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Design and Implementation of a Remote Field eddy Current Sensor

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Devant le Jury

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Before the Jury

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Dedications

To my dear parents, for all their sacrifices, their love and their prayers throughout my studies. To my dear sisters for their constant encouragement and moral support.

To my dear sister kheira for her support and encouragement. To all my family for their support throughout my university career.

May this work be the fulfillment of your alleged wishes and the fruit of your infallible support.

Khaled toudji

Dedication

I dedicate my dissertation work to my family and many friends. A special feeling of gratitude to my loving parents, whose words of encouragement and push for tenacity ring in my ears. My brothers and sisters never left my side and are very special.

I also dedicate this dissertation to my many friends and who have supported me throughout the process. I will always appreciate all they have done.

Bouzid mohammed abdelhay

Dedication

I dedicate this work to my parents and my little family, my wife and my children. In addition, I give special thanks for my friends that they helped me to finish this thesis.

Special thanks to all who helped me in this process from far or near.

I say thank very much.

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First, we would like to thank the Almighty and Merciful GOD, who gave us the strength and the patience to do this modest work

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Table of content

Table of content

Table of content

Table of figures:

List of tables:

Notations and Symbols

NDT: non-destructive testing.

RFEC: remote field eddy current.

PRFEC: pulsed remote field eddy current.

CNC: Computer numerical control.

PWM: Pulse width modulation

Lift-OF: The height of the sensor from the test piece

$\boldsymbol{\delta}$: Skin depth.

$\boldsymbol{f}$: Excitation frequency.

$\boldsymbol{\mu}$: conducting material permeability.

$\boldsymbol{\sigma}$: conducting material conductivity.

B: magnetic flux density

ABSTRACT:

Non-destructive testing has a large number of techniques, with different characteristics, advantage and limitation a make the NDT a fertile field for scientific research. Pulsed remote field eddy current technique has utilized broadly in the detection of tubular structures because it proves good results with minimum requirements. a novel PRFEC sensor design is proposed with coaxial coils shape and simple signal processing circuits, this sensor moves by a CNC machine on X-Y and Z-axis in order to automate the inspection and enhance the stability of the sensor. A number of experiments with different values of lift-off, duty cycle, excitation amplitude, excitation frequency and with different defect depths have carried out. The results show a deep penetration depth up to 8mm with high sensitivity where it can differentiate between cracks with 1mm difference in-depth, the designed sensor proved a good detectability .

ملخص:

يحتوي مجال الاختبارات غير المدمرة عددا كبيرا من التقنيات والتي تختلف من حيث المميزات والمعيقات ما يجعل منه مجالا خصبا للإبداع والبحث العلميين .استخدمت تقنية التيار الدوام النبضي للمجال البعيد على نطاق واسع في اختبار الهياكل الأنبوبية لما أثبتته من نتائج جيدة مع استهلاك أقل للمصادر بالمقارنة مع التقنيات الأخرى

صممنا مستشعر جديد يعمل بتقنية التيار الدوام النبضي للمجال البعيد يتكون من ملفين متحدي المحور ودوائر بسيطة لمعالجة الإشارة محمولا بواسطة آلة تصنيع ذات تحكم رقمي ذات محور تحريك ثلاثي الأبعاد وهذا لتعزيز ثبات المستشعر وأتمت عملية الاختبار .تم إجراء عدد من الاختبارات من خلال تغيير إعدادات إشارة الإدخال كالسعة والتردد والدور لمعرفة الإعدادات المناسبة ثم تمَّ اختباره على شقوق ذات أعماق مختلفة .أظهرت النتائج أن هذا المستشعر له عمق اختراق للعينة يصل إلى ثمانية ملمتر مع حساسية استشعار قوية حيث يستطيع اكتشاف فرق واحد ملمتر بكل سهولة ودقة.

Summary

In the industry and manufacturing domain, it is very important to test the machine parts and the products in the end lines of the production. Moreover, these tests must be no destructive to avoid the losing of products and parts in addition it is very important and more flexible if the part tested without disassembling. NDT (nondestructive testing) put these advantages in the hands of the industry fields. NDT came with many methods that offers many advantages for testing the parts and these methods changes its advantages according to the test piece materiel and its shape. The Pulsed remote field eddy current (PRFEC) from the most NDT methods that offers high skin Penetration on the test sample and more sensitivity and high resolution moreover the PRFEC its developing every year. The using of the NDT testing in many fields related with CNC machines because these machines used to hang the NDT sensor above the test piece and moving it in the x, y, and z-axes. The precision and the stability of the CNC machine makes the testing process more efficient and quality.

General introduction

General introduction:

The non-destructive testing known as a useful technique in the industry filed since the Romans ages where they used flour and oil to find cracks in marble slabs that used in construction. In these days the industry field depends on non-destructive testing (NDT) to estimate the lifetime of industrial machines part to avoid any failure that my leads to catastrophic accidents or expansive losses. The purpose of non-destructive testing is to identify when the part is near failing without damaging it in the process of testing. The problem is that there a limitation in most known NDT methods such as both side access in radiographic technique, skin effect in ACFM (Alternating current field measurement) and ECT (Eddy current testing). Cannot examine multilayer structure with an air gap like acoustic emission testing. Pulsed remote field eddy current is an NDT method that passes through most of those limitations it gives access to both sides of the sample without any need to move it because of its deep penetration depth and the pulsed signal give it a high test speed and sensitivity and more information about defects profiles. This thesis will discuss a pulsed remote field eddy current sensor design with multilayer shielding structure driven by a router CNC machine. The first chapter was a generality about NDT methods and its advantages, disadvantages and applications and more details about remote field eddy current Principe with the key selection parameters that effects on it, this chapter also give a brave on eddy current sensor modules and parameters . While in chapter tow, we proposed a router CNC machine as a driver part that moves the sensor over the test sample in place of the human hand to offer more stability and flexibility and precision to the sensor. In the beginning of this chapter, we define the CNC machine and its block diagram and its main parts and we discussed the advantage and disadvantage of a CNC machine. After that, we describe the practical CNC machine that we use to move our sensor, which control based on control program software control the moving of the CNC machine using ARDUINO Uno microcontroller as MCU for it. The sensor design described in chapter three. The sensor tested with different pulse duty cycle and excitation frequency, excitation amplitude to define the effective parameters for an operative sensor. Also the sensor signal exanimate under different lift-off value to estimate which lift-off provide good signal strength and sensitivity moreover a different crack depths has been controlled by the designed sensor to occur its sensitivity and cracks detectability.

Chapter I Non-destructive testing generalities

1.1. Introduction:

In the industry field the testing and the controlling of the parts of the machines are very important because if there any problem in the machines the cycle of the industry it will be harmed and that occur problems on the production of the company and sometimes it be stops. Therefore, for those machines, parts testing needed and it must be very efficient and the testing cannot stop the machines or harm the parts. For that, we have NDT (non-destructive testing). This method started from the 1895 in that year Wilhelm Conrad Rontgen discovered the X-Ray and he predicted the cracks using this ray in his first published research. Moreover, there is many inventors developed many techniques to predict the crack like oil and bleach method in the years 1880-1920 that used to detect cracks in the railroad. In addition, in the year 1927-1928 it used a device that can use the magnetic induction to detect the cracks on the railroad, after that in the years 1940-1944 were developed a method that uses the ultra sound waves. Moreover, in the year, 1950 G Kaiser introduced acoustic emissions as an NDT method; in 2008, it created the NDT international academy.

Nowadays the NDT is widely used in the metal industry to control the quality of the materiel specially on the soldering. The eddy current technique is mostly non-destructive technique used to inspect the conductive materiel at very high speed sensing and it does not need a touch between the sensor and the tested part, and there is other NDT techniques such as ultra-sonic, liquid testing.

1.2. Definition of NDT:

NDT (non-destructive testing) in French CND (contrôle non destructif) non-destructive techniques are used widely in the industry and science to explore the materiel properties without causing any damages to the part. The most used non-destructive techniques are ultrasonic, electromagnetic, liquid penetrant testing. The electromagnetic and ultrasonic techniques they introduce sound waves or electromagnetic into the inspected materiel to export its properties. Liquid penetrant testing use either fluorescent or no fluorescent dyes to detect the cracks on the materiel, in addition to this methods the scientist such as shujuan and noorian and aliaoune they researched a combination between the electromagnetic and ultrasonic wave using the electromagnetic acoustic transducers.[1]

1.3. Non-destructive methods:

There is many methods of Non-destructive testing and it used in many fields we will mention just a six methods.

1.3.1. Acoustic emissions testing (AE):

The NDT technique known as passive techniques, this technique can detect the cracks from the short bursts ultrasound the emitted by the active cracks under load. Sensors dispersed over the surface this structure of sensors detect the AE. This method gives the possibility of detecting the crack before it forms from the plasticisation in highly stressed areas, this method it used during proof test for a pressure vessel, and it is a structural health monitoring (SHM) method. Leaks and corrosion are detectable AE source too. [1]

1.3.2. Electromagnetic testing (ET):

This method uses an electromagnetic filed passed into a conductive part, there are three types of this method eddy current (ET), alternating current field measurement (ACFM) and remote field. The principal of this method is to use an alternating current coil to induce a primary electromagnetic field into the test piece this create an eddy current in the test piece and this current make a secondary electromagnetic field that against the primary field. The secondary filed will affect by the primary field. This affectation will make changes on the impedance of the sensor coil form Z_0 to Z_c. Moreover, if there is cracks in the test piece that will make changes to the secondary field witch will make changes to the primary field that will make changes to the impedance of the sensor coil from Zc to Z_{c1}. The difference between Z_c and Z_{c1} present the cracks. [2]

1.3.3. Ground Penetrating Radar (GPR):

Ground penetrating radar (GPR) it based on propagating an electromagnetic waves EM that respond to the changes of properties of shallow of subsurface. The principal controlling factor of generation of reflections is the velocity of EM waves. That determined by relative permittivity contrast between the background material and the target martial or (contrast between the layers), relative permittivity defined as the ability of material to store and permit the passage EM energy when a field is imposed on the martial and can be measured. [3]

1.3.4. Laser testing method (LM):

Laser testing its NDT method based on the use of laser and there are three categories of this method includes holographic testing, laser profilometry, laser shearography. [1] Holographic testing uses a laser to detect changes in the surface of the material, which been subjected to stress such as heat, pressure or vibration. The results compared to an undamaged reference sample to show defects. [1] Laser profilometry uses a high speed rotating laser light source and miniature optics to detect corrosion, pitting, erosion and cracks by detecting changes in the surface via a 3D image generated from the surface topography. [1] Laser shearography uses laser light to create an image before the surface stressed and a new image created. These images compared to one another to determine if any defects are present. [1]

1.3.5. Leak testing (LT):

There are four methods for leak testing, bubble leak testing, pressure change testing, halogen diode testing and mass spectrometer testing. [1] Bubble leak testing is based on the using of liquid tank or soap solution for the large parts to detect the gas usually air leaking if there any leaking it will create a bubbles. [1] Pressure change testing used only on the closed systems it use pressure or vacuum, any change on the pressure or vacuum on set time means that there is a leaking. [1] Halogen diode testing it uses also the pressure like LT except in this case the air and gas tracer based on halogen are mixed and with halogen diode (sniffer) can detect the leaking. [1] Mass spectrometer testing uses helium or a helium and air mix inside a test chamber with a 'sniffer' to detect any changes in the air sample, which would indicate a leak. Alternatively, a vacuum can used, in which case the mass spectrometer will sample the vacuum chamber to detect ionised helium, which will show that there has been a leak. [1]

1.3.6 Magnetic flux leaking (MFL):

It’s one of the most popular methods used in the oil and gas pipeline inspection.[4] Consists of magnetizing the pipe in the axial direction and detecting defect-induced magnetic leakage fields using circumferentially arranged magnetic sensors. [4] A corrosion pit in a background magnetic field acts as a region of high magnetic reluctance. [4] Most of the flux lines diverted around the defect, generating opposite magnetic polarities or a dipolar magnetic charge (DMC) on the defect walls.it comprise of three steps:

1. Conducting MFL runs on calibration samples and recording of MFL patterns of known defects.[4]
2. In situ inspection of pipelines.[4]
3. Analysis of results, with data from the field compared with MFL profiles generated by the calibration defects.[4]

1.4 Eddy current testing method (ET):

Eddy current method it one of the most used methods of NDT. It has very high speed and does not require any contact between the test piece and the sensor. [2] The principal of the eddy current testing based on introducing an electromagnetic field into a test piece that will induce an eddy current on the test piece and the sensing of changes on electromagnetic field of the sensor to detect the impacts of the test piece electromagnetic field. [2] And we can divide this method into three types.

