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# Non-Contact Wire Diameter Measurement Using Magnetic Fields: A Study and Design

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**Abstract:** this paper aimed to investigate the feasibility of using the principle of Contactless Diameter Measurement system. This study will concentrate on building a simple and inexpensive system to study the relationship between the diameter of the sample and the characteristics of the output signal induced by the application of a pulsed magnetic field to the sample.

We have sought to develop a modern method to measure the diameter of an insulated and conductive material with circular cross section area (such as wires and nails, etc.). After the measurement system had been building and a comprehensive study of the problem and its impact on the industry, a method to measure the diameter has been implemented and improvement. The performance of the measurement method had proved to be competition to other based methods in costs and simplicity of implementation and operation. In this case, the measurement method has proved to be useful in quality control mechanism to monitor the fluctuations in diameter of various materials.

The study concluded that a contemporary technique was created for determining the diameter of insulated and conductive objects with circular cross sections, such as cables, nails, and other objects. A method to measure the diameter has been improved upon after the measurement system had been built and a thorough analysis of the issue and its effects on the industry. The measurement method's efficiency shown that it may compete with other based approaches in terms of prices and ease of use. In this instance, the measurement technique has shown to be helpful in quality control to track changes in material diameter.

**Keywords**: Non-Contact Wire, Diameter, Measurement, Magnetitic Fields, Techniques.

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# قياس قطر السلك غير الملامس باستخدام المجالات المغناطيسية: دراسة وتصميم

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## الملخص

هدف البحث إلى دراسة جدوى استخدام مبدأ نظام قياس القطر اللاتلامسي، حيث ركزت هذه الدراسة على بناء نظام بسيط وغير مكلف لدراسة العلاقة بين قطر العينة وخصائص إشارة الخرج الناتجة عن تطبيق مجال مغناطيسي نابض على

العينة. تم تطوير طريقة حديثة لقياس قطر مادة معزولة وموصلة ذات مساحة مقطع عرضي دائري (مثل الأسلاك والمسامير وغيرها). وبعد أن تم بناء نظام القياس وإجراء دراسة شاملة للمشكلة وتأثيرها على الصناعة، تم تنفيذ وتحسين طريقة قياس القطر. وقد ثبت أن أداء طريقة القياس ينافس الطرق الأخرى من حيث التكلفة وبساطة التنفيذ والتشغيل. في هذه الحالة، أثبتت طريقة القياس فائدتها في آلية مراقبة الجودة لمراقبة التقلبات في قطر المواد المختلفة.

وخلصت الدراسة إلى أنه تم ابتكار تقنية معاصرة لتحديد قطر الأجسام المعزولة والموصلة ذات المقاطع العرضية الدائرية، مثل الكابلات والمسامير وغيرها من الأشياء. تم تحسين طريقة قياس القطر بعد بناء نظام القياس وإجراء تحليل شامل للمسألة وتأثيراتها على الصناعة. وأظهرت كفاءة طريقة القياس أنها قد تنافس الطرق الأخرى من حيث الأسعار وسهولة الاستخدام. في هذه الحالة، أظهرت تقنية القياس أنها مفيدة في مراقبة الجودة لتتبع التغيرات في قطر المادة

**الكلمات المفتاحية:** الأسلاك غير المتصلة، القطر، القياس، المجلات المغناطسية، التقنيات.

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## Introduction

The measurement of the diameter of a metal product during the production process is an important quality control activity in many industries including the manufacturing of wires, nails, metal tubes and similar products. Diameter measurement can be classified into contact and non-contact (contactless) measurements. In the contact method, some difficulties are encountered due to inaccurate measurements. The process is time consuming and slow. This method is not applicable to advanced manufacturing technology.

Using conventional measuring techniques in such situations is impractical because it is slow and time consuming. Because of the increased demand for production diagnostics, the development of new and improved contactless techniques has become a focus of diameter measurement This will ensure that all the materials have dimensions within the specified tolerance.

Many attempts have been made to automate the monitoring of the diameter of manufactured wires, without contact and without disruption to the manufacturing process, but some systems are either too complicated to set-up, or very expensive [1].

Modern industry favours the use of contactless measurement methods to monitor the diameter of metal products during manufacturing without any disruption to the production process. The following sections describe some of the methods which are currently in use.

## Measurement of cylindrical objects through laser telemetry

The well-known laser telemetry under structured lighting is an optical method exploiting a strictly geometrical approach The principle is based on laser telemetry under structured lighting, where laser planes create lines on the object under test, which are observed by a CCD camera (Charge-Coupled Device cameras). Supposing (Figure 1) the cylindrical object under test is standing vertically, it is illuminated by a laser plane formed by a low power a few mill watts red laser diode crossing a line generator slightly tilted on the horizontal plane, thus creating a curved line on the object, which is observed by a standard monochrome (CCD) camera standing horizontally. A narrow-band interference filter, centered on the laser diodes wavelength, is set up in front of the camera's objective in order to increase the contrast between the curve to be extracted and the rest of the scene. The camera is connected to a Personal computer (PC) for data extraction and calculation [2].

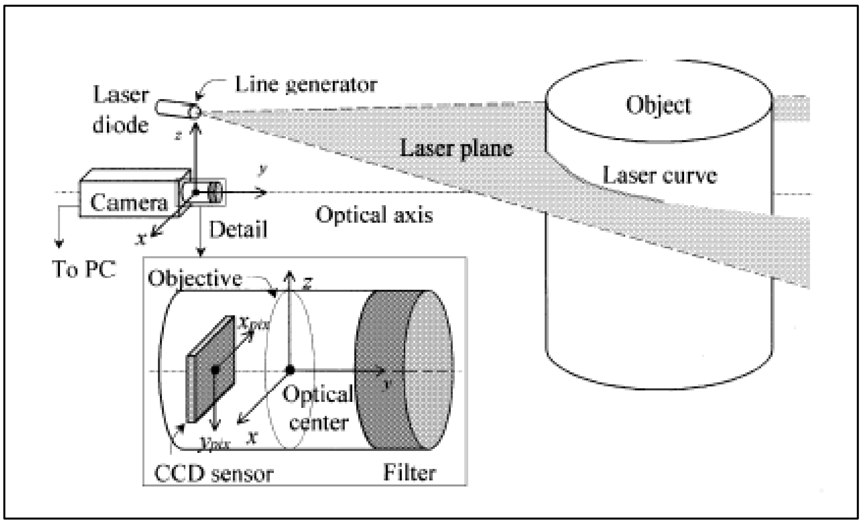

**Figure 1.** Laser telemetry under structured lighting [3]

**Measurement of wire diameter in manufacturing processes (Wire-line)**

Wire-line is a laser measuring system which has been specially designed to be used on line in the wire industry, to monitor the finished diameter. The Figure (2.2) illustrates all the components of a complete Wire-line system. The Integral base unit (IBU) 10 controller is in charge of the monitoring process. This includes the alarms, proximity switch, and the printer. The PC can be included in a dedicated system and or in a network system with multiple Wire-line gauges [4].

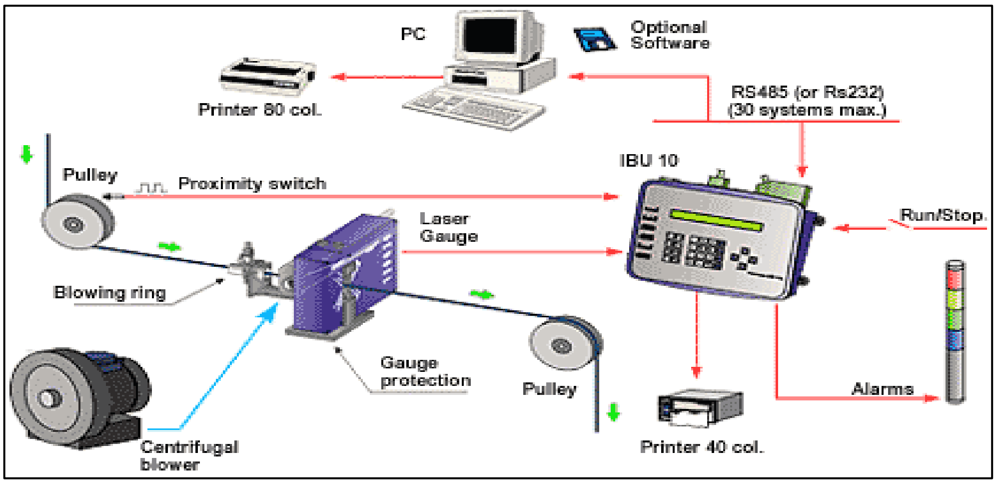

**Figure 2**. System layout for measuring the diameter of a wire.[4]

In principle, the laser gauge is installed after the finishing die and it gauges the wire along two orthogonal directions, X & Y, to obtain the average diameter. The signals from the laser gauge are processed by an electronic unit, which displays the measurements and compares the actual values with the nominal set point. When the wire diameter, due to the wearing of the die, exceeds tolerance limits, suitable output signals are activated to stop the machine or to alert the operator. All values measured during production can be stored and processed in order to print detailed statistical reports and are available for quality assurance and certification [5].

