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Assessment of inadvertent initiation of bridge wire electro-explosive devices by radio-frequency radiation – Guide

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Assessment of inadvertent initiation of bridge wire electro-explosive devices by radio-frequency radiation – Guide

Evaluation de la création par inadvertance de dispositifs électro-explosifs par pont métallique, par rayonnement de radiofréquence – Guide

Leitfaden zur Verhinderung des unbeabsichtigten Auslösens einer Zündeinrichtung mit Brückendraht durch hochfrequente Strahlung

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
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Foreword

This Technical Report was prepared by the Technical Committee CENELEC TC 31, Electrical apparatus for explosive atmospheres - General requirements.

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Contents

Introduction

Electromagnetic waves produced by radio-frequency (RF) transmitters (e.g. radio, television and radar) will induce electric currents and voltages in any firing circuit including leading wires of the electro-explosive device (EED) on which they impinge. The magnitude of the induced current and voltages depends upon the configuration of the firing circuit and leading wires relative to the wavelength of the transmitted signal and on the strength of the electromagnetic field. If the induced current which is transferred to the EED is in excess of the no fire current then the EED could initiate. This European Technical Report provides a systematic approach to assist transmitter operators, quarry managers and all others concerned with a logical method for the assessment and elimination of the initiation of EED by RF. The assessment procedures contained in this European Technical Report are based on measurements of the powers and current that can be extracted from typical firing circuits and leading wires and on the physical electrical parameters of various types of EED.

1 Scope

This European Technical Report provides guidance on assessing the possibility of inadvertent extraction of energy from an electromagnetic field propagated from radio frequency (RF), radar or other transmitter antennas and the coupling of this energy to an electro-explosive device (EED) in a manner capable of causing initiation. The frequency range covered by this European Technical Report is 9 kHz to 60 GHz. This European Technical Report only applies to bridge-wire devices which are directly initiated by radio frequency current and does not apply to special detonators, for example, electronic detonators. It does not cover the similar hazard arising from electromagnetic fields generated by other means, for example electric storms, electricity generating plant or power transmission lines.

This European Technical Report does not apply to the following equipment:

– air bag igniters for automotive applications (including the igniters before they are fitted);
– special pyrotechnic devices;
– pyromechanisms;
– igniters for fireworks;
– special military devices;
– special safety equipment.

NOTE The methods of assessment from 9 GHz to 60 GHz are based on extrapolation of data for frequencies below 9 GHz.

2 Normative references

No normative references are made in this standard.

3 Terms and definitions

For the purposes of this European Technical Report the following terms and definitions apply.

3.1
duty cycle
product of pulse duration (in seconds) and the pulse repetition frequency (in pulses per second)

3.2
electro-explosive device (EED)
one shot explosive or pyrotechnic device initiated by the application of electrical energy

NOTE EED is used to refer to either a single electro-explosive device or several devices, to comply with general practice within the industry.

3.3
hazard
potential source of danger to life, limb or health, or of discomfort to a person or persons, or of damage to property

3.4
safe distance
distance outside which it is considered that there is no potential hazard

3.5
no-fire energy/power/voltage/current
maximum energy or steady state power/voltage/current that will not cause initiation of the most sensitive EED of any particular design

NOTE The manufacturing tolerances permitted during the production of EED will cause normal statistical variation in their firing characteristics. The most sensitive EED permitted by this variation sets the appropriate no-fire level, which is generally accepted as a probability no greater than 0,01 %, with a confidence level of 95 %.

3.6
round of charges (shot)
one or more primed explosive charges or shots, for example main charge, primer (if used) and detonator

3.7
toe shot
shot designed to clear the foot of a face, for example a quarry face

3.8
hazard area
area, of any shape, containing the transmission source or sources and within which the radiation magnitude exceeds the designated hazard threshold

3.9
hazard threshold
mean power flux density or field strength that would permit only a negligible probability of EED initiation

3.10
exploder
means whereby a round of charges (shot) is fired electrically

3.11
equivalent isotropically radiated power (EIRP)
product of the power supplied to the antenna and the antenna gain in a given direction relative to an isotropic antenna (absolute or isotropic gain)

3.12
effective field strength
value of electric field strength due to a single transmitter which is derived from the transmitter characteristics, modulation factors (see 6.5) and distance, and is used for the calculation of extractable power

3.13
antenna gain
gain produced by an antenna concentrating radiation in a particular direction

NOTE 1 The gain of an antenna is always related to a specified reference antenna.

