Standardized Test and Evaluation of Metal Detectors

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Abstract

Test and evaluation trials of metal detectors that have been made in recent years have shown the need for common testing specifications so that the results of such trials are useful to the wider demining community.
Stemming from initiatives to promote standardization within Humanitarian Mine Action, a CEN Workshop (an "informal" international standardization process) was established to standardize the testing of metal detectors. This has produced a "CEN Workshop Agreement" that gives principles, guidelines and procedures for detector testing. In particular a method for quantifying detection capability has been agreed.

1. Introduction

Metal detectors are an essential part of the toolkit of a humanitarian deminer. Metal detection is one of the few "non-contact" methods available to search for mines in most of the areas of the world where humanitarian mine clearance operations are carried out.

Modern metal detectors are extremely sensitive, being able to detect small amounts of metal in their vicinity. Most detectors are designed to be simple to use, with few user adjustments and a go/no go audio alarm to indicate the presence of metal.

Despite the fact that metal detectors have been used for finding mines since the Second World War, there is no universal specification for any performance standards. In recent years, demining end-users have required testing and evaluation of the available metal detectors prior to making procurement decisions. Many trials of the capabilities of metal detectors have been performed, stimulated by the greater international effort to combat the threat posed to civilian populations by mines and unexploded ordnance. However, the lack of an agreed standard for comparing the performance of these instruments has limited the value of this work to the end-users. Without a testing standard, it is difficult to make cross-comparison between instruments to determine which is best-suited to any particular needs.

The response to this need is CEN Workshop 7, "Humanitarian Mine Action - Test and Evaluation - Metal Detectors" (CW07). CW07 was established with the objective of developing and agreeing on specifications for the testing and evaluation of metal detectors used in humanitarian mine clearance. In this paper the background to CW07 is presented, as well as a summary of the tests that have been specified.

2. History of CW07

Following a mandate given to CEN (European Committee for Standardization) by the European Commission, the Working Group CEN BT/WG 126 was set up with the aim of to make recommendations and initiating standardization within humanitarian mine action. One of the first conclusions of CEN BT/WG 126 was that a CEN Workshop be started to standardize the testing and evaluation of metal detectors. It was proposed that the Joint Research Centre of the EC (JRC) be the "driving force" of this process.

In addition, the International Test and Evaluation Program for Humanitarian Demining (ITEP) gave its support to the idea of standardization of metal detector test and evaluation and requested that JRC initiate the CEN Workshop. Support has also been given by the United Nations Mine Action Service (UNMAS) and by the Geneva International Centre for Humanitarian Demining (GICHD), which is responsible for International Mine Action Standards (IMAS). Close co-operation has been maintained with GICHD.

CW07 was launched on 8 November 2001 in Brussels, with the approval of the Business Plan [1]. The Chairmanship and the Secretariat of CW07 were both provided by JRC, with standardization support from CEN via UNI, the Italian CEN member. The aim of CW07 was to produce a CEN Workshop Agreement (CWA) giving principles, guidelines and testing procedures for the testing and evaluation of metal detectors.

Full meetings of the Workshop took place at JRC, Ispra, Italy in December 2001, April 2002 and December 2002 at which the decisions were made about the tests that should be performed, how they should be done and how the test specifications should be written in the CWA. Between the April and December 2002 meetings, a small Drafting Working Group met twice - at DRDC, Suffield in Canada in June 2002 and in Ispra in September 2002 - to make faster progress in writing the CWA.

Following the full meeting of CW07 in December 2002, a final version of the CWA was prepared. The final version was submitted to CEN in May 2003 for approval and publication [2]. The Agreement is issued by CEN as CWA 14747:2003 [3].

3. Experience Applied in CW07

In formulating the standardized test procedures for the CWA, extensive use has been made of the test procedures developed and followed during the International Pilot Project for Technology Co-operation (IPPTC) for commercial off-the-shelf (COTS) metal detectors [4]. Previous standardization work on demining testing has also been useful in the preparation of the CWA, for example the International Test Operations Procedures (ITOPs) [5],[6],[7]. Studies of metal detector responses [8] and tests used in other previous metal detector trials [9],[10] gave valuable information. In addition, an existing US military Performance Specification [11] for metal detectors and a standard for metal detectors used for detection of concealed weapons and contraband in the US penal system [12] were considered in CW07.

