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METAL DETECTORS AND PHYSICS EDUCATION

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Abstract

Metal detector equipment has become a profound and ubiquitous geophysical device class widely available not only to scientists, but to general public, hobbyists, recreational enthusiasts and sport addicts alike. Handheld metal detectors are by no doubt the most widespread geophysical apparatus existing. Models range from simple toy-like inexpensive models to extremely sophisticated computerized systems with plenty of features and modes of operation.

The use of metal detectors during the years has found applications such as military demining operations, archaeology, treasure hunting, mineral analysis, ground infrastructure surveying, etc. But being such an elaborate instrument, the metal detector has ever been neglected for its potential as a mobile handheld physics educational laboratory that is capable of showing to students at schools and universities many physical phenomena concerning electricity and electromagnetism, radio-electronics, soil and rock properties, water and mineral properties, microprocessors and computer technologies and even astronomy.

The present publication strives to disclose those hidden capabilities of metal detectors to the reader and concentrate the physics teacher attention to the metal detector avenue as being a fruitful laboratory for tutoring many branches of physics in a pleasant and involving way to the young and not only the young generation.

1. Introduction

Metal detectors are geophysical devices and as such exhibit a number of physical phenomena to the observer. With this regard, they incorporate systems that utilize physical properties of the ground substances and construction materials in order to extract information about the objects that are underneath or to study the ground, soil, rock, water, concrete, or other material properties.

Metal detectors utilize various physics laws and areas such as electromagnetism, acoustics, ionizing radiation, etc. However, ubiquitous are those instruments that use electromagnetic properties of objects. These metal detectors are the ground penetrating radar, the pulse induction detectors and the induction balance detectors. Of the most widespread kind are the latter, due to their moderate cost, moderate weight and lowest power consumption. Being handheld devices low power consumption directly translates into cheaper and lightweight batteries.

The affordability of the induction balance metal detectors accompanied with their discrimination properties between ferrous and non-ferrous metals make them most suitable to use for teaching physics to students and pupils at schools and universities.

However, before we continue with the concrete implementation of the metal detectors in teaching physics we should make a brief retrospection of the metal detector development milestones and reveal to the reader its invention and refinement history.

2. Brief history of metal detectors

The first metal detector is assumed to be the Alpha (see Fig. 1). It was used for finding unexploded bombs right after World War I (WWI). M. Guitton who was a professor of physics at Nancy invented it in France. It used the principle of inductive balance – a method and circuit invented in 1879 by British scientist David Hughes (Honoré, 1919).

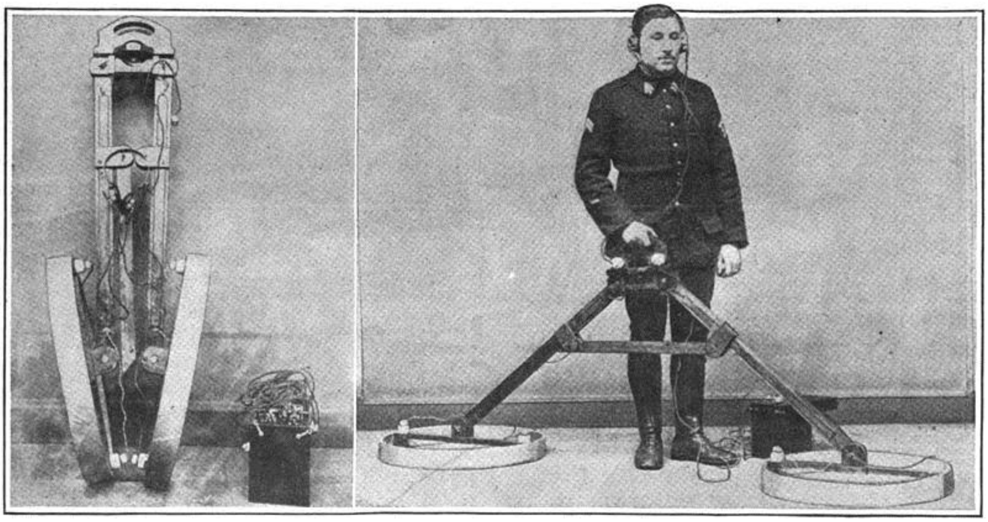

Fig. 1. "Alpha" metal detector. Invented immediately after WWI in France by M. Guitton

First metal detectors were used for discovering artillery shells, mines and other military ammunition that was buried underground and was dangerous for the trespassers. Thus, during the years between the World Wars work continued on refining the designs and making them more sensitive and lightweight. One of the first models to resemble modern handheld metal detectors and to be comparable with them, in terms of sensitivity and functionality, is the Polish mine detector 'Mark I' (see Fig. 2). It was a metal detector for searching of landmines and was developed during the Second World War (WWII). After Germany invaded Poland in 1939 and occupied France in 1940, work on the detector was interrupted and was restarted in the winter of 1941–1942. The inventor of this modern detector was Polish lieutenant Józef Kosacki.