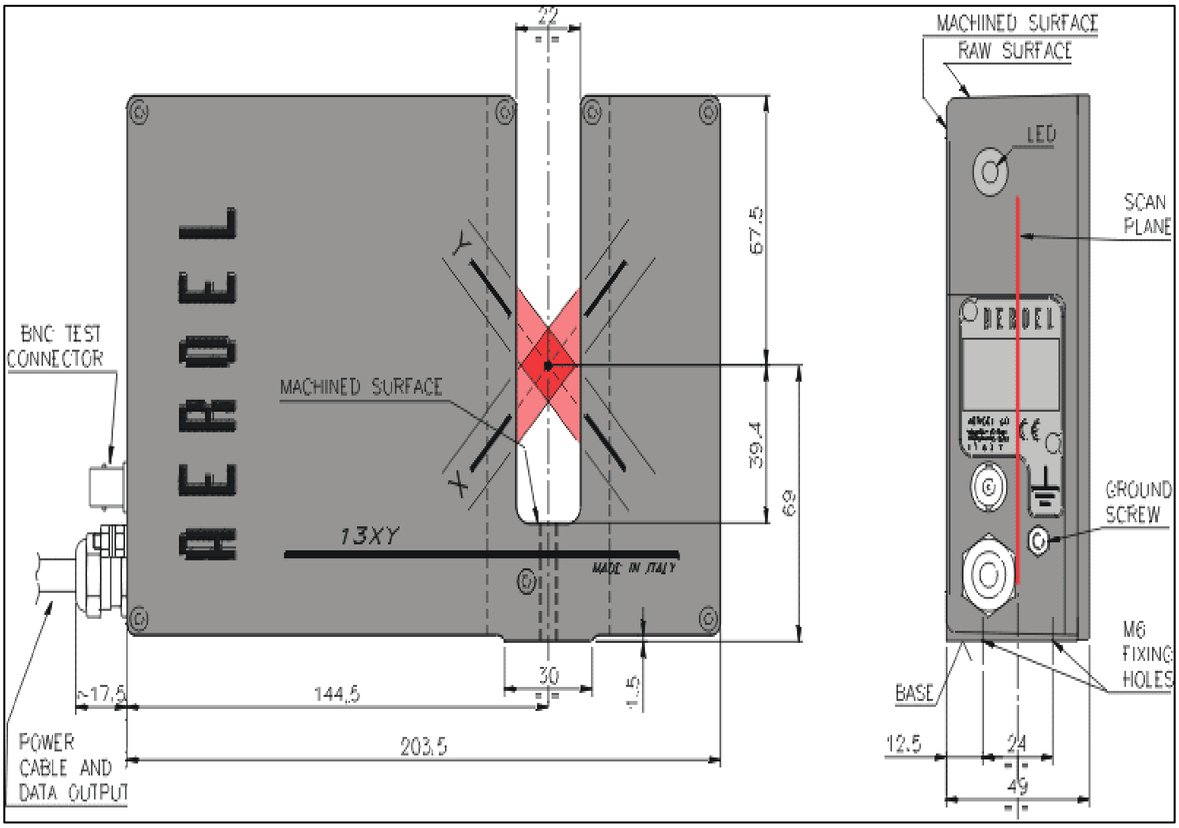

**Figure 3.** Block diagram for Wire-Line system for measuring the diameter of a wire.[5]

## Laser- scanning measuring technology

The manufacturing of strip-like products requires non-contact system with high precision of measuring the thickness to keep specified tolerances while guiding the manufacturing process securely. NORKA company developed a measuring system to be integrated in a production line for a contactless online thickness measurement as in Figure (4). These systems measure the thickness continuously without any delay providing the decisive information to improve the manufacturing process and to achieve an efficient quality assurance as in Figure (5) that shows the block diagram for non-contact online thickness measurement system using laser [6].