The most important contribution was the combined experience of the members of CW07 that was brought to the Workshop. Manufacturers, testing laboratories, researchers into metal detection and those with experience of using and testing detectors in the field all contributed to creating the test specifications.

4. The CEN Workshop Agreement

The CEN Workshop Agreement (CWA) produced by the CEN Workshop defines the principles for testing metal detectors and gives guidelines for how such testing should be performed. As far as possible, procedures for testing have been closely specified.

The order of the testing followed in the CWA follows a logic that begins with tests of the basic operating performance. These tests are in the most controlled conditions, for which targets are in air not soil. Next the CWA describes tests on targets in soil – again as controlled as possible. Tests then follow on targets buried in conditions that are closer to field conditions.

4.1. General Principles

The CWA establishes the general principles for detector testing. One of the most important of these is that all of the tests of detection capability are based on the idea that the only output that the detector gives is a yes/no alarm signal. This means that all of this testing is based upon a correct alarm/no alarm judgement. For some detectors this is clear; for others, less so. A criterion is therefore defined; detection has occurred when a repeatable, non-intermittent alarm indication is produced.

To quantify detection capability, the maximum detection height or depth of a target is used. The distance is always measured from the top of the target concerned. When testing in air, the height of the sensor from the top of the target is measured. In soil, the depth of the top of the target below soil level and the sweep height of the sensor above the soil are measured. Figure 1 shows this convention schematically.

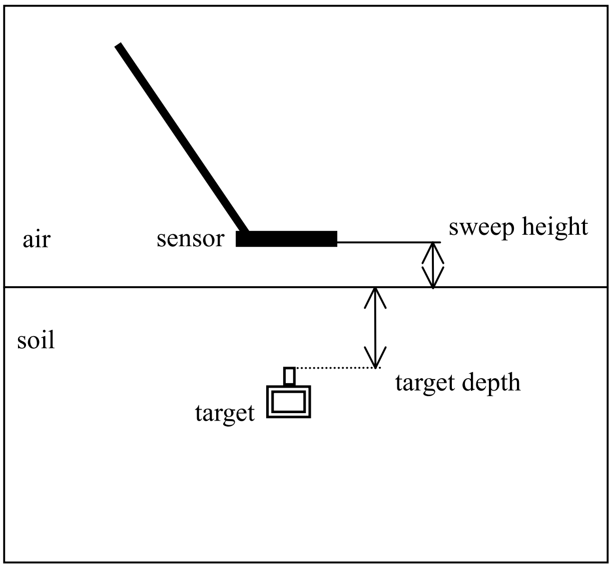

Figure 1 — Geometry for Testing Metal Detectors

4.2. In-air Tests

The first tests defined in the CWA are tests of detection capability in air. The benchmark test of detection capability is defined as the in-air maximum detection height of a 10mm-diameter chrome-steel ball. This test is used to check whether detection capability changes with sweep speed over a target, whether it is repeatable on set-up and whether it drifts. These tests are intended to be performed in controlled conditions.

Specifications are given to measure the way that detection capability changes as a function of sensor height above target. This is actually done by measuring the maximum detection height of metal balls. The results are then expressed in terms of a minimum target that is detectable at a given height. Metal balls do not closely resemble most of the metal components found in mines, but this exercise is a way of quantifying detection capability and gives an reference (albeit an arbitrary one) against which other targets can be compared. The reasons for using metal balls are given in more detail in another paper at this Conference [13].

Chrome steel balls are chosen as reference standards, but tests for other metals are also included. These give an indication of the relative detection capability for these metals. The results are reported as minimum target detection curves as shown in Figure 2.

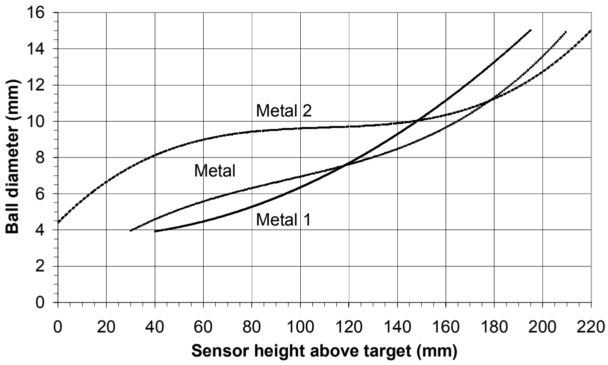

Figure 2 — Minimum Target Detection Capability Curves for Balls of Three Metals

Two forms of a test to measure the sensitivity profile (often called the "footprint") of a detector are included. One of these requires that the alarm output level is recorded in some way – this is the only part of the CWA where this is needed. The other test uses the maximum detection height principle already established.

