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Technical Performance Testing of Conducted Energy Weapons

Recommended Practices to Ensure Consistent and Quality Results

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Defence R&D Canada – CSS

Technical Report
DRDC CSS TR 2013-025
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Canada

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Abstract

Performance of a conducted energy weapon (CEW) can be evaluated from three perspectives: how well it immobilizes a subject (efficacy), how safe it is and how it performs technically. This report addresses the technical performance of CEWs such as those used by Canadian law enforcement. It does not address either the efficacy or the safety. This report provides recommendations to be used by law enforcement, policing policy-makers and test laboratories to ensure consistent and quality results when testing CEWs. Test laboratories are provided with a detailed analysis of the parameters that can be measured including the appropriate algorithms as well as the required test equipment specifications, recommended test procedure and reporting requirements. Law enforcement agencies and policing policy-makers are provided with recommendations related to qualifications of test laboratories, test strategies and recommended acceptance specifications.

Résumé

On peut évaluer le rendement d'une arme à impulsions (AI) sous trois angles : sa capacité à immobiliser un sujet (efficacité), sa sécurité et son fonctionnement technique. Le présent rapport traite de la performance technique des AI comme celles qu'utilisent les services de police du Canada. Il ne porte pas sur leur efficacité ni leur sécurité. Le rapport renferme des recommandations à suivre par les responsables de l'application de la loi, les décideurs des services de police et les laboratoires d'essai afin d'obtenir des résultats cohérents et de qualité au moment de faire l'essai des AI. Les laboratoires d'essai disposent d'une analyse détaillée des paramètres pouvant être mesurés, notamment les algorithmes appropriés ainsi que les caractéristiques de l'équipement d'essai requis, la procédure d'essai recommandée et les exigences relatives à la production de rapports. Les organismes responsables de l'application de la loi et les décideurs des services de police disposent de recommandations relatives aux qualités des laboratoires d'essai, aux stratégies d'essai et aux caractéristiques d'acceptation recommandées.

Executive summary

Technical Performance Testing of Conducted Energy Weapons: Recommended Practices to Ensure Consistent and Quality Results

Donna Wood; Joey Bray; Bill, Simms; DRDC CSS TR 2013-025; Defence R&D Canada – CSS; October2013.

Introduction or background: The incident at the Vancouver International Airport that resulted in the death of Mr. Robert Dziekanski and the subsequent British Columbia provincial inquiry, headed by Justice Braidwood raised the question of periodic testing of CEWs for their electrical output. A series of workshops were held with stakeholders representing police, industry, research, policy and standards groups that resulted in the generation of an initial test procedure commonly referred to as Version 1.1. The Conducted Energy Weapons Strategic Initiative (CEWSI) Project was a project led by Defence Research and Development Canada's Centre for Security Science in cooperation with Public Safety Canada. One of the objectives of this project was to recommend a CEW test procedure and performance measures for possible inclusion in Canadian national guidelines for CEWs.

Results: The objective of this report is to provide recommendations to be used by law enforcement, policy-makers and test laboratories to ensure consistent and quality results when testing CEWs. While CEWs can also be evaluated in terms of efficacy or safety, this report only addresses technical performance. This report draws on the results of several parallel efforts to investigate different aspects relevant to testing of CEWs. The Quality Engineering Test Establishment conducted detailed technical and environmental testing on the TASER M26 and TASER X26 models and the Royal Military College of Canada conducted initial testing on the TASER X2 as well as a quality and statistical analysis of legacy test data. The test protocol outlined in this report provides recommendations on the relevant waveform parameters, specifications for test equipment, a test methodology, reporting requirements, and qualifications for test laboratories. Included in the annexes of this report are performance specifications that can serve as acceptance criteria. Where the information was not provided by the manufacture the values have been determined as a result of experimental analysis.

Significance: This report provides recommendations that can be used to standardize the collection and analysis of test results while ensuring quality and consistent measurement. Consistency in testing will provide law enforcement agencies with greater confidence in the results so that appropriate operational decisions can be made. The recommended standardization in reporting will enable future analysis of test results. The proposed parameters go beyond those identified by the manufacturer and are flexible enough to account for changes in CEW waveforms.

Future plans: This report does not address either efficacy or safety. Concurrent to this study is an effort by an independent expert medical panel, led by the Canadian Academy of Health Sciences, to understand the physiological effects of CEWs. This report should be reviewed when available with the objective of identifying those parameters and thresholds that should be

measured for safety and efficacy. Future work to be considered includes the development of baseline software code to support the waveform analysis as well as longitudinal studies for any new CEW in order to validate any performance specifications and for lifecycle and trends analysis. The recommendations in this report will be provided to policing policy-makers for consideration for input to national CEW guidelines.

Sommaire

Technical Performance Testing of Conducted Energy Weapons: Recommended Practices to Ensure Consistent and Quality Results

Donna Wood; Joey R. Bray; Bill Simms ; DRDC CSS TR 2013-025 ; R & D pour la défense Canada – CSS; octobre 2013.

Introduction ou contexte : l'incident qui s'est produit à l'aéroport international de Vancouver, ayant causé la mort de M. Robert Dziekanski et donné lieu, ultérieurement, à une enquête de la Colombie Britannique dirigée par le juge Braidwood, a fait en sorte de soulever la question de la vérification régulière du courant électrique produit par les armes à impulsions. Des ateliers organisés avec des représentants de la police, de l'industrie, de la recherche, de groupes des politiques et des normes ont permis d'élaborer une première procédure d'essai communément appelée Version 1.1. L'initiative stratégique sur les armes à impulsions (ISAI) est un programme dirigé par Recherche et développement pour la défense Canada – Centre des sciences pour la sécurité en collaboration avec Sécurité publique Canada. Un des objectifs de ce projet était de recommander une procédure d'essai et des mesures de performance des AI qui pourraient être incluses dans les lignes directrices canadiennes sur les armes à impulsions (AI).

Résultats : le présent rapport a pour objectif d'élaborer des recommandations à suivre par les responsables de l'application de la loi, les décideurs des services de police et les laboratoires d'essai afin d'obtenir des résultats cohérents et de qualité au moment de faire l'essai des AI. Bien que les AI puissent également être évalués en terme d'efficacité et de sécurité, le présent rapport ne porte que sur leur performance technique. Il traite des résultats de plusieurs démarches parallèles visant à enquêter sur divers aspects propres à l'essai des AI. Le Centre d'essais techniques de la qualité a effectué des essais environnementaux et techniques détaillés sur les modèles TASER M26 et TASER X26 alors que le Collège militaire royal du Canada a effectué l'essai initial du TASER X2 de même qu'une analyse statistique et de la qualité des données d'essai existantes. Le protocole d'essai contenu dans ce rapport fournit des recommandations sur les paramètres appropriés de l'onde, les caractéristiques de l'équipement d'essai, une méthodologie d'essai, les besoins en matière de production de rapports et les qualités des laboratoires d'essai. Les annexes du rapport renferment les caractéristiques du rendement pouvant servir de critères d'acceptation. Lorsque les renseignements n'étaient pas fournis par le fabricant, les valeurs ont été déterminées dans le cadre d'une analyse expérimentale.

Importance : le rapport fournit des recommandations qui peuvent être utilisées pour normaliser la collecte et l'analyse des résultats des essais tout en assurant des mesures cohérentes et de qualité. La cohérence des essais donnera aux responsables de l'application de la loi une plus grande confiance à l'égard des résultats de façon que des décisions opérationnelles appropriées puissent être prises. La normalisation recommandée dans la production de rapports permettra l'analyse future des résultats des essais. Les paramètres proposés vont au-delà de ceux qui ont été déterminés par le fabricant et sont suffisamment souples pour justifier les changements aux formes d'onde des armes à impulsions.

Perspectives : le présent rapport ne porte ni sur l'efficacité, ni sur la sécurité. En même temps que la présente étude, un comité indépendant d'experts médicaux, dirigé par l'Académie canadienne des sciences de la santé, a entrepris de comprendre les incidences physiologiques des AI. Ce rapport doit être examiné, lorsque ce sera possible, dans le but de déterminer les paramètres et les seuils qui devraient être mesurés à l'égard de la sécurité et de l'efficacité. Les travaux éventuels comprennent l'élaboration d'un code informatique de référence pour appuyer l'analyse des formes d'onde ainsi que des analyses longitudinales de toute nouvelle arme à impulsions (AI) dans le but de valider les caractéristiques du rendement et les analyses de tendance. Les recommandations du rapport seront transmises aux décideurs des services de police pour analyser leur inclusion dans les lignes directrices canadiennes sur les armes à impulsions (AI).

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1 Introduction

1.1 Identification

For purposes of clarification, this test procedure should be referred to as DRDCVer1. When referencing this report, the following citation should be used:

> Wood, D., Bray, J.R., Simms, B. (2013) *Technical Performance Testing of Conducted Energy Weapons: Recommended Practices to Ensure Consistent and Quality Results*. Defence Research and Development Canada Centre for Security Science. DRDC CSS TR 2013-025.

1.2 Background

In October of 2007, an incident occurred at the Vancouver International Airport that resulted in the death of Mr. Robert Dziekanski. The use of conducted energy weapons (CEWs) by the Royal Canadian Mounted Police (RCMP) during this incident resulted in many questions related to the use, safety and testing of CEWs in Canada. This incident prompted several provincial governments, the federal government and police to initiate discussions to explore the concerns raised. In 2008, the first phase of a British Columbia provincial inquiry, headed by Justice Thomas Braidwood, was launched to investigate the safety of CEWs. Justice Braidwood's first report was published in June 2009 and one of the recommendations was that governments should mandate the testing of CEWs in police inventories [2].

In December 2008 CBC News/Radio-Canada broadcast the results of a series of tests they conducted on 41 CEWs acquired from seven US police departments [7]. The tests were performed by National Technical Systems (NTS), a United States laboratory, and the results indicated that some of the weapons delivered excessive amounts of current. After reviewing the results of these tests TASER International expressed objections to the test procedure used and the interpretation of the results. CEWs received further public attention in 2010, with the television broadcast of an investigative report in February [8], followed by the publication of Justice Braidwood's second report in May 2010 [9].

Although Canadian commercial testing firms seized the opportunity to provide testing services, the test procedures did not initially follow an accredited protocol (although an industry consensual standard would later be developed [10]) and Canadian laboratories experienced difficulties replicating results obtained by TASER International. Reasons for these discrepancies were explored by examining differences in equipment specification, resistor loads, data capture, and data analysis techniques [3]. As a result, there was uncertainty as to the technical worthiness of the test results. In the absence of a comprehensive test procedure, the only widely known source of guidance was the set of testing guidelines promoted by the manufacturer, TASER International [4][5]. Although this can be considered as the first test procedure, there are a number of deficiencies associated with it, including loose tolerances, limited tests and specifications, and the absence of clear relationships to public safety.

A series of workshops were held with stakeholders representing police, industry, research, policy and standards groups with the goal of developing accurate, repeatable and systematic testing of CEWs. The first workshop was held at Carleton University, Ottawa, Ontario 5-6 May 2009 supported by the Defence Research and Development Canada's Centre for Security Science). A follow-up workshop was held, again at Carleton University, 10-12 May 2010. That resulted in the forming of a committee of independent subject matter experts to develop a test procedure that would provide a methodology to test CEWs and to determine whether or not they operated within the manufacturer's specification.

The procedure, released in July 2010, commonly referred to as 'Version 1.1', represented the first attempt to adopt a Canadian CEW test procedure and was based on a best consensus at the time of the technical requirements for CEW testing with the intent to enable organizations to test in a controlled and repeatable manner so that a consistent approach is followed [10]. The initial test procedure included and improved upon the guidelines provided by TASER International and although it is not officially mandated, it has been adopted by most of the Canadian test agencies.

Given the urgency that led to the creation of this initial test procedure, it was acknowledged that the Version 1.1 test procedure had limitations, as documented in the Lauren report of Sept 2010 [11]. Among others, major technical concerns that were raised included quality assurance and accuracy, environmental effects on the weapons, the identification of common failure modes, physiological risks, frequency and types of tests, and the data format that should be adopted by the testing laboratories.

Another workshop was held at the Quality Engineering Test Establishment (QETE) in November 2010 to discuss these shortcomings and requirements for research and analysis related to testing of CEWs. Participants at this workshop included members from law enforcement, policing policy agencies, and one commercial testing firm. A large number of technical and nontechnical concerns were discussed during this meeting, such as: the need for government involvement in the setting of standards, cost effectiveness, guidance as to what labs could perform the tests, expected product life, use of force guidelines, whether or not corrective measures could be applied during testing, clear guidance for operators, and battery testing [12].

The latest workshop on testing was held in Ottawa in October 2011 to solicit ideas on all technical and test methodological aspects of CEW testing in Canada [13]. The meeting included representatives from law enforcement, government policy makers, commercial testing firms, and technical experts.

1.3 Relationship to other Work in the CEWSI Project

Further to direction received from the Federal/Provincial/Territorial (FPT) Ministers responsible for Justice in November 2007, a FPT Conducted Energy Weapon (CEW) Working Group (WG) was created to support ongoing dialogue and information sharing on CEW policies and practices. This led to the Ministers Responsible for Justice and Public Safety issuing a joint statement in November 2010 endorsing national guidelines for CEWs and supporting a CEW research agenda that included the Conducted Energy Weapons Strategic Initiative (CEWSI) a collaborative project with Defence Research and Development Canada (DRDC) and Public Safety Canada (DRDC) [6].

Defence Research and Development Canada (DRDC) initiated the Conducted Energy Weapons Strategic Initiative (CEWSI) research project in August 2010 in order to address questions related to conducted energy weapons and less lethal weapons. The high level objectives of the CEWSI project are to:

a) Develop a CEW test procedure and performance measures for current models in use in Canada as an immediate and interim measure to ensure CEWs are meeting manufacturer's technical specifications;

b) Recommend a CEW test procedure and develop comprehensive performance measures for possible inclusion in Canadian national guidelines for CEW employment in Canada as part of an enduring capability;

c) Convene a panel of medical experts to conduct an independent evaluation of existing research to examine the physiological impact of CEWs, to identify gaps in the research and to recommend steps to address those gaps, and

d) Develop a Less Lethal Weapons approval process that could be applied to emerging less lethal technologies.

The Canadian Academy of Health Sciences (CAHS) has been contracted to convene an independent expert medical panel to look at the questions raised in sub-para c) above. The results are expected in the fall of 2013. The recommendations included in this report have been made for the purpose of ensuring the weapons continue to operate as expected and make no claim related to testing for safety; however, once the CAHS results are available, the results will be reviewed to integrate the two components.

The work related to the development of a Less Lethal Weapons approval process has been completed and is presented in the following report: *Canadian Less Lethal Technology Approval Process: A Structured Approach to the Selection and Implementation of Less Lethal Technologies for Canadian Law Enforcement* [14].

The lack of a consistent method for measuring the electrical output of conducted energy weapons is recognized as a constraint in the implementation of a confirmation assessment program by several countries. A project has been initiated under the International Electrotechnical Commission Technical Sub-Committee 85 to develop a measurement standard for electroshock weapons. Canada is an active participant in this development effort with the aim of ensuring any international standard that is developed will meet the needs of Canadian manufacturers, operators and test laboratories. While it is not expected that the results of this work will have a significant impact on the implementation of the recommendations made in this report, Canada should continue to be active in the development of the IEC standard.

1.4 Objective

The objective of this report is to provide recommendations that could be used to by law enforcement, policy-makers, and test laboratories to ensure consistent and quality results when testing CEWs.

For law enforcement agencies and policing policy organizations, this document provides recommendations relating to routine actions throughout the life cycle of CEWs that should be taken locally as well as advice on independent testing related to test laboratory qualifications, frequency of testing and reporting requirements.

For test laboratories, this document recommends a comprehensive set of test procedures for CEWs, data standards and reporting requirements. It provides guidance and recommendations regarding test equipment, tests, procedures, calibration, and accreditation.

1.5 Scope

This document applies primarily to the law enforcement models of CEWs that are marketed and sold by TASER International, currently the sole manufacturer of CEWs sold to Canadian law enforcement agencies. As of the date of publication, of the thousands of CEWs in inventory, it is believed that the majority of these are the model X26 manufactured by TASER International. This model is still in production although the manufacturer has recently announced the production of two new models, the TASER X2 and the TASER X26P [15]. Detailed testing has not been conducted on either of these models, however the results of an initial look at the TASER X2 can be found in the report by Bray [16]. TASER International ceased production of its older model TASER M26 at the end of 2010 and it is no longer supported.

The procedures described in this document were designed primarily for TASER models M26, X26 and TASER X2 weapons. They are intended to replace both the TASER Certified Test Procedures [4][5] and Version 1.1 test procedure [10].

1.6 Limitations

This document provides guidance that is restricted to confirming the technical performance of CEWs. This document does not include a cost-benefit analysis. In addition, situational and use of force guidance are not covered by this work. The decision to remove a CEW from service remains solely at the discretion of the law enforcement agency although this document provides technical recommendations that can be used to justify a removal. It must also be noted that the test procedure described herein does not imply effectiveness for an operational purpose - it determines whether or not a CEW has passed a number of technical tests.

The acceptance test parameters listed in this document are specifically for the TASER M26, TASER X26 and TASER X2 models of CEW, as these are the most widely available commercial CEWs at the time of writing. Canadian forensics labs are often required to test ‘street’, modified or illegal CEWs for evidentiary purposes. Measurement against manufacturer specifications is not relevant in these circumstances however the contents of this report may still be useful to the forensics labs. In addition, CEWs that are involved in police incidents and are therefore subject to investigations should be dealt with as required under the ensuing investigation. The need for handling of CEWs under evidentiary rules is outside the scope of this report.

Under some circumstances, the manufacturer may provide a replacement of a weapon under warranty that no longer works. The test procedures being proposed in this report have not been developed for the purpose of making claims under warranty.

The test procedures described herein are used to characterize the physical properties and functional performance of the CEW only – they make no comment on the weapon's physiological effect. It is beyond the scope of this document to comment on what constitutes the safe use of a CEW. At the time of writing this report, the results of the expert medical panel have not yet been released and potential insights of the medical panel have not been incorporated.

1.7 What is a Conducted Energy Weapon?

The CEWs approved for use by Canadian law enforcement are the TASER M26 and TASER X26. The TASER M26, shown in Figure 1, is an older model and is being phased out of service. The manufacturer no longer supports this model. The TASER X26, also shown in Figure 1, is the model predominately used by Canadian law enforcement.

Figure 1: Side profiles of the TASER M26 (top), TASER X26 (middle) and TASER X2 (lower) Weapon Bodies [16]

These weapons deliver a series of controlled electrical pulses into a subject in order to immobilize the subject by inducing an effect called neuromuscular incapacitation. The TASER X26 is comprised of four interrelated components, namely: the main weapon body (as shown in Figure 1), the cartridge, the firmware, and the power magazine. The power magazine, which slides into the hollow grip of the TASER X26 body, contains batteries that supply energy to the weapon. The weapon cannot be fired without its power magazine. The TASER X26 power magazine also contains the weapon's firmware, which is the set of computer instructions that are required by the digital microcontroller (computer) inside the weapon body. The firmware is uploaded automatically to the microcontroller's memory upon inserting the power magazine into the body. The combination of the firmware, power magazine, and weapon body allow the TASER X26 to be used as a stun gun (also known as using the CEW in *drive stun* mode), in which physical contact is required between the front of the weapon and the subject to achieve pain compliance.

The addition of the final component, the cartridge, into the hollow cavity at the front of the TASER X26 allows the weapon to be fired in *probe* mode, in which two tethered probes are violently ejected from the cartridge and into the subject, thereby delivering the electrical pulses into the subject at a distance. Although other peripherals may be available for these weapons, such as the TASER CAM for the TASER X26, their impact has not been considered in this report.

Two modules inside the weapon body control the function of the weapon: the microcontroller and the high voltage module (HVM). Following the set of instructions contained in the firmware, the microcontroller controls the overall operation of the TASER X26: it senses inputs from the user via a number of switches found on the weapon (including the trigger), it monitors the estimated remaining power of the power magazine, it displays information to the user via a small screen, it controls the flashlight and laser functions of the weapon, it communicates with a host computer if connected via USB, and it instructs the HVM to generate the electrical pulses used for immobilization when the weapon is triggered. The HVM contains the patented electrical network that boosts the power magazine's small battery voltage into the series of high voltage pulses that are delivered to the subject.

More elaborate descriptions of the four components are given below.

a. Main weapon body. This part of the weapon contains the switches, flashlight, laser sight(s), microcontroller, memory, and the high voltage module that generates the electrical pulses. It is this component that is the target of independent testing.

b. Power source. Both the TASER M26 and the TASER X26 have removable power magazines that supply the energy to the weapon. These magazines are specific to the model of the weapon and are not interchangeable. In addition to containing lithium batteries, the digital power magazine (DPM) of the TASER X26, shown in Figure 2, is unique in that it also contains a memory chip that supplies the weapon's microcontroller with its set of computer instructions called the firmware. New versions of the firmware have been periodically released by TASER International and placed on new DPMs. When a DPM containing a more recent version of the firmware is inserted into the weapon, the firmware is automatically loaded into the weapon's memory. The DPM is annotated with the version number of the firmware.

Figure 2: TASER X26 DPM [17]

c. Firmware. Within the weapon body, the function of the weapon is controlled by a microcontroller (computer chip) that follows instructions that are stored its memory.

The set of instructions is called the *firmware*. Although the firmware is not visible to the operator, it is critical to the operation of the weapon. Given that the manufacturer updates the firmware from time-to-time, the weapon may be controlled by multiple firmware versions throughout its life. Although the firmware is proprietary and not easily testable, the manufacturer should describe the changes that are incorporated in any new releases. For reference purposes, the latest firmware version for the TASER X26 at time of publication is version 22.

d. Cartridge. As previously mentioned, the cartridge allows the TASER CEW to be used at a distance by firing a pair of tethered probes into the subject. The internal operation of the cartridge is as follows and as shown in Figure 3. The first high voltage pulse from the weapon detonates a small explosive primer in the cartridge that forces a compressed nitrogen capsule rearward into a hollow puncture pin that pierces the capsule, thereby releasing the nitrogen. The high pressure of the released gas propels the blast doors, probes, probe wires, foam Poron® pads, ejectors and anti-felon identification tags (AFIDs) forward and out of the cartridge, as shown in Figure 3. The probes are intended to embed in the body of the subject so that the electrical circuit can be completed, thereby immobilize the subject. The cartridges are available in several wire lengths (15, 21, 25 and 35 feet). The XP variants of the cartridges (Extra Penetration), supplied exclusively for the 25 and 35-foot wire lengths, have longer probes to better penetrate thick layers of clothing. The cartridges are single-use components and can only be tested by sampling in batches and generalizing the results.

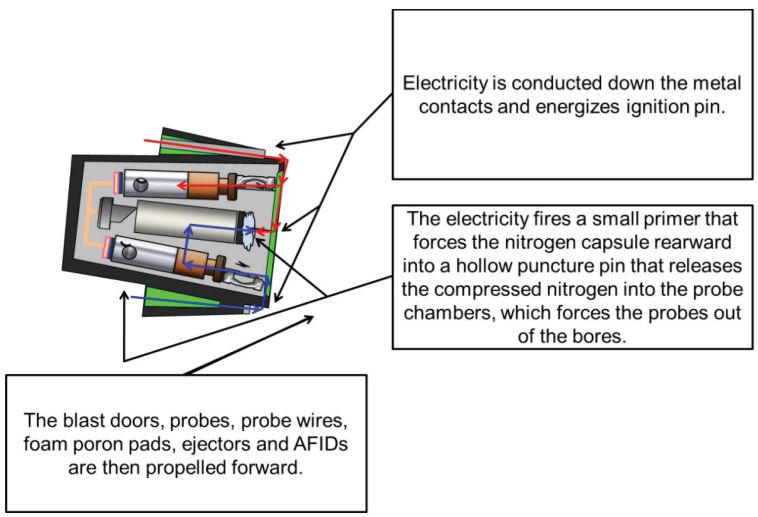

Figure 3: Internal Components of a TASER X26 Cartridge [18]

A failure in the system should be examined in terms of the performance of each of the components. Although the four components of the CEW are designed to operate as a system, the failure of one component does not necessarily imply the disposal of the entire system. For example, the failure of a single cartridge to fire properly does not mean that the entire weapon should be disposed of and a broken safety switch on the main weapon does not mean the DPM should be disposed of.

The CEWs used by Canadian law enforcement can operate in several modes:

a. Probe. The weapon is fired with a live cartridge installed. When the trigger is pulled, the probes are fired into the subject. A complete electrical circuit, in which both probes make contact with the subject is required for neuromuscular incapacitation.

b. Drive-Stun. Without a cartridge installed (for the TASER M26 and TASER X26) or with-or-without a cartridge installed for the TASER X2 model, the weapon is pushed against the subject and the trigger is pulled. Contact with the subject allows the electrical circuit to be completed, resulting mostly in a pain compliance response from the subject.

c. 3-point mode. In this mode of operation, the officer fires the weapon with the cartridge installed at close range to the subject and then moves the weapon to make contact at another location on the subject's body in order to provide an alternate path for the completion of the electrical circuit. This mode provides a mix of pain compliance and neuromuscular incapacitation (NMI).

1.8 CEW Waveform Characterization

When the trigger is pressed and released, TASER CEWs produce a series of high voltage, short duration pulses for a period of 5 seconds. Depending on the model, TASER International recognizes different regions within each pulse, such as the *main phase* and the *arc phase*. The current pulse of a TASER M26, when fired into a 500-ohm load, is shown in Figure 4. The current pulses of the TASER X26 and TASER X2, when fired into 600-ohm loads, are shown in Figure 5 and Figure 6, respectively. The entire 5-second discharge cycle of a TASER X2 is shown in Figure 7, but because the approximately 100 pulses contained in this discharge cycle are so short (0.0001 seconds) compared to the 5-second span, they only appear as impulses in this figure. Additional details on the TASER CEW pulses and their applicable performance specifications are found in Annex A.