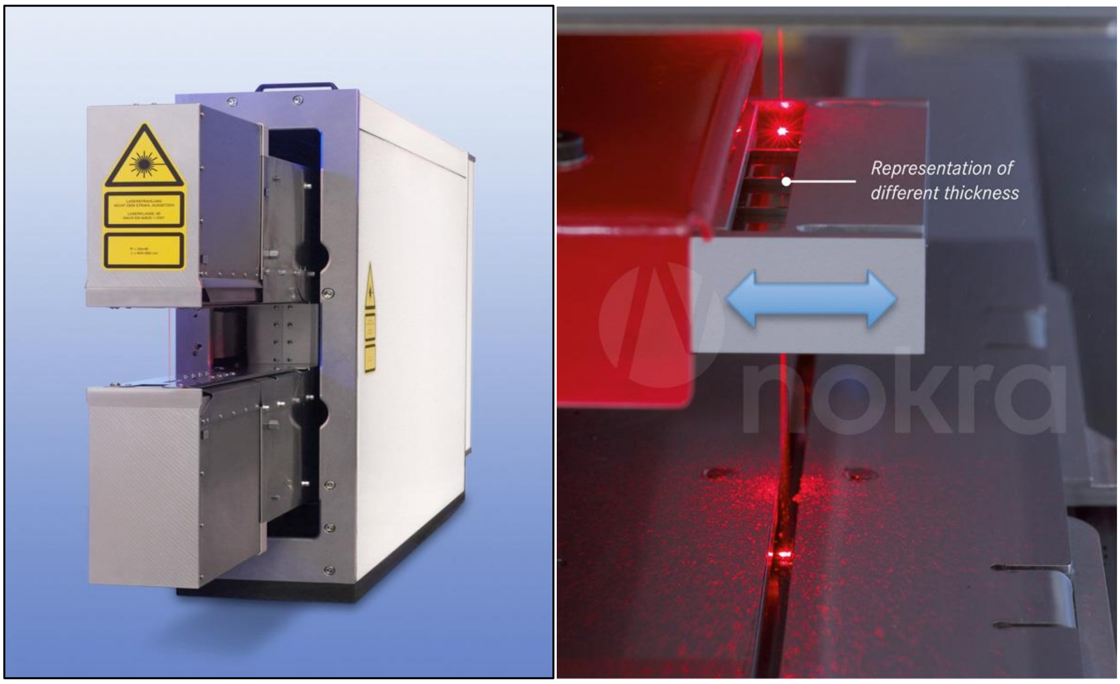

**Figure 4.** (Non-contact online thickness measurement Laser system for metal sheets) [6]

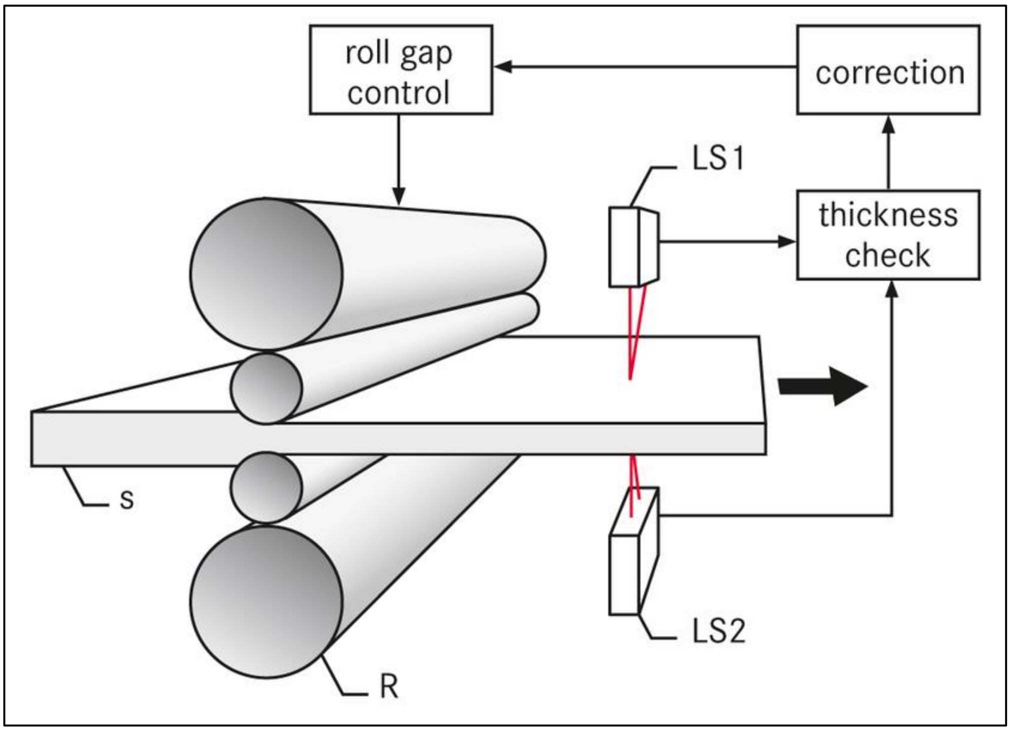

**Figure 5.** the block diagram for non-contact online thickness measurement system using laser [7]

## Modelling and Mathematical Analysis of The Measurement System

This part provides a detailed analysis of mathematics for the telemetry system. It begins with Theoretical foundations of non-contact diameter measurement then the abbreviation of magnetic field theory and eddy current phenomena, also we will study (Resistance Inductance Capacitance) RLC circuit analysis and associated overdamped, underdamped circuits AC seriously damped (AC circuits).

## Theoretical foundations of contactless diameter measurement.

The changes in the magnetic induction B inside a conducting medium are governed by diffusion constant and to prove the equations of magnetic field we need to define diffusion constant first, according to Maxwell the following set of equations is a good starting point:

$$curl\left(\vec{E}\right) = -\frac{\partial}{dt}\vec{B}\,, \tag{1}$$

$$curl\left(\vec{H}\right) = \vec{j} + \frac{\partial}{dt}\vec{D} \tag{2}$$

$$div\left(\vec{D}\right) = \rho \tag{3}$$

$$div\left(\vec{B}\right) = 0 \tag{4}$$

Here the fields are defined as $\vec{D} = \varepsilon\varepsilon_0\vec{E}$ and $\vec{H} = \mu\mu_0\vec{B}$.Where $\mu_0$ is permeability constant or permeability of free space and μ is called permeability, the other symbols have their usual meaning (ρ is the charge density, $\vec{j}$ the current density, $\frac{d\partial}{dt}\vec{D}$ is the displacement current density). And (curl) it means A vector operator is a differential operator used in vector calculus Vector operators, and include the gradient, divergence, and it Symbolizing it by (curl) or ($\vec{\nabla}\times$) [38].

The equation from which we will start here is the first equation $curl\left(\vec{E}\right) = -\frac{\partial}{dt}\vec{B}$. It can be shown using integration around a suitably chosen contour and using Stoke's theorem that a time dependent magnetic field B will induce a current in a closed loop. The negative sign in front of the time derivative $\frac{\partial}{dt}\vec{B}$ indicates that the current is directed such as to oppose the change in the magnetic field (Lenz's rule). The whole process is known as induction [39].

With Maxwell's equations and in particular consider the equation $curl\left(\vec{H}\right) = \frac{1}{\mu\cdot\mu_0}curl\left(\vec{B}\right) = \vec{j} + \frac{\partial}{dt}\vec{D}$. Take the curl on both sides to obtain

$$\frac{1}{\mu\cdot\mu_0}\vec{\nabla}\times\left(\vec{\nabla}\times\vec{B}\right) = \vec{\nabla}\times\left(\vec{j} + \dot{\vec{D}}\right) \tag{5}$$

Using the identity:

$$\vec{\nabla}\times\left(\vec{\nabla}\times\vec{B}\right) = curl(curl(\vec{B})) = \vec{\nabla}\left(\vec{\nabla}\cdot\vec{B}\right) - \left(\vec{\nabla}\cdot\vec{\nabla}\right)\vec{B} = grad\left(div(\vec{B})\right) - \Delta\vec{B} \tag{6}$$

With the help of the Maxwell equation [40] , $div\left(\vec{B}\right) = 0$ one arrives at

$$grad\left(div(\vec{B})\right) = 0 \tag{7}$$

On the right-hand side of equation $\frac{1}{\mu \cdot \mu_0} curl\left(curl\left(\vec{B}\right)\right) = curl\left(\vec{j}\right) + curl\left(\frac{\partial}{dt}\vec{D}\right)$ there are 2 contributions. The term related to the time derivative of $\vec{D}$ is related to radiation, which for the type of phenomenon of interest here is not important. This is due to the low frequencies involved in the physical process, resulting in a small correction only. This term will be dropped and will not be considered here. The second term is proportional to $curl\left(\vec{j}\right)$. With the help of Ohm's law, which takes the form

$$\vec{j} = \sigma \vec{E} \tag{8}$$

(Here σ is the conductivity (i.e. the inverse of the specific resistance) and $\vec{E}$ is the electric field) the above equation can be changed to

$$\vec{\nabla} \times \vec{j} = \vec{\nabla} \times \left(\sigma \vec{E}\right) = \sigma \vec{\nabla} \times \vec{E} \tag{9}$$

Using another one of Maxwell's equations, namely $curl\left(\vec{E}\right) = -\frac{\partial}{dt}\vec{B}$, the above equation can be changed to

$$\sigma \vec{\nabla} \times \vec{E} = -\sigma \frac{\partial}{dt}\vec{B} = -\sigma \dot{\vec{B}} \tag{10}$$

Combining the various contributions are obtains a diffusion equation for the magnetic induction

$$\Delta \vec{B} = \mu \mu_0 \sigma \frac{\partial}{dt}\vec{B} \tag{11}$$

The general form of a diffusion equation is

$$\Delta \vec{B} = D_{diff} \dot{\vec{B}} = D_{diff} \frac{\partial}{dt}\vec{B} \tag{12}$$

Where $D_{diff}$ is the diffusion constant. A comparison with equation (13) reveals that the diffusion constant is related to other physical entities by

$$D_{diff} = \mu \mu_0 \sigma \tag{13}$$

Thus, if the diffusion constant can be measured experimentally, its magnitude will reveal the value of the conductivity.