1.4.1 Eddy current testing:

The principal of the eddy current testing based on the interaction between the sensor magnetic field and the test piece that induces the eddy current on the test piece witch will induce magnetic field on the opposite direction of the sensor magnetic field. That weakens the sensor magnetic field. [2] If there is any defects on the test piece that will weakens the test piece magnetic field that will occur some improvements to the sensor magnetic field. [2] The system detect this change to decide there is a defect on the test piece. [2]

1.4.2 Alternating current field measurements:

The ACFM technique based on the principle that an alternating current (AC) can induced to flow in a thin skin near the surface of a conductor. By introducing a remote uniform current into an area of the component under test, when there are no defects present the electrical current will be undisturbed. If a crack is present, the uniform current is disturbed and the current flows around the ends and down the faces of the crack. [5]

1.4.3 Remote field-testing:

An electromagnetic-field-focusing remote-field eddy current probe for inspecting anomalies in a conducting plate. The probe is designed to have the electromagnetic energy released from an excitation coil penetrate through the plate twice, so that the signals received by one or more receiver units (pickup coils, magneto-resistors or SQUIDs) have passed twice through the plate Wall; from one side of the plate at the excitation coil to the other side. Then back to the original side at the receiver units. The probe detects flaws, with good and equal sensitivity, irrespective of their depth in the plate. It can detect, from one side of a plate, flaws located on the other side of the plate, which is useful for inspecting the bottom plate of a huge tank, which is sitting on the ground. The thickness of inspected plates can go up to one inch for aluminium plates and to 3/8“for ferromagnetic plates. The probe generates a periodic magnetic field. The excitation coil and an auxiliary device direct the electromagnetic field into the plate inspected. In one embodiment, the auxiliary device is a coil driven by a signal having a phase and amplitude relationship to the excitation coil's signal. The excitation and the receiver units covered by one or more shields made of highly con ducting materials, or of highly conducting materials laminated with alternating layers of ferromagnetic materials. [6]

1.4.3.1. Principle of remote field eddy current testing

In tube structure:

Remote field eddy current (RFEC) has drawn more and more attention in the nondestructive testing. A process characterizes the phenomenon of (RFEC) where the energy released from the excitation coil traverses the tube/pipe wall twice before it reaches the pick-up coils/sensors that is located 2-3 diameters away from the excitation. In other expression, it depends on

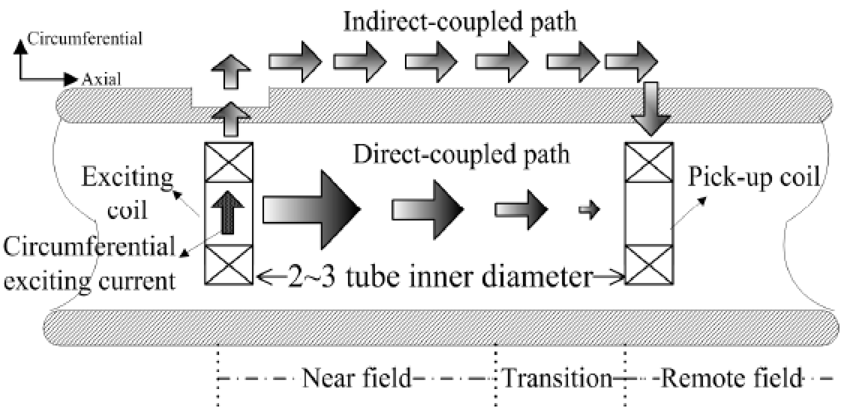


Figure 1.1 Schematic of a remote field eddy current probe inspecting a tube showing the two energy flow paths

indirect-coupled electromagnetic energy, which passes through a pipe wall twice, as shown in Figure 1.1.

This technique used routinely for metallic tube inspection. It has a few distinguishing features such as equal sensitivity to both OD and ID defects, independence of phase signals to lift-off, and approximately linear signal phase/thickness relationship.

In conductive Plate:

In fact, RFEC phenomenon exists not only in pipeline, but also in flat conductive plates, when low frequency excitation is used. Therefore, it implements the through wall evaluation of structural integrity, and has the higher detect ability of deep buried defects [8].

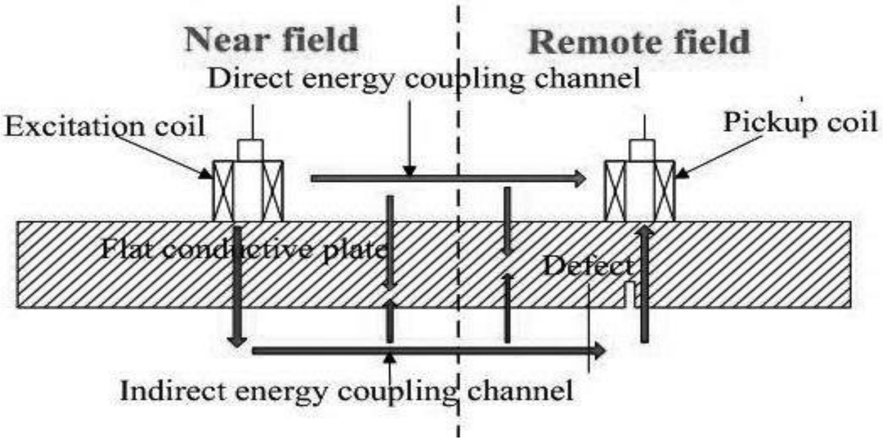


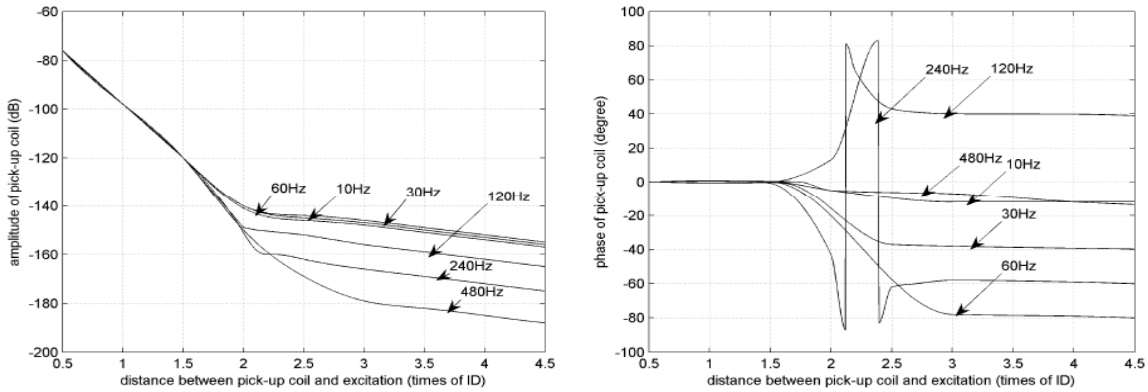
Figure 1.2 Principle of remote field eddy current for flat conductive plate

The principle of RFEC inspection of flat conductive plates shown in Fig. 1.2. Two transducers normally placed on the conductive plates. One is the excitation coil and another is the magnetic sensor (or pickup coil). Excitation coils with alternating current generate electromagnetic energy, which transmitted in two manners: (1) Direct energy coupling channel, which spreads from near to far along the top surface of the flat conductive plates; (2) Indirect energy coupling channel, which penetrates the test sample twice as shown in Fig. 1.2. This is similar to RFEC applied in inspection of pipeline. If there are any defects in the transmission path there has defects, they would affect the amplitude and phase of the energy, which picked up by magnetic sensors placed at a distance from the excitation coils. Observing the variation in amplitudes and phases, material status can be evaluated, particularly the detection of deep buried defects.

1.4.3.2. Key Parameters Selection:

Frequency:

Figure 1.3 shows RFEC characteristic curves under different frequency conditions (10, 30, 60, 120, 240 and 480 Hz). When the frequency increases the signal, strength decreases rapidly as shown in Figure 3a. In figure 3b the “phase knot” effect can be clearly observed and the maximum appears at 60 Hz (about 60° phase difference) indicating that a frequency between 30 and 240 Hz can be appropriate for proper signal strength and maximum phase difference which will be helpful for crack identification.



(a) (b)

Figure 1.3 Characteristic curve under different frequency. (a) Amplitude; (b) Phase.

Shielding facility:

In the remote field eddy current testing system, a pick-up coil should be located about 2 ~ 3 times the inner diameter away from an exciting coil. Taking into account the influence of wobble or off-center movement, the distance between pick-up coil and exciting coil always be 4 ~ 5 times the inner diameter. The most effective method to reduce sensor length is to use a shielding facility to prevent the direct-coupled field from entering the pick-up coil. In the Inspection of metallic objects that have a flat geometry [8]. If an AC coil placed above a conducting plate and the field over the upper surface of the plate is measured, it is not possible to observe the RFEC phenomenon there, since the energy coupled via the direct path dominates. A complex structure involving magnetic cores and shields utilized in the RFEC probe to minimize the direct coupling of energy and to maximize the indirect coupled energy [9] as shown in Figure 1.4.

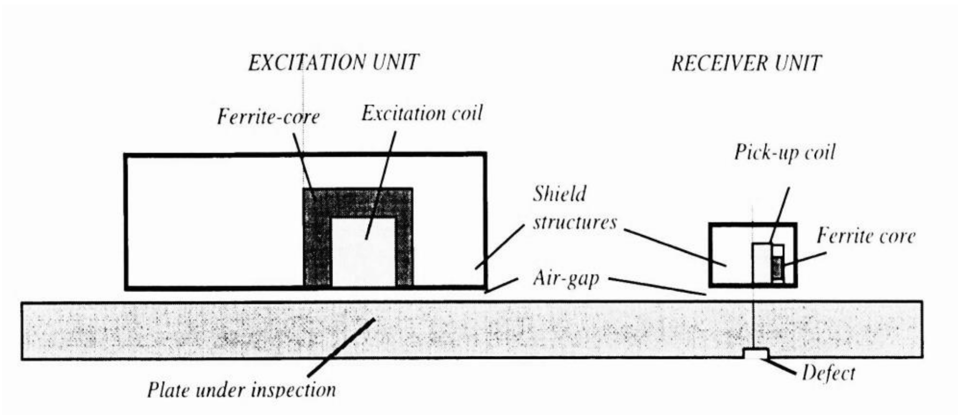


Figure 1.4 Complex structure for inspecting metallic

Pulsed excitation effect on RFEC inspection:

Studies have shown that the eddy current technique can benefit from applying pulsed excitation for detecting hidden flaws [10]. Studies have also shown that the RFEC effect also observed using FEM. with pulsed excitation [11].and [12] that the use of pulsed excitation increases the amount of information contained in the RFEC signal. The differences between the conventional excitation and pulsed excitation are:

1. Pulsed RFEC requires less power.
2. Shorter distance possible between excitation and sensor coils.
3. A sensor close to the excitation coil senses the near field signal during the initial period represents surface conditions. After some time remote field signal measured by the sensor.

