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^{14}N-NQR based device for detection of explosives in landmines

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Abstract

A short survey of technologies proposed and implemented so far for landmine detection is given. A laboratory prototype device intended for RDX and HMX explosive detection in landmines by means of ^{14}N-NQR (nuclear quadrupole resonance) spectroscopy is described. This NQR based landmine detector is essentially a fully automated and computer controlled FT-NQR spectrometer equipped with a planar r.f. measure coil. The temperature dependencies of NQR frequencies $\nu_Q(T)$ in RDX and HMX in the temperature range of practical interest for explosive detection were measured. Final testing of the device has been carried out on samples of sodium nitrite ($NaNO_2$) which had to be used to simulate real landmines in order to obey the safety regulations. Experimentally optimized SORC (strong off-resonance comb) multipulse sequence were used for optimum NQR signal. The time of detection was 30 and 90 s for sodium nitrite simulants buried in depths of 7 and 10 cm under ground, respectively. The sensitivity of detection was limited mostly by the external r.f. interferences, both man-made and naturally occurring, which enter the NQR detection system through the unshielded measure coil. Possible means to circumvent these limitations are also discussed.

Keywords: Nuclear quadrupole resonance (NQR); Landmine detection; Explosive detection; Pulsed NQR spectrometers; RDX explosive (hexogen); HMX explosive (octogen)

1. Introduction

Since the invention of antipersonnel landmine the number of mine casualties have changed dramatically. It has been estimated that if in World War Two civilians accounted for about 50% of those killed or injured by landmines then in the 130 armed conflicts since 1980, 80–90% of the landmine casualties have been civilians. According to various sources 60–100 million landmines have been buried in 62 countries over the past century and during the past 20 years approximately one million people have died from landmine accidents. One source states [1] that in an average week landmines – the lethal remnants of armed conflicts of the past, cause about 500 injuries and deaths and as many as 26,000 people, especially women, children and farmers in developing countries loose lives or limbs due to abandoned mines each year. At present most of the humanitarian demining is done with conventional methods

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like prodders, metal detectors, and sniffer dogs, making the procedure of removing 100 million abandoned antipersonnel landmines slow and very dangerous. Regarding metal detector method, one has to remember that makers of modern antipersonnel landmines widely use plastic landmine casing and metal parts reduced to minimum making metal detector useless. Novel technologies are needed to speed up the demining process. Other such explosive detection technologies which have been developed and commercialized for airport security systems in the past several years [2] and could at least in principle be applied for landmine detection are backscatter X-ray, thermal neutron analysis (TNA), ion mobility spectrometry (IMS) and gas chromatography. The drawback common to all above mentioned methods is that they are atom rather than compound specific. The principle of backscatter X-ray method is that lower atomic weight elements such as nitrogen (constituent of all important explosives) will scatter X-rays back toward the direction from which they came. Using this information one can only conclude that mapped regions of low atomic mass may represent explosive materials as well as any other substance containing low atomic mass elements and this may result in false alarms. The same applies to TNA which uses thermal or low-energy neutrons to irradiate nuclei in a matter undergoing evaluation. The capture of low-energy neutrons by a nucleus results in the release of gamma radiation of energy characteristic for the nucleus in question, e.g. 10.8 MeV for nitrogen. High fluxes of 10.8 MeV gamma rays coming from objects evaluated by TNA could indicate the presence of explosives or other substances with similar nitrogen densities. Moreover, neutron-generating equipment and the shielding needed to protect the operators from harmful radiation made the TNA instruments extremely large and their cost prohibitively high for humanitarian demining. IMS and gas chromatography, sometimes referred to as bomb "sniffer" methods, relay on the availability of trace vapors of explosives. However, the buried mine may not exude volatiles through its casing in appreciable concentrations. Another technology that has been proposed for landmine detection is ground penetrating radar (GPR) [3]. A GPR system transmits an ultra-wideband signal through the ground and detects the weak backscattered signal from the target. The shape of the target response recorded with typical GPR instruments does not resemble the real shape of the target though, so this method is able to detect some "anomaly" in a field only but is usually unable to identify the buried objects and the operator of the instrument has to be qualified for interpreting GPR images.

The advantage of ^{14}N-NQR (nuclear quadrupole resonance) spectroscopy when used for the detection of explosives results from the high chemical and crystallographic specificity of NQR spectra which depend very strongly on but a small changes in electronic charge distribution over the whole molecule, especially when the latter is embedded in a crystal lattice. Due to this specificity one can identify chemical compounds unambiguously by measuring the frequencies of NQR spectra e.g. in nitrogen containing explosive substances. On the other hand NQR detection of explosives suffers from relatively low sensitivity caused by low resonance frequencies (0.5–6 MHz) inherent in NQR spectroscopy of ^{14}N nuclei. To some extent sensitivity problem can be relaxed by application of one of the double nuclear quadrupole resonance (NQDR) or the nuclear magnetic resonance (NMR) methods [4,5] yet the most effective NQDR schemes rely on additional source of not only intense but also homogeneous magnetic field and this adds complexity and makes landmine detector system less practical, especially when cost effective and portable instrument is considered. What is worse, in applications of NQR method for detection of antipersonnel or antitank landmines, usually buried at some depth under ground, an NQR probe head cannot employ extensive r.f. shielding to prevent external noise, both man-made and naturally occurring, from entering the mine detection system. Usually this external noise surpasses the thermal noise of the NQR probe head measure coil so application of low noise preamplifiers helps little or nothing. The articles on NQR detection of landmines published so far focused mostly on physical basics of NQR method [6–10], certain selected hardware problems [11–20], optimization of pulse sequences for maximum detection sensitivity [21–25] or merely on final results of testing and overall performance of NQR detector systems [26–29] without giving more detailed description of a complete NQR system that would facilitate design principles of an NQR landmine detector to emerge. Possibly the latter approach is understood given the sensitive nature of the subject. A little more details including electric circuit diagrams can be found in [30,31]. This article is aimed at the detailed and complete description of a prototype device we have constructed which is