A physical interpretation of the above expressions is that changes in the magnetic induction B inside a conducting medium are governed by a diffusion equation Thus we need to solve for the form of B using it's derivative, which can be obtained using manipulations of Maxwell's equations. We begin with Ampere's Law

$$\nabla \times \vec{B} = \mu_o \sigma \vec{E}, \tag{14}$$

Where $\sigma\vec{E}$ has been substituted in for $\vec{J}$ and we have ignored displacement currents, which are small. If we take the curl of both sides of this equation and substitute

$\sigma = {}^{1}/_{\rho}$ , we obtain

Using Faraday's Law, $\nabla \times (\nabla \times \vec{B}) = \frac{\mu_o}{\rho}(\nabla \times \vec{E}).$ (15)

and substituting into Eqn. [16], we get

$$-\nabla^2 \vec{B} = -\frac{\mu_o}{\rho}\frac{\partial \vec{B}}{\partial t}, \tag{16}$$

Multiplying the constants, switching to $\mu$ in the material rather than $\mu$o, and cancelling the negative signs, we have

$$\kappa\nabla^2\vec{B} = \frac{\partial\vec{B}}{\partial t},$$

(17)

Where $k = \frac{10^9 * \rho}{4\pi\rho}$ this gives us three equations for B in cylindrical coordinates:

$B_r$; $B_\varphi$ ; and $B_Z$. However, the fields from the decaying eddy currents are only in the $\widehat{\emptyset}$ direction, and those fields depend solely on r and t. Using the fact that only the radial derivatives of $\wedge$ 2 will return terms when acting on $B_\varphi$ (r, t), we have

$$\nabla^2 B = \frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial B}{\partial r}),$$

(18)

Where we are now calling B (r; t) simply B. Substituting Eqn. [19] into Eqn. [ 18] for $\nabla^2 B$ we obtain, with some simple action,

19)

$$\frac{\partial B}{\partial t} = \kappa\left[\frac{\partial^2 B}{\partial r^2} + \frac{1}{r}\frac{\partial B}{\partial r}\right].$$

This is the deferential equation we need to solve for B. We have the following boundary conditions:

### System Design and Measurement

This part discusses in details the experimental set-up of the non-contact dimension measurement system for this project. In particular, the following will be covered:

- The experimental objective;
- Overview of the system hardware;
- Overview of the system software;
- System Set-up;
- Sample measurement and data collection;

### The experimental objective

The main objective of the experimental system was to investigate the relation between the diameter of samples and the strength of the pick-up signal induced by the application of applying a pulsed magnetic field to the sample to determine the minimum measurable diameter for isolated brass and steel samples could the system determined also to investigate the variation of room temperature changes on the experimental system. This was repeated for different diameter ranges with different materials. The results were made available in digital format using data acquisition software so that the data was collected and processed using a personal computer (PC). With comparing the measurement system in Figure (6a) that we built and designed at STC with Figure (6b) that the room temperature variation including during the process of measurement and to apply very small diameters for isolated conductive brass sample and a conductive steel sample not isolated.

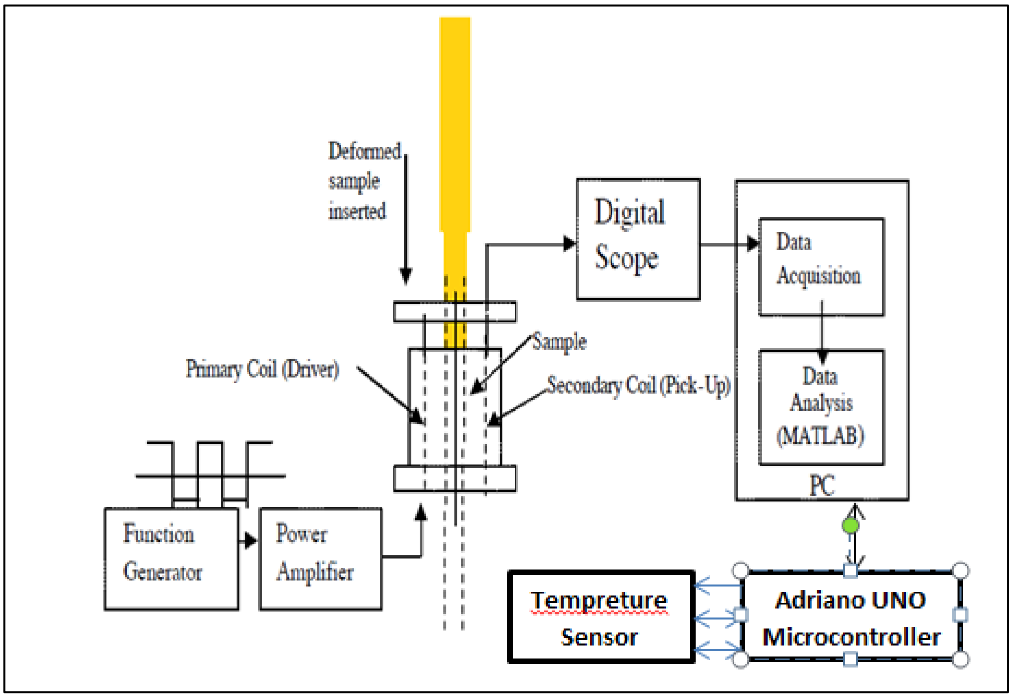

**Figure 6a.** The block diagram of the system

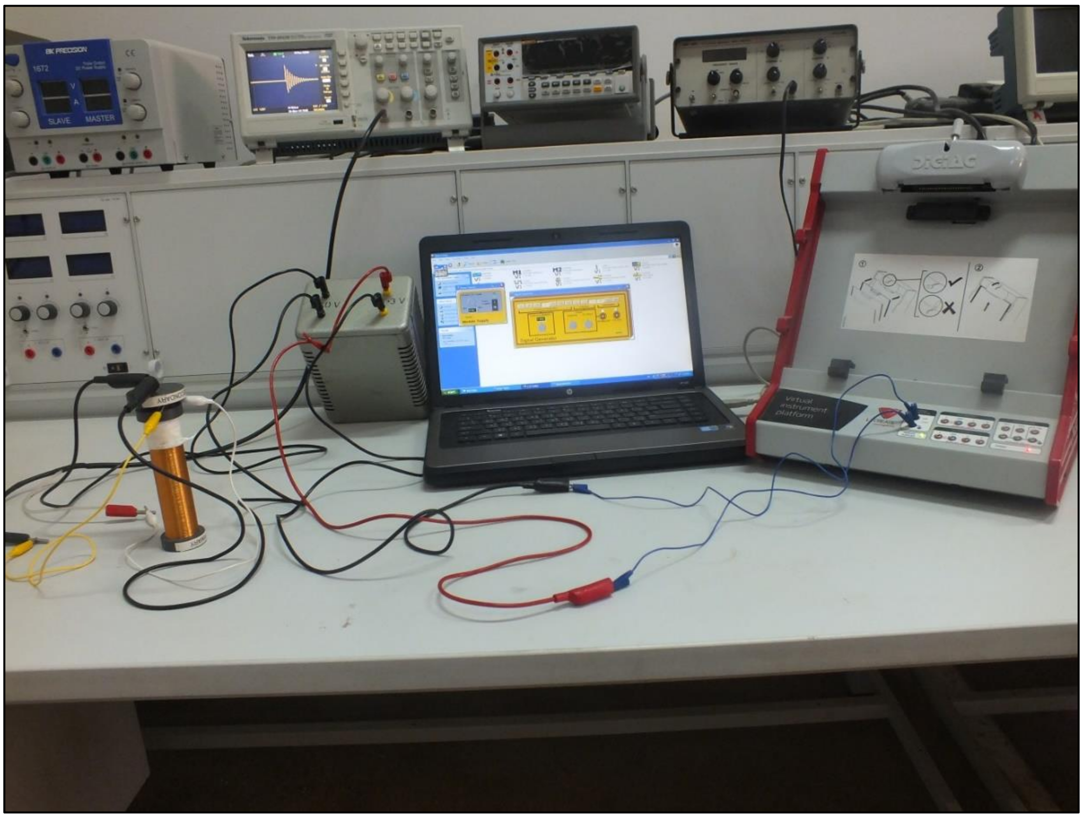

**Figure 6b**. Experimental setup at STC in Zawia

**The Signal Generator**

The signal generator built inside DIGIAC 3000 Platform device was as in figure 7(a) is used in this **e**xperimental system to provide the driving excitation signal to the primary coil. The signal needed was a square wave with controllable amplitude and frequency measured using

Tektronics Digital Oscilloscope type Tektronix TDS 2022b as shown in Figure 7 (a) Since the output of the signal generator is limited in power as shows in Figure 7 (b), we were chosen this device because it has the ability to generate high input signal can be achieved to the power amplifier for purpose amplified the signal.