NOTE 2 The gain, G, of an antenna in a particular direction is given by the equation:

$$G = \frac{R}{A}$$

where

R is the power in Watts, W, that should be radiated from the reference antenna;

A is the power in Watts, W, that should be radiated from the given antenna to give the same field strength at a fixed distance in that direction.

NOTE 3 The gain, which is often expressed in logarithmic form, is stated in decibels.

3.14
far field
region, distant from the transmitter, in which the field strength is inversely proportional to distance in the absence of ground reflection

NOTE The inner limit of the far field is generally regarded as the distance *d* from the transmitter defined as follows. For frequencies up to and including 30 MHz, $d = 8H^2/\lambda$ where *H* is the height of the top of the antenna above ground and λ is the wavelength. At frequencies above 30 MHz, $d = 2W^2/\lambda$ where *W* is the width of the antenna.

3.15
near field
region close to the transmitter, which lies within the far field region

NOTE In the near field region the dependence of the field strength on distance is complex and mutual coupling effects can also affect the value of extractable power.

3.16
leading wire resistance
total d.c. resistance of the leading wires excluding that of the EED itself

3.17
bridge wire resistance
internal d.c. resistance of the EED alone

3.18
safety resistor
resistor or resistors placed within the casing of an EED in order to desensitize it to the external electrical environment

4 Symbols and abbreviations

4.1 Modulation codes

AM	Amplitude-modulated speech or music transmission. Carrier power quoted
MCW	Amplitude-modulated tone transmission. Carrier power quoted
TV	Amplitude-modulated video transmission. Peak power quoted
R ( )	Pulse-modulated radar transmission. Peak power quoted. The number in brackets indicates the pulse duration in s where known
FM	Frequency modulation
FSK	Frequency shift keying
GFSK	Gaussian frequency shift key modulation
SSB	Single sideband transmission. Peak envelope power quoted
CW	Continuous wave
MSK	Minimum shift keying
GMSK	Gaussian minimum shift keying

CDMA Code division multiple access.

PCM Pulse code modulation

PSK Phase shift keying

PM Phase modulation

DQPSK Differential quadrature phase shift keying.

4.2 Polarization codes

V Vertical polarization.

H Horizontal polarization.

V/H Either vertical or horizontal polarization, or both simultaneously.

5 General considerations

5.1 Radio-frequency hazard

For radio-frequency hazard assessment detailed consideration should be taken of the conditions that have to be satisfied simultaneously for the hazard to exist. These are as follows:

a) an electromagnetic field of sufficient intensity;

NOTE 1 An electromagnetic field of sufficient intensity may be generated by a fixed/mobile or portable transmitter, the magnitude of the field depending upon the transmitted power, the antenna gain and the proximity of the site under consideration.

NOTE 2 Intense electromagnetic fields are also generated by the intentional radio frequency sources in industrial, scientific and medical (ISM) equipment. Field strengths in the order of 10 V/m may be present in the near vicinity of the equipment.

Typical characteristics of industrial equipment are:

2,5 GHz to 10 kW 915 MHz to 100 kW	industrial microwaves
27 MHz to (10 to 50) kW 13,56 MHz to (10 to 50) kW	welding or drying techniques

b) a means of extracting power from the electromagnetic field;

c) an EED in a situation such that it can accept power or energy from the extracting device.

The procedures contained within this European Technical Report for assessing the presence of a potential hazard are based on a number of reasonable “worst-case” assumptions. They are based upon both experimental evidence and engineering judgement. Taken together these give a substantial margin of safety due to the extremely low probability of concurrence of all the worst-case factors. No extra, arbitrary, safety factors are included.

All conducting materials behave as receiving antennas, but the magnitude of the induced current and voltage depends upon the circuit configuration, that is, whether the EED is in a firing circuit or by itself. Experience gained indicates that for frequencies below 7 MHz it is the loop firing circuit which is the most sensitive whereas for higher frequencies it is the EED and its leading wires alone. The behaviour of these circuit configurations is described in Clause 7.

5.2 Philosophy of the systematic method of approach

A potential hazard only exists in relatively few locations, with only a small number of incidents reported that are possibly attributable to this cause.

This European Technical Report is based on a series of graded assessments, each requiring a progressively more detailed analysis.

The initial assessments are designed to eliminate from further consideration those locations where it is highly unlikely that a hazard exists. They are based on “realistic worst-case” estimates of the minimum distance of safe approach around different classes of transmitter within which a hazard might exist from the presence of a particular circuit configuration in this area.