These differences highlight the potential benefits of applying pulsed excitation to the **RFEC** techniques.

1.5 Eddy current sensors:

Non-destructive testing uses many sensors Such as solenoid, Hall Effect sensor, coil probe etc. In this section, we will mention the most used sensors. [2]

1.5.1 Coil probes:

These the widely used sensor on the eddy current inspection in this subsection we will mention the most important coil probes on the eddy current testing.

1.5.1.1 Encircling coil probes:

These probes commonly used on tubes and bars testing either external or internal figure 1.5(a) shows the sensor. [2] This probes are sensitive to the parallel discontinuities on the axis of the tubes and bars as eddy current describe the radial circumference in an opposing sense of

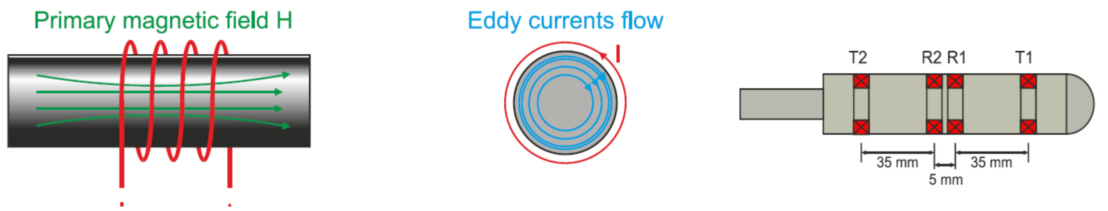
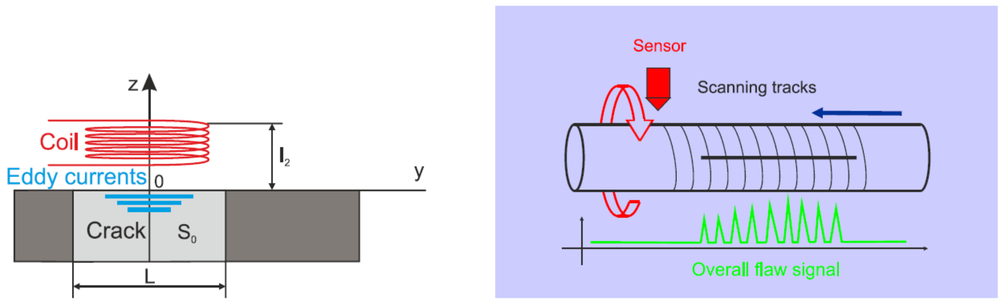


*Figure 1.5 External encircling-type coil for tube or bar inspection. **(b)** Eddy currents flow in an external encircling-type coil. **(c)** Internal encircling-type coil for tube inspection. [2]*

currents around the energized coil figure 1.5(b). [2] Internal encircling coil probes permit internal testing of tubes. Guidance system, which incorporate an encoder to locate the cracks by measuring the distance between the tube edge and the defects. Internal encircling probes usually test heat exchanger tubing at power plants at a constant rate of speed figure 1.5(c). [2]

1.5.1.2 Pancake probe:

The pancake probe are coil that is perpendicular for the axis of the test piece. It can be either air-core or ferrite core. [2]The ferrite have high permeability and the initial coil impedance is higher than the air-core. [2] Pancake-type probes are very sensitive to lift-off and inclination with respect to the flat surface. [2] These type of probes used on the flat of the test piece that make the eddy current parallel to the test piece figure 1.6(a). If there's a crack the current flow on the surface will strongly altered from that can detect the cracks. [2] This type of probe are not suitable for laminar flaws and they not strongly distorted. [2] Pancake probe used manually for detecting defects on the surface of parts that require supervision and are suitable for aeronautic maintenance. [2] And it used automatically on the bars and tubes these probes rotates at a high speed around the tube to detect the longitudinal cracks figure 1.6(b). [2]



(a) **(b)**

Figure 1.6 ***(a)*** *Pancake-type coil probe and eddy current flow (adapted from [24]).* ***(b)*** *Rotating eddy current testing [2]*

1.5.2 Double function probe:

Double function probes also called reflection probes it uses the same coil or same coils to introduce the eddy current on the test piece and receive the eddy current field from the test piece Figure 1.7. [2]

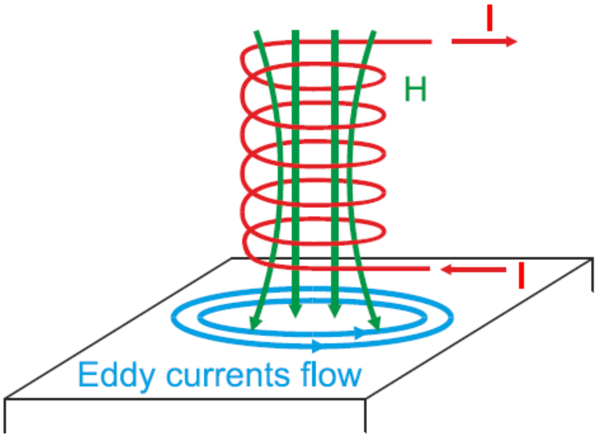


Figure 1.7 Double-function single coil probe. [2]

1.5.3 Separate function probes:

It uses a primary coil that designed especially for eddy current generating on the test piece and it uses secondary small coils designed especially for receiving the eddy current field with high sensitivity figure 1.8. [2]

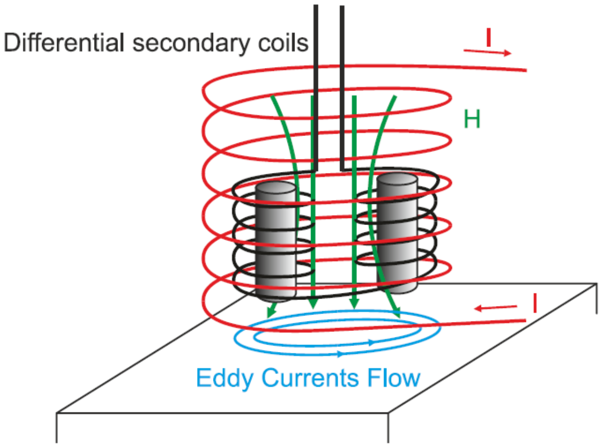


Figure 1.8 separated function probe. [2]

1.5.4 Absolute mode probe:

It uses a single coil to generate eddy current and senses changes from eddy current figure 1.9(a) this type of probes provides absolute voltage signal as figure 1.9(b) but the disadvantage of this probes their high sensitivity to temperature variations. [2]

These probes may have additional coils as reference that far from test piece used for voltage compensation figure 1.10. [2] Thy will give null voltage signal when there is no defects witch increase the instrument dynamic range. [2] This model is not sensitive to the temperature variations. [2] Absolute probes detect long flaws or slow dimensional variations in tubes or bars, which differential probes cannot detect. In addition to crack detection, the absolute change In impedance of the coil probe provides much information about the test material such as grain size, hardness and stress measurement. [2]

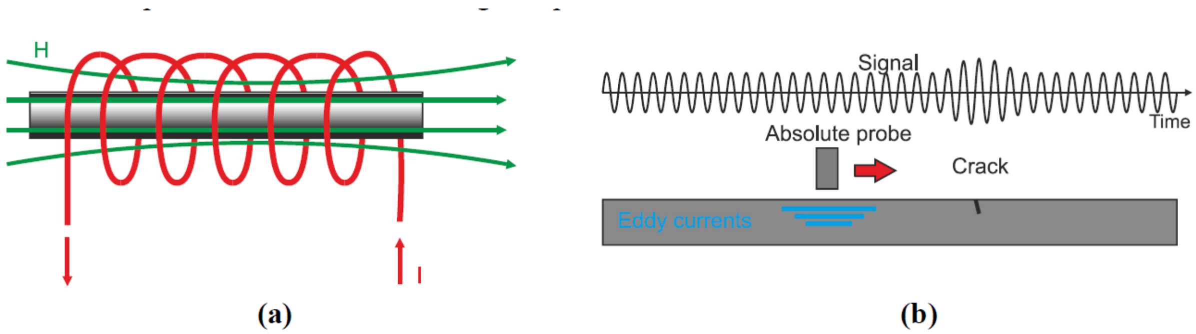


Figure 1.9 (a) Non-compensated absolute encircling coil probe. (b) Absolute signal from non-compensated absolute encircling coil probe when a cracked bar is tested. [2]

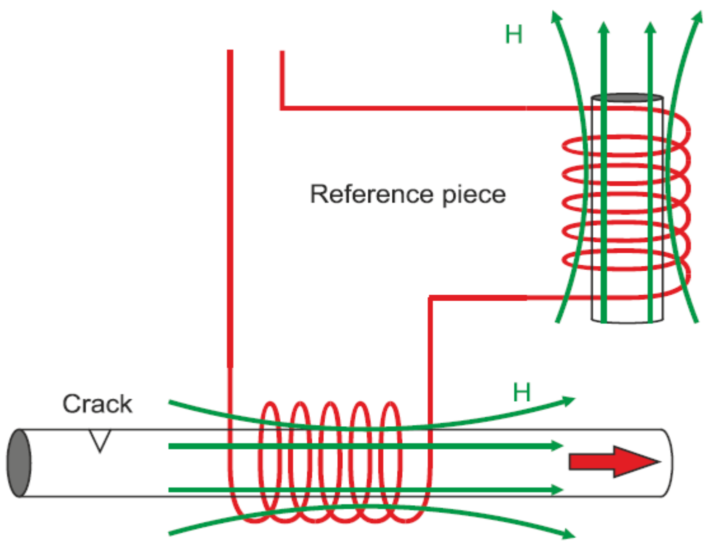


Figure 1.10 Compensated absolute encircling coil probe.

