance of about 50 cm apart to cause muscle contraction and pain over a larger group of muscles. Fig. 1 shows a typical circuit for the Taser M26 [3]. The battery drives a 500 Hz oscillator with transformer step up from 2.5 to 6 V up to 2 kV, which is rectified and forms a high-voltage power supply to charge up the capacitor. When the capacitor voltage reaches about 2 kV, the spark gap breaks down and the 2 kV is delivered across the primary of the transformer, which steps it up to about 50 kV, which will ionize an air gap of 50 mm. If the barbs strike the skin, the 15 A through the typical body resistance of 300 Ω yields 4500 V. If the barbs strike clothing, the arc jumps through the air but the body voltage is still 4500 V. Numerous groups of skeletal muscles contract, and the person loses his ability to maintain an erect, balanced posture and falls to the ground and is temporarily incapacitated.

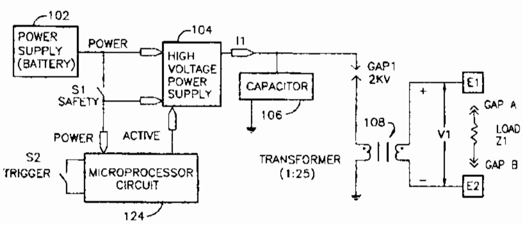

Fig. 1: When the 0.88 μF capacitor voltage reaches 2 kV, the spark gap breaks down. The 1:25 transformer creates 50 kV. From [4].

The effective charge delivered to the subject that might excite the heart and cause ventricular fibrillation (VF) is contained in the first one-half sinusoidal waveform and is 9 μs duration times 15 A peak times 0.63 (to convert to average current) = 85 μC.

Fig. 2 shows an improved Taser X26 EMD [3]. Capacitor 1 generates 50 kV at the output to break down the air resistance. Then capacitor 2 provides a sustaining current at lower voltage. The result is lowered battery requirement.

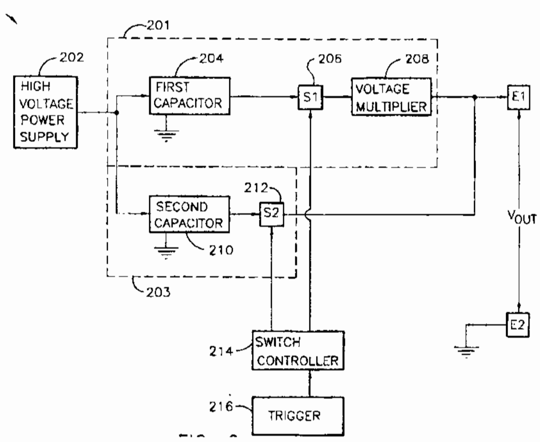

Fig. 2: 0.07 μF capacitor 1 breaks down the air gap in 1.5 μs (arc phase). 0.01 μF capacitor 2 yields a 50 μs low voltage sustaining current (stim phase). From [4].

Fig. 3 shows a standard waveform of about 2 A for about 50 μs for a charge of 100 μC. The larger currents were used to determine cardiac safety factor, which varied from 15× to 42×, as swine weight increased from 30 to 117 kg.

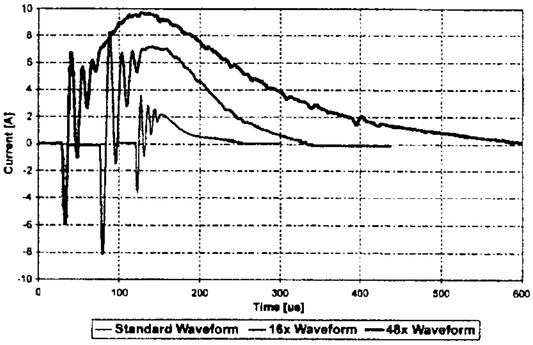

Fig. 3: The standard waveform from the TASER model X26 EMD delivers about 2 A for about 50 µs. From [2]

Results

To estimate safety, we can use [5] Fig. 22. For durations of 1000 µs there is no VF up to 1.4 A (1400 µC). For durations of 100 µs there is no VF up to 7 A (700 µC). While a durations of 9 or 50 µs are not on Fig. 22, extrapolation would yield no VF well in excess of the M26, 85 µC or X26, 100 µC. [5] Fig. 18 shows that for the low duty cycle of less than 0.1, the threshold for VF for multiple shocks as used in the Taser does not change.