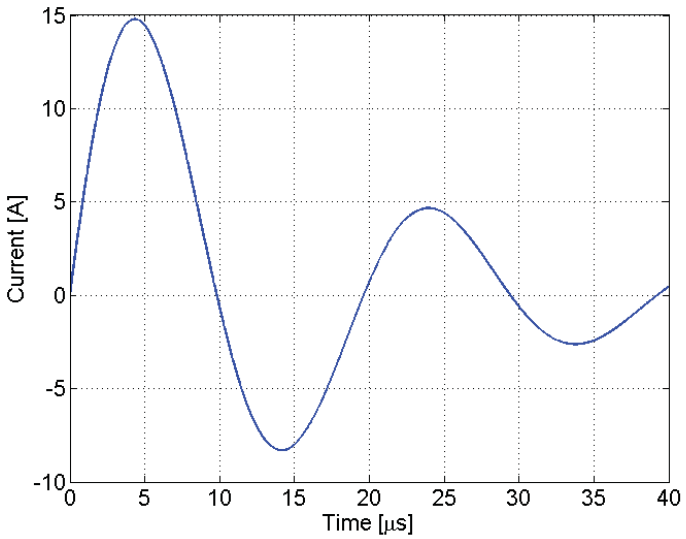

Figure 4: Modelled TASER M26 Current Pulse

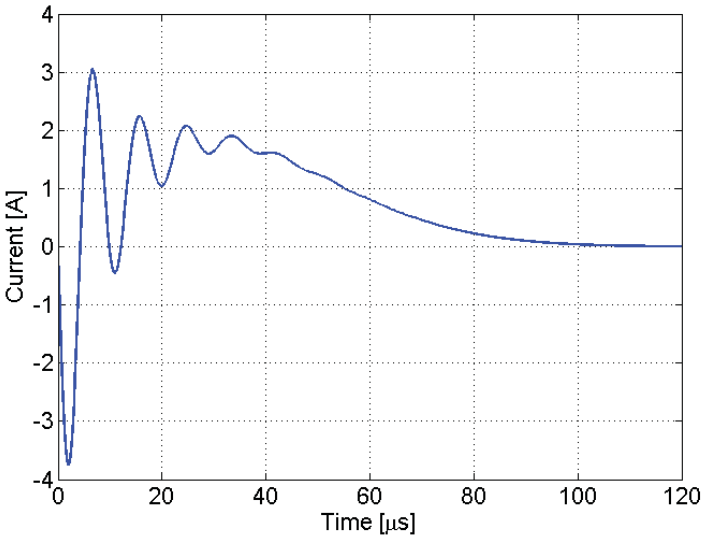

Figure 5: Modelled TASER X26 Current Pulse

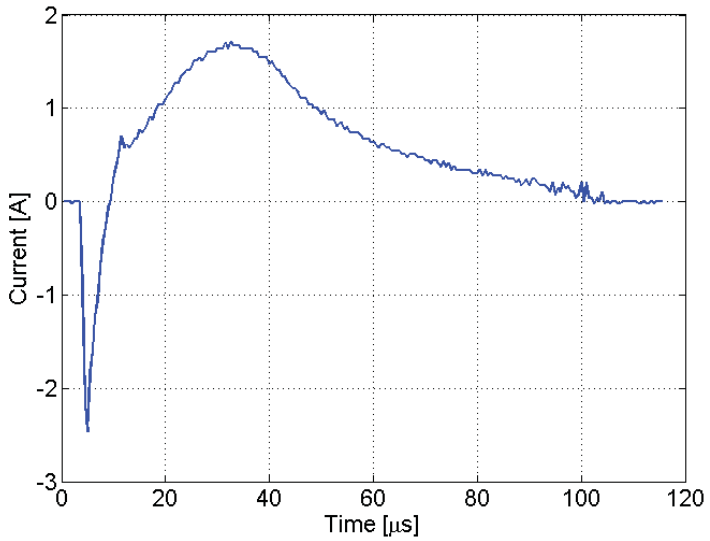

Figure 6: Typical Measured TASER X2 Current Pulse

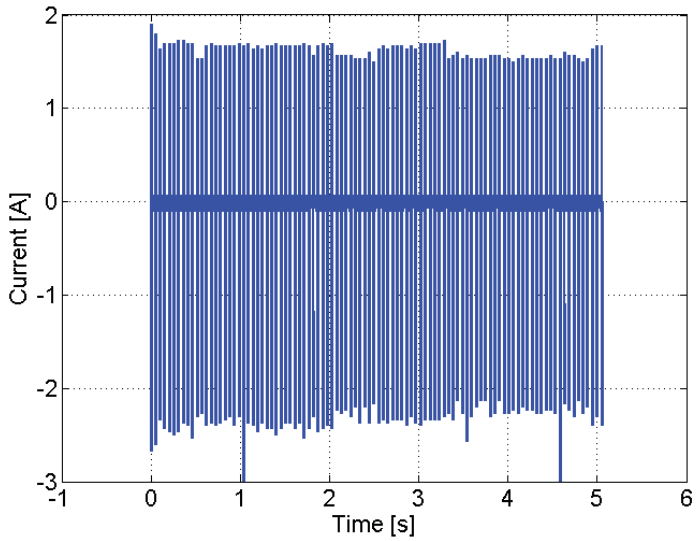

Figure 7: Typical Measured Current of a Complete TASER X2 Discharge Cycle, Containing 98 Pulses

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2 Waveform Parameters

The International Electrotechnical Commission (IEC) defines detailed parameters for the characterization of waveforms and signals for use by test laboratories. The descriptive parameters below are not intended to replace the parameters identified by IEC, but are meant to explain the parameters in language that can be more easily understood by police services and policy-makers. Annex D contains a more detailed description of the same parameters using technical language that is more suitable for test laboratory staff.

The following sections discuss the waveform parameters from three perspectives. First, the parameters recommended by Taser International in their test procedures are presented (Section 2.1). Second, modifications are recommended to the parameters identified by Taser International to fully characterize the entire waveform (Section 2.2). Finally, new parameters are introduced that go beyond those recommended by the manufacturer (Section 2.3).

2.1 Testing to the Manufacturer Specification

2.1.1 TASER Certified Test Procedures

TASER International has developed Certified Test Procedures for both the TASER M26 and the TASER X26. The TASER waveform parameters are of limited scope and TASER International explicitly identifies the make and model of the measurement equipment that must be used. The TASER Certified Test Procedure calls for two trigger pulls – the first to capture the TASER Pulse Rate and the second to determine voltage, charge, and pulse duration.

The following versions of the test procedure were consulted:

TASER M26: Version 1.0 Release Date: 2/21/2011 [4]

TASER X26: Version 5.0 Release Date: 3/15/2011 [5]

The recommended waveform parameters that will be presented in Section 2.3 are intended to complement and to augment the parameters listed in the TASER Certified Test Procedures. TASER CEWs should always be tested according to the TASER Certified Test Procedures for warranty claims.

2.1.2 TASER Pulse Rate

Pulse rate refers to the number of individual pulses, such as the one shown in Figure 4, that are produced by the CEW during a given interval of time. The units of pulse rate are therefore "pulses per second". According to the TASER International Certified Test Procedure, the TASER Pulse Rate is defined as the *average* pulse rate that is measured during *only* the last second of the 5-second discharge cycle.

2.1.3 Pulse Duration

According to the TASER International Certified Test Procedure, the TASER Pulse Duration is the average time duration of each of the last 8 pulses in the 5-second discharge cycle.

2.1.4 TASER Peak Loaded Main Phase Voltage

According to the TASER International Certified Test Procedure, the TASER Peak Loaded Main Phase Voltage is the *average* of the highest positive voltage of *only* the last 8 pulses contained in the 5-second discharge cycle, as depicted in Figure 8. Measuring only at the end of the discharge could be misleading.

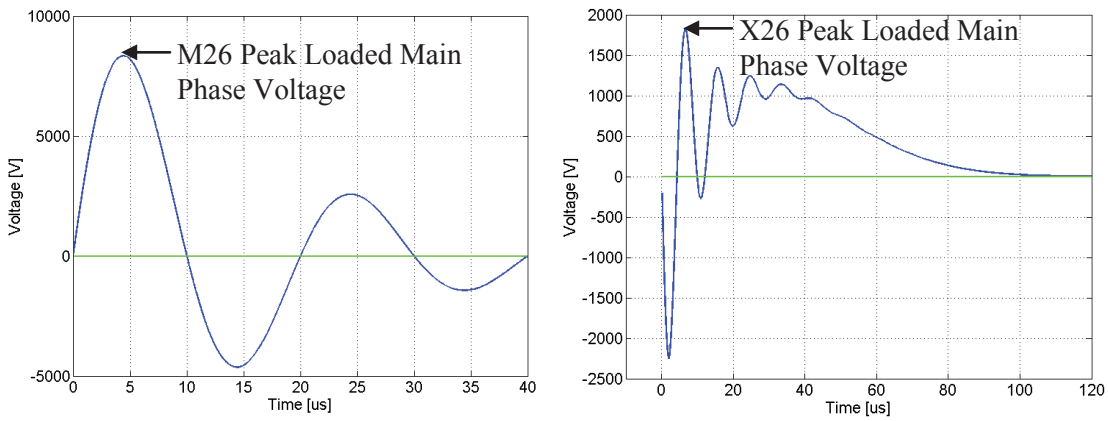


Figure 8: TASER Peak Loaded Main Phase Voltage

2.1.5 TASER Main Phase Charge

The overall amount of charge that has moved during a given period of time can be calculated by analyzing the current waveform. There are, unfortunately, different ways of "counting" this overall charge, which can lead to a great deal of confusion. In this section, *net charge* is used, which is determined by counting how much charge has moved in the positive direction, and then *subtracting* the amount of charge that has moved in the negative direction. Because of this subtraction, net charge tends to be a small number. It only represents how much *more* charge flowed in a given direction compared to the other direction.

According to the TASER International Certified Test Procedure, the TASER Main Phase Charge is the average *net charge* of *only* the last 8 pulses contained in the 5-second discharge cycle.

2.2 Recommended Changes to the Use of TASER International Waveform Parameters

The previous section described the parameters identified by TASER International in their test procedures. Unfortunately, they do not fully characterize the waveform and more detail is needed

to fully understand the weapon behaviour. Specific concerns relating to the TASER International waveform parameters and recommendations for changes are as follows:

a. Pulse Rate. The TASER Pulse Rate only calculates an average pulse rate from the last second of the discharge. Given that a waveform recorder can record the entire discharge cycle, information should be gathered for all of the pulses in the discharge cycle.

b. Pulse Duration. The TASER Pulse Duration is only an average taken over the last 8 pulses. Information should be gathered for all of the pulses in the discharge cycle.

c. Charge. The TASER Main Phase Charge definition is a good approximation of what is termed the *net charge*; however, it is only an average taken over the last 8 pulses. Information should be gathered for all of the pulses in the discharge cycle. Charge can also be defined in many different ways, as shown in [10]. Some charge definitions are thought to pertain to the physiological effects of the weapon, whereas other definitions are used to describe the charge characteristics of the waveform in general. More descriptive definitions of charge will be provided in Section 2.3.7.

d. Peak Voltage. Although the TASER Peak Loaded Main Phase Voltage is a relevant parameter, it is only an average taken over the last 8 pulses. Voltage information should be recorded for all of the pulses in the discharge cycle. Both the minimum negative and the maximum positive *peak voltages* should be recorded.

2.3 Recommended Waveform Parameters

This section contains the definitions of parameters that could be measured during CEW testing, which are above-and-beyond any manufacturer-specific parameters that may be measured at the same time. While this report does not specifically identify the parameters that are relevant from an efficacy or safety perspective, the parameters defined in this section form a more complete set of data that may be useful in the future should new information be discovered concerning efficacy and safety. The parameters listed herein represent an exhaustive list of parameters and only subsets of these are recommended for inclusion in the test report. In addition to the parameters listed here, a test laboratory may include other parameters, or parameters that are derived from those listed here, at its discretion. Algorithms and more technical descriptions of the parameters are included in Annex D.

2.3.1 Current or Voltage

Whether to measure voltage or current is left to the discretion of the test laboratory because they are related to each other in a predictable way when a standard test load is used. In the text that follows, references to both voltage and current are made and they can be considered interchangeable using Ohm's Law.

2.3.2 Discharge Cycle Definition

When fired, a CEW usually produces a series of similarly-shaped pulses. The *Discharge Cycle* refers to all of the pulses that are produced after the trigger is pulled, such as the one shown earlier in Figure 7. The discharge cycle of TASER International CEWs lasts for approximately 5-seconds.

2.3.3 Pulse Definition

A *pulse* is the small portion of the Discharge Cycle that contains energy and that is repeated multiple times during the Discharge Cycle. Examples of pulses were given earlier in Figure 4 to 6.

2.3.4 Lobe Definition

Taser International has identified two components of the waveform: an arc phase and a main phase. In order to avoid confusion with different models and different waveforms, the term *lobe* will be used to represent different portions of a pulse. A *lobe* is a portion of the pulse that is usually delimited by a zero crossing on either side, as illustrated in Figure 9.

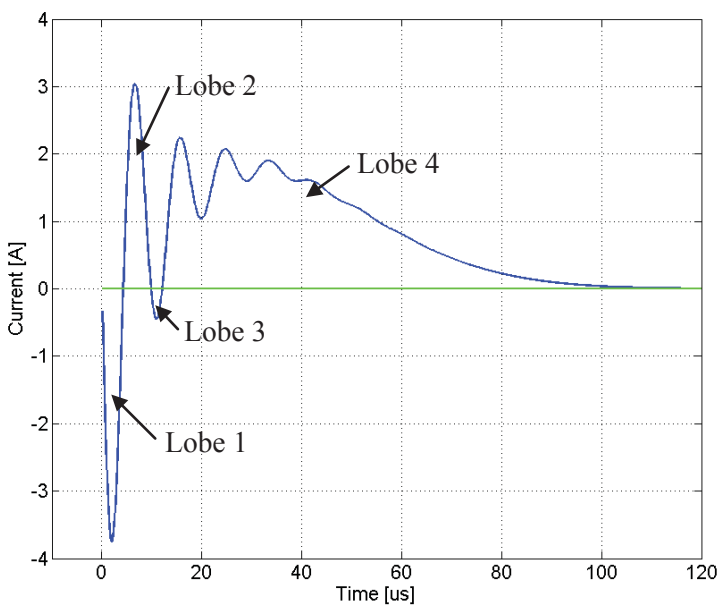


Figure 9: Example Current Pulse with Four Distinct Lobes

2.3.5 Time-Related Parameters

The measured parameters that follow are related to the time duration of the discharge cycle, of the individual pulses, and of the lobes within each pulse.

2.3.5.1 Discharge Cycle Duration

The Discharge Cycle Duration, measured in seconds, is the time duration of one CEW firing. The test report should contain the Discharge Cycle Duration.

2.3.5.2 Number of Pulses

Missing pulses, additional pulses, or erroneous pulses may be symptoms of a malfunction; hence the number of pulses contained in a discharge cycle should be reported. The Number of Pulses counts the number of times that a significant voltage event has occurred (likely corresponding to a pulse) during the Discharge Cycle Duration, as defined in Appendix D. The test report should contain the Number of Pulses.

2.3.5.3 Pulse Duration

The individual pulses within the Discharge Cycle are expected to be consistent. Deviations may be symptoms of a malfunction. The Pulse Duration, measured in seconds, is the duration of each individual pulse contained in the Discharge Cycle Duration. This parameter is determined for all of the pulses in the Discharge Cycle. The test report should contain the Maximum Pulse Duration and the Minimum Pulse Duration.

2.3.5.4 Pulse Repetition Interval (PRI)

The pulse rate of the CEW discharge is related to the time interval between successive pulses. Figure 10 shows a segment of a discharge cycle containing 4 individual pulses. The Pulse Repetition Interval (PRI), measured in seconds, is the elapsed time between two consecutive pulses. This parameter is determined between all of the pulses in the Discharge Cycle. The test report should contain the Mean PRI and Maximum PRI.

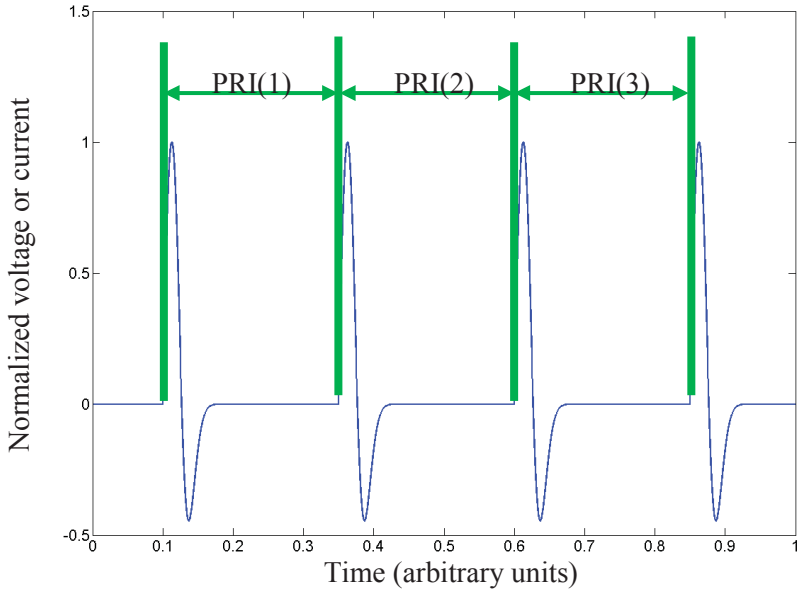


Figure 10: Pulse Repetition Interval (PRI)

2.3.5.5 Pulse Repetition Frequency (PRF)

The Pulse Repetition Frequency (PRF), measured in pulses-per-second (or hertz), is synonymous with the Pulse Rate. The PRF is the reciprocal of the PRI. The test report should contain the Mean PRF, the Maximum PRF and the Minimum PRF.

2.3.5.6 Peak-Voltage-Lobe Duration

Some CEW models rely on a short-duration, high voltage lobe, sometimes called an *arc phase*, to establish a conductive path in the subject. This lobe will be called the *Peak-Voltage-Lobe* in the text that follows. Peak-Voltage-Lobe Duration seeks to quantify the duration of this arc phase, when present, as illustrated in Figure 11. This parameter provides a means of ensuring that the CEW circuitry responsible for generating the arc phase is functioning properly. The Peak-Voltage-Lobe Duration may also be of interest in the context of the CEW's physiological effects [19]. This parameter is determined for all of the pulses in the Discharge Cycle.

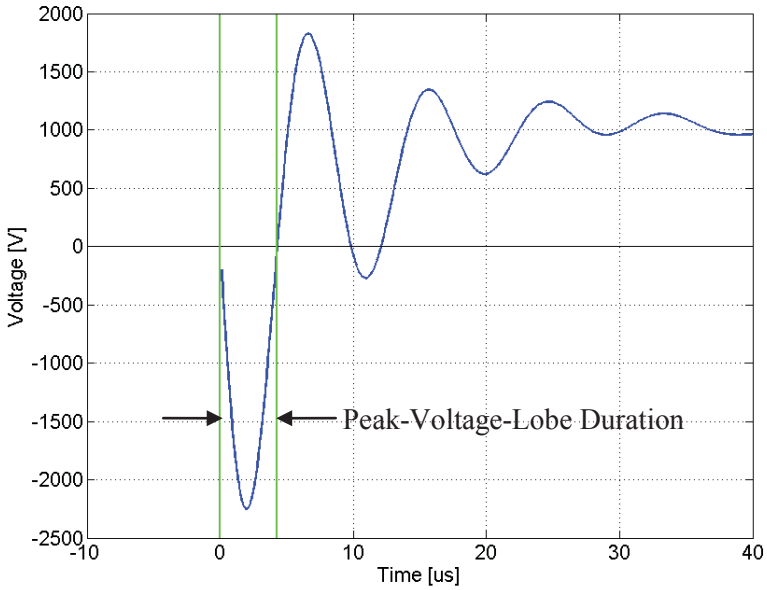


Figure 11: Peak-Voltage-Lobe Duration

2.3.5.7 Peak-Charge-Lobe Duration

Within each pulse, the lobe that delivers the most charge is called the Peak-Charge-Lobe. The duration of the Peak-Charge-Lobe may be related to the CEW's physiological effects [10],[19]. For some CEWs, this is sometimes known as the *main phase* duration, or *stimulation phase* duration. The Peak-Charge-Lobe Duration, measured in seconds, seeks to quantify this value. The Peak-Charge-Lobe Duration will be determined for all of the pulses in the Discharge Cycle. An example of the Peak-Charge-Lobe Duration is shown in Figure 12 and is consistent with the *tp+* variable defined in [19].

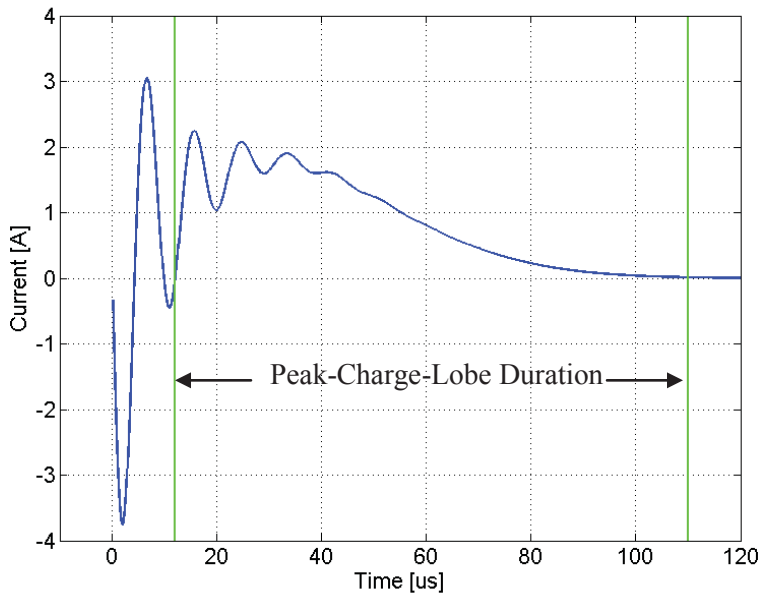


Figure 12: Peak-Charge-Lobe Duration

2.3.6 Voltage Parameters

The following parameters are related to the measured waveform voltage.

2.3.6.1 Pulse High Voltage and Pulse Low Voltage

The Pulse High Voltage and Pulse Low Voltage seek to quantify the high voltage lobe (arc phase), when present. Depending on the shape of the waveform, one of these parameters may also represent the maximum excursion of the remainder of the waveform. The Pulse High Voltage and Pulse Low Voltage, measured in volts, will be determined for all pulses in the discharge cycle. An example of the Pulse High Voltage and of the Pulse Low Voltage is shown in Figure 13. These definitions complement the *Main Phase Peak Loaded Voltage* already specified by TASER International [5]. The laboratory report should contain the Minimum Pulse High Voltage, the Maximum Pulse High Voltage, the Minimum Pulse Low Voltage, and the Maximum Pulse High Voltage.

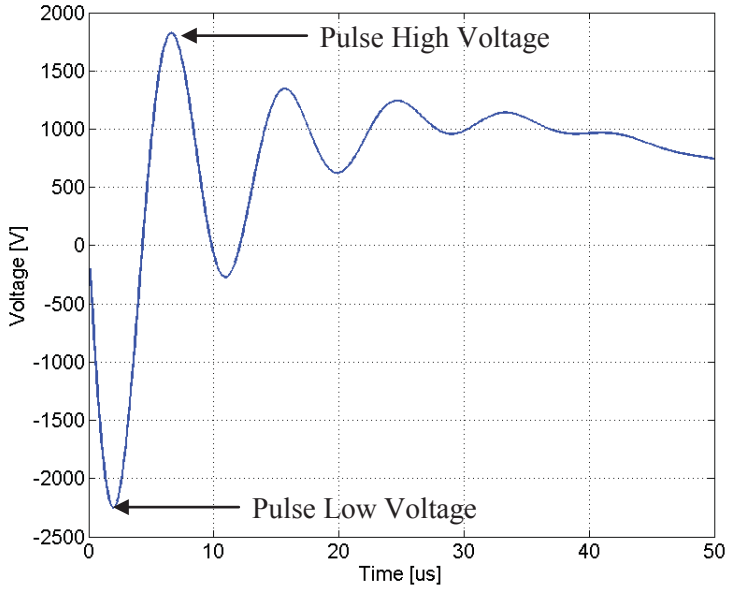


Figure 13: Pulse High Voltage and Pulse Low Voltage

2.3.7 Charge Parameters

Most CEW current waveforms oscillate between positive and negative values. When the positive current is symmetric with respect to the negative current, the waveform is said to be *biphasic*, and household alternating current (AC) is one example of this. When the current of a waveform flows in only one direction (positive or negative), the waveform is said to be *monophasic*. Direct current (DC) is one example of this. The current waveforms that are produced by many CEWs often lack the symmetry to be truly biphasic, and are not monophasic either because they contain both positive and negative current lobes. As such, CEW current waveforms display both biphasic and monophasic attributes, which makes the selection of charge parameters difficult if they are to be applied to a wide variety of waveforms produced by different CEW models. For these reasons, a number of different charge definitions will be recommended.

There are many different definitions of charge [10]. Certain definitions of charge, such as the Peak-Charge-Lobe Charge, may be relevant to the CEW's physiological effects [19]. Some definitions of charge may be related to the safety of a CEW, but there is currently no clear medical evidence for choosing one type of charge over another. Manufacturers may warrant their product based on a particular type of charge, such as the net charge [5]. A more conservative estimate of delivered charge is the *total charge*. In an attempt to capture the key charge attributes of different CEW current waveforms, the following charge parameters are recommended. Definitions of charge that are applicable to entire pulses include: Total Charge, Positive Current Charge, Negative Current Charge, and Net Charge. Charge will also be calculated for individual lobes within each pulse, including the Peak-Charge-Lobe Charge and the Peak-Voltage-Lobe Charge.

For clarity, the term *monophasic charge* defined in [10] will be avoided, as it implies taking only the maximum value of two charge parameters. Monophasic charge can be added to the test report at the test laboratory's discretion, by selecting the maximum value of either the Positive Current Charge or the Negative Current Charge.

2.3.7.1 Positive Current Charge

The Positive Current Charge is the quantity of charge, measured in coulombs, that flows in the positive direction during a pulse. The Positive Current Charge should be determined for all of the pulses in the discharge cycle. As an example, the shaded area shown in Figure 14 is proportional to the Positive Current Charge. This parameter complements the *Main Phase Charge* that is already specified by TASER International [4],[5].

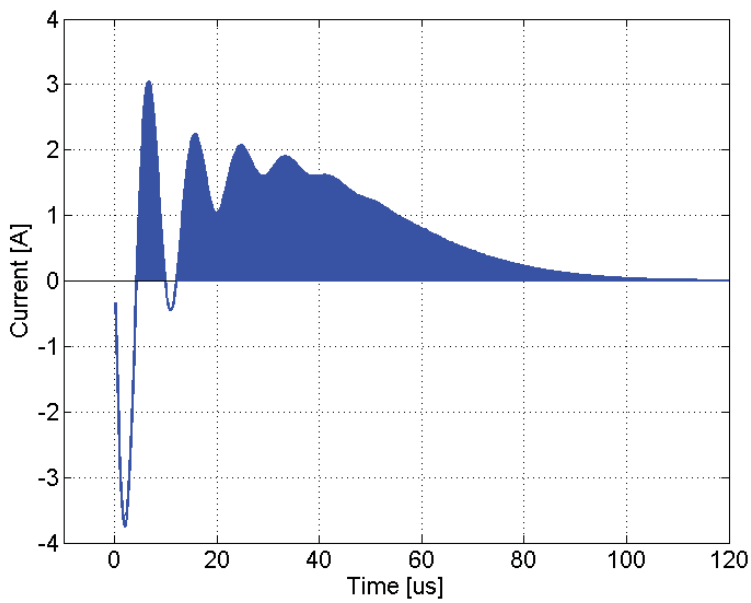


Figure 14: Positive Current Charge

2.3.7.2 Negative Current Charge

The Negative Current Charge is the quantity of charge, measured in coulombs, that flows in the negative direction during a pulse. The Negative Current Charge, which has a <u>strictly positive value</u>, must be determined for all of the pulses in the discharge cycle. As an example, the shaded area shown in Figure 15 is proportional to the Negative Current Charge.

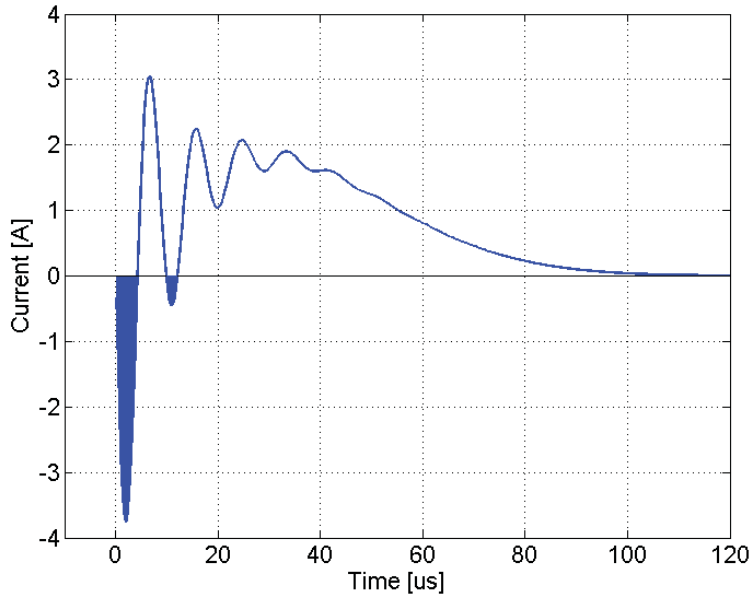
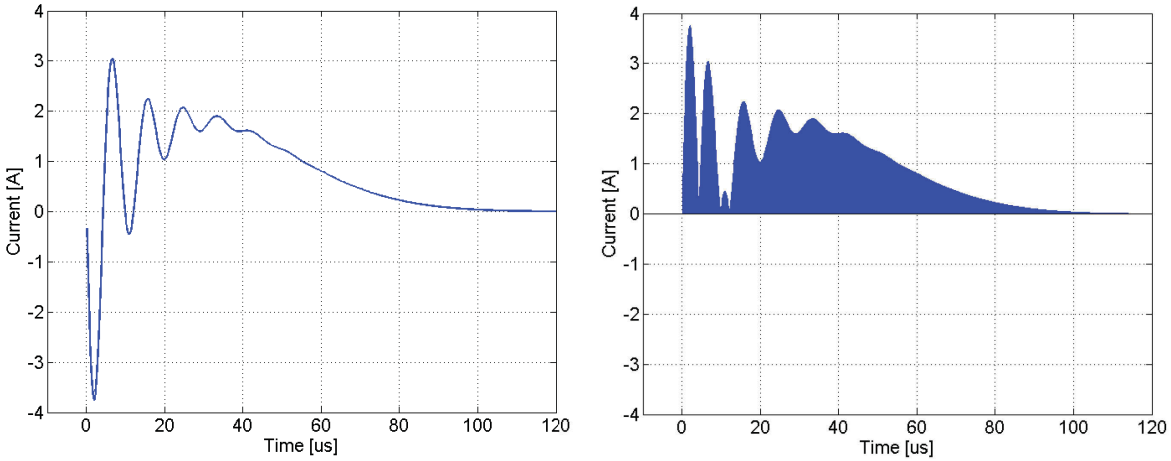


Figure 15: Negative Current Charge

2.3.8 Total Charge

The Total Charge, measured in coulombs, is the total amount of the charge per pulse that moves across a load, or subject. Total Charge is the sum of the Positive Current Charge and the Negative Current Charge, which are both strictly positive values, and therefore Total Charge will always be the highest reported value of charge. The Total Charge should be determined for all of the pulses in the discharge cycle. As an example, the graph in Figure 16a shows the current pulse, whereas the graph in Figure 16b shows the magnitude of the same current pulse. The shaded area shown in Figure 16b is proportional to the Total Charge. The test report should contain the Mean Total Charge, the Maximum Total Charge and the Minimum Total Charge of all of the pulses in the entire pulse train.