1.5.5 Differential mode probes:

Differential probes consist of two coils that compare two adjacent parts of the inspected material as Figure 1.11(a) and Figure 1.11(b) show. [2] The detecting coils wound in the opposite directions to one another in order to equalize the induced voltages originated by the excitation primary field as Figure 1.11(a) illustrates. [2] The output voltage of the differential coil probe is zero when there is no crack inside the probe as Figure 1.11(c) illustrates. [2] Cracks in the test material, which moves at a constant speed, alter the balance, and two pulses in the voltage signal detected as Figure 1.11(c) shows. [2] Differential coils have the advantage of being able to detect very small discontinuities. However, differential coils do no detect gradual dimensional or composition variations of the test piece, as the coils are typically very close. [2]

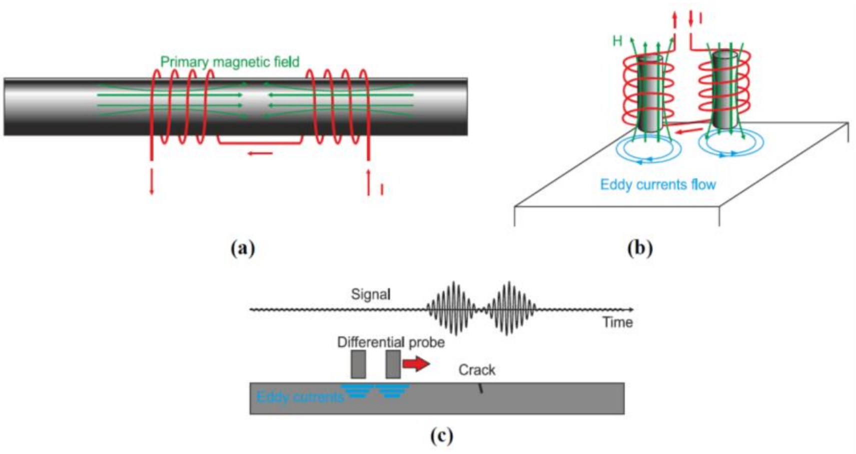


Figure 1.11 Differential mode probes

1.5.6. Penetration depth parameter:

The density of induced eddy current decreases exponentially from the surface with depth into the specimen. The standard depth of penetration is the depth from the surface at which the eddy current strength has dropped to 37% of the value at the surface [7].

Penetration depth defined as:

$$\delta = \frac{1}{\sqrt{\pi f \ \mu\sigma}}$$

δ: Skin depth.

f: Excitation frequency.

μ: conducting material permeability.

σ : conducting material conductivity.

1.6 Application of eddy current testing:

Eddy current testing has a wide variety of application. We will mention the most of them.

1.6.1 Characterization of the microstructure state:

Using the absolute probes can measure the physical parameter by the impedance witch is related to the electrical conductivity and magnetic permeability of the test piece. [2] The eddy current testing permits heat damage detection and heat treatment control using the relation between the hardness and the electrical conductivity and magnetic permeability variables. [2]

1.6.2 Metallurgical industry:

Many researcher and manufacturers that they found solutions for extra fine wire of tungsten and molybdenum testing up to 10 m/s such as the author stander. [2] And in the field of transportation the researcher pohl have proposed railroad testing at the speed 70km/h. [2]

1.6.3 Production lines:

In the production line, there is tow type of defects periodic and random defects. [2] Random defects may indicates poor overall quality of the material. [2] Some researchers devise techniques based on FFT technique for detecting the periodic defects that generated by damage rollers or guide rollers. [2] The cracked rollers can revealed by calculating the speed of the roller and the size of their rolled wire. [2]

1.6.4 Residual stresses in structure engineering:

The eddy current can provide early indications of stress status and eventual failure by coil probes that can detect small stress variations in ferromagnetic steels due to the magneto-elastic effect based on the measurements of changes in impedance. [2]

1.7 Conclusion:

Nowadays the destructive or none destructive testing techniques used widely to control the quality of the product but the destructive techniques verifies only samples that destroyed unlike the non-destructive techniques are very efficient on the industry because they verify the product without any permanent damage. There is many none-destructive techniques and they use many technologies ultrasound, laser, electromagnetic, radio frequencies ...etc. this give the widely using of this techniques on many fields in the industry. The eddy current testing is one of the most popular testing of the NDT and it’s widely used in the industry field to test the pipeline, tubes, bars …etc. and this widely using because of the huge number of probes for this techniques and this sensors are easy to use and they don’t take big space.

Chapter II Non-destructive testing using CNC machine

2.1. Introduction:

NDT testing methods its useful on many industry fields for scanning ferromagnetic and non-ferromagnetic parts or product to ensure the best status and quality. To ensure the quality of these tests there is many ways to take as solution depends on the materiel of test pieces (ferromagnetic, non-ferromagnetic) and the form (Plate, Tube …). One of this solution it is the CNC machine solution, which can scan many types of the test pieces on the form and the materiel by carrying the NDT sensor and scan a specified area that contains the test pieces. there is huge number of the CNC machine and each one are different to the other such as CNC milling machine, CNC lathes, CNC routers and more.

2.2. Definition of CNC:

CNC (Computer Numerical Control) machine are computer-controlled machine tools, before CNC machine were mainly controlled. CNC is that the computer controls servos operate the machine [13]. The CNC starts during the cold war when the US navy commissioned Parson Company to increase the productivity of its production line for helicopter blades, for that Parson motorised the axes of the machines to make these blades, and starts working with IBM to study the possibility of controlling the machine-using computer. The commercial birth of the CNC technology was in 1958 when Richard keg field a patent for "Motor controlled apparatus for positioning machine tool "[14]. The main idea of CNC is that a dedicated computer used to execute program stored in the computer memory this system directs commands to the drives of servos and motors, solenoids, etc. this drivers will initiate the operations such as motor stop and run, coolant on and off. To ensure the completion of specified function a "Feed Back Device" is used these devices such as encoder, proximity sensor, resolver, etc. ensure the monitoring the work of the CNC machine [15].

2.3. CNC Machine Block Diagram:

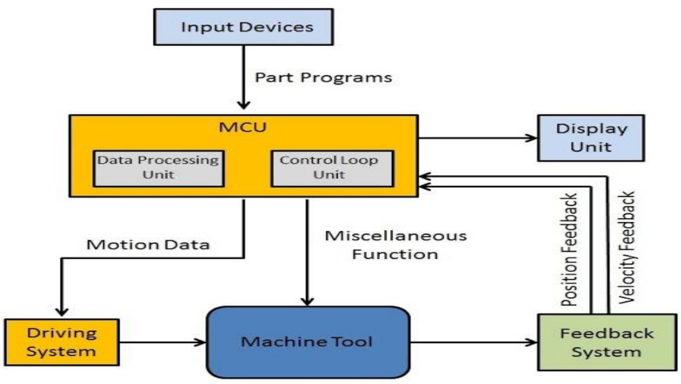


Figure 2.1 CNC machine Block diagram [4]

2.4. CNC main parts:

There is lot types of CNC machines in the industry field, and these types have common main part, there is six main parts of CNC machine according to the Block Diagram.

2.4.1. Input Devices:

These devices used to input the programme part on the CNC machine MCU, there is three commonly used input devices computer via RS232 cable, Punched tape reader and magnetic tape reader [16].

2.4.2. Machine Control Unit (MCU):

This part is the heart of the CNC machine because it is the part that perform all the controlling action of CNC machine it has various actions:

- ✓ Reading the code instruction fed into it by input device.[16]
- ✓ Decoding the code instruction.[16]
- ✓ Implementing interpolation (linear, circular, and helical) to generate axis motion commands.[16]
- ✓ Feeding the axes motion commands to amplifier circuit for driving axes mechanism.[16]
- ✓ Receiving the feedback signal of position and speed for each axes.[16]
- ✓ Implementing auxiliary functions such as coolant on/off, tool change.[16]

2.4.3. Machine tool:

CNC machine tool always has slide table to control the speed and position for the X and Y-axes and it has spindle to control the speed and position for the Z-axes. [16]

2.4.4. Driving system:

The CNC machine driving system consist of amplifier circuit, drive motors. The MCU feeds the position and speed signals of each axes to the amplifier circuit and then these signals amplified to actuate the motors. Moreover, the actuated motors rotate the ball lead screw to position the machine table. [16]

2.4.5. Feed Back System:

This system consist of speed and position sensors, these sensors monitor continuously the axes position and speed. The MCU receive this signals and compare it to the reference for correcting the speed and position errors. [16]

2.4.6 Display Unite:

A monitor it used to display the programs, commands and useful data of the CNC machine. [16]

2.5. CNC Machine Advantages:

CNC offers the following advantages on manufacturing:

- ✓ Productivity increasing.[16]
- ✓ Higher flexibility.[16]
- ✓ Consistent quantity.[16]
- ✓ Reduced scrap rate.[16]
- ✓ Fewer workers are required to operate a CNC.[16]

2.6. CNC Machine Disadvantages:

Even the CNC machine have many advantages but it have some disadvantages:

- ➢ Very high cost compared by mainly controlled machines.[16]
- ➢ The parts of the CNC machine are expensive.[16]
- ➢ Quit high cost of the maintenance.[16]
- ➢ It does not eliminate the need of the costly tools.[16]

2.7 CNC Machine Applications:

The CNC machine it used in many industry fields, and the demand for CNC usage has increased largely. The industries that are using CNC machine are the automotive industry, metal removing industries, industries of fabricating metals, electrical discharge machining industries, wood industries, etc.[17]

2.8 The Practical CNC Machine Model:

The practical model of the CNC machine used for moving the (PRFEC) pulsed remote field eddy current sensor above the surface of the test piece. For that, the best CNC machine type that can do this is the CNC routers type.

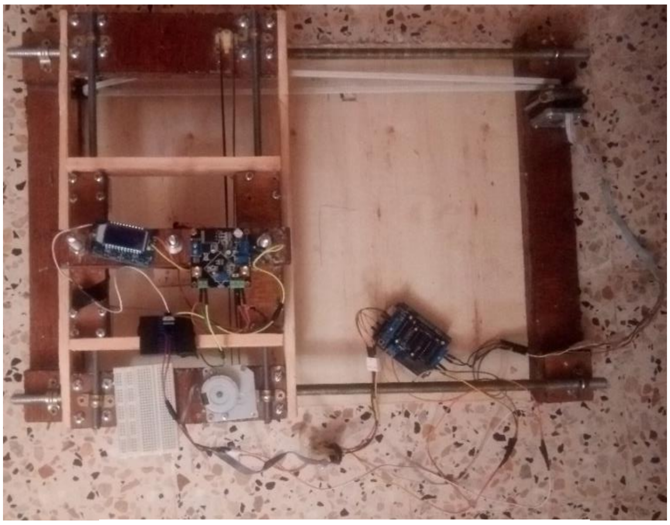


Figure 2.2 The Practical CNC machine

2.8.1 Main Parts:

Laptop: the input device of the CNC machine the laptop that used is DELL INSPIRON I3 7th gen. used with serial cable to download the programme file to the arduino and to display sensor output

Figure 2.3 Laptop input

Arduino Uno R3: the MCU of the CNC machine it’s a widely used micro-controller on many projects it can be programmed by its software application ARDUINO IDE with the C language. There is many types of the arduino such as arduino mega, due, nano, etc.

Figure 2.4 Arduino UNO R3

L293D Motor driver: driving system of the CNC machine l293d is widely used motor driver in many projects this driver contains tow l293d ICs and 74HC955 this design give the motor driver the ability to drive tow stepper motors and tow servo motors and four DC motors.

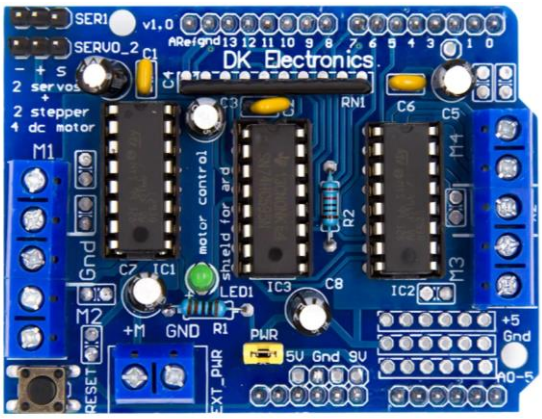


Figure 2.5 L293D motor driver

Stepper motors: the machine tool of the CNC. This CNC machine consist of two stepper motors that moving the sensor X and Y. there is many types of the stepper motors the type that used to move the X axes is RB-DFR-265 this motor is two phase motor and it have step 1.8 degree step angle and 200 step per revolution. The motor that used to move the Y axe is Epson printer (em-293) motor its two-phase motor and 200 step per revolution with step angle of 1.8 degree.