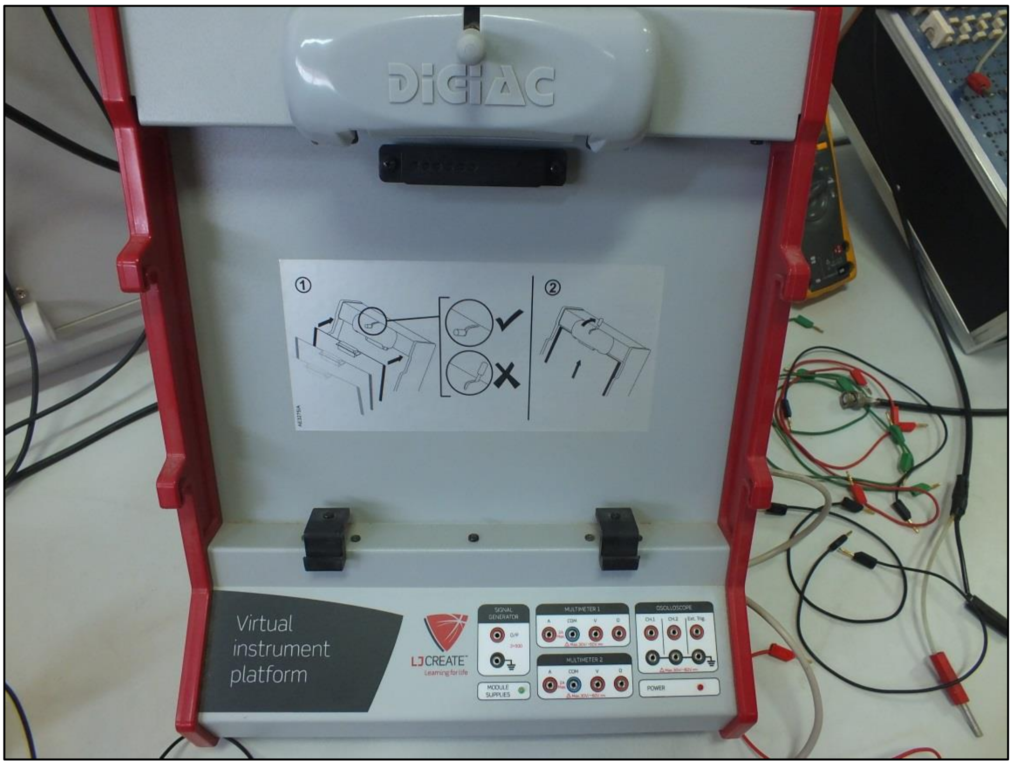

**Figure 7a.** DIGIAC 3000 Platform device (signal generator)

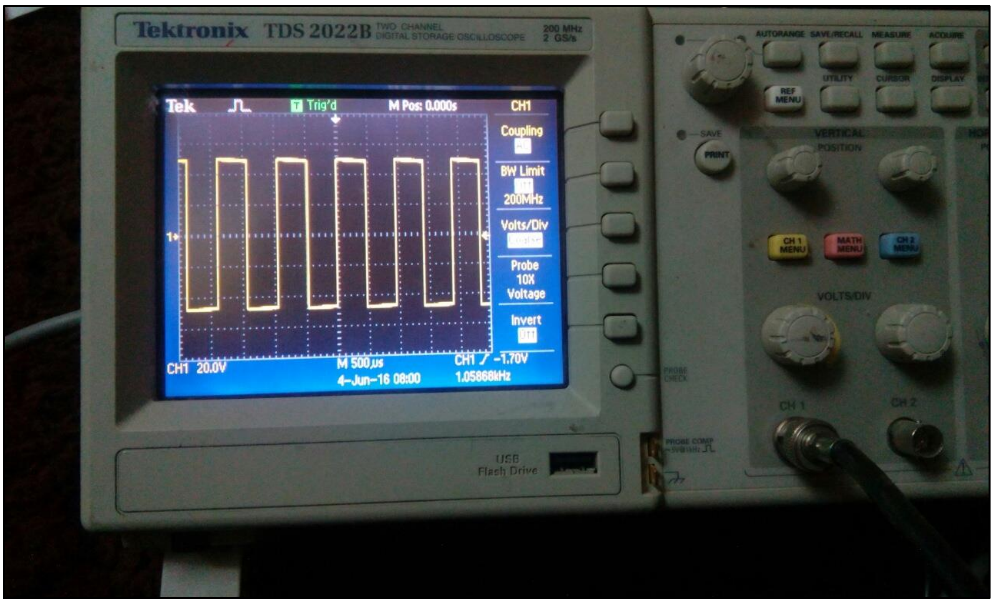

**Figure 7b.** Output of the signal generator (input signal).

The voltage must be chosen 0.7v regarding to previous research to get less distortion and to achieve high accuracy but the voltage had chosen 12v maximum value because the step-up transformer that used to amplify the signal gave weak voltage on the input so that the higher the voltage input, the stronger the electric field it generates. However, this article achieved accepted and satisfied results.

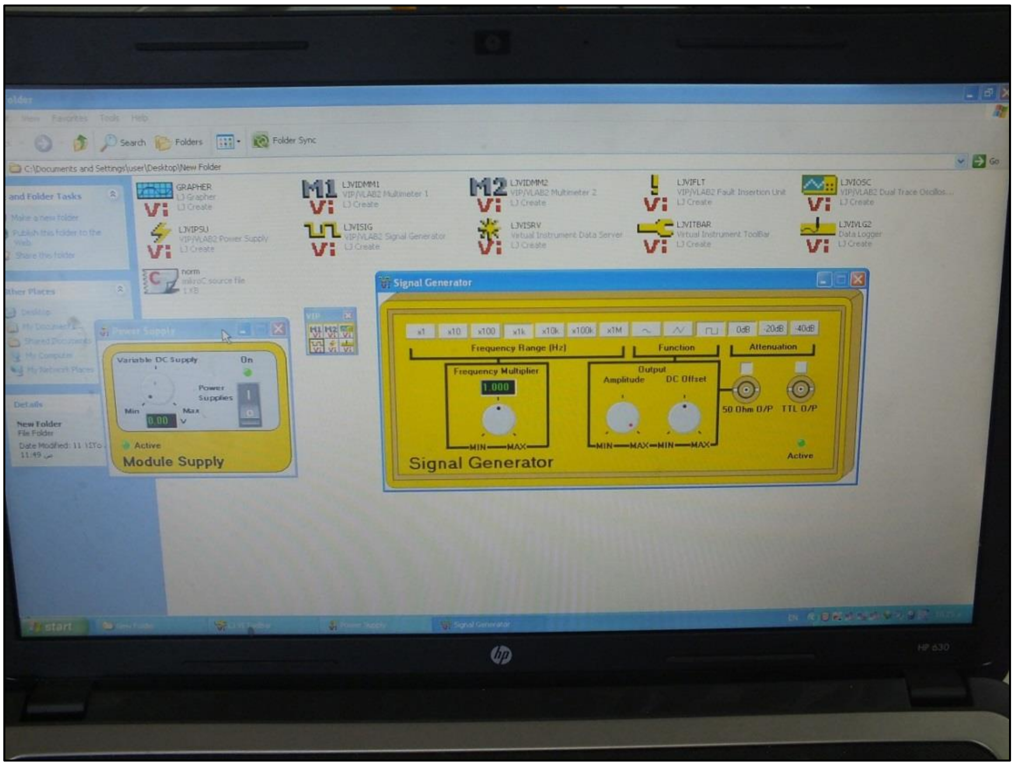

**Figure 8.** The adjustment program for the signal generator of the desired input signal.

**Power amplifier**

The output signal from the signal generator was relatively small comparing with the required Signal for execution the primary coil so that a power amplifier was needed to amplify this signal to an adequate level so that the signal picked up by the pick-up coil was high enough. The signal was a square wave with controllable amplitude and frequency as shown in figure 4.3 above, on channel 1. The amplifier should have a relatively high bandwidth (126kHz) but this device not exist in our country so we had made up a step-up transformer works as a power amplifier, the power amplifier had wounded with a special copper wire that can handle signals with 1000 Hz, a step-up transformer with an input voltage 6.3v and output voltage 80v. The number of turns for the primary coil is 70 and the secondary coil is 900 turns as shows in Figure (9). Step-up transformer capable of amplifying signals that have frequencies between 10Hz up to 1300Hz but with limited current. The output power of the amplifier is 2W, this power very small comparing to the power needed in our experiment, and the output voltage was ±90V and the frequency was ≈1k Hz.