(a) (b)

Figure 16: Total Charge Example: (a) Actual Current Pulse, (b) Current Pulse Magnitude

2.3.9 Net Charge

As previously mentioned, Net Charge, measured in coulombs, characterizes only the difference between the Positive Current Charge and the Negative Current Charge. Net Charge is found by subtracting the Negative Current Charge from the Positive Current Charge. It must be stressed that Net Charge does not indicate the amount of charge that has actually flowed across a load (or a subject). The Net Charge usually has the smallest value among the charge parameters associated with a pulse. The Net Charge should be determined for all of the pulses in the discharge cycle.

2.3.10 Peak-Charge-Lobe Charge

For most CEWs, one lobe within every pulse will consistently deliver the highest amount of charge, and this lobe is called the Peak-Charge-Lobe. The Peak-Charge-Lobe Charge is the amount of charge, measured in coulombs, in that lobe. The Peak-Charge-Lobe Charge should be determined for all of the pulses in the discharge cycle. For example, the shaded area shown in Figure 17 is proportional to the Peak-Charge-Lobe Charge. The Peak-Charge-Lobe Charge is consistent with the definition of the $Q(max+)$ parameter, which may be relevant to the CEW's physiological effects [19]. The test report should contain the Mean Peak-Charge-Lobe Charge, the Maximum Peak-Charge-Lobe Charge and the Minimum Peak-Charge-Lobe Charge.

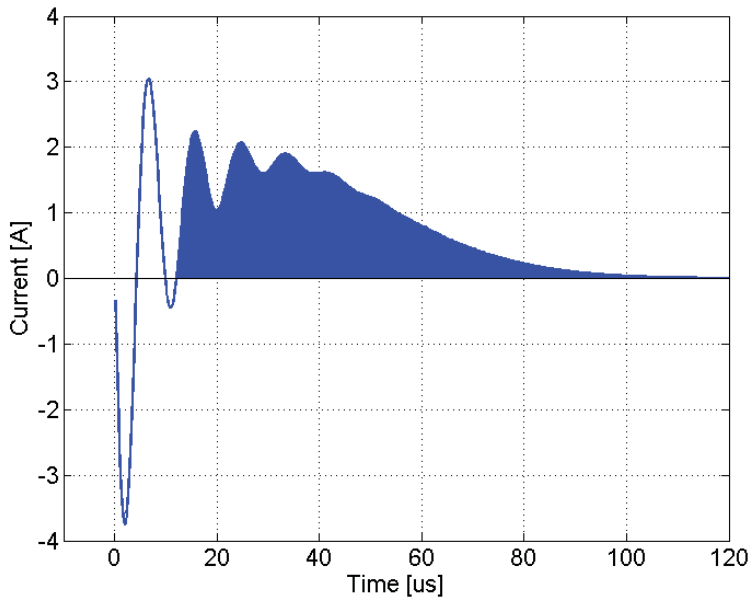


Figure 17: Peak-Charge-Lobe Charge Example (shaded)

2.3.11 Peak-Voltage-Lobe Charge

For most CEWs, one lobe within every pulse will consistently have the highest voltage, called the Peak-Voltage-Lobe. The Peak-Voltage-Lobe Charge seeks to quantify the amount of charge associated with the Peak-Voltage-Lobe. For some CEWs, this parameter provides a means of quantifying the charge delivered by the weapon's arc phase circuitry. The Peak-Voltage-Lobe Charge may also be relevant to the CEW's physiological effects [19]. The Peak-Voltage-Lobe Charge should be determined for all pulses in the discharge cycle. As an example, the shaded area shown in Figure 18 is proportional to the Peak-Voltage-Lobe Charge. The definition of the Peak-Voltage-Lobe Charge is consistent with the $Q(max-)$ parameter described in [19].

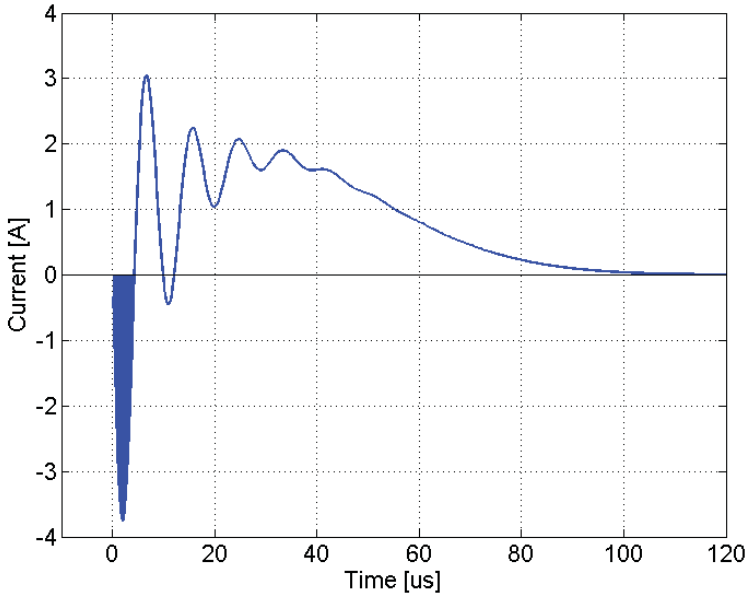


Figure 18: Peak-Voltage-Lobe Charge Example

2.3.12 Energy as a Parameter

Although energy has never been discussed previously as a parameter of interest related to CEWs, energy is referred to when discussing radiation dosage (rems or rads), heat transfer (BTU), kinetic energy (joules), electricity (kilowatt-hours) or light (photon). More work is needed to determine whether or not energy should be included as a valid parameter for consideration.

3 Testing Equipment Specifications

3.1 Environmental Conditions

There is no requirement for the testing to be conducted under tightly controlled laboratory conditions; however, the testing should be conducted at ambient temperature, pressure and humidity. Recommendations are given in Table 1.

Table 1: Environmental Conditions for Testing

Environmental Condition	Value
Temperature	21°C ± 4°C
Humidity	Maximum 95% non-condensing
Barometric Pressure	Approx. 101.3 kPa

3.2 Measurement System

There are several components contained in the generic measurement system that are required to accurately record and analyze a CEW waveform, as indicated in Figure 16. Performance specifications for each of the components are described further in the following sections.

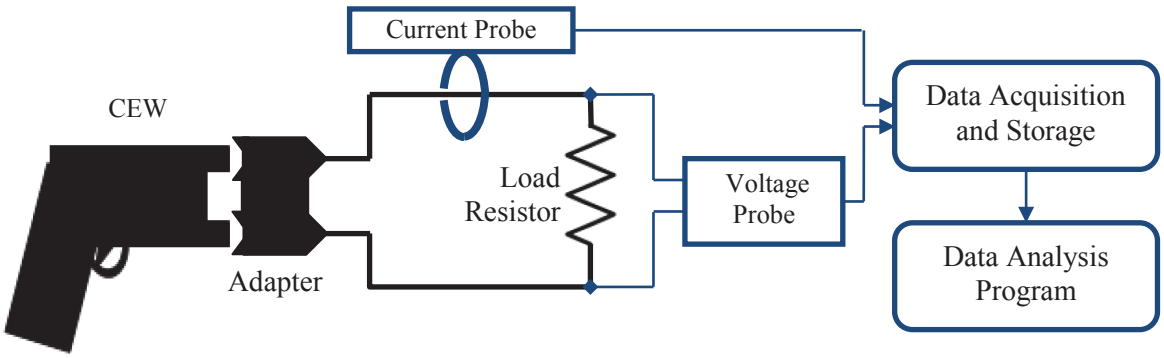


Figure 19: CEW Measurement System

The Data Acquisition and Storage units should rest on a grounded, static-dissipating surface that has a ground-to-surface resistance of at least 1 MΩ. The CEW, lead wires, load, and probes should rest on a high-voltage insulating surface and be kept clear of any grounded surfaces to reduce the effects of parasitic capacitance.

3.3 TASER International Recommended Test Equipment

TASER International recommends very specific equipment to conduct testing. The makes and models are listed in the Certified Test Procedures for the TASER M26 and TASER X26 only [4][5]. Although the specified equipment is readily available, it has limitations in memory such that the waveform of the entire 5-second discharge cycle cannot be captured. For this reason, the equipment identified in the TASER Certified Test Procedures is not recommended. It is expected that professional test laboratories conducting CEW testing will have the means to access the equipment that meets or exceeds the higher performance specifications that are identified in the following sections.

3.4 Adapters and Test Leads

A means of connecting the measurement apparatus of the Data Acquisition and Storage unit to the CEW is required. Since most CEWs will be returned to service after testing, care must be taken not to scratch or otherwise damage the high voltage terminals of the CEW when the connections are made. An appropriate adapter is therefore required to connect the lead wires of the measurement system to the (usually) flat metallic terminals of the weapon. Although a customized adapter can be conceived and used, a commonly used adapter consists simply of a spent cartridge. A compatible cartridge, being an OEM product, will connect easily to the weapon without causing excessive wear to the terminals. Modifications and wiring to a spent cartridge is an inexpensive solution because a spent cartridge is a disposable item. Keep in mind, however, that carbon deposits may accumulate, caused by electrical arcing, on the metallic leads of any adapter that is used frequently for testing. Any such carbon accumulation should be removed by suitable means. Care should be taken to replace the spent cartridge adapter if there is noticeable wear on the metallic leads or degradation of the mechanical fit of the cartridge to the weapon body.

The way in which the test leads of the measurement system make electrical contact with the adapter is also important and is dependent on the CEW model being tested. For example, the test leads of the measurement system can be connected directly to the terminals of a spent cartridge from a TASER X26, as shown in Figure 20. However, such a direct connection is inappropriate for the TASER X2 model, which requires the inclusion of a small (1-mm) air gap between the measurement system's two test leads and the cartridge's terminals, as shown in Figure 21. Failure to include these air gaps will lead to erroneous measurements [16].

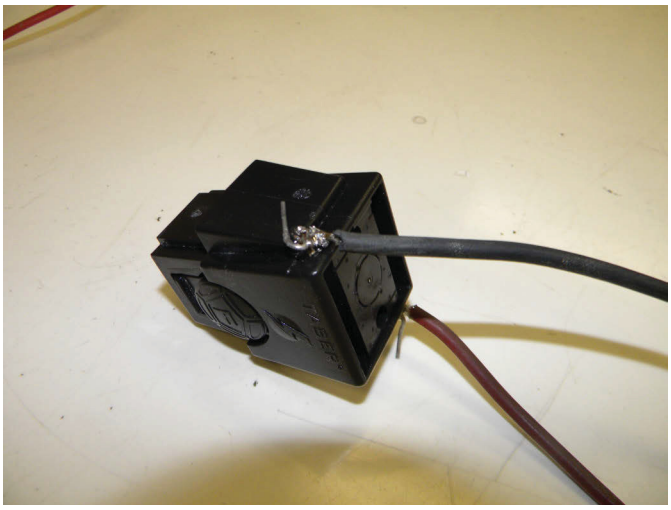


Figure 20: Proper, Direct Connection to a Spent Cartridge of a TASER X26 [Source: Quality Engineering Test Establishment]

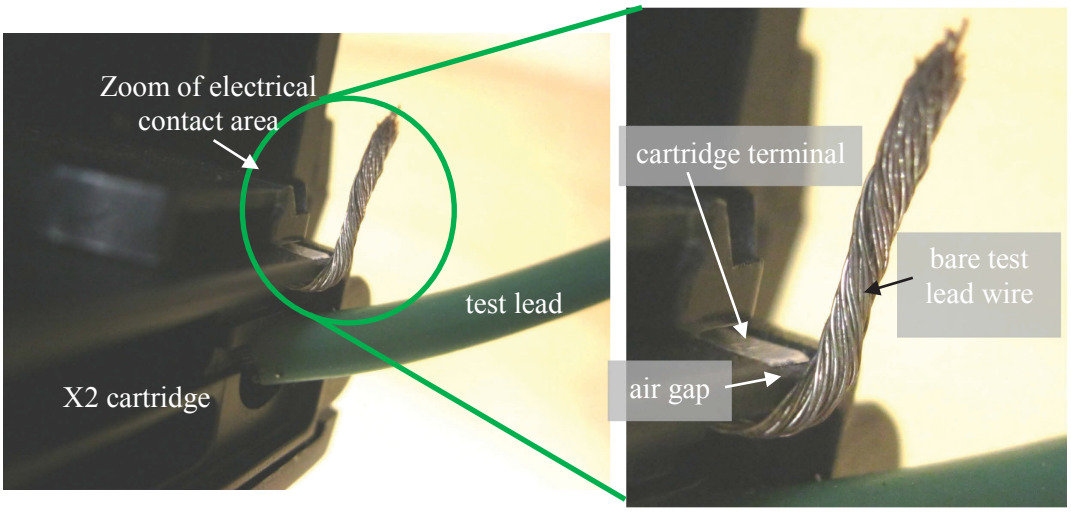


Figure 21: Proper, Indirect Connection of a Test Lead to a Spent Cartridge of a TASER X2 [16]

Standard test lead wires have been found to be an acceptable means of connecting the adapter to the load resistor and voltage/current probes. For example, the 18-gauge, PVC-insulated wires that are commonly used as laboratory patch cables typically sustain a maximum current of 15 amperes and a maximum hands-free DC voltage handling of 5000 volts, which is adequate for testing the TASER X26 and TASER X2 [16][20], but not the TASER M26 because the latter's output voltage may exceed 9000 volts during testing [21]. For safety reasons, the operator must ensure that the wire insulation is rated to handle the expected peak voltage. The two oppositely-polarized wires from the adapter should lie straight on a non-conductive surface and be separated from each other during testing to reduce the potential for arcing, and the operator should ensure not to touch the wires during the test. The resistance of the wires, which should be periodically tested, should be negligible compared to the load resistor.

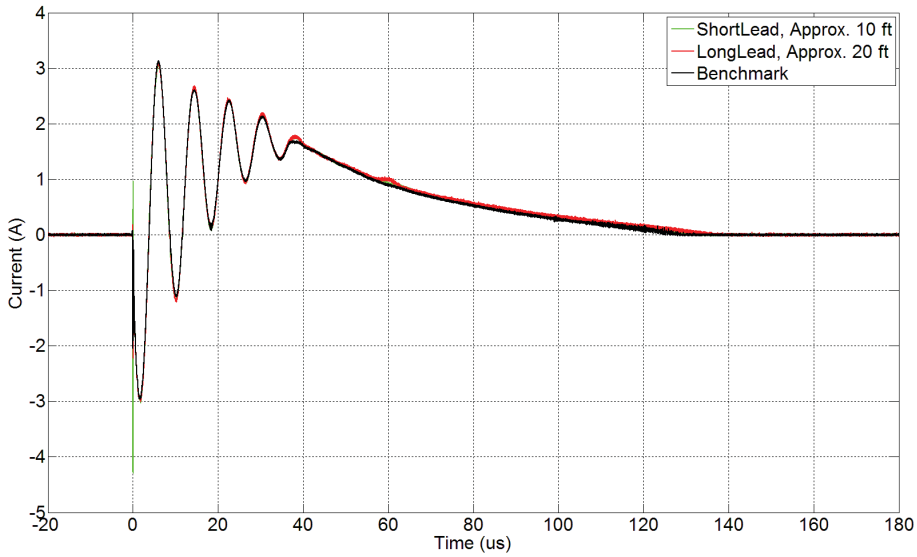


Figure 22: Test Leads' Length Effect on the TASER X26 Pulse [18]

The length of the test leads connected between a spent TASER X26 cartridge and the test equipment has also been evaluated. Measurements were recorded using a benchmark lead length of 7.5-inches and were compared to 10-foot and 20-foot lead lengths. The results shown in Figure 22 indicate that the length of the test leads does not have a significant impact on the measured results.

3.5 Load Resistor

The load resistors proposed by TASER International are deemed to be acceptable for testing purposes. The resistance values, which differ according to the TASER model under consideration, are thought to approximate the resistance of human tissue. The recommended loads for testing the TASER M26 and TASER X26 are the Ohmite LN100J500 500-ohm resistor and the Ohmite LN100J600 600-ohm resistor, respectively [4],[5],[22]. Both models are part of Ohmite's 270-Series of high-wattage, wire-wound, vitreous enamel-coated resistors. Both of these resistors are rated for 100 watts of continuous power, which is deemed to be excessive given that the TASER M26 delivers, at most, approximately 26 watts (at a high pulse rate of 25 pulses-per-second) and the TASER X26 delivers less than 3 watts (at a rate of 19 pulses-per-second) [20],[21]. Given that the weapons are unlikely to be triggered continuously during testing, it is likely that lower-wattage resistors would also be adequate for testing purposes. For instance, TASER International has not specified the load for the TASER X2 model and therefore an Ohmite B12NJ600R 12-watt resistor was used for its initial characterization [16], which is part of Ohmite's lower-wattage 200 Series of wire wound, vitreous enamel-coated resistors [22]. The operator should undertake a calculation of the expected output power of the weapon, and a sufficient safety factor should be added before choosing a suitable load resistor. If high duty-cycles are encountered during testing, compensation for possible resistor heating should also be performed. In all cases, the operator must ensure that the resistor selected is specifically a "non-inductive" model. Wire-wound resistors, in particular, are prone to parasitic inductance owing to their internal windings. For the

Ohmite models listed above, the "N" in the model number indicates that the resistor windings have been compensated to eliminate the parasitic inductance. Any inductance in the load will alter the assumed linear relationship between the CEW's current and voltage, and should be avoided.

Figure 23 below demonstrates the measured current waveform from the same TASER X26 using different load resistor values, where the benchmark represents the measurement taken with the recommended 600-ohm resistor. The graph indicates that the current waveform is largely independent of the load resistance value, which is expected given that the TASER X26 output is modelled electrically as a current source.

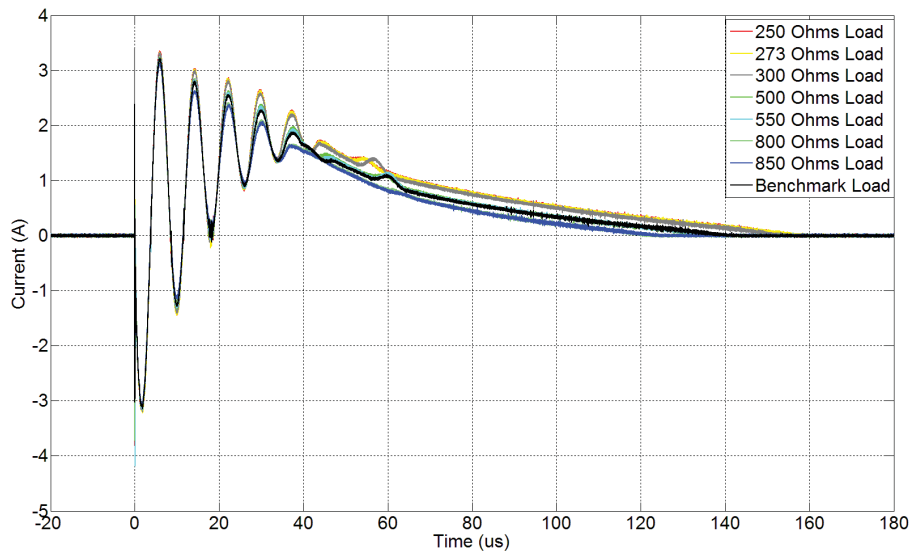


Figure 23: Effect of Variable Resistance for the TASER X26 [18]

Even though the output current is not strongly affected by the resistance, it is important to measure the actual value of the resistor being used during testing. This is especially true if the measurement system uses only one type of probe (be it voltage or current), in which case the other quantity (be it current or voltage) must be calculated via Ohm's Law $V = IR$, where V is the voltage (in volts), I is the current (in amperes) and R is the measured value of the load resistor (in ohms). The actual value of the resistance (and inductance) of the load resistor must be measured prior to testing. This measured resistance value, and <u>not</u> the rated value, must be used in all calculations that may be performed subsequently by the Data Analysis Program. The value of the resistor is prone to drift as a function of temperature, so it is recommended that its value be re-measured periodically during testing, especially if a high duty cycle is being used.

3.6 Probe Specifications

Either a current probe or a voltage probe, or both, may be used for measurement. Of the three TASER models tested (M26, X26, X2), negligible spectral content was present above 500 kHz. A bandwidth analysis should be performed for all other models of CEW as they become available.

The 500 kHz bandwidth requirement for the listed TASER CEWs is modest and their waveforms can be captured, without significant spectral distortion, by a large number of commercial probes.

According to the Nyquist-Shannon sampling theorem, the minimum sampling frequency to unambiguously capture a waveform should be twice the bandwidth of the waveform. To further reduce amplitude errors, a sampling frequency that is at least four times the bandwidth of the waveform is recommended. For the 500 kHz bandwidth of the waveforms associated with the Taser models M26, X26 and X2, this implies a sampling frequency of at least 2 MHz, or a sampling rate of at least 2 MSa/s, which is readily achieved by many commercial oscilloscopes and is near the low-end of the sampling rate ranges available on many high-performance oscilloscopes.

The bandwidth of the probes should be greater than 10-times the minimum Nyquist-Shannon sampling frequency to ensure that the probe bandwidth does not interfere with the measurement. For example, given an assumed 500 kHz bandwidth of interest, the minimum Nyquist-Shannon sampling frequency is 1 MHz and the probe bandwidth should be at least 10 MHz.

3.6.1 Current Probe

A current probe may be used to record the current I flowing through the load resistor. Despite their purely oscillatory appearance, CEW waveforms often contain a finite DC component. As such, the current probe should be capable of measuring both DC and AC waveforms. This usually implies that the current probe should contain a Hall sensor. Current probes consisting only of a *current transformer* (CT) are insufficient. Standard engineering practice should be followed when selecting an appropriate current probe. A current probe is often limited by: (1) its bandwidth, (2) the peak current that it can measure, and (3) the amount of output power that it can produce without damage.

As previously mentioned, the bandwidth of the current probe should be at least 10 MHz. It should be noted that most current probes have bandwidths well in excess of this modest value.

The typical maximum peak current of the TASER M26 is 15 amperes, which is the highest of the three TASER models, and so a current probe maximum peak current of 30 A is recommended. It should be noted that many commercially available current probes have maximum peak current values well above this value, and so this specification should not be a limiting one. Lower values may be used in accordance with the expected peak current for the particular CEW being tested.

Finally, to avoid damage caused by excessive output power, the current-time product of the current probe should not be exceeded. The current-time product (in units of ampere-seconds) of a waveform is conservatively estimated by multiplying the peak current by the pulse duration. TASER CEWs have typical pulse duration of 100 μs, and multiplying this number by the peak current will yield the current-time product. The peak value for the TASER M26 is 0.0019 A·s, whereas it is 0.00042 A·s for the TASER X26, where the peak currents were for weapons functioning according to TASER customer specifications [20], [21]. A safety margin should be factored into the current-time product to handle any weapons that may be operating well outside of specification, and a factor of 5 has been selected herein. The current-time product of commercial current probes varies widely, and this will be a key parameter for selecting a suitable

probe. If multiple models satisfy the current-time product, the one with the best sensitivity should be chosen. Current probes should meet the following specifications:

Table 2: Current Probe Specifications

Specification	Recommended Value
Current Type	DC and AC
Bandwidth	> 10 MHz
Maximum Peak Current	> 30 A
Current-Time Product	> 0.002 A·s (X2, X26) > 0.01 A·s (M26)

3.6.2 High Voltage Probe

CEWs, by their nature, produce high voltage levels at their output. When terminated in their TASER recommended loads, the TASER M26 and TASER X26 can produce peak voltages exceeding 9000 volts and 2500 volts, respectively [20],[21]. Despite these high values, a number of high-voltage probes are available commercially to measure these voltages directly. The advantage of using this method is that the load voltage is measured directly without the use of an intervening voltage-reducing network that can introduce a source of uncertainty in the measurements. The disadvantage of this method is that high voltage probes are expensive. High voltage probes should meet the following specifications:

Table 3: High Voltage Probe Specifications

Specification	Recommended Value
Voltage attenuation	1000:1
Bandwidth	> 10 MHz

3.6.3 Low Voltage Probe

If a high voltage probe is unavailable, voltage measurements may still be performed using a standard commercial voltage probe and a resistive divider. A resistive divider is a series connection of resistors wherein each resistor sustains only a fraction of the total voltage drop, as illustrated in Figure 24.

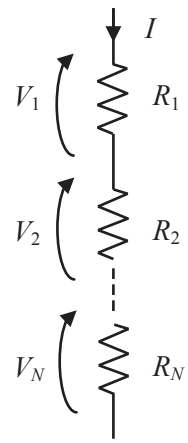


Figure 24: Resistive Divider Network

The sum of the resistances $R_{tot} = R_1 + R_2 + \ldots + R_N$ must equal the value that is specified for testing the CEW, for example, 600 ohms for a TASER X26. The voltage V_n across any one resistor is given by the voltage divider rule:

$$V_n = \frac{IR_n}{R_{tot}}$$

Knowing R_{tot} and R_n, a measurement of V_n allows the unknown current I to be calculated. Given that V_n may be much lower than the total voltage across all of the resistors, using a resistive divider network may allow the use of standard oscilloscope voltage probes to perform CEW testing. The resistor values may also be customized to maximize the dynamic range associated with the probe-oscilloscope combination, which may serve to reduce the relative uncertainty associated with quantization error. However, increasing the number of resistors in the network also increases the uncertainty of the total resistance value. Regardless of the probing method that is used, an uncertainty analysis is strongly recommended in order to place error bounds on all subsequent measurements.

3.7 Data Acquisition and Storage

Specific makes and models of suitable equipment for the Data Acquisition and Storage unit will not be provided herein, thereby granting flexibility to the test laboratories. Either an oscilloscope or a data logger may be used as long as it meets the requirements below and is capable of capturing the entire waveform, from the start of the discharge cycle to the end, including inter-pulse intervals. For example, this implies capturing the entire 5-second discharge cycle of a TASER X26. The following performance specifications ensure that the equipment can capture the entire waveform at the recommended resolution.

Table 4: Data Acquisition and Storage Unit Specification

Specification	Recommended Value
Analog bandwidth	> 1 MHz
Sampling Rate	≥ 2 MSa/s
Effective number of bits (ENOB)	≥ 6
Input impedance	1 MΩ
Epoch	Long enough to capture the entire discharge cycle

The waveform that is captured should be retained in its native format (i.e. using either manufacturer-native file format or another common industry standard) without any modification (including the application of any data filters or parsing of the data).

3.8 Calibration Requirement

To ensure accurate measurements, all equipment used must be maintained using the calibration requirements identified by the equipment manufacturer. All test laboratories are required to maintain sufficient records to ensure the calibration can be traced back to an appropriate reference system.

3.9 Uncertainty Analysis

The test laboratory should perform an uncertainty analysis of the measurement system such that the errors associated with the measurements are known. Accepted engineering practice should be followed to determine the uncertainty value [23]. The test laboratory should provide the uncertainty analysis upon request. Uncertainty values should be included in the test report.

3.10 Data Analysis Program

The Data Analysis Program reads the stored waveforms, calculates the parameters associated with the waveforms, and generates the test report. The Data Analysis Program would likely consist of a sequence of computer routines that automatically perform these tasks.

3.10.1 Software Language

The routines that analyze the waveforms can be written in any computer language at the discretion of the test laboratory, as long as the original recorded data is retained without modification. This would allow the analysis routines to be re-applied, if necessary, or to corroborate the findings of another test laboratory. The routines should calculate all of the parameters that are defined in Section 5.