For land based operations, if the initial assessments given in 9.3 indicate that a hazard might exist, the full assessment procedure given in 9.4 should be followed. For offshore operations the assessment in 9.7 should be followed. These provide a method of computing the field strength available from the transmitters, based on detailed information about the transmitters and their location relative to the site. The calculated field strength should then be compared to those that are required to initiate an EED in various circuit configurations, whether in a loop firing circuit or with the leading wires acting as a dipole.

When this systematic assessment procedure is followed, it will quickly become apparent whether the available information is adequate for an assessment to be made with a high degree of confidence or whether additional information is required from practical on-site measurements (see Clause 10 and Annex B). If doubt exists, then expert opinion should be sought (see Annex C).

The assessment procedures recommended in Clause 9 apply generally to most circumstances. For offshore and land based well-perforating operations the special considerations described in 7.3, 9.5.5 and 9.6.3 should be taken into account.

5.3 Responsibility for making the hazard assessment

The radio-frequency (RF) environment is becoming increasingly severe, with the proliferation of transmitting sources and increased transmitter powers and the exploitation of new techniques.

NOTE 1 Legislation, (for example in the UK see [1]) requires that employers safeguard both their employees and others who may be placed at risk by their activities. Hence, both operators of RF transmitters and users of EED have a responsibility to ensure safe operation.

NOTE 2 Particular locations such as mines and quarries may exist where additional responsibilities are placed on the owners and managers.

Operators of a proposed site in which EED are to be used should request details from the transmitter operators about relevant transmitters in the locality of the site. The transmitter operators should include details of transmitters for broadcast, commercial, military, air traffic and emergency services such as police, fire and ambulance. The site operator should then use the assessment procedures given in this European Technical Report, if necessary in consultation with the transmitter operators concerned.

Similarly, an operator of a proposed new (or altered) transmitter should contact all operators of sites where EED are used within the minimum distance of safe approach for the transmitter, and use the procedure given in this European Technical Report to assess the potential hazard at each location.

Where both the site and the transmitter already exist but an assessment is required, the site operator should be held responsible for ensuring that the assessment is made. If for some reason relevant information cannot be made available to the body responsible for the assessment, the responsibility for having the assessment carried out should be assumed by the body unable to release the necessary information.

NOTE 3 As an aid to those who need to make a hazard assessment but do not have the necessary technical resources, a list of sources of information and specialist organizations capable of providing consultation or test facilities is given in Annex C.

5.4 Recommended practices for radio silence in offshore operations

The position adopted by many offshore operators has been to switch off all transmissions from the installation during the surface preparation of the explosive tool until its immersion in the well at 70 m below sea bed level. At this point services would be restored until the explosive tool was returned to a similar depth on the upward journey when all services would again be cut off. Following its removal from the well and inspection to ensure its safe condition, services would be restored provided no further explosive handling was to take place.

However, too great a reliance on all-embracing curtailment of services can itself present a potential hazard to structures which employ radio communication for safety reasons and as an integral part of product transportation systems (pipelines). The identification of these difficulties has highlighted the need for the hazard to be more accurately quantified in order to minimize the disruption of other necessary operations and to avoid the creation of further potential hazards.

6 Transmitters and transmitter output parameters

6.1 Types of transmitters

This clause provides information on various types of transmitter and transmitting systems. This information is necessarily rather brief for certain types of radar and other military equipment but basic details are given and further information may be sought from the specialist organizations listed in Annex C. Typical types of antenna installations are shown in Figure D.1.

6.2 Frequency range

The main frequency range covered is 9 kHz to 60 GHz. The types of transmitter considered include the following:

a) radio and television broadcast transmitters in specific bands in the range 0,15 MHz to 1 000 MHz;

b) fixed and mobile transmitters for communication purposes, private, commercial and amateur, in specific bands above 0,4 MHz and for military use above 0,15 MHz;

c) radar, in specific bands at 220 MHz, 600 MHz and above 1 GHz;

d) navigational equipment, non-directional beacons, etc., from 9 kHz upwards.

6.3 Transmitter output power

Transmitter output power from several watts up to megawatts may be encountered depending on the frequency range and the application. The method of specifying the power varies, which is significant for the hazard assessment when highly directional antennas are in use and when considering different modulation systems. In general, values are specified in the technical documentation for either the carrier or peak power output from the transmitter together with the antenna gain, although the product of the two is often quoted in the technical documentation to give the equivalent isotropically radiated power (EIRP).