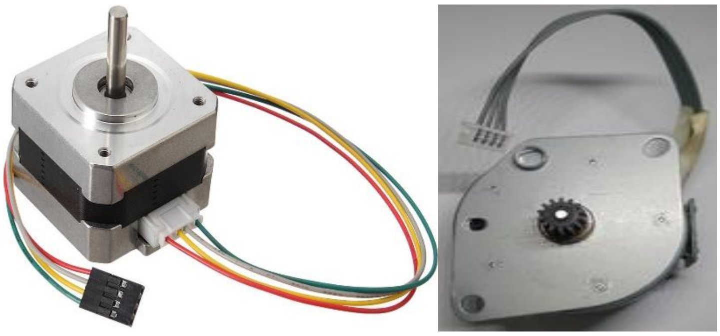


Figure 2.6 RB-DFR-256__EM

2.8.2. Working programme:

A user interface software in the pc and a driving programme in the arduino can control the CNC machine.

2.8.2.1. User interface software:

This software designed with Python programming language. The software give the ability to the user to control the CNC machine axes. This software sends the commands over the ARDUINO serial port.

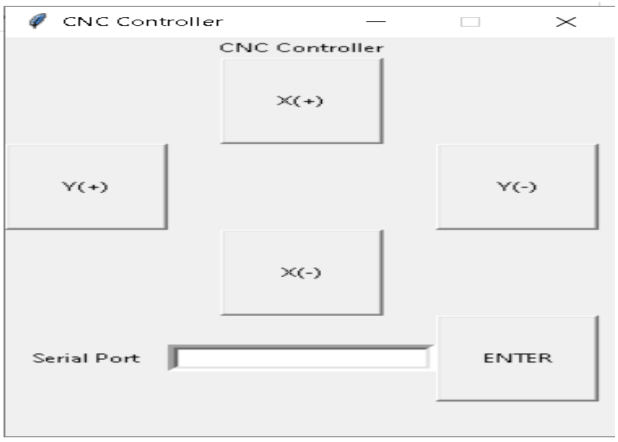


Figure 2.7 User interface Software

The software Flowchart:

First, the programme define a variable that will contain the software serial port. After that when the user type the port on the textbox and press enter the programme will check if there is a port typed on the textbox or no, if not will appear a dialog message asking for serial port and if there's a serial port it will add the port to the serial object (SER). Moreover, if the user pressed the button X+ the programme will check if there is a serial port if there is a serial port the programme will send X+ character on the serial port using the serial port object (SER). Moreover, if there is no serial port the programme will appear a dialog message asking for port and it will back to the first test. Moreover, the same steps will repeat for X- , Y+ and Y- buttons.

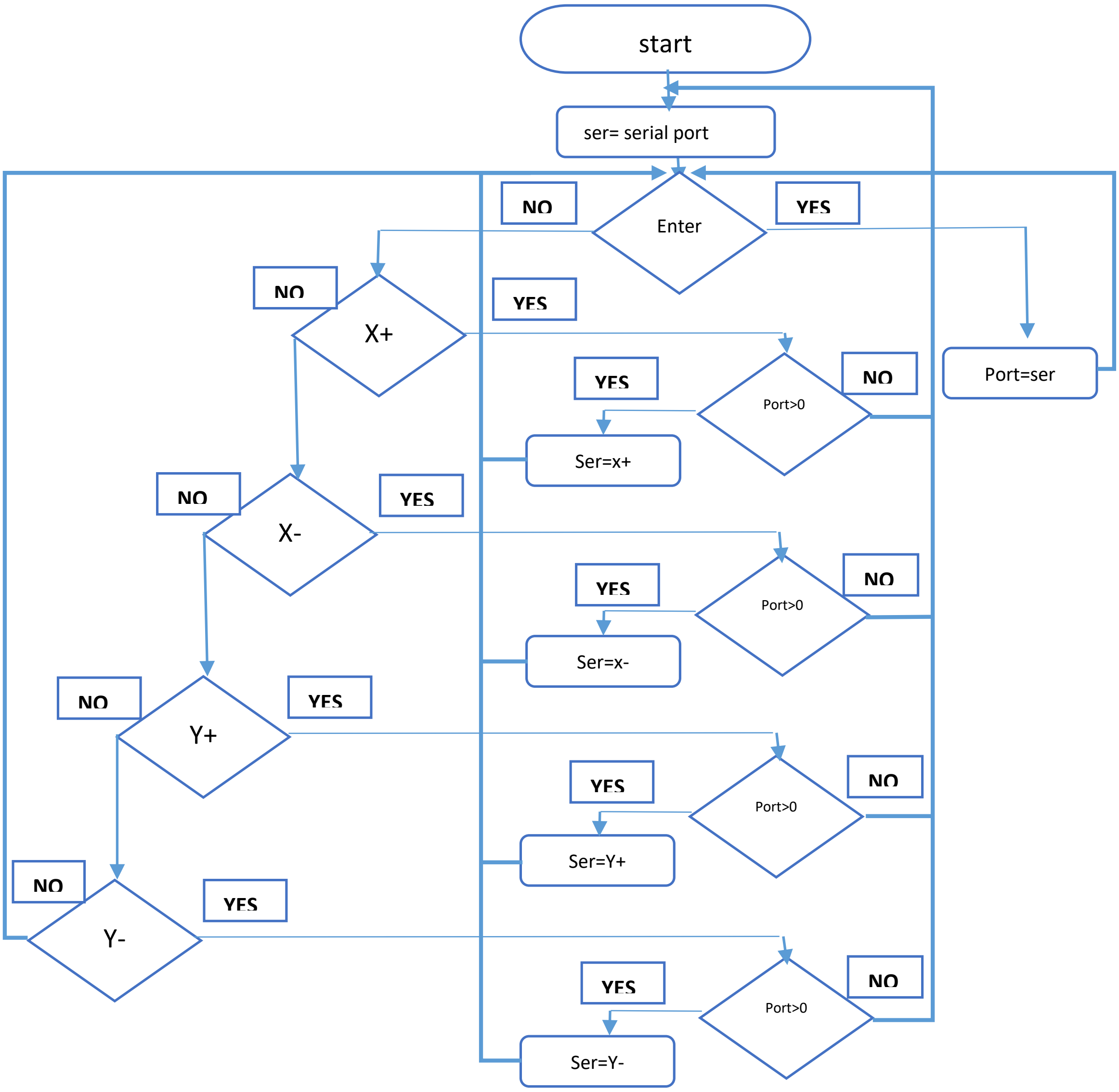


Figure 2.8 User interface software Flowchart

2.8.2.2 Arduino programme:

This program of the ARDUINO reads the commands that sent by user interface software over serial port and it would send commands to the L293d motor driver to move the axes of the CNC machine.

Arduino Program Flowchart:

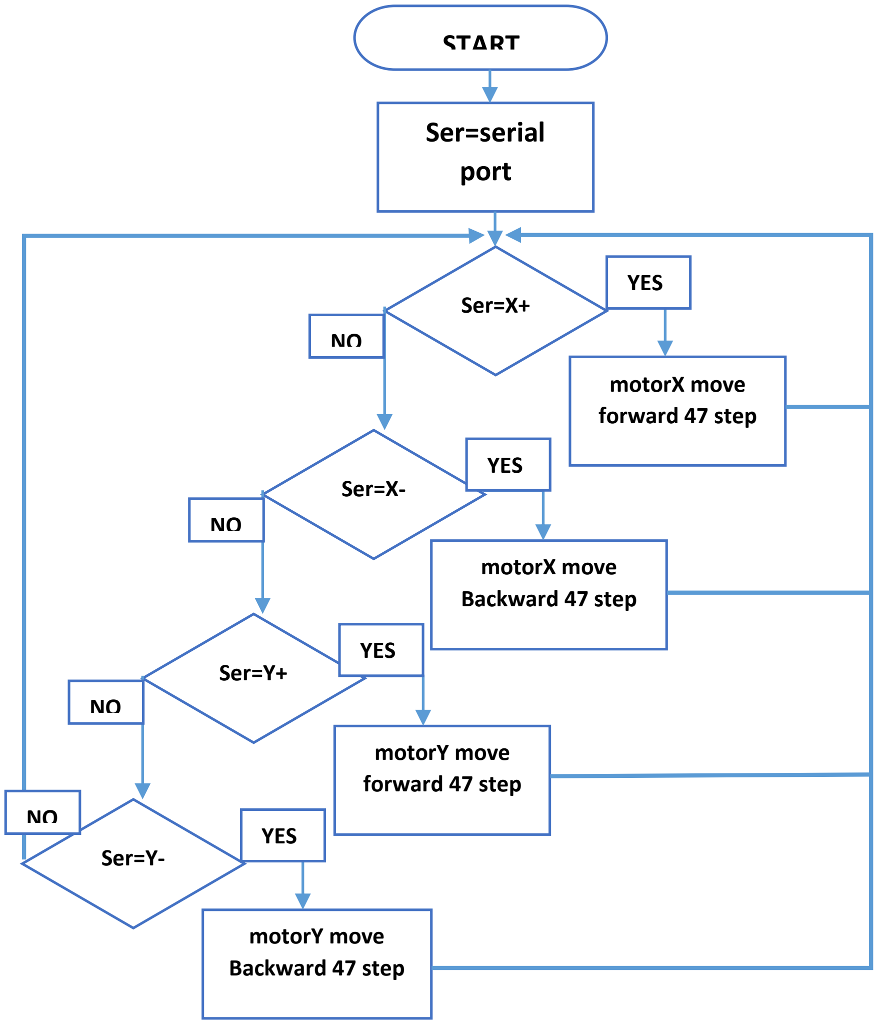


Figure 2.9 Arduino program flowchart

Firstly, we declare a variable (SER) that contain the information readied from the serial port. Secondly, we will check the character that contained in the variable SER if it x+ the X axe motor will move forward by 47 steps and if it x- the motor will move backward by 47 step. Moreover if the character is y+ the Y axe motor will move forward by 47 step and if it y- the motor will move backward by 47 step.

2.8.3. Specifications:

The specification of this CNC machine mentioned in the table below:

Operating Voltage V_{OP}	12V
Current consumption $\mathbf{I}_c$	700 mA
Scanning area	30cm for X axe 10cm for Y axe (300cm^2)
Scanning speed	150 rpm

Table 2.1 CNC machine specifications

2.9. Conclusion:

According to the widely use of the CNC machine and its advantages in many industry fields such as automotive, metal shaping, etc. In addition, the important of using non-destructive testing in many industries. All this made the devices that designed with CNC machine and non-destructive testing a very helpful because it will reduce the workers of non-destructive testing and it will reduce the time of scanning. In addition, increasing the scanned test pieces number increasing the scanning precision that what will make the scanning quality better than the mainly scanning.