3.10.2 Data Format

The file names of the recorded waveforms should be chosen following the rules described in Section 5.3. The test report, which should be generated in a comma-separated values (CSV) file, should place the calculated waveform parameters in specific locations (or fields) within the file. Details on the format of the CSV test report are found in Annex E.

3.10.3 Calculation of Charge by the Data Analysis Program

Although the electrical waveform generated by the CEW is continuous in time, the Data Acquisition and Storage unit will only sample this waveform at discrete time intervals, where the interval between the samples is Δt and the sampling rate is $1/(\Delta t)$. As was discussed in Section 2, charge is an important waveform parameter. For a continuous waveform, charge Q (measured in coulombs) is calculated by performing an integral from time t_1 to time t_2 of the current waveform $I(t)$ (measured in amperes). Depending on the definition of the charge parameter of interest, the absolute value of $I(t)$ may be called for in the integrand. For simplicity, this distinction will not be made here. Therefore, for a continuous waveform,

$$Q = \int_{t_1}^{t_2} I(t)\, dt$$

For discrete (sampled) waveforms, the integral will be approximated using the Sample-and-Hold method, in which the continuous waveform is approximated by holding the last sample point constant for the duration of the sampling interval Δt. The resulting waveform has the appearance of a bar graph, as shown in Figure 25.

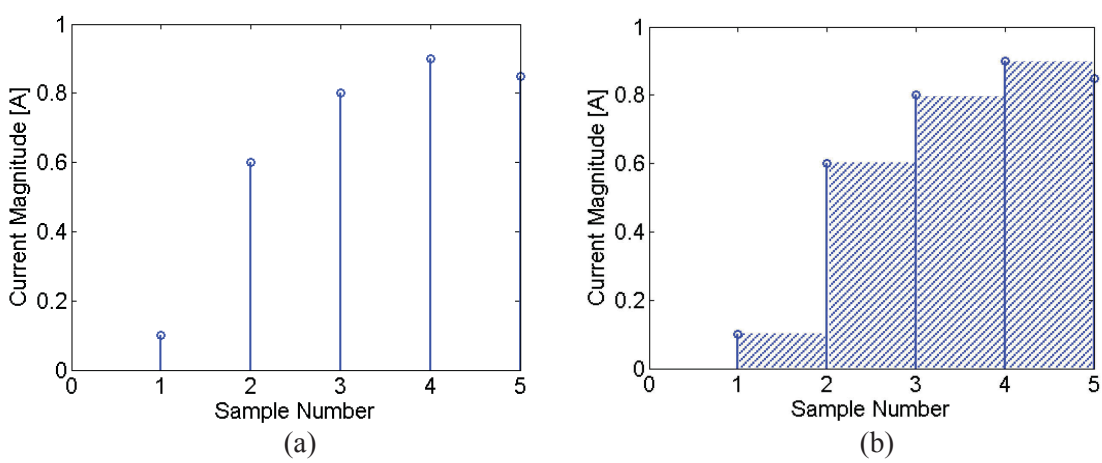


Figure 25: Sample-and-Hold Concept (a) Discrete Current Samples and (b) Bar Graph Approximation

The charge of the continuous waveform is approximated by the area under the bar graph (shaded region), which is obtained by summing the amplitudes of all of the discrete sample points (k_1 to k_2) contained within the time span t_1 to t_2 of interest and multiplying by the sampling interval:

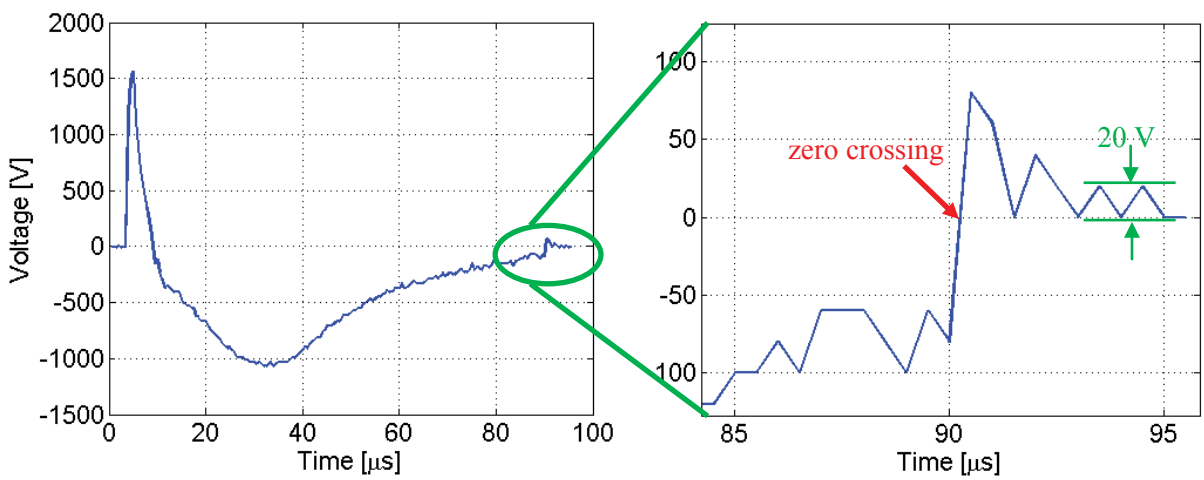
$$Q \approx \Delta t \sum_{k_1}^{k_2} I_k$$

where Δt is the sampling interval (in seconds), I_k is the current amplitude (in amperes) of the kth data point, k_1 is the *start index*, and k_2 is the *end index*. The start and end indices (k values) depend on the parameter of interest and are defined in Section 2.

3.10.4 Low Pass Filtering and Zero Crossings

Given its digital nature, the Data Acquisition and Storage unit can assign only a limited number of discrete levels to the sampled voltage and/or current amplitude. The number of discrete levels, known as *quantization levels*, is dictated by the *number of bits* of the analog-to-digital converter. The price of measurement equipment is often related to the number of bits it provides.

The quantization levels add a further degree of jaggedness (quantization error) to the measured CEW waveform, which already contains noise. The quantization level becomes apparent when zooming-in on a particular level, such as the zero level. The zero level is of particular interest because the Data Analysis Program needs to decide when a waveform ends, which is usually where the waveform remains at zero for a certain period of time. This is illustrated in Figure 26,



which shows a measured voltage waveform from a TASER X2 and a zoom of its tail.

Figure 26: End of a TASER X2 Pulse

For this measurement, the Data Acquisition and Storage unit consisted of an oscilloscope and voltage probe. The oscilloscope has 8-bits, or $2^8 = 256$ quantization levels. The vertical setting of the oscilloscope was set to 500 volts per division, and the oscilloscope displays 10.24 divisions on the screen by default. This means that voltages between –2560 volts and +2560 volts could be

displayed on the screen. The quantization increment is therefore 2(2560)/256 = 20 volts. This means that the minimum step between quantization level is 20 volts, which is apparent on the right-hand side of Figure 26.

Filtering: As indicated in Section 3.6, the probe's bandwidth will exceed the sampling frequency; therefore, a low-pass anti-aliasing filter having a cutoff frequency that is half the sampling frequency should be applied prior to recording the measurement.

As illustrated in Figure 26, despite the application of an anti-aliasing filter, the tail of the recorded waveform might not be very smooth and could include a lot of noise. As such, there may be a desire to apply a digital low-pass filter before the calculation of the parameters is performed by the Data Analysis Program. The problem with such filtering is that the results that are obtained will vary with the filter that is applied. To reduce ambiguities related to the choice and application of filters, a standardized bandwidth should be specified. If the cut-off frequency of the anti-aliasing filter is greater than the minimum Nyquist-Shannon sampling frequency, the Data Analysis Program should apply a low-pass digital filter having a cut-off that is equal to the minimum Nyquist-Shannon sampling frequency to the recorded measurement prior to performing the data analysis. This filter reduces the noise content in the data and standardizes the bandwidth of the data prior to analysis.

Although there may be some debate as to when a waveform actually becomes or crosses zero in the presence of noise and quantization error, for simplicity, a zero crossing is defined as follows:

Zero Crossing: the interpolated zero value between two successive data points having opposite signs, or any time the measured waveform is exactly equal to zero. Therefore the first zero crossing of the tail in Figure 26 corresponds to the location of the red arrow.

4 Full Test Methodology

4.1 General

Figure 27 below shows the flowchart for testing CEWs. Each of the major steps is described in the following sections:

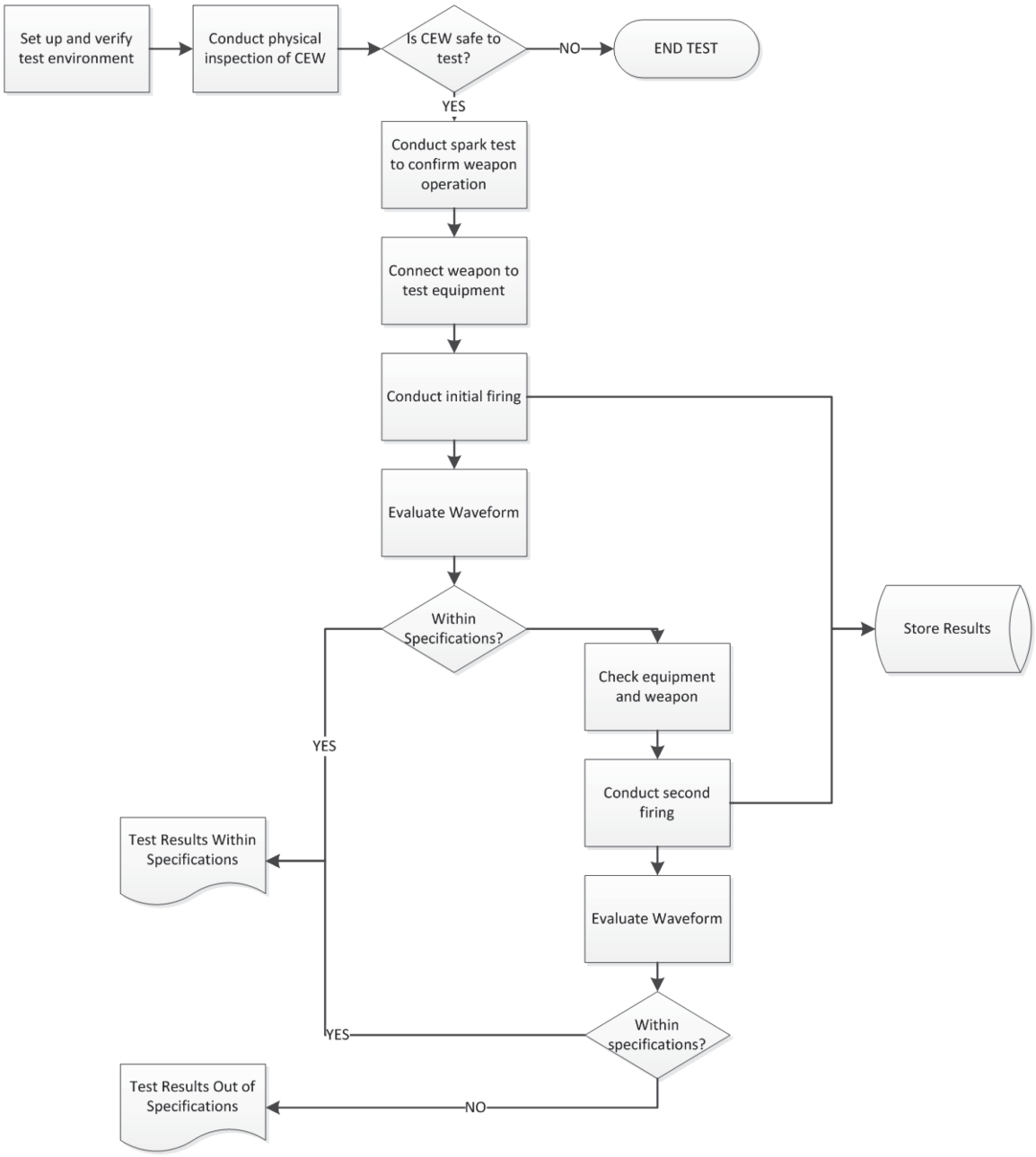


Figure 27: General CEW Test Procedure

The objective of the confirmation testing as described in this section is to confirm that the CEW is performing as expected. This information may be used by police services to decide whether or not to remove the weapon from service or to replace it. The purpose of this testing is not to determine if law enforcement agencies are taking appropriate care of the weapon.

As indicated in Section 1.6 the CEW is a system with four components. This test procedure only confirms the weapon performance and cannot make any determination of the state of any battery pack or cartridge. For this reason, it is expected that the testing will be conducted with a battery pack known to function correctly. Unfortunately, there is currently no mechanism to perform a confirmation assessment on battery packs.

4.2 Test Methodology

Additional details for each of the steps in the test procedure are included below. It is important to note that the purpose of the preparation activity is to ensure as clean and reliable a test as possible. Old protocols, including Version 1.1, required that the weapon be tested as received, This procedure recommends three trigger pulls including a spark test; however, it is not recommended that the data on the first trigger pull be retained and that only the second and the third be used to determine weapon condition.. The primary reason behind this is that testing and retaining data for a test that the technician has every reason to suspect may result in a less than optimal capture will only negatively affect the data quality when grouped with legitimate test results. The purpose of this testing is not to evaluate the state of the weapons as received from the police services. There may be many reasons why a weapon could be received in less than perfect condition, some of which may not be related to the weapon's use in operations (such as shipping problems). The objective of this testing is to confirm whether or not the weapon should be retained in inventory or if it should be disposed of as a faulty weapon. This however does not preclude the need for the technician to make note in the written report of the condition the weapon is received so that the police service can take appropriate corrective action as necessary. There may also be situations where a police service has specifically asked the test lab to provide detail on the condition in which the weapon is received.

4.2.1 Test Equipment Setup

This activity involves the test laboratory connecting their probe(s), Data Acquisition and Storage unit, resistor, and other equipment. The test laboratory should ensure the calibration of the equipment is up-to-date and that equipment initialization activities are conducted as recommended by the manufacturer. This includes any necessary zeroing of probes or setting of offsets. These activities are core to a test laboratory's business and any laboratory that is operating under quality systems such as ISO 17025 will know the appropriate actions to be taken.

It is the responsibility of the test laboratory to calculate the measurement error that applies to the specific test set up. This measurement error will vary depending on the equipment and the value should to be calculated and provided in the report to the client.

As part of the set up procedure, the test laboratory should measure the actual resistance of the resistor. This is the value that should be used in all calculations. Because operation of the CEW

has the potential to affect the resistor value, test laboratories need to validate prior to testing to determine if there have been any changes.

4.2.2 Weapon Preparation

The weapon to be tested should only be handled by someone that is fully familiar with conducted energy weapon operations, and who meets the specific legal requirements as per Section 6.3. Before commencing testing, there are some preparatory activities that should be undertaken:

a. The technician should conduct a physical inspection of the weapon to ensure there are no cracks, broken parts or any other observable damage. Testing should not proceed if the weapon is physically damaged. If the state of the battery is unknown, the technician should confirm that it has a good battery installed.

b. All identifying details concerning the weapon need to be properly recorded. This will include as a minimum the Model, Serial Number and Version.

c. Prior to placing the weapon in the test set up, the technician should disengage the safety and without a cartridge, pull the trigger (i.e., perform a spark test). A complete discharge is not necessary as the purpose of this step is simply to confirm that the weapon will fire when placed in the test set up. There is also no way of knowing if the weapon has been sitting for a while, so following a consistent procedure will ensure that test results are comparable. This also correlates with operational procedures for the weapon to be checked at the beginning of a shift. If the weapon does not fire, there is no need to conduct an official electrical test it and it may be returned to the police service for appropriate disposal. There is no need to capture the data for this firing.

4.2.3 Connect weapon to test equipment

As indicated in Section 3.4, a spent cartridge is an appropriate adapter to connect to the test equipment. The weapon should seat securely in the spent cartridge. Note that there is no need for the firing to be hands-off as would be recommended with accuracy and precision testing.

4.2.4 Initial firing

The entire waveform of the weapon should be captured during firing (including between the pulses). If the weapon measures within the established performance specifications, no further testing is required and the weapon may be returned to the police service with a condition of "Within Tolerance". This is the expected state for the vast majority of the current weapons.

4.2.5 Corrective Action

If on the first test, the weapon does not measure within the established specifications, then the technician should check the test equipment, check the weapon and connections and if necessary, replace the DPM before retesting.

4.2.6 Second Firing

If necessary, a second firing can be conducted once the technician has checked the equipment and the condition of the weapon. If on the second firing, the weapon still fails to measure within the established specifications, it should be returned to the police service and reported as a condition "Above Tolerance" or "Below Tolerance". In the rare circumstance that the weapon measures above on one parameter and below on another parameter, the weapon should be reported as a condition "Above Specification".

It is recognized that occasionally things go wrong in testing, such as selecting an incorrect setting on the equipment. It is therefore reasonable for the test laboratory to recommence the testing. Faulty test results should not be retained.

4.2.7 Reporting

Once the testing is complete, the test laboratory should have one raw data file and one file containing the summary of the parameters. The test laboratory should provide a final report to the police service indicating the condition of the weapon that was tested. Confirmation assessment should include results of testing against manufacturer specifications plus test laboratory observations against other criteria as indicated in Annexes A to C. Additional details on the reporting requirements are indicated in Section 5.

Although the police service may be looking for a recommendation as to whether or not the weapon should be removed from service, this is not the responsibility of a test laboratory. The test laboratory is only required to provide a professional opinion on the physical state of the weapon. For example if the weapon's performance has degraded or changed significantly since the previous testing, this would be reasonable to report to the police service. It is also reasonable to advise police if the measures are approaching the established limits.

It is not possible with the data that is available and in the absence of clear medical opinion on effectiveness to determine whether or not a weapon should be removed from service for medical reasons. It is more likely that the results of a confirmation assessment will identify a weapon that has an overall poor performance and is not likely a weapon a police officer could depend on to reliably function when needed.

Annexes A, B, and C provide performance limits for the TASER M26, TASER X26 and TASER X2 to be used to determine if a weapon is operating within the manufacturer's specifications. Additional parameters with acceptable values are provided where available. It should be noted that at the time of publication, the manufacturer had not released performance specifications for the X2. It is intended to determine appropriate levels of confidence experimentally for the newer TASER X2 and TASER X26P. Once available, these levels of confidence should be made available and an addendum to this report could be generated.

5 Reporting Requirements

5.1 Report Format

Test agencies are free to use a locally designed report to provide the results to the client. The following information should be included in the written report:

- Name of the test laboratory
- Name of the technician that conducted the test
- Name and signature of the engineer approving the results contained in the report
- Client's name and contact information
- Report identifier including data and report version
- Quantification of the uncertainty in the measures (i.e., measurement error)
- Detailed identification of the test equipment used (including OEM, Make, Model, Serial number, calibration state)
- Description of the test method used
- Test Conditions (Temperature, Humidity, Atmospheric Pressure)
- Weapon identification details (Manufacturer, Model, Serial Number, Firmware version)
- Weapon's manufacture date (if known/provided) and weapon's date of purchase (if provided by the law enforcement agency)
- Weapon Test Conditions (Battery level, measured load resistance)
- Summary for each weapon that describes the status according to the manufacturer's specification:

TASER International Parameters	Measured Value	Within/Above/Below Specification
Pulse Rate		
Main Phase Peak Voltage		
Main Phase Peak Current		
Main Phase Net Charge		
Pulse Duration		

- Summary for each weapon that describes the status according to the additional parameters outlined here:

Additional Parameters	Measured Value	Within/Above/Below Specification
Discharge Cycle Duration, in seconds		
Number of Pulses		
Maximum Pulse Duration, in seconds		
Minimum Pulse Duration, in seconds		
Mean Pulse Repetition Interval, in seconds		
Maximum Pulse Duration, in seconds		
Mean Pulse Repetition Frequency, in hertz		
Maximum Pulse Repetition Frequency, in hertz		
Minimum Pulse Repetition Frequency, in hertz		
Highest Pulse Voltage, in volts		
Weakest Pulse High Voltage, in volts		
Lowest Pulse Voltage, in volts		
Weakest Pulse Low Voltage, in volts		
Mean Total Charge, in coulombs		
Maximum Total Charge, in coulombs		
Minimum Total Charge, in coulombs		
Peak-Charge-Lobe Mean Charge, in coulombs		
Peak-Charge-Lobe Maximum Charge, in coulombs		
Peak-Charge-Lobe Minimum Charge, in coulombs		

- Additional comments such as the state of the weapon and any observations or recommendations as a result of the test.

5.2 Reporting Measured Value with Measurement Uncertainty

Measurement uncertainty represents the sum of error inherent in all test equipment and has the effect of identifying an upper and lower bound to a measured value. This means that the true value will lie somewhere within the lower and upper bounds provided. Test laboratories are required to calculate and report their measurement uncertainty with their test results. When reporting a measured value, the test laboratory should indicate the high and low values taking into consideration the measurement uncertainty. Where the measured value, including the measurement uncertainty, lies within the provided specification, the weapon is to be deemed 'Within Specification'. If the measured value, including the measurement uncertainty, lies above the provided specification, the weapon is to be deemed 'Above specification'. If the measured value, including the measurement uncertainty, lies below the provided specification, the weapon

is to be deemed 'Below Specification'. If a specification is not listed for the particular TASER model, then 'Not Applicable' should be listed in the table. Different specifications are provided for each TASER model in Annexes A through D.

5.3 Specification for Test Data

The absence of a standard data format introduces significant complexity and a high probability of error when legacy data is analyzed by another agency. In order to avoid these difficulties, it is proposed that all data be retained in a standardized format.

In addition to the raw waveform, the details related to the testing method and the results should be stored in a comma delimited text file. The name of the file should be standardized according the following format:

Model_SerialNumber_TestDate_TestSequence.txt

The model number should be for the weapon itself (current options would be M26, X26, X2, X26P). Others are to be added as appropriate. The Serial Number should be the number assigned to the weapon by the manufacturer and should be permanently affixed to the weapon. Together the Model Number and the weapon Serial Number should be unique identifiers.

The Test Date should be expressed as DD-Mon-YYYY and should represent the date that the testing was conducted. The use of the three-character expression of month should eliminate any confusion with the two-digit day. The Test Sequence should indicate which firing the results represent for the given date (beginning at 1 and increasing incrementally by 1 for each test). The combination of Model Number, Serial Number, Test Date and Test Sequence should uniquely identify the specific test conducted.

The raw data retained for the test should be stored in a file with the same file name. The only difference will be the file extension that will vary depending on the specific data format used. It may be necessary to rename this file if it is stored natively using a different filename structure. Consistency in file naming will make matching the test method data with the raw data easier.

A standard has also been developed for documenting the test results in the comma-delimited file. The detailed specification is included in Annex E.

5.4 Data Classification

There has been some discussion as to the classification of the test results. Testing conducted for the purposes of confirmation assessment should be treated as UNCLASSIFIED. Note that any testing for forensic purposes should be treated under rules governing the handling of evidence.

5.5 Data Retention

Police agencies should retain hard copies of the test report from the test agencies for as long as they own the weapon. If the weapon is transferred to another agency, copies of the test results should accompany the weapon.

Digital copies of the raw test data as well as the analysis results should be retained for three years by the test laboratory and then can be turned over to the law enforcement agency for further retention. It is useful for a test laboratory to have access to previous results so that test results can be compared to previous test results. This is to enable the results to be examined more closely should it be required.

6 Qualifications of Test Laboratories

The objective of identifying the qualifications for a test laboratory is to ensure that police services have confidence in the results of the tests.

6.1 Independence

A test laboratory should be independent of the manufacturer, the distributer, the operator and the policy organizations.

6.2 Quality Management System (ISO 17025)

The International Standards Organization has created a standard ISO 17025 *General Requirements for the Competence of Testing and Calibration Laboratories*. This standard is suited to the testing of conducted energy weapons and test laboratories that comply with the requirements of ISO 17025 will also meet the quality management requirements for testing and calibration activities outlined in ISO 9001.

ISO 17025 includes requirements related to the organization, management system, document control, subcontracting of tests and calibrations, purchasing services and supplies, service to the customer, complaints, control of nonconforming testing and/or calibration work, improvement, corrective action, preventive action, control of records, internal audits. The standard also outlines specific technical requirements related to personnel, accommodation and environmental conditions, test and calibration methods and method validation, equipment, measurement traceability, sampling, handling of test and calibration items, assuring the quality of test and calibration results.

The Standards Council of Canada (SCC) is a federal Crown Corporation reporting through the Minister of Industry and is mandated to provide efficient and effective standardization in Canada. They offer a Laboratory Accreditation Program for test and calibration laboratories to ISO 17025. Information about this program and a directory of accredited electrical/electronic laboratories is available on the SCC website: http://www.scc.ca/en/accreditation/laboratories.

> *Accreditation by the SCC is the formal recognition of the competence of a laboratory to manage and perform specific tests or types of tests recognized and listed by the SCC. Accreditation is available for all types of tests, measurements and observations and is currently offered in the following fields of testing: Acoustics and Vibration, Biological, Calibration, Chemical, Electrical/Electronic, Ionizing Radiation, Mechanical, Non-destructive Evaluation, Optics & Optical Radiation, Thermal & Fire.*
>
> *In order to be accredited, labs must meet general requirements of ISO/IEC 17025-2005. In addition, laboratories must demonstrate competence to perform the specific tests or types of test for which they wish to become accredited [24].*

Accreditation to ISO 17025 is voluntary and SCC is not the only organization capable of accrediting test labs. Test laboratories may have received accreditation through other means and police services should ask for evidence that the test laboratory complies with the requirements of ISO 17025.

When contracting for a test laboratory, it is easiest if a mandatory requirement is inserted requiring the test laboratory to be accredited by SCC to ISO/IEC 17025. Alternatively, the following statements could be inserted as mandatory requirements (references relating to ISO 17025 are provided):

a. An independent third party shall conduct all testing. The laboratory shall demonstrate that it is impartial and that it and its personnel are free from any commercial, financial or other pressures which might influence their technical judgement (4.1.4);

b. The laboratory shall have policies and procedures to ensure the protection of its customers' confidential information, including procedures for protecting the electronic storage and transmission of results (4.1.5);

c. The laboratory shall have a quality policy statement issued under the authority of top management that provides their commitment to good professional practice and to the quality of its testing service (4.2.2);

d. The laboratory shall have documented and approved procedures to control all documents that form part of its management system (regulations, standards, methods, drawings, specification, manuals, etc.) (4.3.1);

e. When a laboratory subcontracts work, this work shall be placed with a competent subcontractor that complies with the quality standards of the test laboratory (4.5.1);

f. The laboratory shall be willing to cooperate with customers or their representatives in clarifying the customer's request and in monitoring the laboratory's performance in relation to the work performed, including providing reasonable access to relevant areas of the laboratory for the witnessing of tests for the customer (4.7.1);

g. The laboratory shall establish and maintain procedures for the identification, collection, indexing, access, filing, storage, maintenance and disposal of quality and technical records (4.13.1.1)

h. The laboratory shall have procedures to protect any back-up records stored electronically and to prevent unauthorized access to or amendment of these records (4.13.1.4);

i. The laboratory shall retain records of original observations, derived data and sufficient information to establish an audit trail, calibration records, staff records and a copy of each test report for a defined period. (4.13.2.1). For the purpose of CEWs, this time period is recommended to be 3 years.

6.3 Legal and Safety Requirements

Conducted energy weapons are prescribed either as prohibited weapons or prohibited firearms, depending on their design, in the *Regulations Prescribing Certain Firearms and Parts of Weapons, Accessories Cartridge Magazines, Ammunition and Projectiles as Prohibited or Restricted*, SOR/98-462 [25], which are made pursuant to Section 84 of the *Criminal Code*. Companies undertaking testing must comply with all applicable laws, including the *Criminal Code* and the *Firearms Act* and all related Regulations.

6.4 Certification of Results

It is expected that an authorized individual will have reviewed any results of formal testing conducted by a test laboratory. In the circumstance of CEW testing, the nature of the testing is such that it is recommended that a Professional Engineer sign off on the final results.

6.5 Portable Test Devices

There are several portable test devices on the market currently. Evaluation of these test devices was outside of the scope of the CEWSI project and therefore no comment can be made as to the suitability of these devices to replace independent testing.

6.6 Public Sector Test Agencies

While some public sector test agencies may hold a 17025 certification, others may not. Public sector test agencies testing CEWs should also have in place a quality system in line with ISO/IEC 17025 to ensure consistent results.