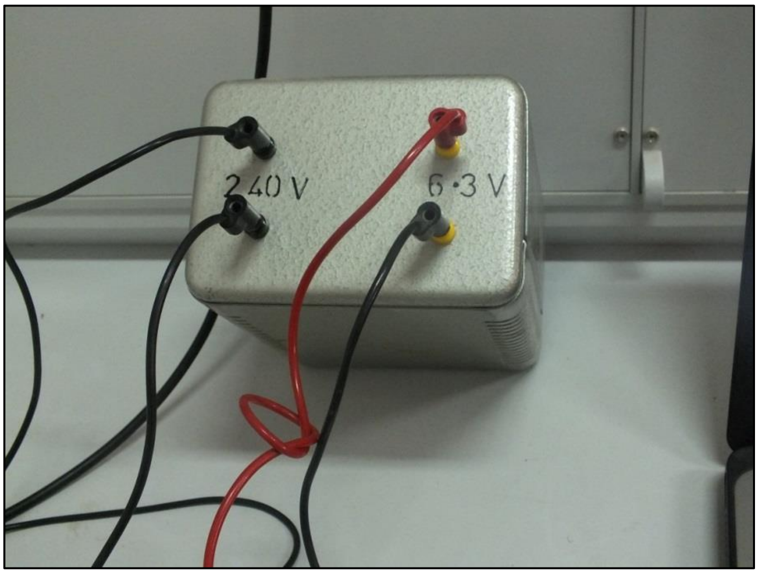

**Figure 9.** The step-up transformer

The output of the amplifier was fed to the primary coil to execution the signal to an adequate level so that the signal picked up by the pick-up coil.

### Primary (Driver) coil

The driver coil used in this experiment is shown photographically and diagrammatically in figures (10a &10b) below. The primary coil is wound around a cylindrical plastic bobbin that was specifically machined for this experiment. The cylindrical bobbin is hollow inside to allow the sample and the pick-up coil to be inserted. The length of the cylindrical bobbin was 140mm and its diameter was 22 mm. The driver coil has 370 turns of 0.5 mm diameter copper wire. It was chosen from previous research a PhD "An Investigation and Development of a Novel Quality Control System Based on Contactless Resistivity Measurement" at the University of Wales Institute, Cardiff (UWIC).[4]

The primary coil was used to provide the excitation signal to the sample. This signal will cause induced eddy currents on the sample surface. On the other hand, the primary coil converts the energy in the input current into a magnetic field.

This time varying magnetic field induces a decay voltage picked up by the secondary coil, it means that will be transferring electrical energy without having electrical contact. The voltage input signal to the driver coil was not sufficient as it must be to generate enough current into the pick-up coil.

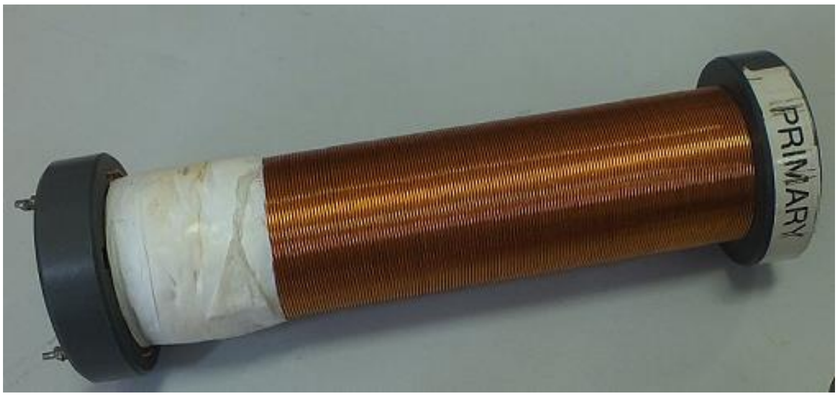

**Figure 10 a.** Excitation coil (Primary coil)

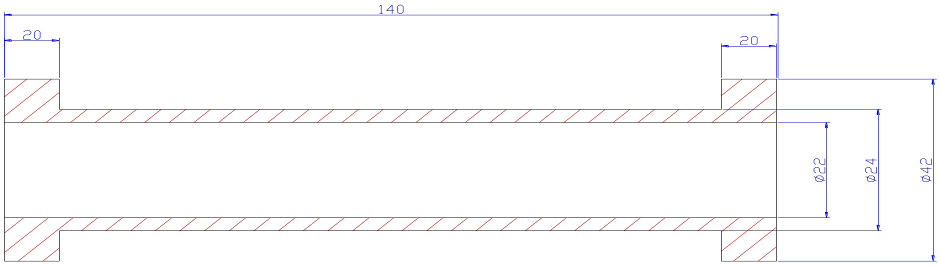

**Figure 10 b.** The driver coil dimensions.

### Secondary (Pick-Up) coil

The pick-up coil used in this experiment was made with a specific dimensions and shape is and it's shown diagrammatically and photographically in Figures 4.6 (a, b) below. It had 3000 turns of 0.25mm diameter copper wire randomly wounded and a length of 20 mm. The holder is also a cylindrical bobbin made of plastic, a nonmagnetic material. The output of the pick-up coil is connected to a digital oscilloscope for further processing the signal.

**Figure 10b.** Sample holder and pick-up coil**.**

### Digital oscilloscope

The digital oscilloscope used in this experiment was a Tektronics Digital Oscilloscope TDS2022b as shows in Figure (11) which was supplied with a PC interface. The PC interface allows signals measured or monitored on the oscilloscope to be captured and saved onto a standard PC computer. In this experiment, the oscilloscope was used to measure the output signal from the pickup coil. The results of these measurements were passed during a series cable USB then the data were displayed on open choice Tektronics software on the Personal Computer through the interface for further processing and analysis. The oscilloscope was also capable of automatically measuring amplitude, frequency and time.