Chapter III Sensor design and result analysis

3.1. Introduction:

Rapid technological developments in the field of science and technology over the last Couple of decades have resulted in a tremendous demand to for new NDE techniques that. Are efficient, reliable and economical to use in sensitive industrial field such as Aviation, nuclear and many other industries that utilize critical components requiring high reliability and structural integrity [18] .The failure to detect defects that may lead to the structural failure of critical components could prove to be catastrophic. one of the most commonly used non-destructive testing techniques is Eddy-current testing (ECT) , which defined as technique for inspecting electrically conductive materials at very high speeds without requirement of any contact between the test piece and the sensor. This technique is used to detect defects (cracks, corrosion, etc.) in conducting materials [19].The field of eddy-current (EC) non-destructive evaluation (NDE), beginning with Faraday's discovery of the law of electromagnetic induction following the discovery of electromagnetic induction [20]nearly 50 years elapsed before Further experiments suggested a path toward practical application of the phenomenon In materials testing. David Edward Hughes (1831–1900) was a Welsh experimental Scientist and accomplished musician. He conducted some important experiments of Relevance to EC NDE in 1879, when he showed that the properties of a current carrying Coil changed when the coil placed in contact with metals of different conductivity and permeability. Here, lies the foundation for identification of metals and alloys by eddy-current testing. The researchers in this century discover new eddy current technique that prove Haigh sensitivity to cracks , this technique called remote field eddy current break through the limits of eddy current method such as skin effect and signal strength ,but steel a Haigh energy consummation technique with long testing time and less information about defects profile.

To breaks through those problems the researcher proposed a pulsed excitation as enhancement in remote field eddy current technique, pulsed remote field eddy current show higher sensitivity and detectability of different crack parameters [21] moreover a low energy consummation [22].

3.2. Pulsed remote field eddy current sensor design with multilayer shielding structure:

The main and the most difficult phase in the eddy current NDT is the probe design, its combinations between the electrical and the magnetic field analyses, and properties. How to design a sensor with appropriate, exciting coils and pick _up coils is critical to the sensitivity of pulsed remote field eddy current testing, in this article we designed a pulsed remote field eddy currents probe with multilayer magnetic shielding structure based on energy shielding theory. The excitation coil and the pick-up coil in this structure are both coaxial. This reduces the size of the probe, which improve the resolution. The shielding structure adopted has the advantage that the shielding material is not required to be the same as the testing material. Thus it provides potential ability to expand in wide application with much deeper penetration depth especially for ferromagnetic material, besides, the pulse excitation with a wide range of spectral components give the proposed sensor the potential to inspect a range of depths simultaneously [21] and, therefore, it will be able to offer more information about defect profile.

3.2.1. Sensor design:

The sensor is tow coils in coaxial shape with parameters shown in Table 3.1, and shielding structure proposed in figure 3.1.

	driver coil	Pick-up coil
Inner diameter (cm)	2	3
Outer diameter (cm)	2.4	4
Number of turns	400	1000
Height (cm)	3	3
Wire conductivity σ (S/m)	5.96×10^{7}	5.96×10^{7}

Table 3.1 the proposed sensor parameter

Figure: 3.1 the proposed shielding

3.3. Experimental Study:

In order to prove that the sensor is valid for generating RFEC phenomenon and find the appropriate operating parameters as excitation amplitude, pulse width, excitation frequency. In this study, the focus was in the detectability on cracks of height in ferromagnetic material the block diagram of materials used in this paper shown in Figure 3.2.

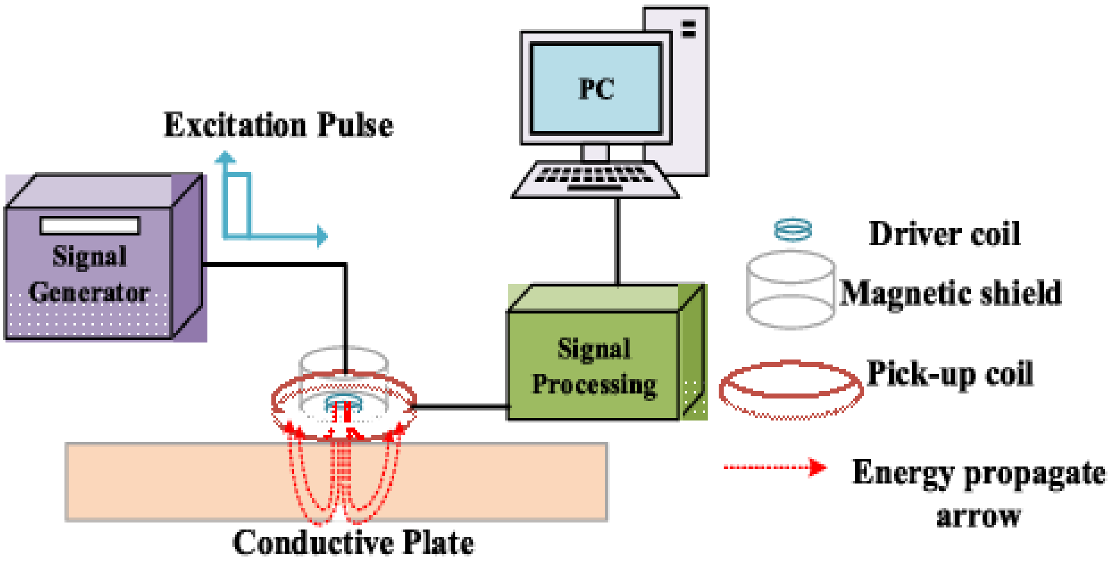


Figure 3.2 the block diagram

3.4. Experimental validation:

The experimental validation of this study performed with two coaxial coils as a driver and pick-up coil and the dimension described in table 3.1.

The system includes PWM generator, oscilloscope, a specimen of steel has 8slots located in the front side which simulates the surface cracks, the 8slots are 1mm width with different depths,1mm,2mm,3mm,4mm,5mm,6mm,7mm,8mm as shown in figure 3.8.

An AD620 instrument amplifier module determined as the signal processing circuit for this system. The amplifier and the PWM generator powered by a 15V 2A lab power supply, the driver and pick-up coil connected as shown in figure 6.a, the appropriate amplitude of the exciting pulse is 5V [22], the cycle is 100ms with a 1ms pulse width (1% duty cycle). This experimental study analyzed in the first part the impact of excitation frequency, duty cycle and the lift-off on the sensor signal strength and sensitivity. In addition, the detectability of different crack height in the second part.

3.4.1. Experiment platform:

The coronavirus situation forces ass to work on the sensor with the minimum of equipment that we could provide.

3.4.1.1 HANTEK 1008C 8Channel Diagnostic PC Digital Oscilloscope:

Hantek 1008c is a 8 channels oscilloscope for vehicle testing with 2.4MSa/s real time sampling rate 12 bits vertical resolution. Spectrum analysis function, DAQ card function USB 2.0 interface plug and play, and no need extra power supply and Input Sensitivity from 10mV/div to 5V/div. 1008c is perfect for our measurements it can measure:

Voltage Measurement: Vpp, Vamp, Vmax, Vmin, Vtop, Vmid, Vbase, Vavg, Vrms, Vcrms, Preshoot,Overshoot.

Figure: 3.3 *HANTEK 1008c oscilloscope*

Time Measurement: Frequency, Period, Rise Time, Fall Time, Positive Width, Negative Width, Duty Cycle.

3.4.1.2. AD620 Instrumentation Amp Module:

This device uses an AD620 as an amplifier that is capable of amplifying small voltage signal (e.g. µV) AC or DC. By adjusting the on-board potentiometer, the magnification can beadjusted to go as high as up to 1000 times This module has a low voltage offset, great linearity, and also, an adjustable zero potentiometer to improve its accuracy figure 3.4.

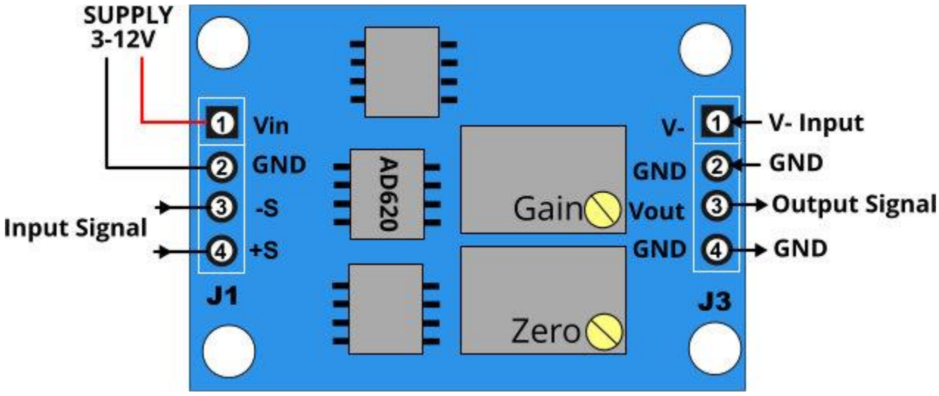


Figure: 3.4 AD620AMP MODULE PINS

3.4.1.3. PWM generator:

The XY_LPWM style PWM Signal Generator Module combines an accurate 0-150kHz output frequency range and 0-100% duty cycle, with pushbutton controls and LCD display that shows frequency and duty cycle, 3-30V operation and output pulse amplitude, 5-30mA maximum current output, Serial TTL interface, 3.3V logic compatible. All this features make this module

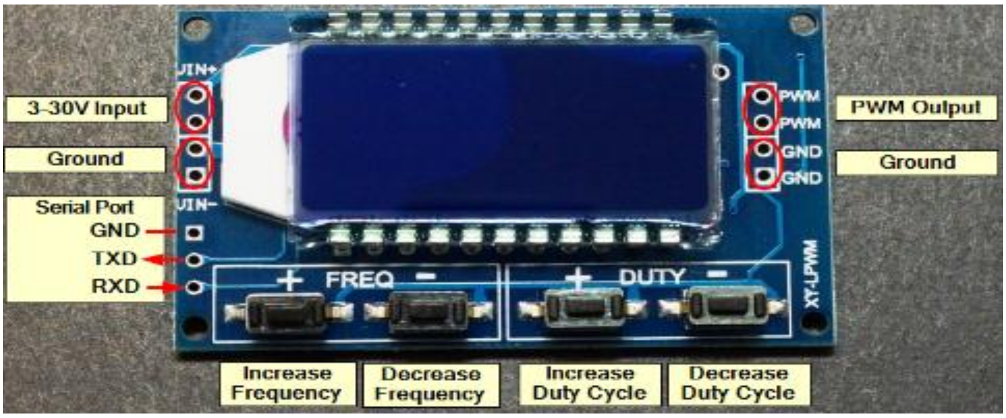


Figure: 3.5 *XY-LPWM generator module (proto*

great choice for conducting experiments, testing and controlling devices that require a PWM input. Having the display and simple pushbutton interface makes it easy to set. Adding an output driver allows it to drive motors, solenoids, servos, dim LEDs and other pulse applications.

3.4.1.4. Power supply ps-1502d+:

Ps-1502d+ adjustable digital dc power supply 15v 2A Laboratory Switching Power Supply 220v, rated output voltage 0-15 v, rated output current 0-2Amp, power 15w, Header display resolution: 2.5% Ripple, noise: <0.5mVRMS,Recovery function cutoff protection,0.6-2A protection current, with LCD voltage and current display and its High precision this device is perfect for our testing.

Figure: 3.6 power supply ps-1502d+

3.4.1.5. Personal computer:

We use dell inspiron personal computer with Intel i3 7th generation processor as a visualization unite for the processed information coming from the hantek 1008c oscilloscope with visualization interface of the hantek 1008c.