Geddes and Baker [6] have developed the strength-duration curve shown in Fig. 4. They estimate the time constant τ for cardiac muscle is about 2 ms. For an EMD duration of 50 µs, current must be increased over that required for long durations by a factor of 50 to cause cardiac excitation.

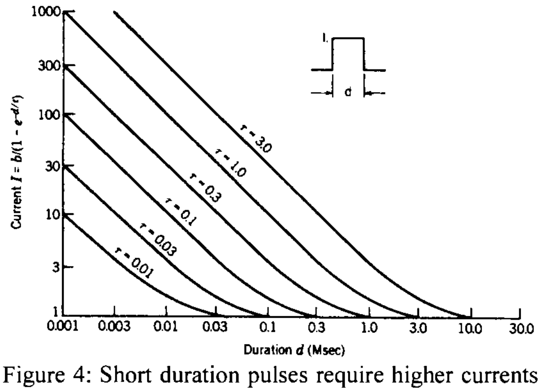

Figure 4: Short duration pulses require higher currents to cause excitation. From [6]. Charge $Q = Id$ remains constant for short pulses.

Skin depth for human tissue is (460 m)/(square root f), where f = frequency [7]. For M26, f = 1/(18 µs) = 55,000 Hz. Skin depth = 1.96 m. Thus there is little skin depth effect in human tissue at Taser frequency.

Discussion

We are developing a computer model of currents that flow through the body in response to EMD darts at a variety of locations. Intuition suggests that a dart is more likely to induce VF if near the heart rather than farther away. We will map the contours of cardiac safety factor for inducing VF. We will verify the model by tests in which we place a 64-electrode Constellation catheter within the anesthetized swine heart. We will also test larger currents from the surface as shown in Fig. 3 and develop a bench test for any EMD.

If the EMD electric shock induces VF, the blood pressure would drop to near zero in about 5 s [8]. The human would lose consciousness within 30 s, which does not occur in the large majority of deaths following EMD. We conclude that the electric shock did not directly cause VF. Alternative hypotheses for death following EMD shock include positional asphyxia, skeletal muscle damage causing hyperkalemia and acidosis, heat, and drugs [9].

References

[1] BERENSON, A. (2004): 'As police use of Tasers rises, questions over safety increase', The New York Times, **CLIII (52,914)**, Sunday July 18

[2] MCDANIEL, W. C., STRATBUCKER, R. A., NERHEIM, M., BREWER, J. E. (2005): 'Cardiac safety of neuromuscular incapacitating defensive devices', *PACE* Supplement 1, **28**, pp. S284-7

[3] Taser M26 and X26 manuals http://www.taser.com/index.htm

[4] NERHEIM, M. H. (2004): 'Electronic disabling device', International patent application WO 2004/073361 A2

[5] IEC (1987): 'Effects of current passing through the human body IEC 479-2, 2nd ed.', (International Electrotechnical Commission, Geneva)

[6] GEDDES, L. A., AND BAKER, L. E. (1989): 'Principles of applied biomedical instrumentation' 3rd ed., (John Wiley & Sons, New York), p. 460

[7] F. OLYSLAGER AND D. DE ZUTTER, Skin effect, in J. G. WEBSTER (Ed.): Wiley Encyclopedia of Electrical and Electronic Engineering, (John Wiley & Sons, New York) Vol. 19, p. 315

[8] ANTONI, H. (1998): 'Electrical properties of the heart', in REILLY, J. P. (Ed): 'Applied bioelectricity from electrical stimulation to electropathology', (Springer, New York), p. 181

[9] LAUR, D. (2004): 'Excited delirium and its correlation to sudden and unexpected death proximal to restraint', (Canada: Victoria Police Department) http://www.taser.com/facts/medical_info.htm

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