Fig. 2. Mine detector Mark I used by sappers of the Royal Engineers corps, North Africa, 28 August 1942

The Polish detector was of the induction balance type. It had two coils in balance – one transmitting and one receiving. Once an object was in vicinity, it disturbed the induction balance and induced alternating acoustic magnetic field in the receiving coil. The latter was connected to headphones and sound was heard.

The stronger the sound, the larger or the closer the object was. The whole apparatus weighted around 30 pounds (14 kg) (Croll, 1998). During the Second World War several hundred thousand of detectors were produced. The British Army used this type of detector until 1995 (Modelski, 1986).

3. Modern metal detectors

One of the early inventors of modern metal detectors is Shirl Herr. In August 1929 Benito Mussolini used his devices in an expedition for finding remaining structures and archaeological artefacts from the Emperor Caligula's galleys at the bottom of Lake Nemi, Italy.

Another early inventor is Gerhard Fisher. He developed a radio direction-finding system for accurate navigation. During testing of the system, which was very successful, Fisher observed that there were errors in navigation in areas where ore-bearing rocks were present. He continued developments in this regard by the clue that metallic objects or substances containing metals distort radio beams. In 1925 Fisher became the first person to be granted a patent for metal detector. Today there are a large number of companies that offer sophisticated metal detectors to the market.

Fig. 3. Modern handheld metal detectors implement microprocessors and LCD display

With the invention of the bipolar transistor in the fifties, metal detectors became much smaller, lighter and cheaper. Modern high-end models are microprocessor controlled (Fig 3). In addition, a non-sinusoidal transmitting frequency is often used. This method is called multi-frequency mode of operation. It enhances the identification and discrimination properties of the detector allowing the discovery of landmines that contain small amounts of metal (Fig. 4).

Fig. 4. US military are using modern metal detectors to discover landmines

4. Physics education using metal detectors

It has been proven, through many experiments and inventions, that physics education strongly benefits from e-learning methods such as utilizing computer aided simulations (Zabunov et al., 2013, Zabunov, 2010, Zabunov, 2004). It is a fact that modern and attractive technologies such as computers always do draw the young people to the tutoring process. Another fruitful approach, for raising interest in physics among students, is demonstrating physical phenomena by the means of metal detectors. The latter are popular and attractive electronic devices that are thrilling to use and handle due to their inherent area of application – the treasure hunting.

Physics education using metal detectors may be performed either in the laboratory or in the field. Using a metal detector in a laboratory setting will enable the teacher to show how a metal detector finds a metal object hidden under the clothes or in the hand. Using discrimination mode the tutor is able to demonstrate to students the ability of the induction balance metal detector to discriminate between metal types, i.e. to find out if a metal object is ferromagnetic or non-ferromagnetic. Furthermore, using the discrimination mode, the nature of ferromagnetic and non-ferromagnetic metal detection may be demonstrated. For example the teacher may hide a ferromagnetic object (a nail) inside a non-ferromagnetic box (aluminium box). The box will shield the ferromagnetic properties of the objects inside. Due to the eddy currents induced in the box walls and the skin effect that prevents the currents to penetrate inside the box the metal detector will recognize a non-ferromagnetic object.