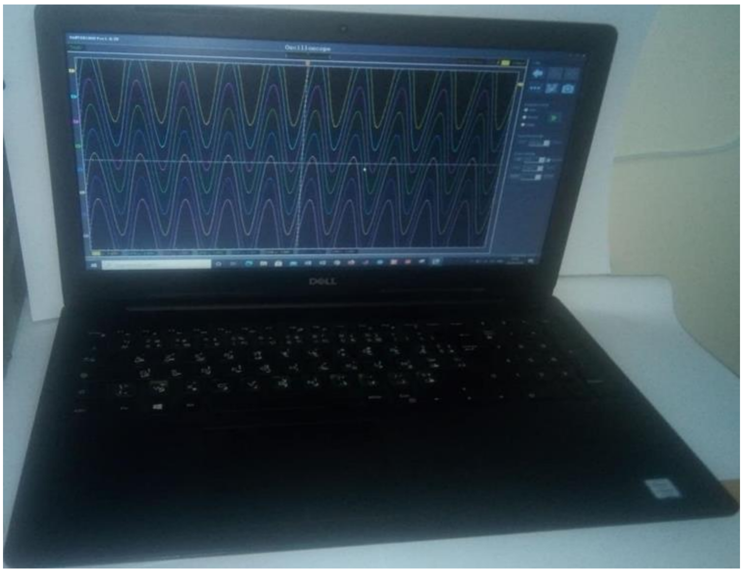


Figure: 3.7 *visualization unite "personal computer"*

3.4.1.6. The test specimen:

The inspected specimen is 445x60x10 mm piece of aluminum/steel with group of defects as shown in figure 3.8 .the defects are in different height from 1mm to 8mm.

Figure: 3.8 *the inspected specimen*

3.5. Experimental result analysis:

3.5.1. The impact of different excitation amplitude:

The figure (13, 14, and 15) shows the pick-up voltage when applying different excitation amplitude (5, 10, 12 volts) respectively, to determine which excitation amplitude is appropriate for the proposed design. We note that the best pick-up voltage appears at an excitation amplitude of 12 volts, but through experiments it appears that, the excitation amplitude 12v is not suitable when applying a frequency of 100 Hz, while voltage 5 shows better results, through either stability or the detectability of the crack

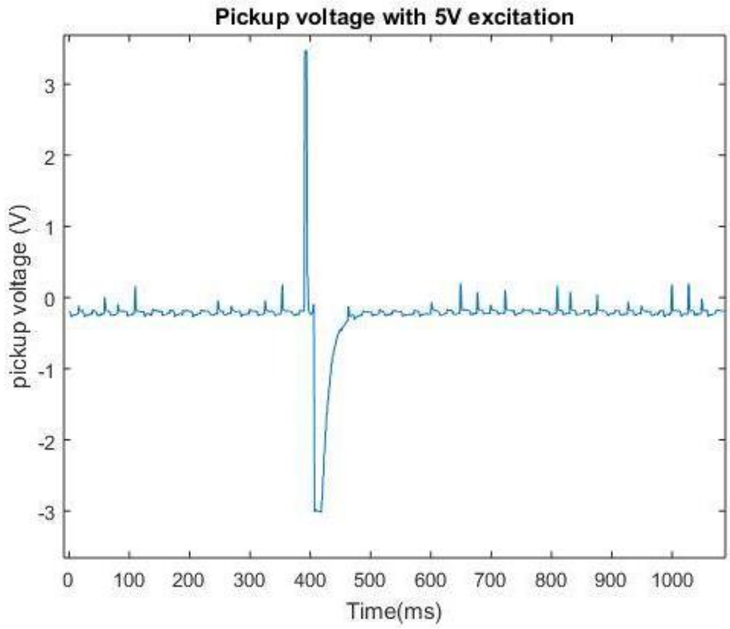


Figure 3.9 pickup voltage 5v

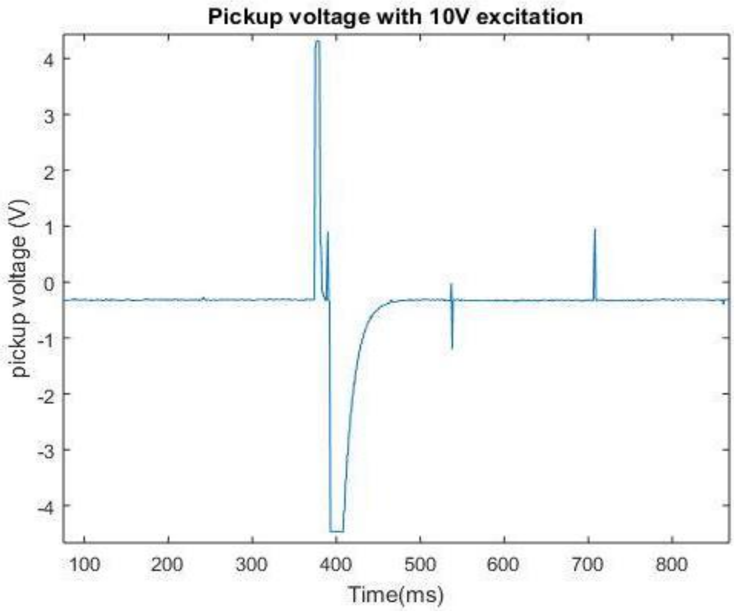


Figure 3.10 pickup voltage 10v

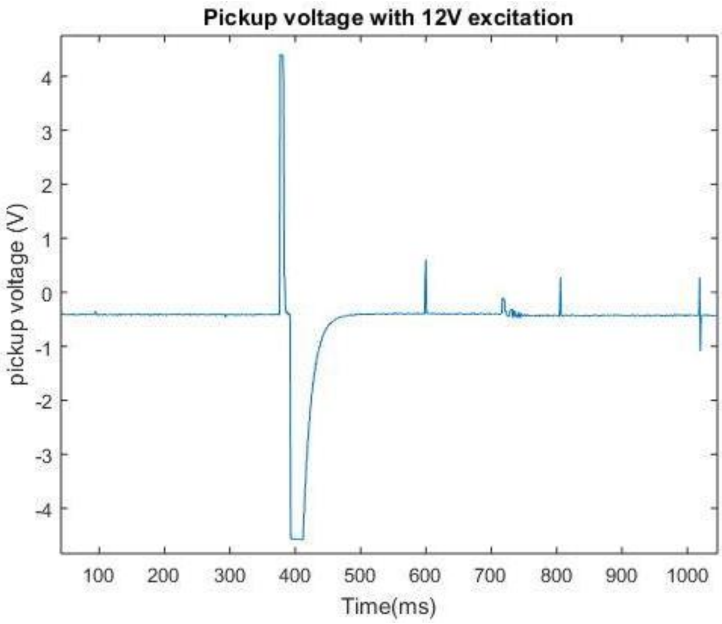


Figure 3.11 pickup voltage 12v

3.5.2. The impact of the excitation frequency and duty cycle:

The excitation frequency is one of the important parameters in the inspection, in this test we fix the duty cycle in lowest value 1%, the pulse excitation amplitude on 5V and varying the frequency (10, 20, 50, and 100).

Figure 3.12 shows the pick-up signal under different frequency; from the figure 3.12 pick-to-pick time increase with the decrement of frequency, the shorter the pick-to-pick time, the faster the inspection, which means that the best frequency is the one that produces the least time, which is the frequency 100 Hz.

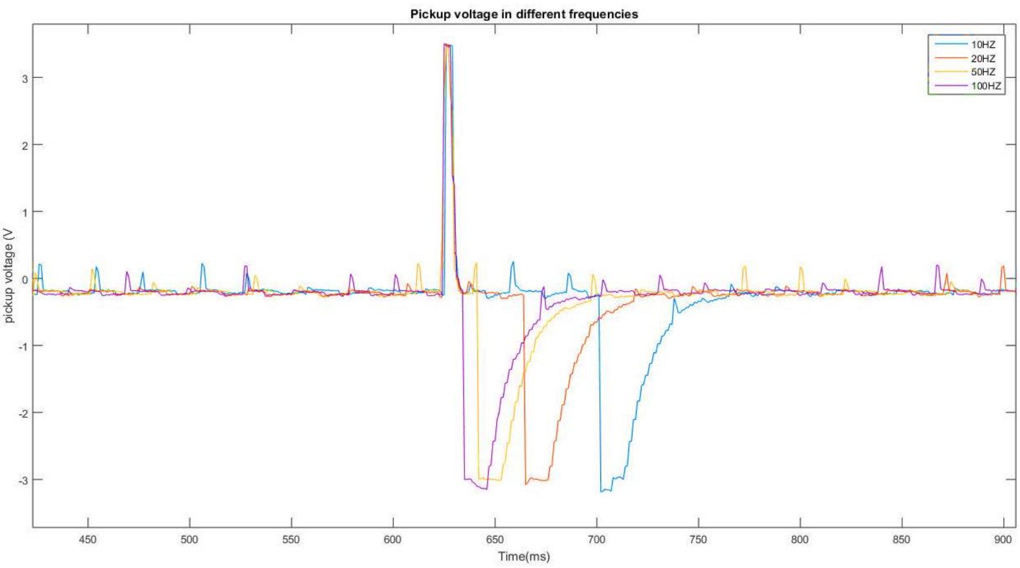


Figure 3.12 pickup Signal in different frequencies

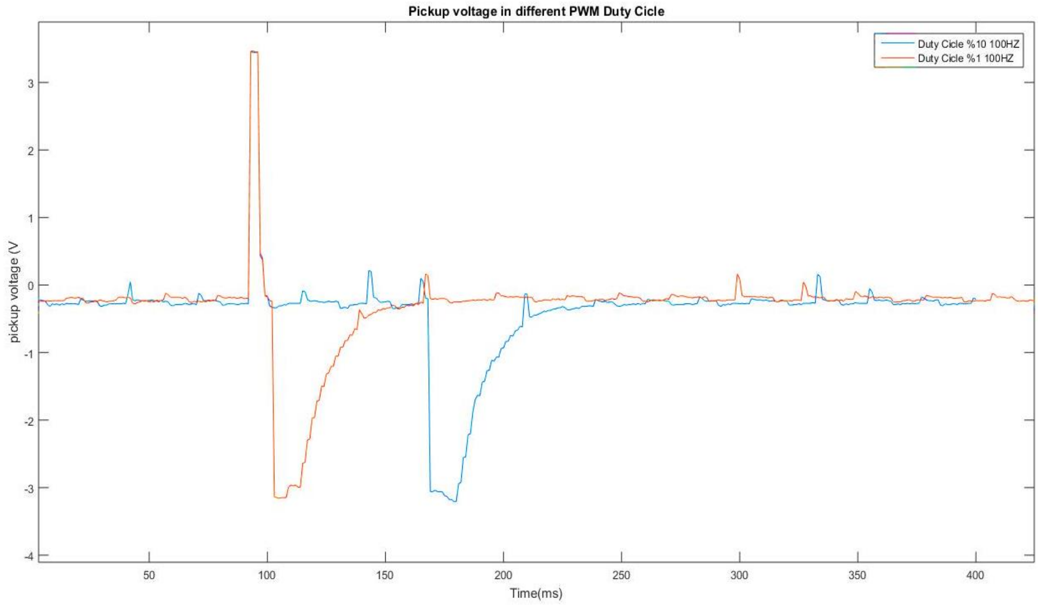


Figure 3.13 pickup Signal in different

The figure 3.13 represent the response of the pickup signal to different pulses. Duty cycle [1% and 10%] with 5V in amplitude and 100 HZ excitation frequency. We observed through this experimental study that the 1% pulse duty cycle provides a more stable signal that enables us to process the information through more simple equipment, while the more the duty cycle increases the noise rate.