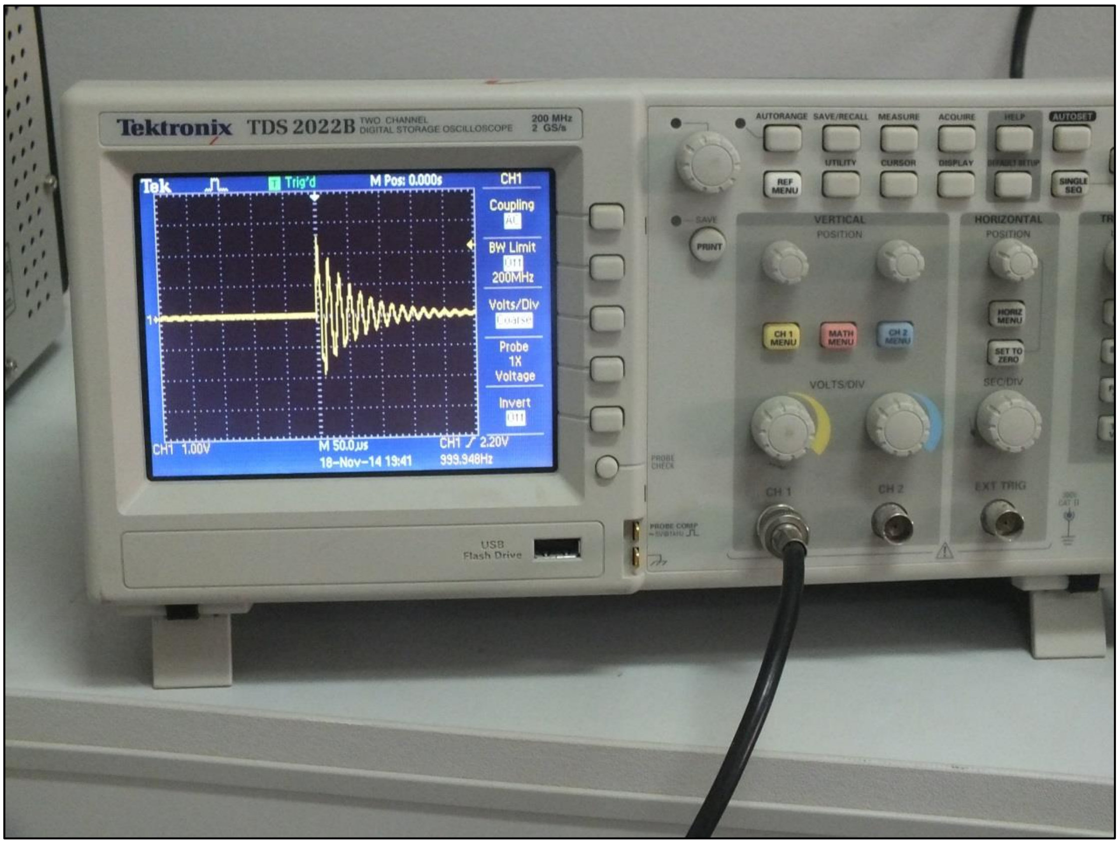

**Figure 11.** The Tektronics 2022b digital oscilloscope

### Adriano UNO microcontroller with temperature sensor

For measuring the temperature of the environment of experiment to study the variation of temperature for the measurement system, the temperature sensor had selected was LM35 it has ranges from $-55^{0}C\ to\ 150^{0}C$ and it can be operated from 3v to 30v,and for programming the temperature sensor we need microcontroller ,so we choosing an Adriano UNO microcontroller because it’s Inexpensive in costs and easy for programming with c language, Figure (12a & 12b) below show Adriano UNO board and temperature sensor LM35.

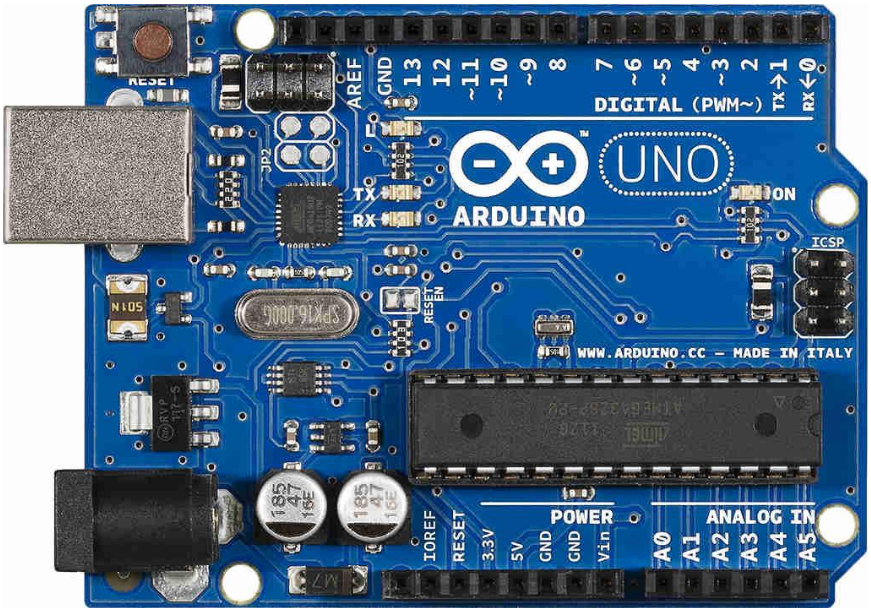

**Figure 12 a.** The Adriano UNO microcontroller board

**Figure 12 b.** The temperature sensor LM35

## Samples

Two materials were used in this project. These were: isolated brass, and steel. For each of the samples, 4 distinct diameters were prepared as shown in Table (1) below.

**Table 1.** Type, Diameter and Length OF the Sample

| Sample type | diameter (mm) | | | | Length (mm) |
|---|---|---|---|---|---|
| Isolated Brass samples | 0.9 | 1.1 | 1.3 | 1.6 | 25mm |
| steel samples | 0.5 | 0.8 | 1.25 | 2 | 25mm |

The sample dimensions were controlled using a digital micro meter and digital veneer

## Data analysis software

The data analysis software used in this experiment was MATLAB version 10 2010Ra. MATLAB is a very powerful mathematical operations and signal analysis package that provides very useful mathematical information about various signal data. In this experiment, the signal data processed by the Tektronix software was made available to MATLAB via a data file. In this experiment, MATLAB was used to performed the data analyse data collected by plotting graphs for determining the statistical unique characteristics and other properties of the signals induced in the secondary coil.

### System setup

This part describes the process of connecting all the hardware and software components together for the purpose of data measurement:

1. The output of the function generator for DIGIAC 3000 was connected to the input of the step-up transformer (power amplifier) for amplify the signal;
2. The output of the step-up transformer was then connected to the primary coil;
3. The sample material rod was then inserted into the shaft of the secondary coil and locked in place using a plastic screw;
4. The secondary (pick-up) coil was then inserted inside the cylindrical shaft of the primary (driver) coil;
5. The output of the secondary coil was then connected to the Tektronics 2022b digital oscilloscope;
6. The output of the digital oscilloscope was then connected with a series connection to the computer for further collecting and analysis the data;
7. The data collected to be processed and analysis using MATLAB 2010 in the Personal Computer.

### Data collecting and measurement

This part discusses data acquisition process it's a specific process of measuring and analysing signals resulting from the electromagnetic properties for the different samples with their different diameters with changes in temperature. We used programming software to collect data measurement from the system called (open choice Tektronics desktop acquisition) as in Figure (13), this program will allow to collect the data from the digital oscilloscope in deferent format directions, txt, or excel.

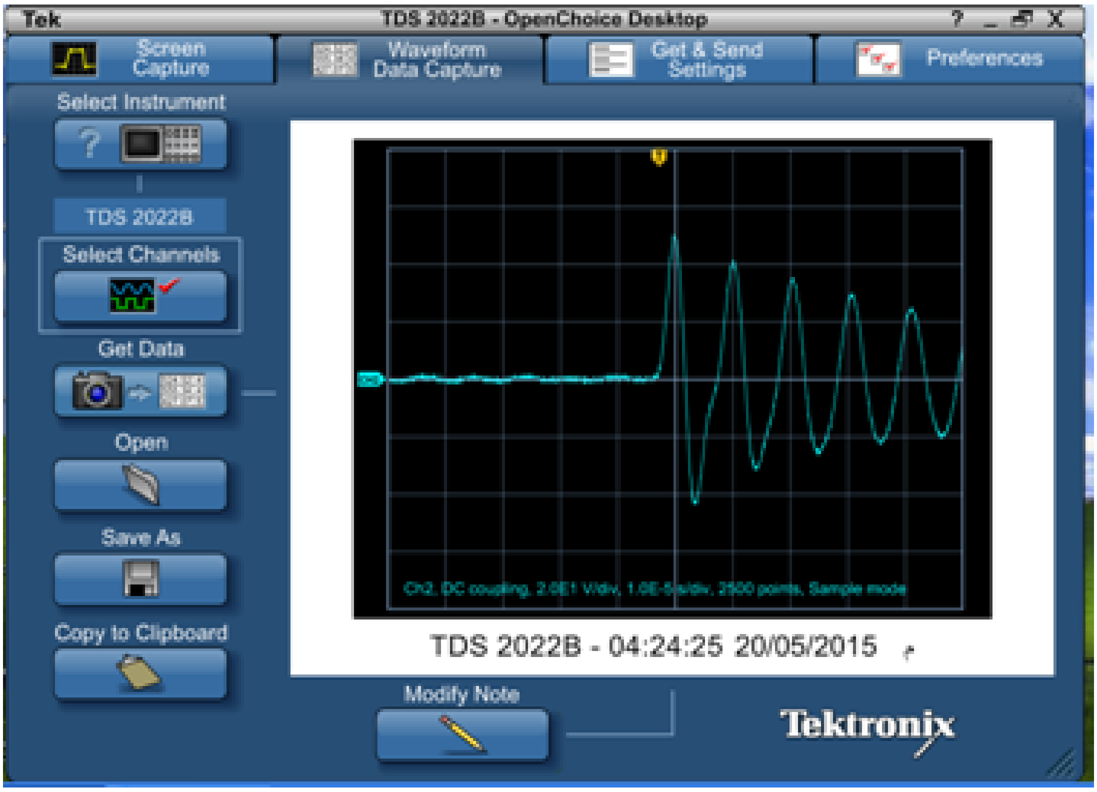

**Figure 13.** A screen sample of data acquisition software

### Analysis and Discussion of Experimental Results

#### 1. Empty sample

While the room temperature is measured about $22^oC$ and the input of the signal generator adjusted to 4 volts Root Mean Square RMS and that is the smallest value of voltage could be exciting the coils to get the justified output signal as in figure (14a), the first set of results collected is for the empty sample holder. This is when there is no sample in the core of the pick-up coil. These results serve as a reference for the analysis of data with samples. These results consist of values of peaks and their corresponding time. The peak values are measured in volts (V) and the times in micro-seconds (μs) as shown in figure (14 b) and Table (2) below shows these results.