6.7 Manufacturer Certification

TASER International has made available a document that outlines the requirements for a test laboratory to become certified by TASER International to perform testing to TASER International Certified Test Specifications [26]. This certification is optional and available for a fee. In general, TASER International looks at many of the same things as are covered in ISO 17025: independence, facilities, standards, test equipment, calibration, quality control, organization, personnel, testing, test reports and experience. The process of achieving TASER International Certification involves an application, on-site evaluation, and follow-up audits. The TASER International Certification does not direct that a specific make and model of equipment is needed, only that it be capable of measuring the parameters outlined in their test procedure. There is also nothing in their requirements that would limit the analysis to the parameters they have identified. While this certification is not deemed to be necessary, it would be an acceptable alternative to the ISO 17025.

7 CEW Test Strategy

7.1 General

The following sections outline the recommended test actions that should be taken to ensure a conducted energy weapon continues to operate as expected and that it is available to support police operations.

7.2 Considering a New Device

As mentioned previously, one of the objectives of the CEWSI project was to develop an approval process for less lethal technologies. A report with recommendations for policy makers and key law enforcement stakeholders has been completed that makes recommendations for testing prior to purchase. [14]. In general, the recommended approval process calls for independent testing of any less lethal technology being considered prior to purchase. This is to validate the performance of the technology in relation to the manufacturer's claims. In addition, this independent evaluation would help determine whether or not a specific technology is effective and suitable for the intended tasks and would help to determine the need for in-service validation or confirmation assessment.

7.3 On Purchase

When new weapons are received from the manufacturer, there are several actions that should be taken on receipt.

a. Create Inventory Record. On receipt of a new weapon from a manufacturer, the police service should ensure a detailed inventory record is created that includes the following information for all components: Manufacturer, make, model, serial number, hardware and/or software version, manufacture date (if known), delivery date and warranty end date.

b. Conduct Physical Inspection. Each weapon should undergo a physical inspection to look for obvious damage or problems. This should include checking and operating the trigger and safety mechanisms as well as seating the DPM. In addition, a quick test fire should be conducted to confirm operation.

c. Document Specifications. Manufacturers may make changes to the performance specifications over the life of a weapon, therefore police services are recommended to retain on file a copy of the manufacturer performance specification and any test specification that was in effect at the time of purchase. Frequently changing performance and test specifications are a sign of a weapon that may also be subject to design changes and could be an indication of an immature or still developing design.

d. Conduct Data Download. Conducted energy weapons currently in use by Canadian law enforcement arrive from the manufacturer with an onboard record of the manufacturer

quality assurance testing. This data should be downloaded and placed on the weapon file before the weapon is issued for operational use. Police services are reminded of the need to order any hardware, software or other accessories needed to support diagnostic activities as recommended by the manufacturer.

e. Firmware Upgrade. There is a possibility that there may be newer versions of the firmware than was shipped with the weapon. Police agencies should ensure that the weapon has the latest version of firmware available and should follow the manufacturer's instructions to do any upgrades necessary. For the TASER X26 model this is accomplished by inserting a DPM with the new version. Updates to the TASER X2 model are accomplished by connecting to TASER International online.

f. Need for Independent Electrical Testing. The TASER M26 model is no longer in production and is being phased out of use in Canada. The TASER X2 and the TASER X26P models are newer model weapons that have not yet been tested or approved for use in Canada. The need for any independent testing as part of acceptance from the manufacturer will be determined during the approval process. As part of the environmental testing conducted by the Quality Engineering Test Establishment, 40 new TASER X26 weapons were purchased. The waveforms were captured in order to establish a benchmark measure prior to environmental testing. The results of this testing are shown in Figure 28 and Table 5 and indicate that the performance of the new TASER X26 weapons had very little variation. Assuming a normal distribution, the peak voltage of a new weapon will measure between 1822 and 2170 Volts with a level of confidence of 99.7%. This is well within the minimum and maximum specification of 1400 and 2520 Volts as indicated by the manufacturer. These results are consistent with an analysis of previous test results of newer (but not necessarily brand new) TASER X26 weapons as seen in Figure 28. The evidence we have seen indicates that police services can use new X26 weapons delivered from the manufacturer with a high level of confidence that they will function as intended on receipt.

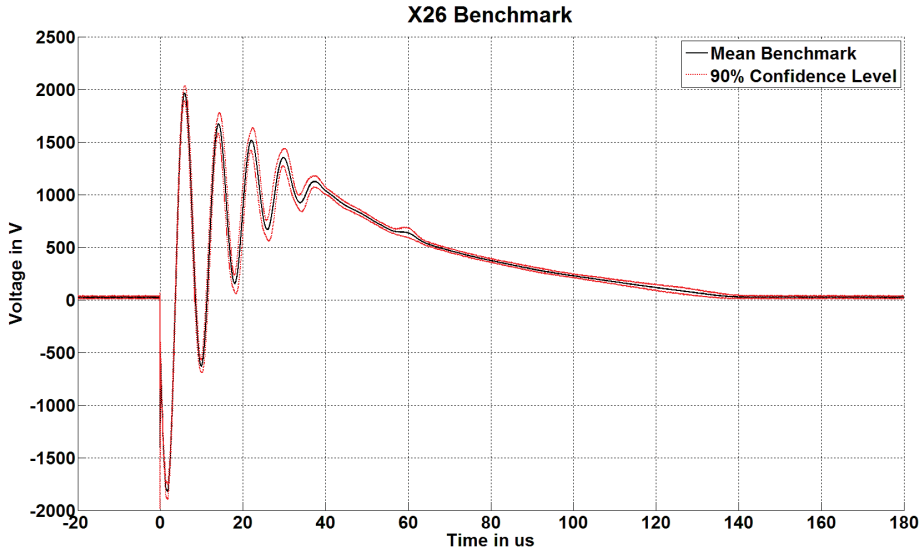


Figure 28: TASER X26 Benchmark Waveforms [18]

Table 5: TASER X26 Benchmark Measurements [18]

Parameter	Mean Value	Standard Deviation
Peak Voltage	1996 V	58 V
Main Phase Charge	109 μC	3 μC
Pulse Duration	132 μs	5 μs
Pulse Repetition	18.36 Hz	0.03 Hz

7.4 Daily/Routine Actions

As with any equipment used by law enforcement, there are certain actions that should be taken at the beginning of a shift or before use to confirm the equipment is ready to use.

a. Visual Inspection. Every component of the weapon (including the cartridges) should be inspected for any signs of obvious damage such as a broken or cracked casing, safety or trigger switch. The operator should also confirm that the contacts are free of any dirt and that the battery pack seats properly in the weapon. A weapon component displaying physical damage should not be used.

b. Power Up. With the safety engaged, the weapon should be turned on. Operators should refer to the specific user manual of the model they are using to ensure any available displays provide the correct ready information for their model.

c. Spark Test. Without a cartridge installed, the operator should disengage the safety mechanism and safely fire the weapon in order to ensure a spark results. While the operator may let the weapon fire its full cycle, this is not required and the officer can interrupt the cycle by reengaging the safety mechanism. Original instructions from the manufacturer indicated that this spark test served a purpose of conditioning internal components. Design changes since approximately 2008 indicate that this is no longer the case, however it is still felt that conducting the spark test serves to provide the officer with confidence that his equipment is ready to use [27]. Because the pulses are audible, some operators have indicated that they can hear if the pulse rate is abnormal. Laboratory experiments have shown that the pulse rate is an easy parameter that could be verified by police agencies using small portable devices. Such a device is not currently commercially available however it would potentially be a useful and low cost option. Analysis of previous test data indicates that the parameter most likely to result in a measure outside of the manufacturer's threshold is the pulse rate [28]. If an operator suspects that the pulse rate is different from what they expect it to be, the weapon should be sent for independent testing.

7.5 First Line Maintenance Actions

There is some maintenance activity that is best controlled within the law enforcement agency to ensure consistency in their application. These tasks are not complex and should be covered in routine operator training.

a. Visual Inspection. As with the daily check, the first step is a check for any physical damage with any of the components (weapon, cartridge, battery). In addition to noticeable cracks or broken parts, the weapon system should be checked for any dirt and the terminals where the battery connects should be clear of dirt and cleaned if necessary on both the weapon and the battery.

b. Data Download. The amount and type of information stored on the weapons varies with the model; however, law enforcement agencies are easily able to access this information through software and special cables available from the manufacturer. The available data should be downloaded and added to the file on purchase, anytime there is a malfunction, prior to sending for independent testing and, if possible, prior to disposal. Some law enforcement agencies have indicated an intermittent problem with data corruption. Testing in laboratory conditions has been unable to reproduce these results. Data stored on the weapon is stored in non-volatile memory that will retain the data even if the battery is removed for an extended period. The components used are rated to retain the data for a length of time significantly longer than the expected life of the weapons [29].

c. Battery Replacement. The manufacturer recommends that the DPM for the TASER X26 be replaced when the power level display indicates 20% [30]. The remaining battery level is a calculated number based on temperature and the number of times the battery has fired a weapon, therefore the actual power remaining may be higher or lower and there is no simple or effective way to measure the actual remaining. In addition, tests have indicated that the temperature has a significant impact on battery performance with the result that operation in cold temperatures will cause the battery to deplete more quickly. The TASER X26 DPM also is used to update firmware with new versions. The clock in the TASER X26 may reset itself after 24 hours without a battery however firing data would not be affected. It is noted that the X2 uses a separate watch battery for the clock, so removing the battery will have no effect.

d. Firmware Upgrade. The firmware for the TASER X26 can be updated by inserting a new version DPM. For the X2, updates are received online by connecting the weapon to Evidence Sync. In all cases, a change to the firmware represents a configuration change to the main weapon therefore this should be recorded on the weapon file.

e. Failure Tracking. As with other equipment in use by law enforcement agencies, CEWs need to be kept in good working order to ensure they are available when needed. If a weapon repeatedly fails to fire correctly, law enforcement agencies should investigate possible causes before sending for independent testing such as replacing the battery pack, trying a new batch of cartridges or making sure the firmware is up to date. Any operational problems encountered using the weapon

should be tracked so that trends can be identified both over the life of the weapon as well as with the entire inventory.

7.6 Independent Testing – Conformity Assessment

7.6.1 Purpose

ISO defines conformity assessment as "the process used to show that a product, service or system meets specified requirements" [31]. In ideal circumstances, the requirements would be contained in formal and independent standards, however in the case of CEWs, no such performance standard exists. In the absence of a performance or technical standard, the only standard that can be used to evaluate conducted energy weapons would be the product specification provided by the manufacturer. In the context of CEWs that are currently in service with Canadian law enforcement, a conformity assessment is intended to confirm that the weapon continues to meet the specifications.

7.6.2 Abnormal Operational Situations

There are circumstances where weapons may be subjected to abnormal operational conditions, including environmental, that would justify sending the weapon to be independently tested before returning it to use (i.e., testing based on situational circumstances). The following are some of the situations that could result in abnormal performance of the weapon or could cause internal damage not readily visible to the operator:

a. Discharge inconsistencies. At any time, if the weapon fires for a longer or shorter time than expected or there is an audible inconsistency in the pulse rate, it should be sent for independent testing before being used.

b. Physical damage. If any weapon or component demonstrates physical damage including to the safety switch, trigger, casing, or display, or if the battery does not seat properly, it should be removed from use. If the weapon or any component is dropped, it should be visually inspected for damage before being used. The weapon is designed as a sealed unit and any damage to the casing could affect the integrity of the internal components. The weapons are non-repairable items however depending on the individual weapon a warranty replacement from the manufacturer may be possible.

c. Exposure to wet conditions. The weapons are not waterproof and if they become wet, water could affect the internal electronic components and cause the weapon to malfunction. Based on tests conducted, weapons exposed to wet conditions (other than salt) that are allowed to dry completely will revert to normal performance [18]. Weapons should be allowed to dry for several days before using. Although environmental testing indicated that the weapons operate properly once allowed to dry completely, moisture inside the weapon could cause the weapon to malfunction and it should be allowed to dry and then sent for independent testing before using.

d. Exposure to salt spray. Environmental tests have indicated that weapons exposed to salt spray could malfunction [18]. Allowing them to dry completely could still result in salt deposits remaining therefore it is recommended that once dry, the weapons be send for independent testing before using.

e. High Static environments. Tests have confirmed that the cartridges are particularly sensitive to high static environments and could result in accidental discharge of cartridges [18]. Cartridges may be affected even if they are not installed in the weapon. Under these circumstances, there is no issue with the weapon, but users should exercise caution when handling cartridges in high static environments.

7.6.3 Routine/Regular Conformity Assessment

The most difficult question posed to this team relates to how frequently CEWs should be sent for independent conformity assessment. This is a difficult question to answer because it requires an understanding of causes of failure with the objective of predicting under what conditions the weapon will not perform as designed. Even conducting a conformity assessment is no guarantee that problems won't occur with the weapon – it is just an indication that at the time of testing, the weapon was operating correctly.

Any conformity assessment program needs to balance risk with cost and availability. There are several factors that could explain changes in weapon performance. An analysis of previous test results from independent agencies was conducted to try and identify any parameters or indicators that would predict when a weapon would be more prone to have a change in performance and potentially measure outside of the manufacturer's specification. The following sections describe some of the factors to be considered that could impact on consistency of weapon performance and there are important considerations in recommending a frequency for conformity assessment.

7.6.3.1 Age of Weapon

As with most equipment, it is reasonable to expect that a CEW will wear with time. While weapon age was not recorded or provided with the previous test data results, the Ontario Provincial Police were able to provide the delivery date and the RCMP the creation date and these dates have been reviewed as reasonable proxies to the manufactured date.

Figure 29 below maps the dates provided by the RCMP and the OPP with the serial number block. It is a consistent relationship and estimates can be made as to the date a serial number block was entered into service. There are a few exceptions where it is possible that the weapon came off the production line and was placed into inventory before being issued to a police agency. In other situations, another serial number may have been assigned to a weapon after warranty work was performed by the manufacturer.

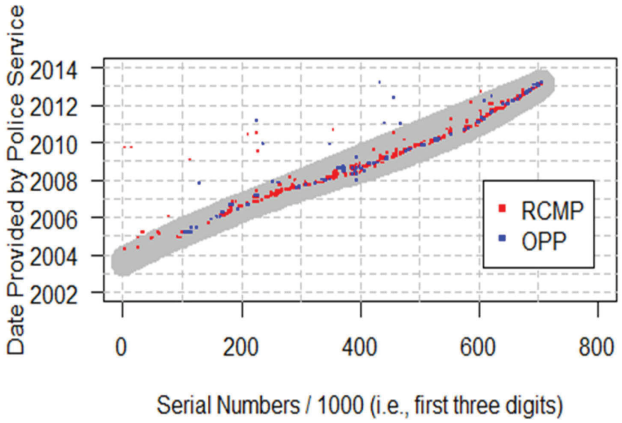


Figure 29: Mapping of Date CEW Record Created Against Serial Number Block [28]

7.6.3.2 Design and Manufacturing Changes

As products evolve, manufacturers will make improvements both in the design (hardware and software) of the weapons and the manufacturing process that may impact on weapon performance. In most cases, these changes are not communicated to the user of the CEW and often are the grounds of intellectual property. While the details may not be available to police agencies, the manufacturer should assign a new model, release or version number any time significant changes are made to the design. Even hardware should be clearly identified as a new configuration. In ideal circumstances, the nature of the change would be communicated to the police agencies and the agencies would evaluate the effect of the change on performance.

In the case of the current models used by Canadian law enforcement, the two models are clearly different in their design and their function. There is however a high possibility that internal design changes have taken place that are not clearly identified. The addition of an LED light internal to the TASER X26 is one such example. On new models, the LED light is clearly visible from the top of the weapon meaning that the design change is only verifiable by visual inspection. As communicated by TASER International, this change was implemented in approximately 2008 [27].

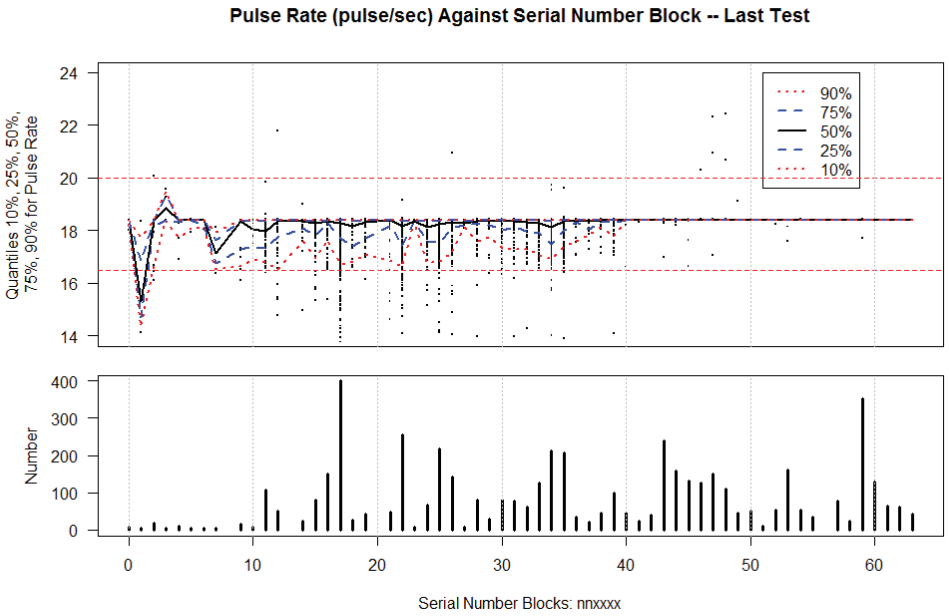


Figure 30: Pulse Rate against Serial Number Block [28]

Figure 30 above indicates that weapons with a serial number beginning with 400 000 and later (approximately 1-2 years old at time of testing) had very little variation in the pulse rate measure while those with serials number earlier than 400 000 have significant variation. This means the earlier weapons are more likely to measure out of specification for pulse rate than the later ones. The difference between the two is significant and could reasonably be due to a design or manufacturing change however this cannot be definitively determined.

7.6.3.3 Firmware Version

As with design and manufacturing changes, firmware changes could result in a change in weapon performance. In the case of the TASER X26, the firmware is updated using the DPM and the DPM version was often recorded during testing and therefore some data was available for analysis. Previous test data included results for Firmware Versions 15, 18, 20, 21, 22 and 24. It is suspected that 24 is a data entry error because it represents a small number of weapons and we are not aware that a version 24 has been produced. Unfortunately, older firmware versions were prevalent in the earlier CEWs (i.e., serial number blocks earlier than 40) and it is not possible to determine if the performance variation was a result of a hardware design change or a firmware change. Considering only weapons with serial number blocks later than 40, firmware versions 21 and 22 are the prevalent versions. With these weapons, the results are very consistent as indicated in Figures 31 and 32 below and therefore there is no significant difference in performance.

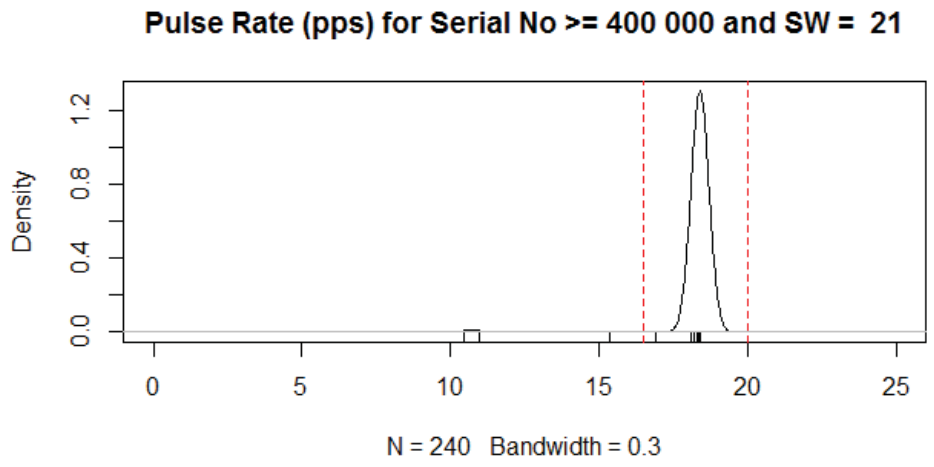


Figure 31: Pulse Rate for Serial No >= 400 000 and Firmware Version 21 [28]

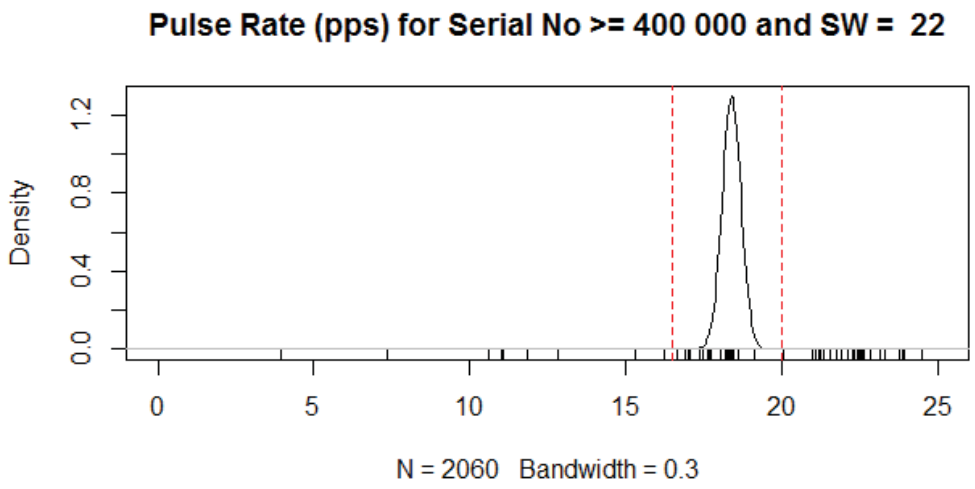


Figure 32: Pulse Rate for Serial No >=400 000 and Firmware Version 22 [28]

7.6.3.4 Operational Use

As with most equipment, heavy use or abuse could be expected to cause a CEW to wear more quickly. Unfortunately, no information about how the CEWs were used operationally was available so the relationship between use and failure rate cannot be determined.

7.6.3.5 Impact of Battery Level

Anecdotal information from the test agencies and police services intimated that the battery condition might have a correlation with weapon performance. This relationship was explored in

two ways. First, QETE fired a single weapon continuously for 25 minutes until the battery indicated zero power remaining. There was however power still available and the weapon continued to perform satisfactorily. The results can be seen in Figure 33 below.

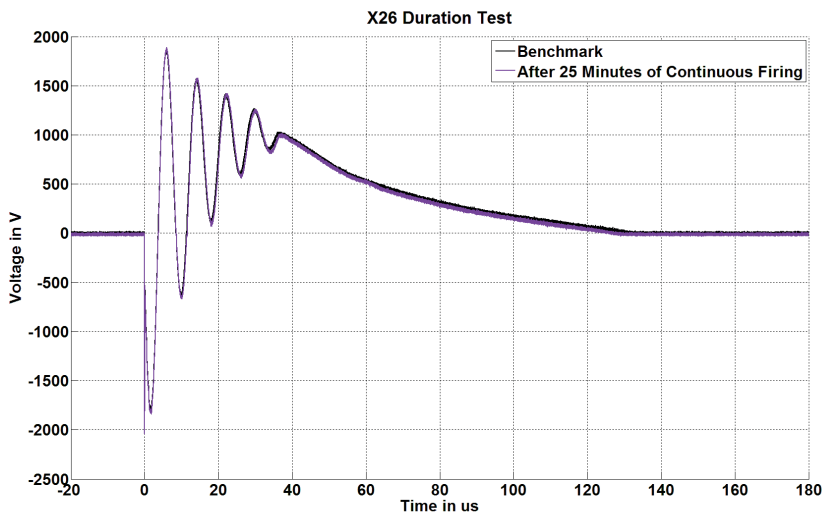


Figure 33: Results of Continuous Firing of a TASER X26 until battery level indicated zero (source: Quality Engineering Test Establishment)

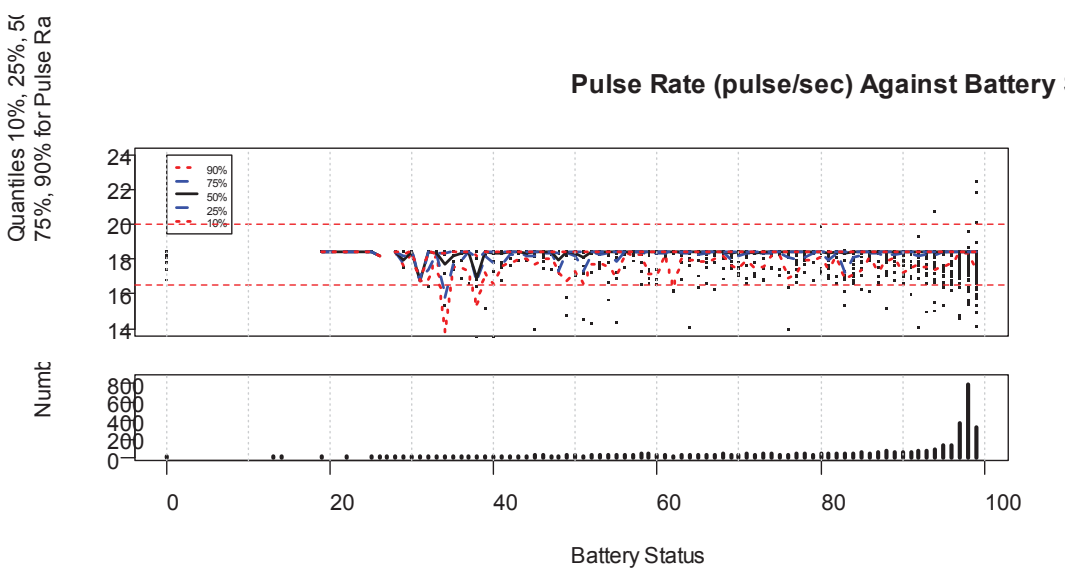


Figure 34: Pulse Rate vs Battery Status (Final Test and Firmware Version 22) [28]

This test supports the idea that the battery level indicator is not a valid judge of power remaining. For comparison purposes, previous test data was examined to determine if battery level remaining was an indicator that the weapon may test out of specification. Considering only the final test

results for weapons that have firmware version of 22, the results are seen in Figure 34 above. It is clear that even weapons that report nearly full battery levels some still measure out of specification. With the data available, it is not possible to make a correlation between battery level and the pulse rate measuring out of specification.

7.6.3.6 System Warm-up

There was at least one example where consecutive firing of a weapon resulted in a significant improvement in performance. Unfortunately, these results are insufficient to be generalized for the entire population of CEWs. The results for one weapon are shown in Figure 35 below for illustrative purposes and clearly indicate that it delivered far fewer pulses than expected until the final firing.

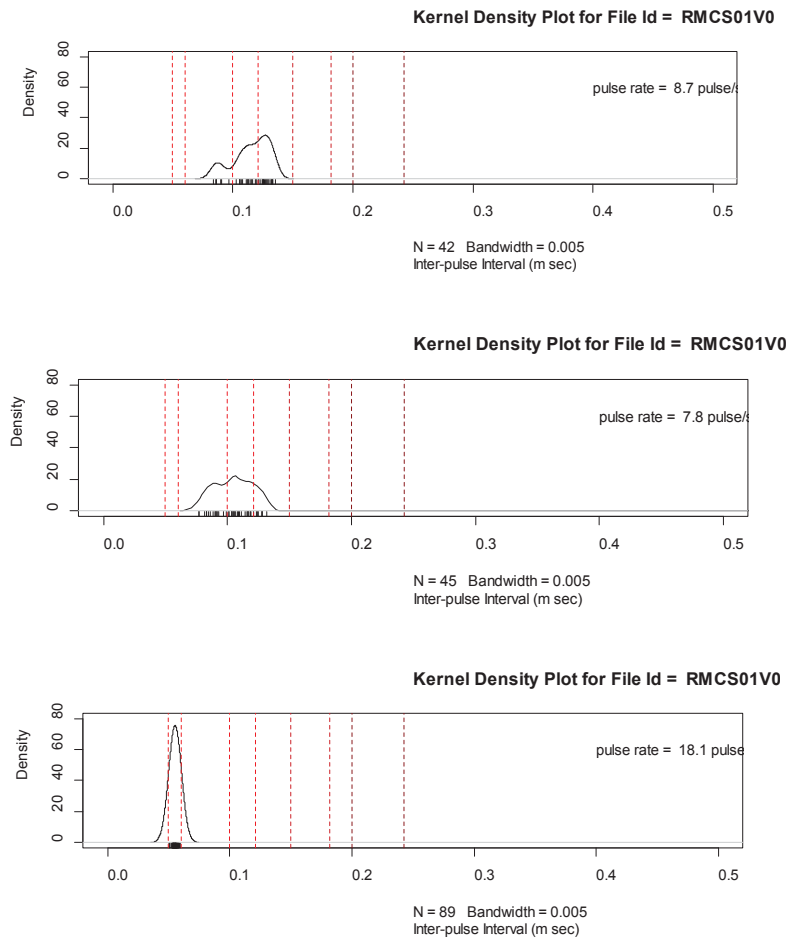


Figure 35: Three Successive Firings (without human intervention) [28]

The implication is that this weapon may not perform correctly in operations if it is not allowed to 'warm-up' first. If this situation is observed for a weapon during testing, it is recommended that it be allowed to sit for a week before being retested. If the same condition is observed, police services should consider removing it from service.