4.3. Immunity to External Factors

There are tests of the immunity to environmental and operational conditions of the detector performance. The detection capability, as measured by maximum detection height is always used to give a quantifiable measure of any variation. Tests are given for the effect of temperature extremes and moisture on the sensor head, for example.

4.4. Detection Capability in Soil

Many soils found throughout the world have electromagnetic properties that can cause problems for metal detectors. It often happens that the most important aspect of a detector to a user is its capability to reject noise signals from the soil and still have a good capability for detecting metal. Therefore tests have been specified to measure in-soil detection capability. The most useful test can be made when some device has been implemented to change the depth of a target within the soil. This enables the minimum target detection curves to be repeated in soil. The results can then be compared to the in-air curves, to show any degradation caused by the soil.

Many detectors have advanced soil-compensation (or ground compensation) functions for rejecting soil signals, others simply require the sensitivity to be reduced when used on certain soils. The tests specified show how these adjustments affect the detection capability. Figure 3 shows the results of such a test.

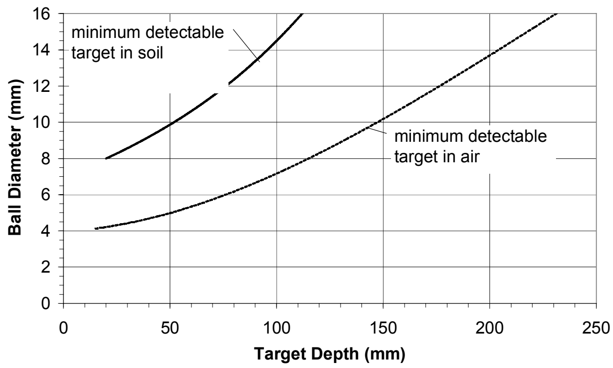

Figure 3 — The Effect of Soil on Detection Capability

As well as this type of in-soil tests, specifications are given for the type of test on targets buried at a fixed depth that will be more familiar to most users of metal detectors in demining.

The in-soil tests that tend to be given most importance by detector end-users are the in-field detection tests in which operators try to detect realistic mine targets (often disarmed real mines) in terrain that is representative of areas to be cleared of mines. Because of the amount of uncertainty introduced by the less-controlled conditions of such tests, they are usually statistical, using large numbers of test targets. CW07 has given guidelines and specification to make such "detection reliability" tests standardized, so that the results of a trial are useful to the wider demining community.

4.5. Operational Performance Tests

As well as the many tests focussing on the detection capability, specifications are given for tests of location accuracy, the ability to characterize target shape as point-like, as linear or as planar, for the capability to resolve adjacent targets. Tests to measure the effect of specific soils and other media encountered in the field are given.

One aspect of metal detector performance that is often important is its ability to operate near to a large, linear metal structure such as a rail. A test is included to measure the minimum operating distance in this situation.

Specific tests to determine whether particular interference sources affect a detector, or to what extent detectors interfere with one another are given.

4.6. Ergonomic and Operational Aspects

Although the major part of the CWA is taken up with measurements of the detection performance in one way or another, part of the document is devoted to other aspects of the evaluation of detectors that are important to users.

Among these aspects is the robustness of the detector. Any equipment used in demining must be sufficiently robust to endure rough handling for many years of operation without breaking.

The weight and balance of detectors are also important concerns; users want operators to be able to use them for long periods of time. Detectors need to be easy to use and the way that they should be used needs to be understandable to deminers.

Guidelines are therefore given for the analysis of ergonomic and operational qualities of a detector.

5. Targets

A number of tests targets have been defined by CW07:

1. Sets of metal balls are used as "parametric" targets" to measure the way that detection capability changes as the sensor height above the target increases. This is the most innovative idea introduced by CW07.
2. A set of targets is specified containing metal components that are intended to be similar to those found in typical low-metal mines. These have been defined previously [14] and have become known as the "ITOP target inserts".
3. A set of specific targets for testing aspects such as shape determination and operation next to linear metal objects.