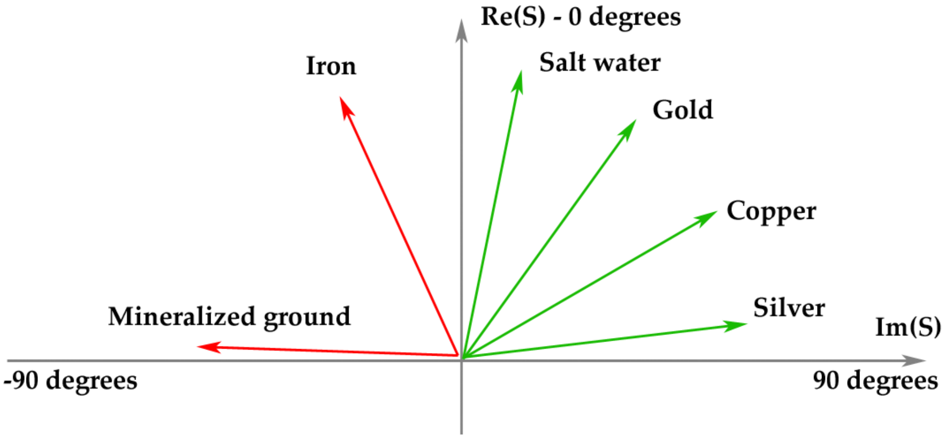

Fig. 5. Resultant magnetic field phase shift for different metals and substances

Discrimination with induction balance technology is possible due to two physical phenomena – ferromagnetic metal magnetization and non-ferromagnetic metal eddy current development. These two phenomena are observed under alternating magnetic field. The field magnetizes the metal on each alternation if the metal is ferromagnetic. Thus the resulting magnetic field has a lag in its phase. On the other hand a non-ferromagnetic metal will not magnetize and will not produce a lag in the resulting magnetic field but due to its conductance it will develop eddy currents on its surface. These eddy currents on their own will develop magnetic field but this time with the opposite phase shift. Thus, the resulting magnetic field will have positive phase compared to the transmitted signal (Fig. 5).

The detection of ferromagnetic metals is not determined by metal electrical conduction thus non-conducting metal materials such as ferrite are easily detected.

If the teaching process is to be performed in the open for field demonstrations, a large number of exercises are possible. One physical phenomenon, that is interesting to students, is the ferromagnetic properties of soils – a mineralized soil will register with a very strong signal as iron or rather as ferrite on the metal detector. This phenomenon prevents metal detectors to work in discrimination mode over ferrous soils and the so-called ground balance procedure should be carried out either automatically or manually depending on the metal detector type.

If the soil is non-ferromagnetic, for example most sandy soils, discrimination mode will be permitted. Furthermore, if the soil is soaked with salt water another phenomenon will appear. The metal detector will register a strong signal on the discrimination mode as if the object were neutral metal with properties in between ferrous and non-ferrous metals (Fig. 5). Such ground conditions allow working in discrimination mode. One could encounter salt water in the ground on sea shores and beaches.

A large number of different objects may be buried in the ground at shallow depths in order to demonstrate how their physical properties allow the metal detector to discover them and discriminate one object from another. The orientation of the buried object also matters. For example, a coin placed horizontally will reflect stronger signal than if it were placed vertically due to the eddy currents which tend to flow in the horizontal plane. Another example is a large ferromagnetic object with wide surface. These objects react as if they were non-ferromagnetic, because the eddy currents, in the surface of the object, prevail over their ferromagnetic properties and effectively shield the inner-part of the object to the alternating magnetic field. On the other hand, if we try to locate a large object of non-ferromagnetic material consisting of a large number of small pieces such as many 100 small coins, we would be surprised to discover that the signal is not as strong as anticipated. The eddy currents will be blocked by the fragmentation of the material under examination and the signal will be diminished. This principle of fragmentation is used in transformers and ferrite coil cores were the magnetic core is fragmented either to small pieces like grit (ferrite) or to thin plates.

Lastly, the metal detector may be used as an astronomical tool. One could discover meteorites in the soil using a metal detector. Most meteorites contain metals of which iron is prevalent. Thus, meteorites register as iron objects with a discriminating metal detector.

6. Conclusions

The utilization of metal detectors as an attractive tool for teaching physics at schools and universities is yet to be implemented. A team at Sofia University, Bulgaria, is planning to utilize metal detectors in tutoring courses both to raise interest in physics among pupils and to increase students understanding of complex electromagnetic processes, which would help their successful graduation in physics and engineering subjects.

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МЕТАЛОТЪРСАЧИТЕ В ОБУЧЕНИЕТО ПО ФИЗИКА

Г. Големшински

Резюме

Метал-детекторите се превърнаха в ефективен и широко разпространен геофизически уред, достъпен не само за учените, но и за любителите, ентусиастите и други групи от обществото. Преносимите металотърсачи са несъмнено най-често срещаните геофизически инструменти. Моделите са разнообразни – от прости уреди, подобни на играчки, до особено сложни компютъризирани системи с много функции и режими на работа.

Металотърсачите през годините са използвани в отбранителната дейност при търсене на мини, в археологията при откриването на съкровища, в геологията при анализ на минерали, проучване на подземни инфраструктури и др., но въпреки своята широка гама от възможности, металотърсачът е неглижиран по отношение на функцията си, като мобилна лаборатория за изучаване на физични явления. Метал-детекторите са способни да демонстрират на учениците и студентите множество явления, свързани с електромагнетизма, радио-електрониката, свойствата на скалите и почвите, водата, минералите т.н. Металотърсачите са също подходящи за изучаване на микропроцесорни системи и даже астрономия – с помощта на металотърсачи могат да се откриват метеорити.

Настоящата публикация се опитва да разкрие тези непознати възможности на метал-детекторите и да привлече вниманието на учителите по физика към областта на преносимите геофизични инструменти, като ефективна лаборатория за изучаване на физиката по приятен и завладяващ начин.