7.6.4 Recommendations

Even with a regular conformity assessment program, there is no guarantee that a weapon will continue to operate without problems until the next scheduled test. It is an electro-mechanical device that can experience failures just as any other electro-mechanical device could. The data indicates that on occasion, CEWs can fail. For this reason, the following is a recommended approach for an overall conformity assessment strategy:

a. TASER M26 weapons appear to be at the end of their life. This model is no longer in production and is being phased out by Canadian law enforcement. If these weapons are still being used, they should be tested annually.

b. TASER X26 weapons purchased prior to 2008 or with serial numbers earlier than 400 000. These weapons have a large variation in performance as seen in Figure 30 and therefore have a higher probability of measuring outside the manufacturer's specification. For this reason, it is recommended that these weapons be tested annually and be considered as a priority for replacement with newer weapons.

c. TASER X26 weapons purchased later than 2008 or with serial numbers later than 400 000. The performance of these weapons appears to be very consistent. When taken care of and not subjected to abnormal operating conditions, they should continue to operate within the manufacturer's specification with a high level of confidence. It is recommended therefore that testing is not required within the first two years unless there are indications of problems as described in Section 7.6.2. Because a longitudinal analysis was not conducted, it is not possible to predict how the performance will degrade with time.

7.7 Expected Life Cycle

There was insufficient data available for the team to determine definitively an optimum life span for the TASER M26 or TASER X26 models that are currently in service. TASER M26 and TASER X26 weapons are electronic devices that will have an expected end of life, however the actual date will be heavily influenced by the operational use of the weapon. Rough handling and exposure to harsh conditions are likely to shorten the effective life span.

The manufacturer does provide an expected life span for the weapon.of five years [33]. This is a common practice for manufacturers but does not mean that the weapon must be replaced when it reaches the recommended replacement date. Instead, this recommended date should be used by police services to plan for replacement and to ensure sufficient funding is available for replacements. As a weapon approaches its recommended end of life, it should be subject to more frequent validation and checks. At any sign of abnormal behaviour, it should be removed from service and replaced.

Some of the weapons may be eligible for warranty replacement. When a weapon is returned to the manufacturer, a copy of the test laboratory's test results should be included.

8 Conclusion

8.1 Summary

A research effort to conduct environmental testing and a data analysis of previous CEW test results was undertaken as part of the work for the CEWSI project. This work has informed the contents of this report which satisfies one of the objectives of the CEWSI project to deliver a comprehensive test protocol for conducted energy weapons used by Canadian law enforcement. This report will be used by a variety of stakeholders including policing policy representatives, law enforcement agencies and test laboratories. Some sections are more technical than others in order to provide sufficient detail to the technical audience.

It should be noted that the development of the advice provided in this report was constrained by the availability of data and there are some areas where substantive recommendations could not be made. In addition, the majority of recommendations are applicable to the TASER X26 (and in some cases the TASER M26). While an initial characterization has been done on the X2, there are plans to do more detailed testing of the X2 for the purposes of establishing thresholds for performance.

This test protocol provides advice for minimum actions that should be taken by the individual officer and at the first line of maintenance at the police agency. Individual organizations may augment these actions by developing their own protocols. The recommended actions are ones that can be taken by a trained officer to ensure the weapon is operating correcting and is ready for use. Recommendations for confirmation assessment are divided into testing to be triggered by abnormal operating circumstances as well as the need for routine test.

Analysis has shown that newer weapons function with very little variation in performance. For this reason, it is felt that there is no need to test for the first two years. An analysis of previous test data shows that there appears to be a clear break in performance for serial numbers lower than 400 000 (manufactured approximately in 2008) where the lower numbers have a larger variance in performance while the higher serial numbers are very consistent in their performance. While it is possible this difference is a result of a manufacturer design change, it is not possible to eliminate age as a factor. For this reason random testing is recommended for weapons that are older than 2 years of age in order to determine if there has been any general deterioration with age in the weapon performance.

It is recommended that test laboratories be required to demonstrate compliance with ISO 17025, a quality standard for test laboratories supported by the Standards Council of Canada. The requirements of ISO 17025 relate to the existence of quality processes and procedures.

Detailed specifications are also provided for all the components of the test equipment. The specifications are defined to enable the appropriate capture of the entire waveform. Significant attention is devoted to defining the relevant parameters. The parameters identified by the manufacturer are explained and suggestions for modifying these parameters are provided. In addition, several new parameters are identified including a pulse interval definition that will determine if any pulses have been skipped.

A simplified test procedure has been described that requires a maximum of 2 firings and a specification for data that is to be retained is provided to ensure consistency in data collection.

8.2 Proposed Next Steps

It is not yet known what will be contained in the report from the expert medical panel. It is expected that better understanding of the physiological effects of CEWs will highlight certain parameters that are relevant to the efficacy and the safety of CEWs. Once the expert medical panel study is released, this report will be reviewed in the context of new information that may become available. It is reasonable that another report will be generated that focuses on parameters of specific interest to the efficacy and safety of CEWs.

As was also noted in this report, in order to ensure consistency in the data analysis, software should be developed that can be used by all test labs in evaluating the waveform. The possibility of DRDC CSS undertaking this work will be explored.

Many police and law enforcement agencies have posed questions related to the newer models of CEW available on the market. DRDC CSS has initiated a new project that will test the Taser X2 and the Taser X26P, carrying on from work initiated by Dr. Joey Bray.

References

[1] CBC News, "Some Tested TASERs Fire Stronger Current Than Company Says: CBC/Radio-Canada Probe," Dec. 2008; http://www.cbc.ca/news/canada/story/2008/12/04/TASER-tests.html (accessed 16 May 2013).

[2] T. R. Braidwood, "Restoring Public Confidence: Restricting the Use of Conducted Energy Weapons in British Columbia," Braidwood Commission of Inquiry on Conducted Energy Weapon Use, June 2009.

[3] A. Adler and D. Dawson. "Towards a test standard for conducted energy weapons". Paper presented at 6th European Symposium on Non-Lethal Weapons 17 May 2011

[4] TASER International, "TASER Certified Test Procedure for Testing to Advanced TASER M26 Specifications," ver. 1.0, Feb. 2011.

[5] TASER International, "TASER Certified Test Procedure for Testing to TASER X26 Customer Specifications," ver. 5.0, Mar. 2011.

[6] Public Safety Canada, "Guidelines for the Use of Conducted Energy Weapons," Oct. 2010; http://www.publicsafety.gc.ca/prg/le/gucew-ldrai-eng.aspx (accessed 16 May 2013).

[7] P. Savard, R. Walter, and A. Dennis. "Analysis of the Quality and Safety of the Taser X26 devices tested for Radio-Canada/Canadian Broadcasting Corporation by National Technical Systems, Test Report 4119608". 2 December 2008. http://www.cbc.ca/news/pdf/taser-analysis-v1.5.pdf (accessed 15 August 2013)

[8] L. Raineault, Joe Media Group Inc., "TASERed," first broadcast Feb. 2010.

[9] T. R. Braidwood, "Why? The Robert Dziekanski Tragedy," Braidwood Commission on the Death of Robert Dziekanski, May 2010.

[10] A. Adler, D. Dawson, R. Evans, L. Garland, M. Miller, and I. Sinclair, "Test Procedure for Conducted Energy Weapons," ver. 1.1, July 2010; http://curve.carleton.ca/papers/2010/CEW-Test-Procedure-2010-ver1.1.pdf (accessed 16 May 2013).

[11] L. Garland, "Conducted Energy Weapons – Gaps Analysis for Test Procedure," ver. 1.1, letter report, contract number EN578-060502/053/ZT, Defence Research and Development Canada Centre for Security Science, Sept. 2010.

[12] D. Wood and L. Goodman, "CEWSI Testing Workshop 4 Nov 10 – Summary of Workshop Results," letter report, Defence Research and Development Canada Centre for Security Science, Dec. 2010.

[13] D. Wood, L. Goodman, A. Adler, P. Kelly, and V. Knezevic, "Testing of Conducted Energy Weapons – Results of Workshop Held in Ottawa, Canada 24-25 October 2011," tech. note DRDC CSS TN 2012-001, Defence Research and Development Canada Centre for Security Science, Mar. 2012.

[14] D. Wood and L. Goodman, "Canadian Less Lethal Technology Approval Process: A Structured Approach to the Selection and Implementation of Less Lethal Technologies for Canadian law Enforcement," tech. report DRDC CSS TR 2012-023, Defence Research and Development Canada Centre for Security Science, Oct. 2012.

[15] TASER International, "New TASER X26P Smart Weapon Announced," press release, Jan. 2013; http://investor.TASER.com/releasedetail.cfm?ReleaseID=733541 (accessed 16 May 2013).

[16] J. R. Bray, "TASER X2 Preliminary Investigation," contract report DRDC CSS CR 2013-001, Defence Research and Development Canada Centre for Security Science, Mar. 2013.

[17] TASER International, "TASER Accessories: Holsters, Batteries & More," http://www.TASER.com/products/law-enforcement/accessories (accessed 16 May 2013).

[18] Quality Engineering Test Establishment, "Conducted energy weapon test report," rev. 2, project number C005811, Mar. 2013.

[19] J. P. Reilly, A. M. Diamant, and J. Comeaux, "Dosimetry considerations for electrical stun devices," *Physics in Medicine and Biology*, vol. 54, pp. 1319–1335, 2009.

[20] TASER International, "TASER Electronic Control Devices Electrical Characteristics – X26," Feb. 2009.

[21] TASER International, "TASER Electronic Control Devices Electrical Characteristics – M26," Feb. 2009.

[22] Ohmite Manufacturing Company, "Power Resistors Catalog," rev. 26 Oct. 2011, pp. 36, 39.

[23] *Uncertainty of Measurement – Part 3: Guide to the Expression of Uncertainty in Measurement*, ISO/IEC Guide 98-3, 2008.

[24] *General Requirements for the Competence of Testing and Calibration Laboratories (Adoption of ISO/IEC 17025)*, CAN-P-4E, Standards Council of Canada, Nov. 2005.

[25] Regulations Prescribing Certain Firearms and other Weapons, Components and Parts of Weapons, Accessories, Cartridge Magazines, Ammunition and Projectiles as Prohibited or Restricted, SOR/98-462, *Government of Canada Regulation*, Dec. 1998.

[26] TASER International, "TASER Certified Test Laboratory: Certification Requirements," ver. 3.0, Feb. 2010.

[27] D. Wood, private communication with TASER International, trip report, Feb. 2011.

[28] B.W. Simms et al, "Statistical Analysis of Data from Past Engineering Tests of Conducted Energy Weapons", Royal Military College of Canada, Apr. 2013 (unpublished).

[29] B. Tardif, private communication with Steve McIver, Mar. 2013.

[30] TASER International. "TASER X26E Operating Manual," MMU0004 rev. B, 2007.

[31] International Standards Organization, "Conformity assessment - ISO," http://www.iso.org/iso/home/about/conformity-assessment.htm (accessed 16 May 2013).

[32] I. Sinclair, "TASER Model X26 Test Concepts," doc. no. ETC-CEW-01012011, rev. 7, Electronics Test Centre, MPB Technologies Inc., Nov. 2012.

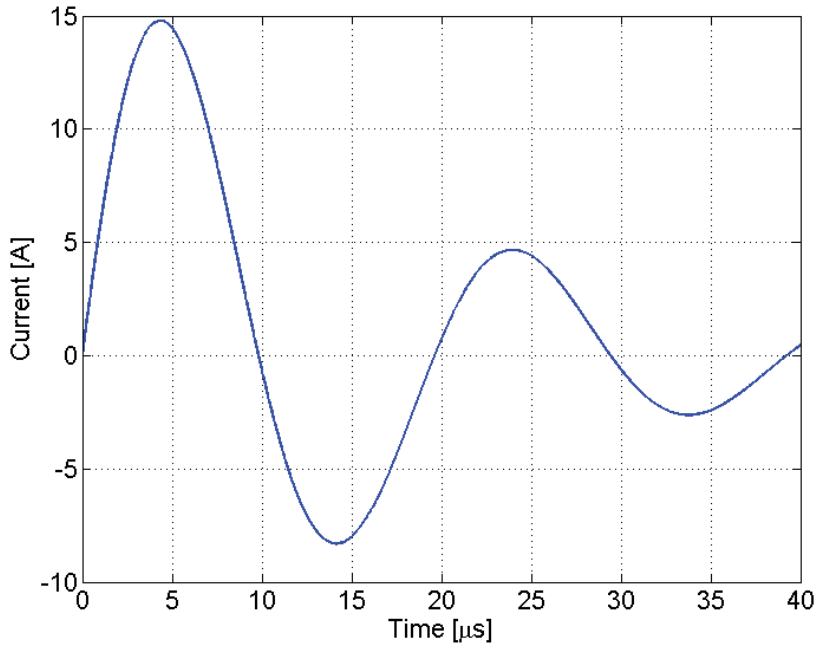
[33] Taser International. *Training Bulletin 17.0-01 TASER X26 ECD and Cartridge Inspection*. Version 2.0. 12 June 2010.

Annex A TASER M26 Detailed Specifications

A.1 TASER M26 Description

Model	Advanced TASER M26
Pictures	  Model 44000 Model 44005
Status	Discontinued. Sales in the U.S. and Canada ceased December 31, 2010
Size	Length 18.1 cm without cartridge, 21.1 cm with cartridge; Height 15.2 cm; Width 4.4 cm
Weight	544 g without cartridge, 614 g with cartridge (approximately)
Power	8 AA batteries (alkaline or nickel metal hydride rechargeable)
Trigger	Single trigger button 5-second discharge cycle, holding down trigger extends the cycle beyond 5 seconds Without a cartridge: drive-stun mode only With a live cartridge: probe-mode or 3-point mode With a spent cartridge: re-energizes deployed probes, can also be used in drive-stun
Capacity	1 cartridge
Cartridges	Compatible with the TASER X26 Yellow 15-foot model 34200 Silver 21-foot model 44200 Green 25-foot XP model 44203 Blue 21-foot LS training model 44205 (non-conductive wires) Orange 35-foot XP model 44206 Standard barb length is 9.65 mm, XP barb length is 13.5 mm
Sighting	Mechanical fin and blade Single laser sight illuminates when armed to estimates top probe impact site
Flashlight	No
Indicator	Single red LED located at the rear of the grip Indicates that sufficient power is available to power the circuit board Does not indicate that sufficient power is available to deliver a discharge
Dataport	Used to download firing data Can be used to recharge rechargeable batteries Can be used to remotely fire the weapon.
Auditing	Unique serial number Stores the date and time of approximately 585 firings Cartridge AFID tags indicate the cartridge serial number
Testing	Spark test with no cartridge, laboratory testing into a 500 Ω load

A.2 TASER M26 Pulse Waveform

Condition	Terminated with a 500 Ω load
Current Pulse	Damped 50 kHz sinusoid with a 17 μs time decay constant 

A.3 TASER M26 Acceptance Specifications

A.3.1 TASER International Acceptance Specifications [4]

The parameters below are defined by TASER International.

TASER Pulse Rate	20 pulses per second (+30/–25%) with rechargeable batteries 15 pulses per second (+30/–25%) with alkaline batteries
TASER Main Phase Pulse Duration	7–12 μs
TASER Pulse Duration	32–60 μs
TASER Peak Loaded Main Phase Voltage	6900–9400 V
TASER Main Phase Charge	70–120 μC
TASER Net Charge	15–55 μC (entire pulse)

A.3.2 Canadian Acceptance Specifications

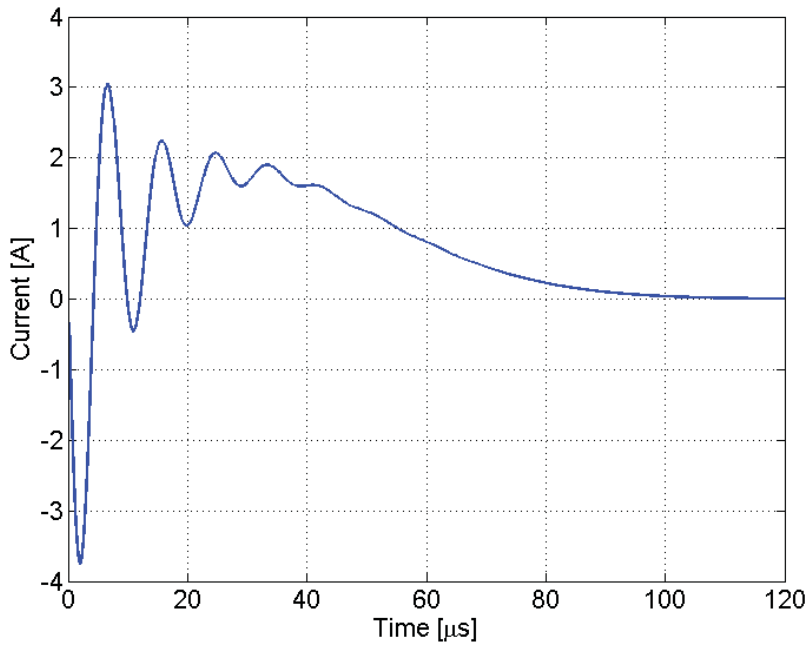
Same as Section A.3.1, subject to change pending further evidence.

Annex B TASER X26 Specification

B.1 TASER X26 Description

Model	TASER X26E
Pictures	  Model 26011 Model 26023
Status	In production in the U.S. and Canada as of August 1st, 2012.
Size	Length 15.2 cm without cartridge, 18.5 cm with cartridge; Height 8.1 cm; Width 3.3 cm
Weight	204 g without cartridge, 274 g with cartridge (approximately)
Power	6 available magazines: DPM, XDPM, CDPM, CCDPM, DCDPM and TASER CAM. Power magazines update the weapon's firmware
Trigger	Single trigger button 5-second discharge cycle, holding down trigger extends the cycle beyond 5 seconds Without a cartridge: drive-stun mode only With a live cartridge: probe-mode or 3-point mode With a spent cartridge: re-energizes deployed probes, can also be used in drive-stun
Capacity	1 cartridge. XDPM power magazine can store a second cartridge on the grip
Cartridges	Yellow 15-foot model 34200 Silver 21-foot model 44200 Green 25-foot XP model 44203 Blue 21-foot LS training model 44205 (non-conductive wires) Orange 35-foot XP model 44206 Standard barb length is 9.65 mm, XP barb length is 13.5 mm
Sighting	Mechanical fin and blade Single laser sight illuminates when armed to estimates top probe impact site
Flashlight	Yes
Indicator	2-digit display located at the rear of the grip Displays estimated remaining power level, the spark duration, and status data
Dataport	Used to download firing data Occupies the same slot in the grip as the power magazine
Auditing	Unique serial number Stores the date, time and duration of approximately 1500 last firings Cartridge AFID tags indicate the cartridge serial number
Testing	Spark test with no cartridge, laboratory testing into a 600 Ω load

B.2 TASER X26 Pulse Waveform

Condition	Terminated with a 600 Ω load
Current Pulse	Rapidly decaying 100 kHz sinusoid plus an over-damped monophasic discharge having a 50 μs approximate decay time constant 

B.3 TASER X26 Acceptance Specification

B.3.1 TASER International Acceptance Specifications [5],[32]

The parameters below are defined by TASER International.

TASER Pulse Rate	16.5–20 pulses per second
TASER Pulse Duration	105–155 μs
TASER Peak Loaded Main Phase Voltage	1400–2520 V
TASER Main Phase (Net) Charge	80–125 μC

B.3.2 Canadian Acceptance Specifications

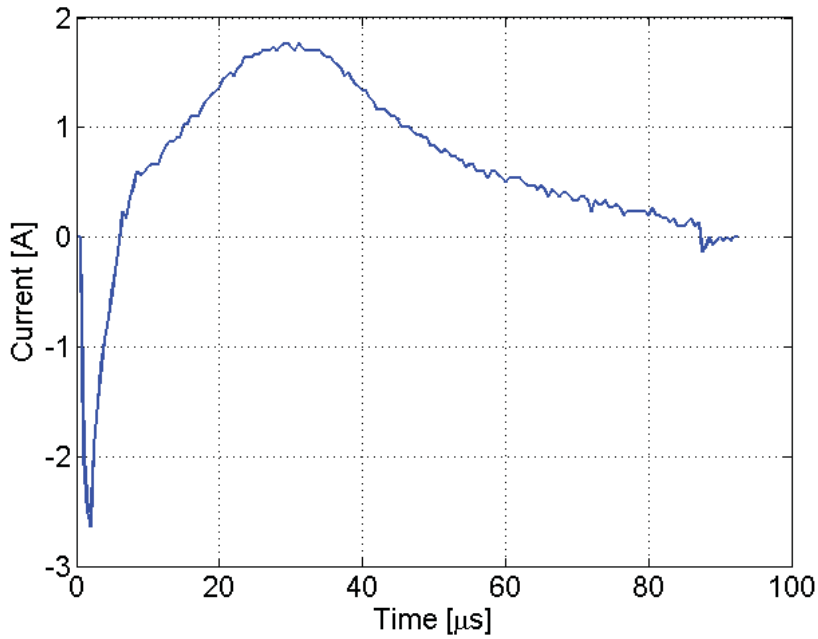
Same as Section B.3.1, subject to change pending further evidence.

Annex C TASER X2 Specification

C.1 TASER X2 Description

Model	TASER X2
Pictures	 Model 22000  Model 22001
Status	In production in the U.S. and Canada as of August 1st, 2012.
Size	Length 19.8 cm; Height 10.7 cm; Width 4.3 cm (with PPM power magazine)
Weight	454 g with a PPM power magazine and two live cartridges
Power	4 available magazines: PPM, APPM, TPPM, and TASER CAM HD
Trigger	One trigger button and two arc buttons Trigger button initiates a 5-second discharge in one bay and fires that cartridge Arc buttons cause discharges in both bays while pressed only, will not fire cartridge Arc buttons fire weapon in drive-stun mode even if live cartridges are loaded
Capacity	2 cartridges
Cartridges	Yellow 15-foot model 22150 Green and black 25-foot model 22151 Orange and black 35-foot model 22152 Blue and clear 25-foot inert model 22155 (training) Blue 25-foot non-conductive wires model 22157 (training)
Sighting	Mechanical fin and blade Dual laser sight illuminates when armed to estimate top and bottom probe impact sites for the 25-foot cartridge
Flashlight	Yes
Indicator	Multipurpose LED display at the top of the grip Displays remaining battery power, cartridge types, cartridge status, next bay to fire, duration of trigger pull, errors, system status, and settings
Dataport	Used to download firing data Occupies the same slot in the grip as the power magazine
Auditing	Unique serial number Stores over 16000 events in Deployment, Event, Pulse and Engineering Logs Self-monitors and stores waveform parameters Evidence Sync software program, remote database capability Cartridge AFID tags indicate the cartridge serial number
Testing	Spark test using the arc buttons, laboratory testing into a 600 Ω load

C.2 TASER X2 Pulse Waveform

Condition	Terminated with a 600 Ω load
Current Pulse	7-μs long Peak-Voltage-Lobe (–2.5 A @ 2 μs), followed by an 82-μs long over-damped Peak-Charge-Lobe (+1.8 A @ 30 μs) Pulse Repetition Frequency: 19.2 Hz 

C.3 TASER X2 Acceptance Specification

C.3.1 TASER International Acceptance Specification

No TASER International acceptance specification has been issued for this CEW at the time of writing this report.

C.3.2 Canadian Acceptance Specification

The following specification has been formulated based on initial measurements of two weapons and is subject to change as more evidence becomes available [16]. For mean values relating to all of the pulses, three standard deviations on either side of the mean were used (representing a 99% confidence interval). For extrema, a 20% margin was allowed compared to the measurements taken in [14]. The parameters below are defined as per Section 2.3 and Annex D.3.

Trigger Level V_t	–50 V, DC Coupled
Discharge Cycle Duration	4.7–5.4 s
Number of Pulses	98 ±1
Maximum Pulse Duration	< 125 μs

Minimum Pulse Duration	> 60 μs
Mean PRI	48.8–55.6 ms
Maximum PRI	< 69 ms (one pulse violation is permitted, as per Section D.3.9.4) One pulse violation: monitor weapon more frequently Two or more pulse violations: weapon fails the test
Mean PRF	18.0–20.5 Hz
Maximum PRF	< 25 Hz
Minimum PRF	> 14.5 Hz (one pulse violation permitted, as per Section D.3.9.4) One pulse violation: monitor weapon more frequently Two or more pulse violations: weapon fails the test
Highest Pulse Voltage	< 1500 V
Weakest Pulse High Voltage	> 720 V
Lowest Pulse Voltage	> –2600 V
Weakest Pulse Low Voltage	< –1000 V
Mean Total Charge	64–85 μC
Maximum Total Charge	< 105 μC
Minimum Total Charge	> 55 μC
Peak-Charge-Lobe Mean Charge	58–77 μC
Peak-Charge-Lobe Maximum Charge	< 96 μC
Peak-Charge-Lobe Minimum Charge	> 49 μC

Annex D Technical Description of Waveform Parameters

The International Electrotechnical Commission (IEC) defines detailed parameters for the characterization of waveforms and signals for use by test laboratories. The descriptive parameters below are not intended to replace the parameters identified by IEC, but are meant to identify parameters in language that can be more easily understood by test laboratories, police services and policy-makers.

D.1 Testing to the Manufacturer Specification

D.1.1 TASER Certified Test Procedures

TASER International has developed Certified Test Procedures for both the TASER M26 and the TASER X26. The TASER waveform parameters are of limited scope and TASER International explicitly identifies the make and model of the measurement equipment that must be used. The TASER Certified Test Procedure calls for two trigger pulls – the first to capture the TASER Pulse Rate and the second to determine voltage, charge, and pulse duration.

The following versions of the test procedure were consulted [4],[5]:

TASER M26: Version 1.0 Release Date: 2/21/2011

TASER X26: Version 5.0 Release Date: 3/15/2011

The recommended waveform parameters that will be presented in Section D.3 are intended to complement and to augment the parameters listed in the TASER Certified Test Procedures. TASER CEWs should always be tested according to the TASER Certified Test Procedures for warranty claims.

D.1.2 TASER Pulse Rate

Upon recording the first waveform following the TASER International Certified Test Procedure, the oscilloscope displays the pulses in the last one-second of the discharge cycle. The TASER Pulse Rate is then determined by measuring the time duration from the first pulse to the last pulse and counting the number of spaces between the pulses. TASER Pulse Rate is then calculated via:

$$\text{TASER Pulse Rate} = \text{number of spaces} / \text{duration} \tag{D.1}$$

The TASER Pulse Rate as an average pulse rate of the last second of the discharge only.

D.1.3 TASER Peak Loaded Main Phase Voltage

Upon recording the second waveform following the TASER International Certified Test Procedure, the voltage waveform displayed on the oscilloscope represents the average value of

the last 8 pulses in the discharge cycle. The TASER Peak Loaded Main Phase Voltage is determined by measuring the highest positive voltage from the beginning of the voltage waveform to the end, as depicted in Figure 36.