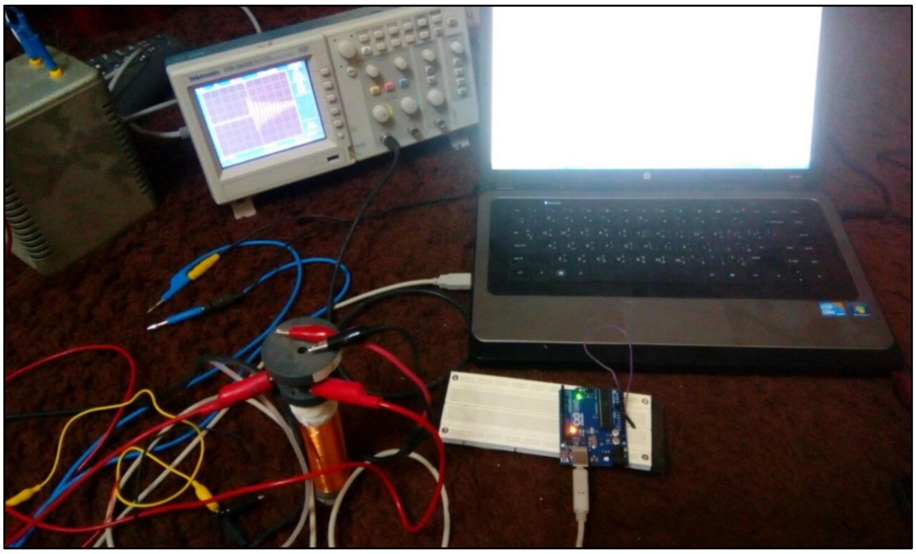

**Figure 14 a.** non-contact dimension measurement experiment system

**Table 2.** Peaks and Time Values recorded for No Sample

| No Sample | P1 | D2 | P3 | D4 | P5 | D6 | P7 | D8 |
|---|---|---|---|---|---|---|---|---|
| **Peak (V)** | 4.80 | -3.94 | 4.00 | -3.40 | 3.36 | -2.56 | 2.88 | -2.24 |
| **Time (us)** | 4.320 | 8.20 | 14.29 | 18.77 | 25.01 | 28.69 | 35.21 | 39.73 |

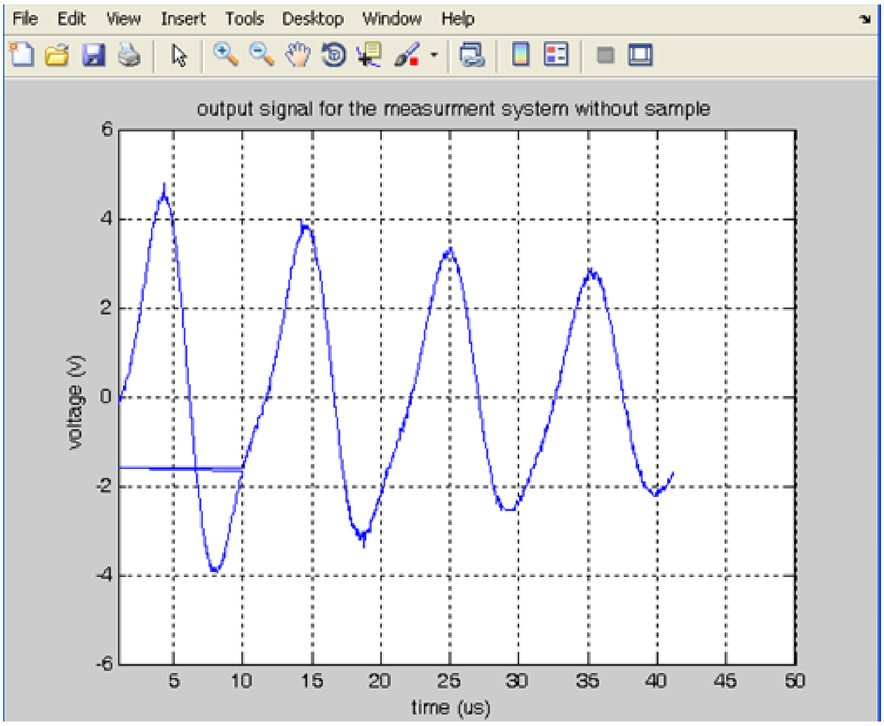

**Figure 14 b.** Output signal for the measurement system without sample.

According to Figure (14b) above, the output signal for the measurement system without holding sample inside the coils, this signal will measured once for each two type of samples, so that this data without sample will be a reference data to be compared with the data with deferent diameter samples, we used a mat-lab programming to use just the first 4 peaks in positive side and 4 dips in negative side each value of voltage has a specific time and frequency , for further analyses the data , this signal shows a relation between voltage and time, the decay voltage has a maximum voltage around 4.8 volts.

## Conclusion

All the analysis results presented for the non-contact diameter measurement experiment. Specifically, the peaks and dips values, calculated constants, average calculated constant for isolated brass and steel samples were that shows there was a clear linear relation between the average constant and the diameter of the samples for the deferent three methods for average constants, The calculated error very small around $10 - 5$, and the method has satisfactorily accuracy also the result shows that the average constant for the dips method obtained high accuracy can be achieved than the other methods. We had seen that temperature change does not change at all in the results of experimental system because the temperature has no effect on the magnetic field and that were proved by previous studies in this field. In the next chapter, a thorough phenomenon of conclusion and future work of these results/ thesis will be presented.

We have sought to develop a modern method to measure the diameter of an insulated and conductive material with circular cross section area (such as wires and nails, etc.). After the measurement system had been building and a comprehensive study of the problem and its impact on the industry, a method to measure the diameter has been implemented and improvement. The performance of the measurement method had proved to be competition to other based methods in costs and simplicity of implementation and operation. In this case, the measurement method has proved to be useful in quality control mechanism to monitor the fluctuations in diameter of various materials.

- This method offers the advantage of being able to measure small samples less than 1mm, which would be problematic for more conventional measurement methods such as manual measurements. The measurement itself is fast and convenient, with a fairly simple and robust experimental set-up.
- In particular, we proved that the experimental system can be used for measure the diameter of samples which need to be encapsulated within non-conducting plastic or glass containers or with other material. In addition, this method eliminates the problems measuring sample with physical contacts, e.g., contact voltages, surface contamination.
- The results shows that the experimental system has proven to be unaffected by temperature change, because the magnetic field theory isn’t affected by the variation of temperature.

## Recommendations

Based on the work presented in this thesis, several suggestions for possible refinements of the methods can be proposed.

- Although the system used in the present work gave good results it is recommended to increase the accuracy and reliability of the system. This will allow the measurement of any sample of material and guarantee better competitive results.
- A physical measurement of thickness of thin metal coats is extremely difficult and complicated. Thus, measuring the thickness of thin metal coats is recommended.
- A better solution could be development the measurement system, to get directly absolute value of the sample diameter, from the linear relationship between the sample diameter and the pick-up signal.
- We suggest to improvement the measurement system which we use it for the possibility of measuring the diameter of samples for more than one sample at the same time, and it’s very important in the monitoring and control in the industry field.

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