6.4 Antenna gain

The reference antenna is often an isotropic antenna that radiates uniformly in all directions. Although this is a purely hypothetical concept it is nevertheless very useful for reference purposes. When the gain of an antenna relative to an isotropic reference antenna is stated in decibels it is denoted by dBi. In practice, the gain of an antenna is often expressed relative to a half-wave dipole which itself has a gain of 1,64 (or 2 dB) relative to an isotropic antenna. In special circumstances other reference antennas may be used, for example a short monopole. It is therefore important that the reference antenna is correctly specified. The maximum gains for typical antennas are included in Table D.1, Table D.2 and Table D.3.

6.5 Modulation factors

6.5.1 General

Most transmissions are modulated in order to convey information or to enable them to carry out specific tasks (for example, radar). The characteristics of the principal modulating systems are described in 6.5.2 to 6.5.5. A modulation factor, *m*, is necessary for calculating the effective field strength *E* (see 9.4.3). Modulation factors are listed in Table 4 for different types of modulation.

NOTE Radio-frequency transmissions may be unmodulated, in which case the radiated power is constant and the quoted power in the technical documentation should be used for assessment purposes. Such transmissions are sometimes referred to as continuous wave (CW).

6.5.2 Frequency modulation (FM)

The frequency of the transmission is varied to carry the information but the output power remains constant as with CW transmissions. Frequency shift keying (FSK) and gaussian frequency shift keying (GFSK), minimum shift keying (MSK) and gaussian minimum shift keying (GMSK), are forms of frequency modulation. Phase shift keying (PSK) and phase modulation (PM) are treated similarly in that no allowance for modulation is necessary since the output power is not affected by the modulation.

6.5.3 Amplitude modulation (AM)

6.5.3.1 General

The amplitude of the transmission is varied to carry the information. The latter may consist of speech or music or coded transmission or it may be a television picture waveform.

6.5.3.2 Speech and music

When speech and music are transmitted, the power quoted in the technical documentation is that of the unmodulated or carrier transmission but the mean power at the modulation peak may be up to 50 % greater when the speech or music is at its loudest volume. Since EED respond to mean power, it is necessary to make some allowance for the power increase when making an assessment; this may be done by assuming an effective field strength which is greater than that due to the unmodulated transmission. As a result of experience gained with amplitude modulated broadcast transmitters, a modulation factor, *m*, of 1,15 should be used for calculations of effective field strengths.

6.5.3.3 Coded transmissions

A version of amplitude modulation used for Morse and other coded transmissions is known as modulated continuous wave (MCW). For modulated continuous wave, whereby the carrier is fully modulated by a continuous tone, a modulation factor, *m*, of 1,22 should be used.

6.5.3.4 Television transmissions (TV)

For television transmissions the peak power is usually quoted in the technical documentation but in this case no allowance for modulation is necessary, because the mean power is approximately equal to the peak power.

6.5.4 Single sideband (SSB) operation

For single sideband (SSB) operation the peak envelope power is usually quoted in the technical documentation and a value of 0,71 for the modulation factor, *m*, should be used.

6.5.5 Pulsed radar

Pulsed radar consists of pulses transmitted at frequent intervals. The transmissions are characterized by a peak power, P_o, a mean power, P_m, a pulse duration t (in s) and a pulse repetition rate of n pulses per second. These are related by the equation:

$$P_o = \frac{P_m}{nt}$$

where

nt is the duty cycle.

Since the interval between pulses is less than the thermal time constant of bridge wire EED, the mean power, P_m, should be calculated and used for assessment purposes.

7 Circuits for blasting and well perforation

7.1 General

Voltage and current may be induced in a metal object or wire in an electromagnetic field. When sufficient voltage and current is transmitted to the initiating device of an EED such as the bridge wire, the EED might initiate. The source of RF power for the EED is in effect an antenna situated in the incident field. The antenna configuration may be formed by the leading wires of the EED itself or by the blasting circuit.

For analogy with simple antenna types, the leading wires of an EED may be considered as a dipole antenna when these wires are separated to form a blasting or well-perforating circuit. After connection the circuit may be considered as a loop antenna.

For the optimum transfer of voltage and current it is essential for the antenna to be tuned. However, even for large loop circuits, untuned loops can carry voltage and current.

Experience gained indicates that below 7 MHz it is the loop which is the most sensitive circuit, whilst at higher frequencies it is the EED and its leading wires alone.