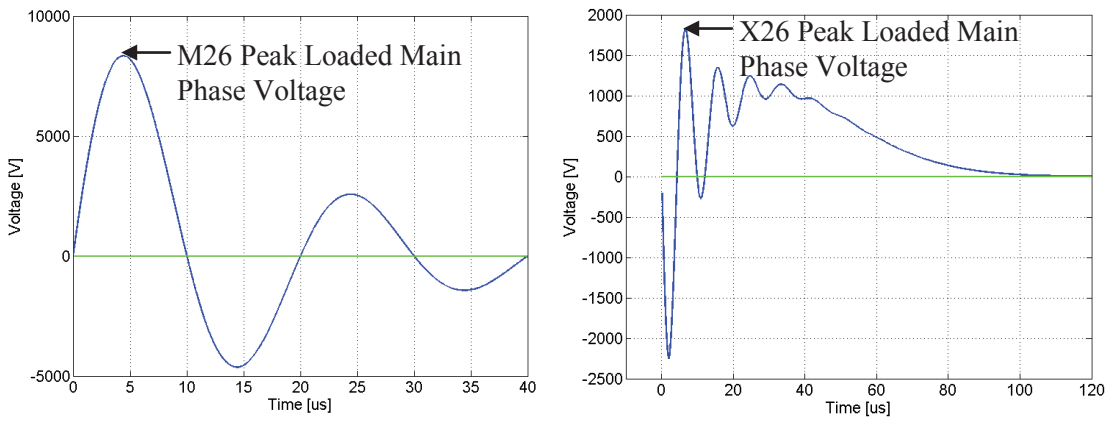


Figure 36: TASER Peak Loaded Main Phase Voltage

In the context of TASER Peak Loaded Main Phase Voltage only, the beginning of the TASER M26 current waveform is defined as the point before the current reaches +500 mA. The end of the M26 current waveform is defined as the point before the current drops below +500 mA at the end of the first lobe. The beginning of the TASER X26 current waveform is defined as the point before the voltage reaches +50 V after the arc phase. The end of the TASER X26 current waveform is defined as the point after the voltage drops below +50 V at the end of the waveform.

D.1.4 TASER Main Phase Charge

Upon recording the second waveform following the TASER International Certified Test Procedure, the current waveform displayed on the oscilloscope represents the average value of the last 8 pulses in the discharge cycle. The TASER Main Phase Charge is calculated differently depending on the model being tested. For the TASER M26, the TASER Main Phase Charge is the *net charge* from the beginning of the waveform to the end, whereas for the TASER X26, it is the *net charge* contained in the portion of the current waveform, beginning after the first negative lobe, to the end. For the TASER X26, the first negative lobe, also called the arc phase, is designed to initiate conduction and not to induce NMI. The areas of the current waveform to be integrated are shown in Figure 37.

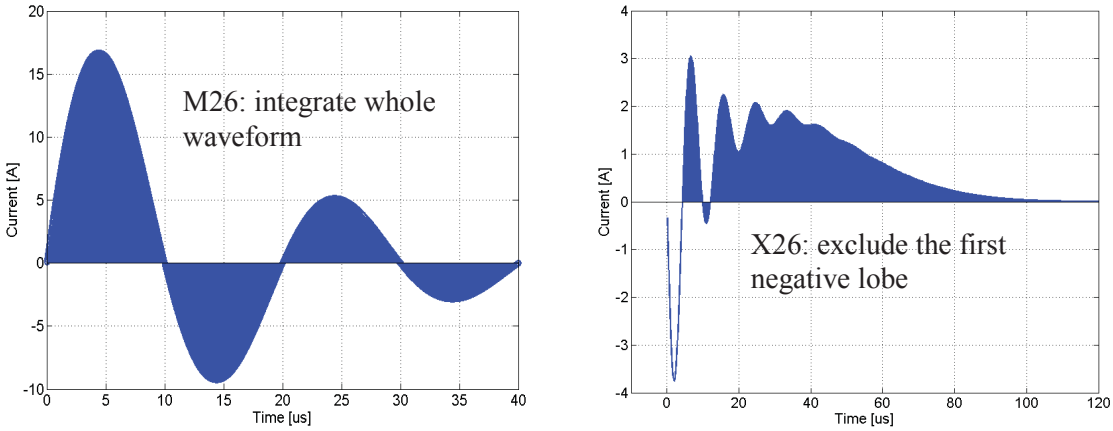


Figure 37: TASER Main Phase Charge Net Charge

In the context of TASER Main Phase Charge only, the beginning of the TASER M26 current waveform is defined as the point before the current reaches +500 mA. The end of the TASER M26 current waveform is defined as the point after the current rises above –500 mA at the end of the waveform. The beginning of the TASER X26 current waveform is defined as the point before the voltage reaches +50 V after the arc phase. The end of the TASER X26 current waveform is defined as the point after the voltage drops below +50 V at the end of the waveform.

D.1.5 TASER Pulse Duration

Upon recording the second waveform following the TASER International Certified Test Procedure, the current and voltage waveforms displayed on the oscilloscope represent the average value of the last 8 pulses in the discharge cycle. The TASER Pulse Duration is the time duration from the beginning of the waveform to the end of the waveform.

In the context of TASER Pulse Duration, the beginning of the TASER M26 current waveform is defined as the point before the current reaches +500 mA. The end of the TASER M26 current waveform is defined as the point after the current rises above –500 mA at the end of the waveform. The beginning of the TASER X26 voltage waveform is defined as the point just before the voltage reaches –50 V in the arc phase (the first negative lobe). The end of the TASER X26 voltage waveform is defined as the point after the voltage drops below +50 V at the end of the waveform.

D.2 Recommended Changes to TASER International Waveform Parameters

Whereas the parameters identified by TASER International are required for warranty claims, they are insufficient to fully characterize the waveform. For this reason, the following changes are recommended. New parameters, and modifications to the TASER parameters, have been defined in Section 2.2.

e. Pulse Rate. The TASER Pulse Rate only calculates an average pulse rate from the last second of the discharge. Given that the waveform recorder will record the entire discharge cycle, statistics should be gathered for all of the pulses in the discharge cycle. As such, new definitions relating to the pulse rate will be defined, including the *Pulse Repetition Interval (PRI)* and the *Pulse Repetition Frequency (PRF)*.

f. Pulse Duration. The TASER Pulse Duration is only an average taken over the last 8 pulses. Statistics should be gathered for all of the pulses in the discharge cycle.

g. Charge. The TASER Main Phase Charge definition is a good approximation of what is termed the *net charge*; however, it is only an average taken over the last 8 pulses. Statistics should be gathered for all of the pulses in the discharge cycle. Charge can also be defined in many different ways for complex waveforms, and this parameter has been given many different definitions already in [10]. Some charge definitions are thought to pertain to the physiological effects of the weapon, whereas other definitions are used to describe the charge characteristics of the waveform in general.

h. Peak Voltage. Although the TASER Peak Loaded Main Phase Voltage is a relevant parameter, it is only an average taken over the last 8 pulses. Voltage statistics should be determined for all of the pulses in the discharge cycle. Both the minimum negative and the maximum positive *peak voltages* should be recorded.

D.3 Recommended Waveform Parameters

This section contains the definitions of all of the parameters that should be measured during CEW testing, which are above-and-beyond any manufacturer-specific parameters that may be measured at the same time. While this report does not specifically identify the parameters that are relevant from an efficacy or safety perspective, the parameters defined in this section form a more complete set of data that may be useful in the future should new information be discovered concerning efficacy and safety. The parameters listed herein represent an exhaustive list of parameters and only a subset of these should be included in the test report. In addition to the parameters listed here, a test laboratory may include other parameters, or parameters that are derived from those listed here, at its discretion.

D.3.1 Current or Voltage

It is assumed that the measured voltage V (in volts) and current I (in amperes) of the waveform are related via Ohm's Law, that is, $V = IR$, where R is the measured load resistance (in ohms). Whether to measure voltage or current is left to the discretion of the test laboratory. In the text that follows, references to voltage and current are made. If only one of the two parameters (be it voltage or current) is measured, Ohm's Law should be used to convert to the other parameter, where necessary.

D.3.2 Symbols

For succinctness, the following symbols will be used in the definitions that follow.

Table 6: Symbols and Units

Symbol	Meaning	Units
V	Measured voltage	Volts
V_k	Measured voltage of the kth data point	Volts
$\|V\|$	Absolute value of V	Volts (strictly positive)
V_t	Trigger voltage	Volts
$\|V_t\|$	Absolute value of the trigger voltage	Volts (strictly positive)
I	Measured current	Amperes
I_k	Measured current of the kth data point	Amperes
$\|I\|$	Absolute value of I	Amperes (strictly positive)
Δt	Waveform Recorder time increment	seconds
k	Index of a data point in a vector	
n	Index referring to the nth pulse of the waveform	$1 < n < N$
m	Index referring to the mth lobe in a pulse	$1 < m < M$

D.3.3 Data Acquisition and Storage Unit Trigger Settings

The Data Acquisition and Storage unit will perform a measurement only after the input waveform crosses a certain threshold, known as a *trigger*. Conceptually, a waveform should begin at a zero-level, but in practice, noise makes it impossible to accurately define the zero-level. If the trigger level is set too low, noise peaks will cause false triggers, causing the Data Acquisition and Storage unit to record garbage data, which can lead to subsequent errors in the Data Analysis Program. Conversely, if the trigger level is set too high, portions of the waveform might not be captured, or significant waveforms may be missed altogether. An adequate trigger level balances the need for noise suppression with the requirement to capture low-level waveforms that may be significant. The type of trigger, and the trigger level of the Data Acquisition and Storage unit are described in Annexes A, B and C. The voltage trigger level is represented by V_t, and $|V_t|$

represents its magnitude, in volts. Ohm's Law may be applied to convert the voltage trigger level into a current trigger level.

D.3.4 Start and End of a Waveform

Once a waveform has been recorded by the Data acquisition and Storage unit, the Data Analysis Program is used to interpret the results, which consists, in part, of identifying significant portions of the waveform. Depending on the context, the waveform in question may refer to a discharge cycle, a pulse within the discharge cycle, or a lobe within a pulse. For the purposes of data analysis, the definition of the start of a waveform will be identical to the trigger level used by the Data acquisition and Storage unit. The end of a waveform will be defined as a zero crossing followed by the absence of a trigger event. Data analysis filters should not be applied before assessing the start and end of a waveform – they should be interpreted as they are measured.

Start of a Waveform: the first data point for which $|V_k| > |V_t|$ following a Null Period.

End of a Waveform: a Zero Crossing followed by a Null Period.

Zero Crossing: the interpolated zero value between two successive data points having opposite signs, or any time the measured waveform is exactly equal to zero.

Null Period: a time duration equal to or greater than 500 μs, during which $|V| < |V_t|$.

D.3.5 Discharge Cycle Definition

When fired, a CEW usually produces an output waveform of finite duration that consists of a repetitive series of N nearly identical pulses. The entire duration of the output waveform is the *Discharge Cycle*.

Discharge Cycle Start Index: the index of the data point that occurs before the very first trigger $|V| > |V_t|$ at the beginning of the Discharge Cycle.

Discharge Cycle End Index: the index of the data point that occurs after the last Zero Crossing prior to a Null Period at the end of the Discharge Cycle.

D.3.6 Pulse Definition

A *pulse* is the portion of the Discharge Cycle that contains energy and that is expected to be repeated N times during the Discharge Cycle. The Pulse Start Index and Pulse End Index will be determined from the data acquisition and Storage unit data without any signal processing or filtering applied, and will be determined for all pulses in the discharge cycle, meaning that each parameter consists of a vector of N values.

Pulse Start Index(n): the index of the data point that occurs before $|V| > |V_t|$ following a Null Period, for $n = 1 \ldots N$.

Pulse End Index(n): the index of the data point that occurs after the Zero Crossing prior to a Null Period, for $n = 1 \ldots N$.

D.3.7 Lobe Definition

A *lobe* is a portion of the pulse and is usually delimited by a Zero Crossing on either side, as illustrated in Figure 38.

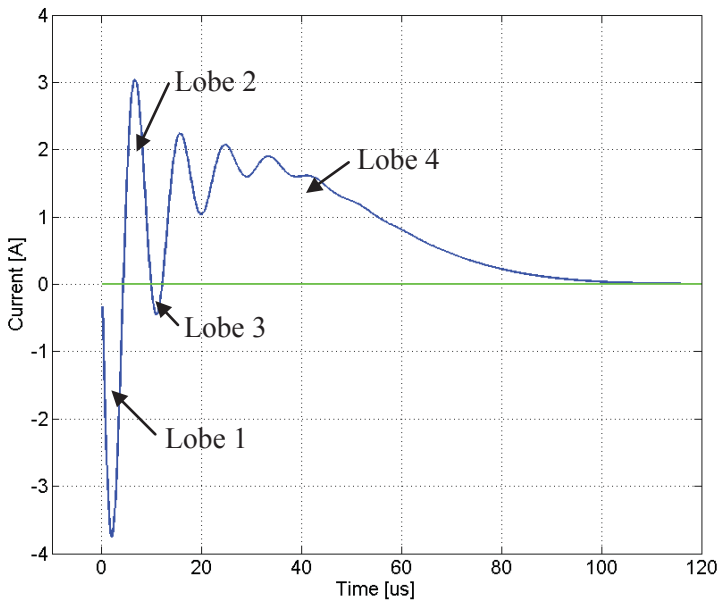


Figure 38: Example current waveform with four distinct current lobes

When required, the Lobe Start Index and Lobe End Index should be determined for all of the lobes in each pulse, meaning that each of these parameters consists of an M-by-N matrix where M is the number of lobes in a pulse and N is the number of pulses in the waveform. For a given pulse n, first lobe's start index, Lobe Start Index(1, n), is defined by the start of the pulse, whereas the last lobe's end index, Lobe End Index(M, n), is defined by a Zero Crossing followed by a Null Period. The remainder of the lobe start and end indices are defined by Zero Crossings only.

Lobe Start Index(1, n): the index of the data point that occurs before $|V| > |V_t|$ following a Null Period, within pulse n.

Lobe Start Index(m, n): the index of the data point that occurs after a Zero Crossing, for $m = 2 \ldots M$, within pulse n.

Lobe End Index(m, n): the index of the data point that occurs before a Zero Crossing, for $m = 2 \ldots M$, within pulse n.

Lobe End Index(M, n): the index of the data point that occurs after the last Zero Crossing prior to a Null Period at the end of the pulse.

Peak-Voltage-Lobe: the portion of the pulse spanning from Lobe Start Index(m, n) to Lobe End Index(m, n), where m is the lobe number containing the highest voltage magnitude in pulse n.

Peak-Charge-Lobe: the portion of the pulse spanning from Lobe Start Index(m, n) to Lobe End Index(m, n), where m is the lobe number containing the highest charge magnitude in pulse n.

D.3.8 CEW Output Terminal Polarity

The definition of polarity is important because it removes a sign ambiguity in the recorded waveform data that may lead to erroneous calculations by the Data Analysis Program. A standard definition of polarity also ensures consistency between the data collected between different test agencies.

The output terminals of a CEW produce a differential output, meaning that polarity (the identification of positive and negative terminals) can only be referenced with respect to the terminals themselves, not to ground. Although a list could be populated, in which the physical locations of the positive and negative terminals for each different CEW model are identified, such a list would require constant updating as the technology evolves. Instead, the recommended approach is to consider the current waveform only and to:

"...define the [positive] *polarity of a waveform as the excursion between successive zero crossings containing the greatest charge."* [19], p. 1323.

Hence determining the polarity consists of calculating the charge contained in each waveform lobe and identifying the one that has the highest charge as being positive. The current lobe containing the highest amount of charge will be called the *Peak-Charge-Lobe* in the text that follows. It should be noted that this definition of polarity agrees with the polarity used by TASER International.

It is likely that the identification of the Peak-Charge-Lobe would only need to be completed once for every new model of CEW.

Referring back to Figure 38, of the $M = 4$ lobes shown, Lobe 4 is the Peak-Charge-Lobe. The polarity used in Figure 38 is already correct. Had Lobe 4 been negative, the entire waveform would have to be multiplied by -1 to make Lobe 4 positive before the waveform is saved.

D.3.9 Temporal Parameters

The measured parameters that follow are related to the time duration of the discharge cycle, of the individual pulses, and of the lobes within each pulse.

D.3.9.1 Discharge Cycle Duration

Some CEWs, when fired, produce an output for a specified period of time. The Discharge Cycle Duration, measured in seconds, is the time duration of one CEW firing and it should be reported using the following definitions:

Discharge Cycle Start Time: the time of the data point corresponding to the Discharge Cycle Start Index.

Discharge Cycle End Time: the time of the data point corresponding to the Discharge Cycle End Index.

⁂ Discharge Cycle Duration = Cycle End Time – Cycle Start Time [seconds]

D.3.9.2 Number of Pulses

Missing pulses, additional pulses, or erroneous pulses may be symptoms of a malfunction, hence the number of pulses contained in a discharge cycle should be reported.

⁂ Number of Pulses N is equal to the number of times, during one Discharge Cycle Duration, that $|V| > |V_t|$ following a Null Period.

Should the duration of the $|V| < |V_t|$ interval prior to the $|V| > |V_t|$ event be less than the Null Period, the $|V| < |V_t|$ interval should be assigned to the pulse that preceded it, thereby extending the duration of that pulse. In this way, in no instance should a recorded voltage magnitude greater than the voltage trigger level be ignored.

D.3.9.3 Pulse Duration

The individual pulses within the Discharge Cycle are expected to be consistent. Deviations may be symptoms of a malfunction. The Pulse Start Time, Pulse End Time, and Pulse Duration, measured in seconds, will be determined from the data acquisition and Storage unit data without any signal processing or filtering applied, and will be determined for all pulses in the discharge cycle, meaning that each parameter consists of a vector of N values.

Pulse Start Time(n): the time of the data point corresponding to Pulse Start Index(n), for $n = 1 \ldots N$.

Pulse End Time(n): the time of the data point corresponding to Pulse End Index(n), for $n = 1 \ldots N$.

Pulse Duration(n) = Pulse End Time(n) – Pulse Start Time(n)

The Mean, Maximum, and Minimum of the Pulse Duration vector should be reported using the following definitions:

$$\text{Mean Pulse Duration} = \frac{1}{N}\sum_{n=1}^{N} \text{Pulse Duration(n)} \quad \text{[seconds]}$$

⁂ Maximum Pulse Duration = max(Pulse Duration) [seconds]

⁂ Minimum Pulse Duration = min(Pulse Duration) [seconds]

D.3.9.4 Pulse Repetition Interval (PRI)

The pulse rate of the CEW discharge is related to the timing between successive pulses. Figure 27 shows a segment of a discharge cycle containing $N = 4$ pulses. The Pulse Repetition Interval (PRI), measured in seconds, is the elapsed time between two consecutive pulses. Given that the Pulse Start Times are often more precise than the Pulse End Times, the PRI is measured between Pulse Start Times only. The PRI should be determined for all pulse intervals in the discharge cycle, meaning that this parameter consists of a vector containing $N - 1$ values. An example of the PRI is shown in Figure 39.

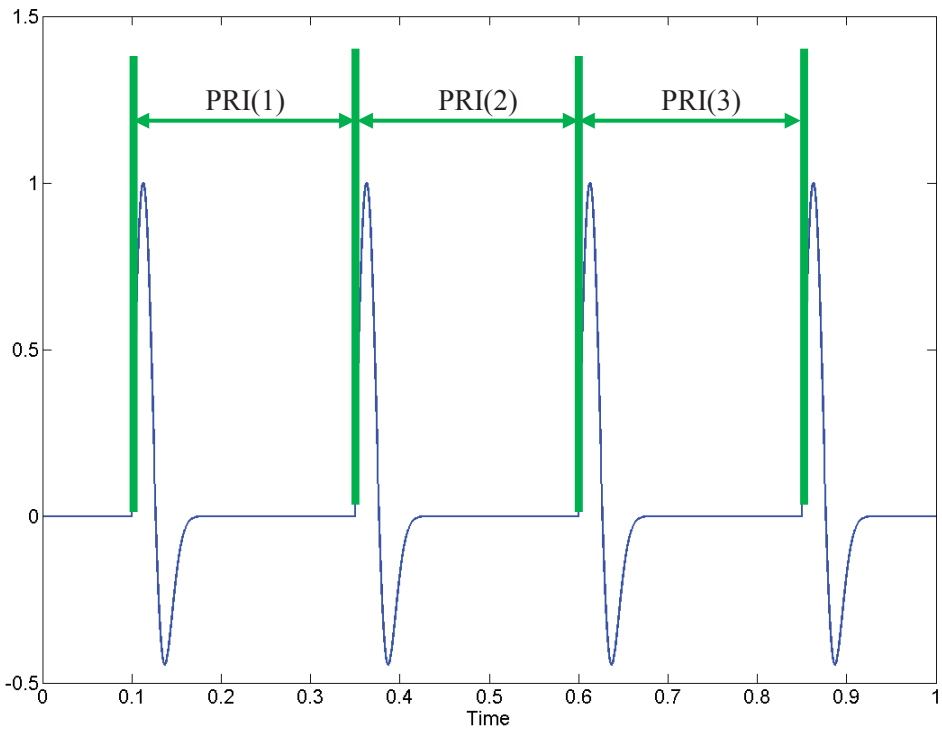


Figure 39: Pulse Repetition Interval (PRI)

PRI(n) = Pulse Start Time(n+1) – Pulse Start Time(n), $n = 1 \ldots N - 1$.

The Mean, Maximum, and Minimum of the PRI vector should be reported using the following definitions:

⁂ Mean PRI $= \frac{1}{N-1}\sum_{n=1}^{N-1} \text{PRI(n)}$ [seconds]

⁂ Maximum PRI = max(PRI) [seconds]

Minimum PRI = min(PRI) [seconds]

Note that if the maximum PRI is greater than twice the mean PRI, then one or more pulses may have been skipped in the discharge cycle. If only one pulse has been skipped, this weapon should be monitored more frequently. If more than one pulse has been missed, the weapon should fail the test.

D.3.9.5 Pulse Repetition Frequency (PRF)

The Pulse Repetition Frequency (PRF), measured in pulses-per-second (or hertz), is synonymous with the Pulse Rate. The PRF is the reciprocal of the PRI, PRF = 1/(PRI). The Mean PRF, Maximum PRF, and Minimum PRF should be reported using these definitions:

⁂ Mean PRF = 1/(Mean PRI) [pulses per second] or [Hertz]

⁂ Maximum PRF = 1/(Maximum PRI) [pulses per second] or [Hertz]

⁂ Minimum PRF = 1/(Minimum PRI) [pulses per second] or [Hertz]

D.3.9.6 Peak-Voltage-Lobe Duration

Some CEW models rely on a short-duration, high voltage lobe, sometimes called an *arc phase*, to establish a conductive path in the subject. This lobe, called the *Peak-Voltage-Lobe*, was defined in Section D.3.7.

Peak-Voltage-Lobe Duration seeks to quantify the duration of this arc phase, when present. This parameter provides a means of ensuring that the CEW circuitry responsible for generating the arc phase is functioning properly. The Peak-Voltage-Lobe Duration may also be of interest in the context of the CEW's physiological effects [19]. The Peak-Voltage-Lobe Duration will be determined for all pulses in the discharge cycle, meaning that this parameter consists of a vector of N values. An example of the Peak-Voltage-Lobe Duration is shown in Figure 40 and is consistent with the $tp-$ variable described in [19].

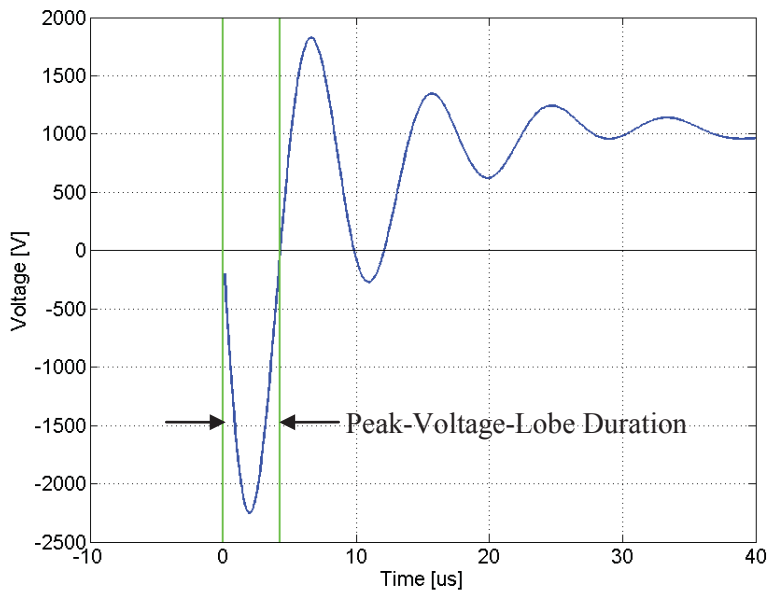


Figure 40: Peak-Voltage-Lobe Duration

Peak-Voltage-Lobe Start Time(n): the time of the data point corresponding to Lobe Start Index(*m, n*), where *m* is the lobe number of the Peak-Voltage-Lobe in pulse *n*, for *n* = 1… *N*.

Peak-Voltage-Lobe End Time(n): the time of the data point corresponding to Lobe End Index(*m, n*), where *m* is the lobe number of the Peak-Voltage-Lobe in pulse *n*, for *n* = 1… *N*.

Peak-Voltage-Lobe Duration(n) = Peak-Voltage-Lobe End Time(n) – Peak-Voltage-Lobe Start Time(n), for *n* = 1…*N*.

The Mean, Maximum, and Minimum of the Peak-Voltage-Lobe Duration vector should be reported using the following definitions:

$$\text{Peak-Voltage-Lobe Mean Duration} = \frac{1}{N}\sum_{n=1}^{N} \text{Peak-Voltage-Lobe Duration(n) [seconds]}$$

Peak-Voltage-Lobe Maximum Duration = max(Peak-Voltage-Lobe Duration) [seconds]

Peak-Voltage-Lobe Minimum Duration = min(Peak-Voltage-Lobe Duration) [seconds]

D.3.9.7 Peak-Charge-Lobe Duration

The duration of the waveform lobe that delivers the most charge, as previously mentioned, is called the Peak-Charge-Lobe. The duration of the Peak-Charge-Lobe may be related to the CEW's physiological effects [10],[19]. For some CEWs, this is sometimes known as the *main phase* duration, or *stimulation phase* duration. The Peak-Charge-Lobe Duration parameter seeks to quantify this value. The Peak-Charge-Lobe Duration will be determined for all of the pulses in the discharge cycle, meaning that this parameter consists of a vector of *N* values. An example of the Peak-Charge-Lobe Duration is shown in Figure 41 and is consistent with the *tp+* variable defined in [19].

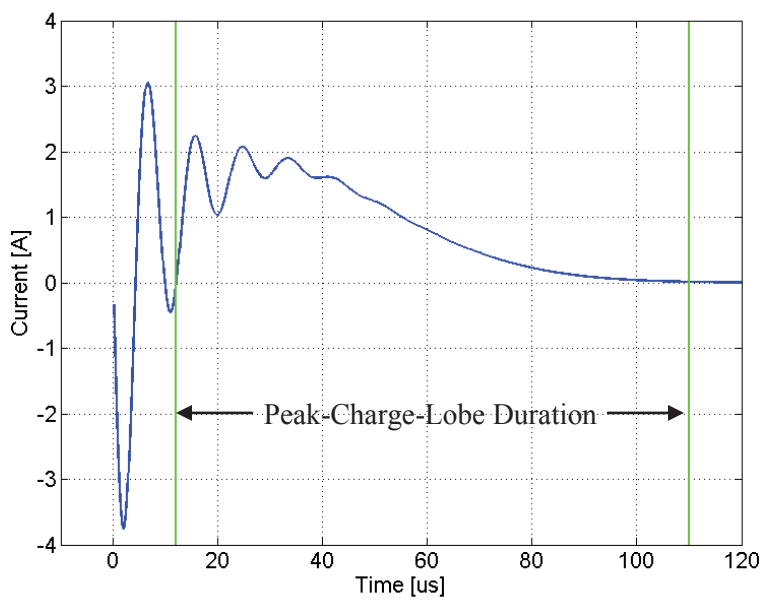


Figure 41: Peak-Charge-Lobe Duration

<u>Peak-Charge-Lobe Start Time(n)</u>: the time of the data point corresponding to Lobe Start Index(*m, n*), where *m* is the lobe number of the Peak-Charge-Lobe in pulse *n*, for *n* = 1… *N*.

<u>Peak-Charge-Lobe End Time(n)</u>: the time of the data point corresponding to Lobe End Index(*m, n*), where *m* is the lobe number of the Peak-Voltage-Lobe in pulse *n*, for *n* = 1… *N*.

<u>Peak-Charge-Lobe Duration(n)</u> = Peak-Charge-Lobe End Time(n) – Peak-Charge-Lobe End Time(n), for *n* = 1…*N*.

The Mean, Maximum, and Minimum of the Peak-Charge-Lobe Duration vector should be reported using the following definitions:

$$\underline{\text{Peak-Charge-Lobe Mean Duration}} = \frac{1}{N}\sum_{n=1}^{N} \text{Peak-Charge-Lobe Duration(n) [seconds]}$$

Peak-Charge-Lobe Maximum Duration = max(Peak-Charge-Lobe Duration) [seconds]

Peak-Charge-Lobe Minimum Duration = min(Peak-Charge-Lobe Duration) [seconds]

D.3.10 Voltage Parameters

The following parameters are related to the measured waveform voltage.