6. Characterization of Soil

The electromagnetic properties of certain soils that so affect metal detectors are known to be the complex (frequency-dependent) magnetic susceptibility and to a lesser extent, the electrical conductivity. Unfortunately it is not yet feasible to make a measurement of these properties on all of the soils ever to be used for testing metal detectors. This means that making strict comparison between the results obtained on different soils is not possible. However, guidelines have been produced that begin to create a classification of soils based on their properties.

7. Controlled Tests and Alternatives

Many of the tests are designed to be performed in controlled conditions, in order to eliminate possible effects from "uncontrolled" external influences. One of the important ideas established is that, where possible, less-controlled alternative versions of tests are given. For example, the ideal way to measure detection height in air is to sweep the detector automatically at constant (optimum) speed over targets, with everything being maintained at constant temperature. Experience shows that it is possible to obtain very good results by using the detector manually, so this manual option is included. Effects from factors such as temperature changes may be missed in this case however.

8. Application of the CWA Tests

Different parts of the CWA are intended to be used by R&D laboratories, manufacturers, operators of test and evaluation facilities, organizations needing to procure metal detectors, Mine Action Centres and metal detector operators in the field.

The order of the testing followed in the CWA follows a logic that begins with tests of the basic operating performance. These tests are in the most controlled conditions, for which targets are in air not soil. To achieve such controlled conditions requires equipment and facilities that are usually not available in field environments so many of these tests need to be performed by specialized laboratories. Analogous tests are however specified for less-controlled conditions. Next the CWA describes tests on targets in soil – again as controlled as possible. Tests then follow that may be feasibly performed in the field with a minimum of equipment.

Few users of the document will wish to, or be able to perform all of the tests specified. A user in the field under MAC control for example, may perform the detection reliability test, some of the tests of operational performance characteristics and some of the basic in-air and in-soil sensitivity measurements. However, the value of testing is greatly increased if a laboratory has already performed controlled tests, for example to determine whether the sensitivity of the detector under test varies with operating temperature.

Users of the CWA who wish to conduct a trial of various metal detectors using the tests specified, may also wish to conduct a pre-trial assessment to exclude detectors at the beginning that clearly do not meet their requirements. Such a pre-trial assessment would include one or more of the tests specified in the CWA, with acceptance levels set by the users according to their own requirements. The basic in-air sensitivity measurement could be used for example, with a minimum acceptance level for the maximum detection height.

In order to help different users get the maximum benefit from using the CWA, a number of categories of testing have been established.

One of the International Mine Action Standards (IMAS 03.40) [14] deals with the test and evaluation of mine action equipment. IMAS 03.40 defines two types of testing trial; a consumer report trial (in which equipment is tested against general requirements) and an acceptance trial (in which equipment is tested against specific - usually local - requirements).

Testing can be "open" in which the operators know the details of where and what the targets are that they are trying to detect, or "blind" when they do not.

Tests can be designed to be "well-controlled" laboratory-type tests or "less-controlled" field-type tests.

Tests can be designed to be on a target in-air or in-soil.

All of the tests in the CWA are put into the above categories to help users of the document to identify what is appropriate for them.

9. Plans for Future Work

The first version of the CWA was issued his year. Rather than just wait for potential users of this testing document to start using it, a programme is planned to publicize the CWA and to explain how it can be used. In the meantime CW07 will be "dormant".

The CWA will be presented to UNMAS and GICHD with a view to its being included, or at least referred to, within the IMAS system.

As well as publicizing the CWA, a project is planned to verify how well the tests specified by the first version work. This would involve performing trials using the test document. Feedback would then be obtained on how well the tests work and what improvements could be made in a short time-scale. CW07 will then be reconvened to produce any possible revision to the CWA that may be required.

The work of CW07 has stimulated research into some of the problems encountered. For example;

- the validity of using metal balls (and particularly ferromagnetic steel balls) as test targets,
- understanding the effect of soil and how best to characterize it,
- devising the best way to measure detection reliability without using huge numbers of targets

10. Conclusions

1. In a short period of time a testing standard for metal detectors used in humanitarian mine action has been produced in response to requests from those using metal detectors in the field.
2. Tests are defined that allow quantitative measurements of detection capability to be made.
3. Tests to measure the effect of soils on detector performance are made.
4. CW07 has started a process of feedback on the testing specifications that have been defined and stimulated research in the "problem areas" that remain.

Acknowledgments

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