D.3.10.1 Pulse High Voltage and Pulse Low Voltage

The Pulse High Voltage and Pulse Low Voltage seek to quantify the high voltage lobe (arc phase), when present. Depending on the shape of the waveform, one of these parameters may also represent the maximum excursion of the remainder of the waveform. The Pulse High Voltage and Pulse Low Voltage will be determined for all pulses in the discharge cycle, meaning that each of these parameters consists of a vector of *N* values. An example of the Pulse High Voltage and of the Pulse Low Voltage is shown in Figure 42. These definitions complement the *main phase peak loaded voltage* already specified by TASER International [5].

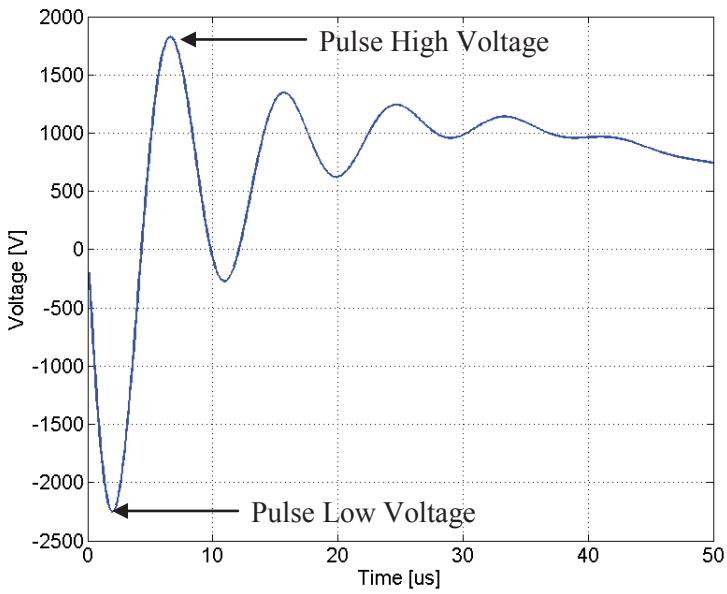


Figure 42: Pulse High Voltage and Pulse Low Voltage

Pulse High Voltage(n) = Maximum voltage of pulse *n*, for *n* = 1… *N*.

Pulse Low Voltage(n) = Minimum voltage of pulse *n*, for *n* = 1… *N*. May be negative.

The Mean, Highest, and Weakest values of the Pulse High Voltage vector, and the Mean, Lowest and Weakest values of the Pulse Low Voltage vector should be reported using the following definitions:

$$\underline{\text{Pulse Mean High Voltage}} = \frac{1}{N}\sum_{n=1}^{N} \text{Pulse High Voltage(n)}\,[\text{Volts}]$$

$$\underline{\text{Pulse Mean Low Voltage}} = \frac{1}{N}\sum_{n=1}^{N} \text{Pulse Low Voltage(n)}\,[\text{Volts}]$$

⁂ Highest Pulse Voltage = max(Pulse High Voltage) [Volts]

⁂ Lowest Pulse Voltage = min(Pulse Low Voltage) [Volts]

⁂ Weakest Pulse High Voltage = min(Peak High Voltage) [Volts]

⁂ Weakest Pulse Low Voltage = max(Pulse Low Voltage) [Volts]

D.3.11 Charge Parameters

Charge, measured in units of Coulombs, is the time-integral of the current waveform. The sign of the current waveform is related to the direction in which the electrons are flowing. Most CEW current waveforms oscillate between positive and negative values. When the positive current is symmetric with respect to the negative current, the waveform is said to be *biphasic*, and household alternating current (AC) is one example of this. When the current of a waveform flows only in one direction (positive or negative) the waveform is said to be *monophasic*, and direct current (DC) is one example of this. The current waveforms that are produced by many CEWs often lack the symmetry to be truly biphasic, and are not monophasic either because they contain both positive and negative current lobes. As such, CEW current waveforms display both biphasic and monophasic attributes, which makes the selection of charge parameters difficult if they are to be applied to a wide variety of waveforms produced by different CEW models. For these reasons, a number of different charge definitions will be recommended.

There are many different definitions of charge, based on how the sign of the current waveform is treated during the integration [10]. Certain definitions of charge, such as the Peak-Charge-Lobe Charge, may be relevant to the CEW's physiological effects [19]. Some definitions of charge may be related to the safety of a CEW, but there is currently no clear medical evidence for choosing one type of charge over another. Manufacturers may warrant their product based on a particular type of charge, such as the net charge [5]. A more conservative estimate of delivered charge is the total charge. In an attempt to capture the key charge attributes of different CEW current waveforms, the following charge parameters are recommended. Definitions of charge that are applicable to entire pulses include: Total Charge, Positive Current Charge, Negative Current Charge, and Net Charge. Charge will also be calculated for individual lobes within each pulse, including the Peak-Charge-Lobe Charge and the Peak-Voltage-Lobe Charge.

For clarity, the term *monophasic charge* defined in [10] will be avoided, as it implies taking only the maximum value of two charge parameters. Monophasic charge can be added to the test report at the test laboratory's discretion, by selecting the maximum value of either the Positive Current Charge or the Negative Current Charge.

For clarity, terms such as *positive charge* and *negative charge* are avoided because current consists of the flow of electrons only, and electrons are strictly negatively charged. Only the direction the current flow may be positive or negative.

D.3.11.1 Positive Current Charge

The Positive Current Charge is the quantity of charge, measured in coulombs, that flows in the positive direction during a pulse. The Positive Current Charge should be determined for all of the pulses in the discharge cycle, meaning that this parameter consists of a vector containing N values. As an example, the shaded area shown in Figure 43 is proportional to the Positive Current Charge. This parameter complements the *Main Phase Charge* that is already specified by TASER International [4],[5] and Peak-Charge-Lobe Charge defined in Section D.3.11.6.

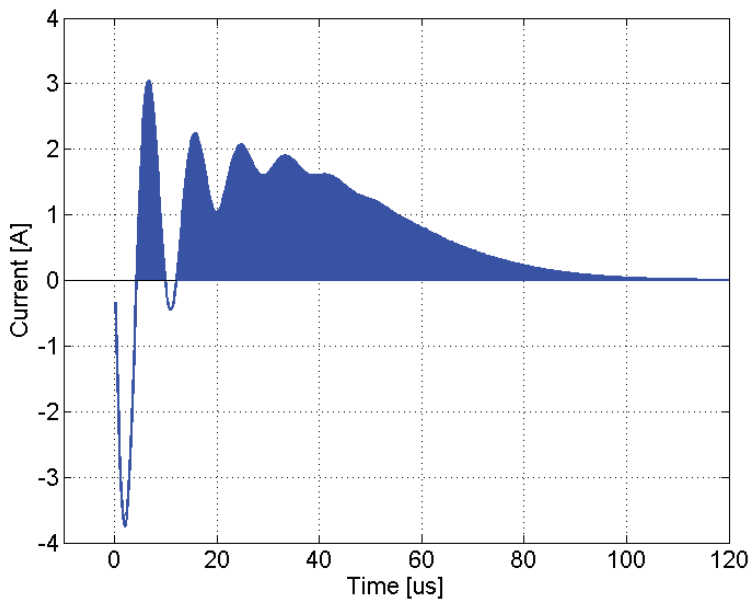


Figure 43: Positive Current Charge

Positive Current, measured in amperes, is defined as any current waveform data point within a pulse that has a positive value. When calculating the Positive Current Charge, the value of the Positive Current data point is held constant for one Data acquisition and Storage unit time increment Δt measured in seconds.

<u>Positive Current Charge(n)</u> = $\sum_k I_k \Delta t$, for all $I_k > 0$ within pulse n, for $n = 1 \ldots N$.

The Mean, Maximum, and Minimum values of the Positive Current Charge should be reported using the following definitions:

$$\underline{\text{Positive Current Mean Charge}} = \frac{1}{N}\sum_{n=1}^{N} \text{Positive Current Charge(n) [Coulombs]}$$

<u>Positive Current Maximum Charge</u> = max(Positive Current Charge) [Coulombs]

<u>Positive Current Minimum Charge</u> = min(Positive Current Charge) [Coulombs]

D.3.11.2 Negative Current Charge

The Negative Current Charge is the quantity of charge, measured in coulombs, that flows in the negative direction during a pulse. The Negative Current Charge, which has a <u>strictly positive value</u>, should be determined for all of the pulses in the discharge cycle, meaning that this parameter consists of a vector containing N values. As an example, the shaded area shown in Figure 44 is proportional to the Negative Current Charge. This parameter complements the Peak-Voltage-Lobe Charge defined in Section D.3.11.7.

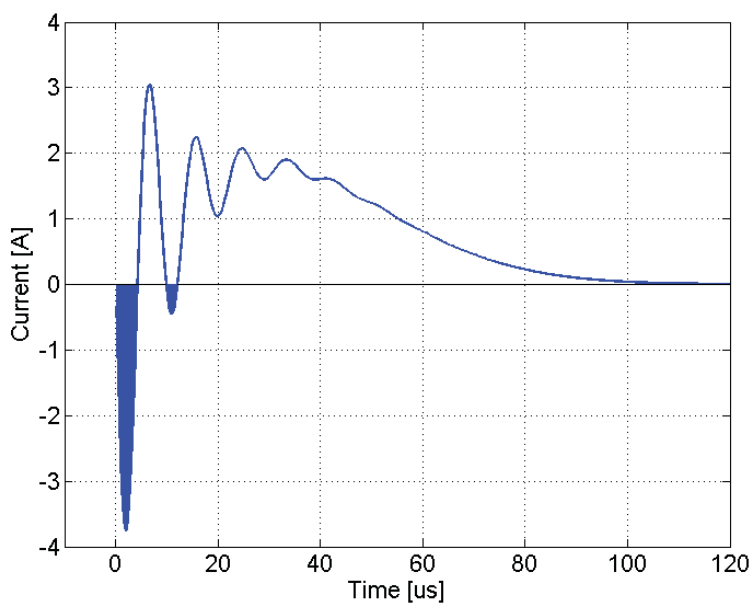


Figure 44: Negative Current Charge

Negative Current, measured in amperes, is defined as the magnitude of any current waveform data point within a pulse that has a negative value. When calculating the Negative Current Charge, the value of the Negative Current data point is held constant for one Data acquisition and Storage unit time increment Δt measured in seconds.

$$\underline{\text{Negative Current Charge}} = \sum_{k} |I_k| \Delta t \text{ , for all } I_k < 0 \text{ within pulse } n\text{, for } n = 1 \ldots N.$$

The Mean, Maximum, and Minimum values of the Negative Current Charge should be reported using the following definitions:

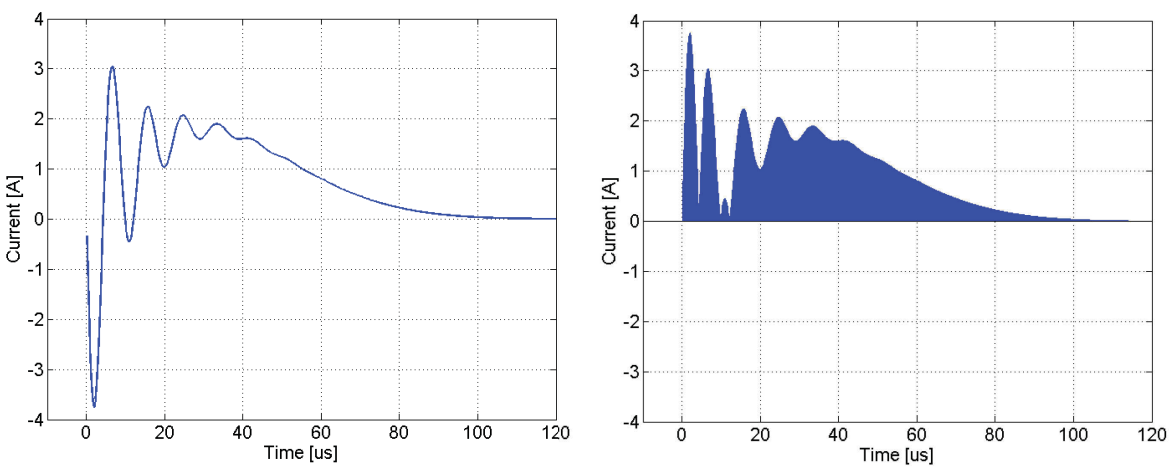
$$\underline{\text{Negative Current Mean Charge}} = \frac{1}{N}\sum_{n=1}^{N} \text{Negative Current Charge(n)} \text{ [Coulombs]}$$

<u>Negative Current Maximum Charge</u> = max(Negative Current Charge) [Coulombs]

<u>Negative Current Minimum Charge</u> = min(Negative Current Charge) [Coulombs]

D.3.11.3 Total Charge

The Total Charge, measured in coulombs, is the absolute magnitude of the charge per pulse that moves across the load. Total Charge is obtained by integrating the magnitude of the current (strictly positive), and will therefore always be the highest value of charge in the report. The Total Charge should be determined for all of the pulses in the discharge cycle, meaning that this parameter consists of a vector containing *N* values. As an example, the graph in Figure 45a shows the current waveform, whereas the graph in Figure 45b shows the magnitude of the same current waveform. The shaded area shown in Figure 45b is proportional to the Total Charge.



(a) (b)

Figure 45: Total Charge Example: (a) Actual Current Waveform, (b) Current Magnitude

When calculating the Total Charge, the current magnitude data point is held constant for one Data acquisition and Storage unit time increment Δt measured in seconds.

<u>Total Charge</u> = $\sum_{k} |I_k| \Delta t$, for all I_k within pulse n, for $n = 1 \ldots N$.

The Mean, Maximum, and Minimum values of the Total Charge should be reported using the following definitions:

⁂ Mean Total Charge $= \frac{1}{N}\sum_{n=1}^{N} \text{Total Charge(n)}$ [Coulombs]

⁂ Maximum Total Charge = max(Total Charge) [Coulombs]

⁂ Minimum Total Charge = min(Total Charge) [Coulombs]

D.3.11.4 Net Charge

Net Charge seeks to characterize the imbalance between the Positive Current Charge and the Negative Current Charge. For a biphasic waveform with perfect symmetry, subtracting the Negative Current Charge from the Positive Current Charge yields zero, because the same amount of charge travels in both the positive and negative direction. Net Charge is representative of the monophasic aspect of the charge, in that a non-null Net Charge indicates that more charge has travelled in one direction than the other.

It must be stressed that Net Charge does not indicate the amount of charge that has actually flowed across a load (or a subject). The Net Charge usually has the smallest value among the charge parameters associated with a pulse.

The Net Charge should be determined for all of the pulses in the discharge cycle, meaning that this parameter consists of a vector containing *N* values.

Net Charge(n) = Positive Current Charge(n) – Negative Current Charge(n), for $n = 1 \ldots N$.

The Mean, Maximum, and Minimum values of the Net Charge should be reported using the following definitions:

Mean Net Charge $= \frac{1}{N}\sum_{n=1}^{N} \text{Net Charge(n)}$ [Coulombs]

Maximum Net Charge = max(Net Charge) [Coulombs]

Minimum Net Charge = min(Net Charge) [Coulombs]

D.3.11.5 Lobe Charge

Use the following definition to calculate Lobe Charge:

$$\underline{\text{Lobe Charge}(m,n)} = \sum_{k=\text{Lobe Start Index}(m,n)}^{\text{Lobe End Index}(m,n)} |I_k| \Delta t$$, for the specified I_k values within lobe m in pulse n.

D.3.11.6 Peak-Charge-Lobe Charge

For most CEWs, one lobe p within every pulse n will consistently deliver the highest amount of charge, and this lobe is called the Peak-Charge-Lobe. The Peak-Charge-Lobe Charge is the amount of charge, measured in Coulombs, in that lobe. The Peak-Charge-Lobe Charge should be determined for all of the pulses in the discharge cycle, meaning that this parameter consists of a vector containing N values. The shaded area shown in Figure 46 is proportional to the Peak-Charge-Lobe Charge. The Peak-Charge-Lobe Charge is consistent with the definition of the $Q(max+)$ parameter in [19].

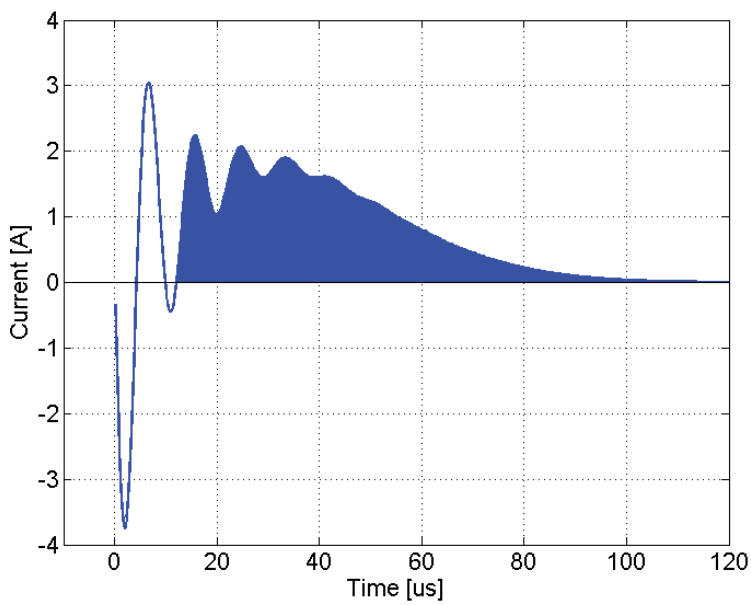


Figure 46: Peak-Charge-Lobe Charge Example

Peak-Charge-Lobe Charge(n) = Lobe Charge(m, n), where m is the lobe number corresponding to the Peak-Charge-Lobe in pulse n, for $n = 1 \ldots N$.

The Mean, Maximum, and Minimum values of the Peak-Charge-Lobe Charge should be reported using the following definitions:

⁂ Peak-Charge-Lobe Mean Charge $= \frac{1}{N} \sum_{n=1}^{N}$ Peak-Charge-Lobe Charge(n) [Coulombs]

⁂ Peak-Charge-Lobe Maximum Charge = max(Peak-Charge-Lobe Charge) [Coulombs]

⁂ Peak-Charge-Lobe Minimum Charge = min(Peak-Charge-Lobe Charge) [Coulombs]

D.3.11.7 Peak-Voltage-Lobe Charge

The Peak-Voltage-Lobe Charge seeks to quantify the amount of charge associated with the Peak-Voltage-Lobe. For some CEWs, this parameter provides a means of quantifying the charge delivered by the weapon's arc phase circuitry. The Peak-Voltage-Lobe Charge may also be relevant to the CEW's physiological effects [19]. The Peak-Voltage-Lobe Charge will be determined for all pulses in the discharge cycle, meaning that this parameter consists of a vector of N values. As an example, the shaded area shown in Figure 47 is proportional to the Peak-Voltage-Lobe Charge. The definition of the Peak-Voltage-Lobe Charge is consistent with the $Q(max-)$ parameter described in [19].

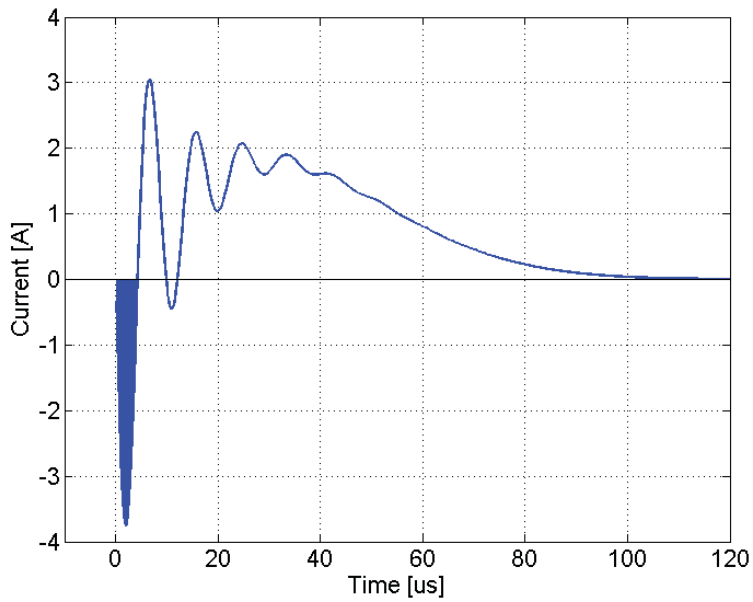


Figure 47: Peak-Voltage-Lobe Charge Example

Peak-Voltage-Lobe Charge(n) = Lobe Charge(m, n), where m is the lobe number corresponding to the Peak-Voltage-Lobe in pulse n, for $n = 1 \ldots N$.

The Mean, Maximum, and Minimum values of the Peak-Voltage-Lobe Charge should be reported using the following definitions:

$$\text{Peak-Voltage-Lobe Mean Charge} = \frac{1}{N}\sum_{n=1}^{N} \text{Peak-Voltage-Lobe Charge(n) [Coulombs]}$$

Peak-Voltage-Lobe Maximum Charge = max(Peak-Voltage-Lobe Charge) [Coulombs]

Peak-Voltage-Lobe Minimum Charge = min(Peak-Voltage-Lobe Charge) [Coulombs]

Annex E Specification for Reporting Test Data and Results

The following table represents the specification to be used in the construction of the CSV file of test results. Fields are to be included in the file in the order indicated, separated by a 'comma'. For decimal numerical parameter values, indicated by 'DEC', use the format following these examples: 1.23e5, -6.78e-10, where 3 significant digits are used, the 'e' represents a multiplication by a factor of 10 raised to the power of the number following the 'e', a dash represents a negative sign and a lack of a dash indicates a positive value.

Sequence	Field Label	Field Type	Description
1	MFR	CHAR	Name of the Manufacturer
2	MODEL	CHAR	Model Number of the Weapon (e.g., M26, X26, X2, X26P)
3	SERIALNO	CHAR	Serial Number of the Weapon Tested
4	PAIN	NUM	Public Agency Identification Number (PAIN)
5	AGENCY	CHAR	Name of Agency that owns CEW
6	TESTCO	CHAR	Name of Organization conducting the test
7	TECH	CHAR	Name of Technician conducting the test
8	ENG	CHAR	Name of Engineer certifying results
9	TESTVER	CHAR	Version of the Test Procedure Used (DRDCVer1)
10	TESTDATE	DATE	Date that the Test was Conducted (DD-MON-YYYY)
11	TESTSEQ	NUM	Sequence of Test Conducted for Specific Date and Weapon
12	UNCERTAINTY	NUM (2)	Total % Error of the Test Equipment Used that is applied to all Readings (rounded to the nearest whole number)
13	TEMP	NUM (2)	Ambient Temperature in Degrees Celsius (rounded to the nearest whole number)
14	HUMIDITY	NUM (2)	Humidity as a Percentage (rounded to the nearest whole number)
15	PRESSURE	NUM (3)	Atmospheric Pressure in kPa (rounded to the nearest whole number)
16	RESISTOR	DEC	Measured Value of the Resistor used
17	HWVERSION	CHAR	Hardware Version
18	SWVERSION	CHAR	Firmware Version
19	BATTERYLVL	NUM	% Battery Level Remaining as indicated on the visual display
20	CYCLE	DEC	Discharge Cycle Duration, in seconds
21	N	NUM	Number of Pulses
22	MAXDUR	DEC	Maximum Pulse Duration, in seconds
23	MINDUR	DEC	Minimum Pulse Duration, in seconds
24	MEANPRI	DEC	Mean Pulse Repetition Interval, in seconds
25	MAXPRI	DEC	Maximum Pulse Duration, in seconds

36	MEANPRF	DEC	Mean Pulse Repetition Frequency, in hertz
27	MAXPRF	DEC	Maximum Pulse Repetition Frequency, in hertz
28	MINPRF	DEC	Minimum Pulse Repetition Frequency, in hertz
29	MAXHIVOLT	DEC	Highest Pulse Voltage, in volts
30	MINHIVOLT	DEC	Weakest Pulse High Voltage, in volts
31	MINLOVOLT	DEC	Lowest Pulse Voltage, in volts
32	MAXLOVOLT	DEC	Weakest Pulse Low Voltage, in volts
33	MEANTOTQ	DEC	Mean Total Charge, in coulombs
34	MAXTOTQ	DEC	Maximum Total Charge, in coulombs
35	MINTOTQ	DEC	Minimum Total Charge, in coulombs
36	MEANLOBQ	DEC	Peak-Charge-Lobe Mean Charge, in coulombs
37	MAXLOBQ	DEC	Peak-Charge-Lobe Maximum Charge, in coulombs
38	MINLOBQ	DEC	Peak-Charge-Lobe Minimum Charge, in coulombs

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List of Acronyms and Units

A	Ampere
A·s	Ampere-second
AC	Alternating Current
AFID	Anti-Felon Identification
APPM	Auto shut-down Performance Power Magazine
cm	centimetre
C	Coulomb
CAHS	Canadian Academy of Health Sciences
CBC	Canadian Broadcasting Corporation
CCDPM	Configuration Controlled Digital Power Magazine
CDPM	Controlled Digital Power Magazine
CEW	Conducted Energy Weapon
CEWSI	Conducted Energy Weapons Strategic Initiative
CSS	Centre for Security Science
CSV	Comma-Separated Values
CT	Current Transformer
DC	Direct Current
DCDPM	De-configuration Controlled Digital Power Magazine
DND	Department of National Defence
DPM	Digital Power Magazine
DRDC	Defence Research & Development Canada
DRDKIM	Director Research and Development Knowledge and Information Management
DRP	Document Review Panel
ENOB	Equivalent Number Of Bits
FPT	Federal Provincial Territorial
g	gram
Hz	Hertz
HVM	High Voltage Module

IEC	International Electrotechnical Commission
ISO	International Standards Organization
kHz	kilohertz
kPa	kilopascal
LED	Light Emitting Diode
mm	millimetre
ms	millisecond
MHz	Megahertz
MSa/s	Mega-samples per second
MΩ	Megohm
NMI	Neuromuscular Incapacitation
OEM	Original Equipment Manufacturer
OPP	Ontario Provincial Police
PPM	Performance Power Magazine
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
PVC	Polyvinyl Chloride
QETE	Quality Engineering Test Establishment
R&D	Research and Development
RCMP	Royal Canadian Mounted Police
s	second
SCC	Standards Council of Canada
TPPM	Tactical Performance Power Magazine
US	United States
USB	Universal Serial Bus
WG	Working Group
XDPM	Extended Digital Power Magazine
XP	Extra Penetration
μC	Micro-Coulomb
μs	Micro-second
Ω	Ohm

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Performance of a conducted energy weapon (CEW) can be evaluated from three perspectives: how well it immobilizes a subject (efficacy), how safe it is and how it performs technically. This report addresses the technical performance of CEWs such as those used by Canadian law enforcement. It does not address either the efficacy or the safety. This report provides recommendations to be used by law enforcement, policing policy-makers and test laboratories to ensure consistent and quality results when testing CEWs. Test laboratories are provided with a detailed analysis of the parameters that can be measured including the appropriate algorithms as well as the required test equipment specifications, recommended test procedure and reporting requirements. Law enforcement agencies and policing policy-makers are provided with recommendations related to qualifications of test laboratories, test strategies and recommended acceptance specifications.

On peut évaluer le rendement d'une arme à impulsions (AI) sous trois angles : sa capacité à immobiliser un sujet (efficacité), sa sécurité et son fonctionnement technique. Le présent rapport traite de la performance technique des AI comme celles qu'utilisent les services de police du Canada. Il ne porte pas sur leur efficacité ni leur sécurité. Le rapport renferme des recommandations à suivre par les responsables de l'application de la loi, les décideurs des services de police et les laboratoires d'essai afin d'obtenir des résultats cohérents et de qualité au moment de faire l'essai des AI. Les laboratoires d'essai disposent d'une analyse détaillée des paramètres pouvant être mesurés, notamment les algorithmes appropriés ainsi que les caractéristiques de l'équipement d'essai requis, la procédure d'essai recommandée et les exigences relatives à la production de rapports. Les organismes responsables de l'application de la loi et les décideurs des services de police disposent de recommandations relatives aux qualités des laboratoires d'essai, aux stratégies d'essai et aux caractéristiques d'acceptation recommandées.

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conducted energy weapons; CEW; Tasers; test procedure; test standards