3.5.3. Lift-off influence:

Through changing of the lift-off ranging from 3to 18 mm with a step of 5mm, we analyze their influence on the output voltage of the pick-up coil. The experimental results for lift-off influence on pick-up voltage are shown in figure 3.14, as can be seen, there is maximum pick-up voltage when lift-off is 3mm and minimum voltage when lift-off is 18mm. Through figure 3.14, we can determine a linear relationship between the pick-up voltage and the lift-off.

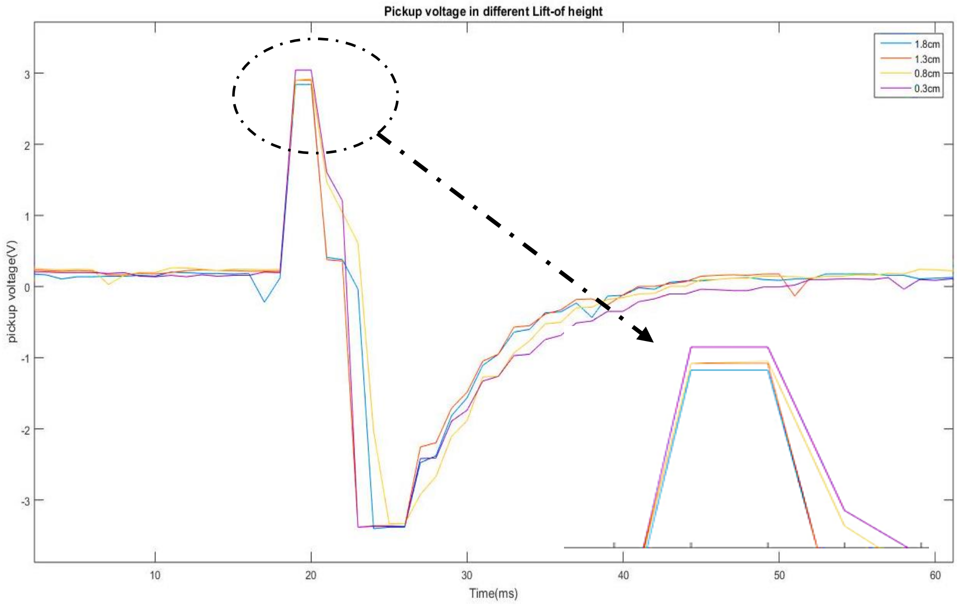


Figure 3.14 pickup signal in different lift

3.5.4. The influence of different defects height on the pick-up voltage:

The defect height is a reference parameter that proves the PRFEC sensor sensitivity limits; we inspect eight surface defects with a different high from 1mm to 8mm with 1mm step. The results shown in figure 3.15 indicate increment in pick-op voltage when increase the defect height, a preferable linear relationship observed between the defect height and pick-up voltage and the sensor is sensitive to 1mm changing in high this means high sensitivity.

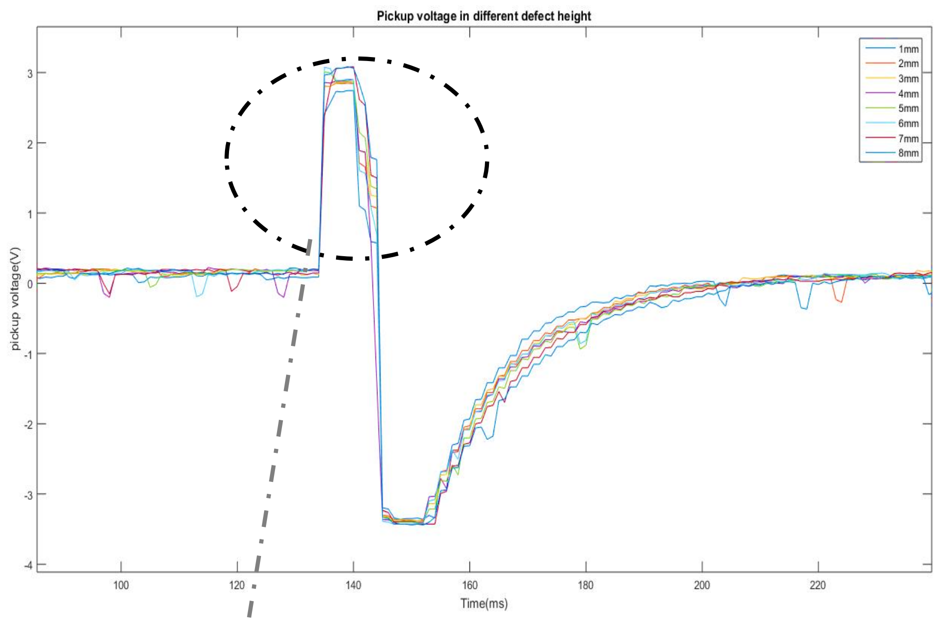
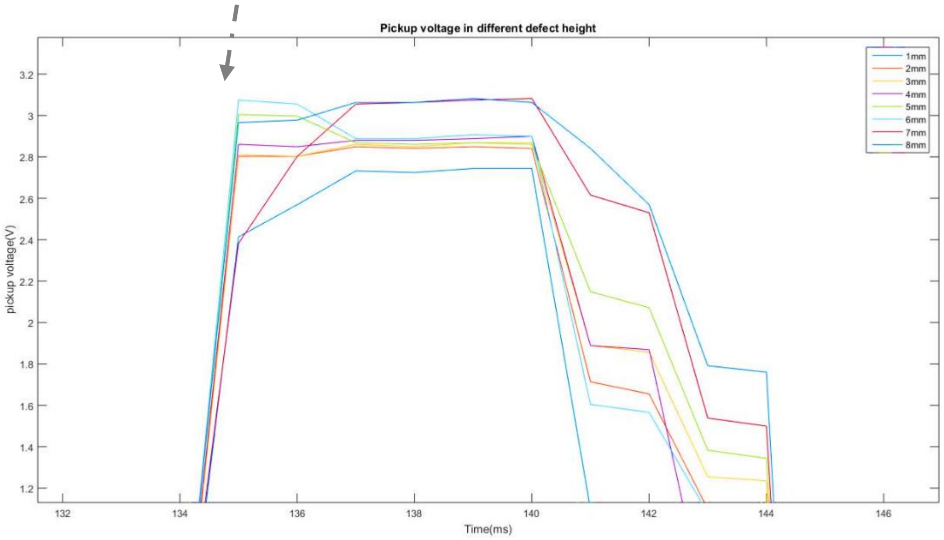


Figure 3.15 pickup signal in different defect height



3.6. CONCLUSION:

In this chapter, we have discussed the eddy current testing method as an effective method in the field of nondestructive testing. And as a technique to break through the limits of skin effect and the weak penetration depth using the proposed pulsed remote field eddy current sensor with multilayer shielding structure that based on the magnetic shielding theory to achieve RFEC phenomenon in a plate. The experiment study showed that the excitation frequency and pulse amplitude are substantial for the stability and sensitivity of the pick-up signal proves a linear relationship between the lift-off and sensor sensitivity. A set of surface cracks with different heights are tested and validated by using the proposed sensor and evidenced that all works have good reaction among the response.

General conclusion

General conclusion:

The non-destructive testing is a field that is developing every day to meet the needs of the industrial world by providing technologies and sensors that overcome the physical obstacles related to the nature of the materials that machines parts made from and their complex structure that may limit the effectiveness of these technologies in this work. We proposed a pulsed remote field eddy current sensor with multilayer shielding structure hanged on router CNC machine that assure the moving of the sensor above the test specimen in X, Y and z-axis, which used to control the lift-off of the sensor. The sensor moved above a test sample marked by eight cracks with depths from 1 to 8mm. The sensor validates with a different excitation amplitude (5, 10, 12 volts) and different excitation frequency (10, 20,50and 100 HZ) and duty cycle (1%and 10%). After the analysis of the results, we found that the best parameter for our sensor is (5v, 100Hz, 1% duty cycle). The Variation in lift-off related to the response signal sensitivity with a linear relationship, the sensor reach to maximum sensitivity when lift-off equal to 3 mm. The proposed sensor detect cracks with different depths up to 8 mm with high sensitivity. We focused on the amplitude of the detection signal, which increase its amplitude with the increasing of the crack depths. This linear relation between the crack depth and the amplitude of the output signal was impressive Compared to the tools that were available to us. We witches to develop this sensor with high standards to be more stable and flexible. We witches to develop a CNC machine and Pulsed remote field eddy current sensor system using artificial intelligence to be able to detect and recognize the cracks on the sample and give the detailed information about it (its location, depth)

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ABSTRACT:

Non-destructive testing has a large number of techniques, with different characteristics, advantage and limitation a make the NDT a fertile field for scientific research. Pulsed remote field eddy current technique has utilized broadly in the detection of tubular structures because it proves good results with minimum requirements. a novel PRFEC sensor design is proposed with coaxial coils shape and simple signal processing circuits, this sensor moves by a CNC machine on X-Y and Z-axis in order to automate the inspection and enhance the stability of the sensor. A number of experiments with different values of lift-off, duty cycle, excitation amplitude, excitation frequency and with different defect depths have carried out. The results show a deep penetration depth up to 8mm with high sensitivity where it can differentiate between cracks with 1mm difference in-depth, the designed sensor proved a good detectability .

ملخص:

يحتوي مجال الاختبارات غير المدمرة عددا كبيرا من التقنيات والتي تختلف من حيث المميزات والمعيقات ما يجعل منه مجالا خصبا للإبداع والبحث العلميين .استخدمت تقنية التيار الدوام النبضي للمجال البعيد على نطاق واسع في اختبار الهياكل الأنبوبية لما أثبتته من نتائج جيدة مع استهلاك أقل للمصادر بالمقارنة مع التقنيات الأخرى

صممنا مستشعر جديد يعمل بتقنية التيار الدوام النبضي للمجال البعيد يتكون من ملفين متحدي المحور ودوائر بسيطة لمعالجة الإشارة محمولا بواسطة آلة تصنيع ذات تحكم رقمي ذات محور تحريك ثلاثي الأبعاد وهذا لتعزيز ثبات المستشعر وأتمت عملية الاختبار .تم إجراء عدد من الاختبارات من خلال تغيير إعدادات إشارة الإدخال كالسعة والتردد والدور لمعرفة الإعدادات المناسبة ثم تمَّ اختباره على شقوق ذات أعماق مختلفة .أظهرت النتائج أن هذا المستشعر له عمق اختراق للعينة يصل إلى ثمانية ملمتر مع حساسية استشعار قوية حيث يستطيع اكتشاف فرق واحد ملمتر بكل سهولة ودقة.

Index Terms :

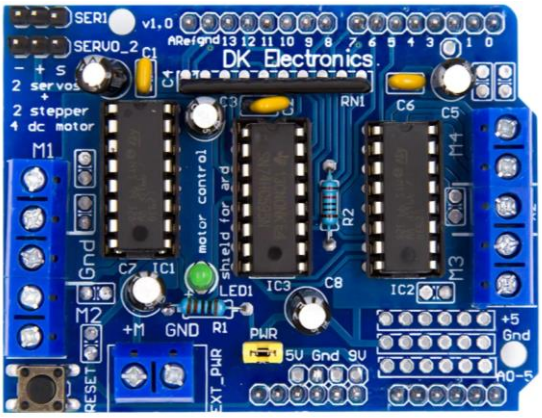
non-destructive testing ,remote field eddy current ,pulsed remote field eddy current ,Computer numerical control ,Pulse width modulation ,The height of the sensor from the test piece (**Lift-OF)**

Annex

Arduino uno R3 :

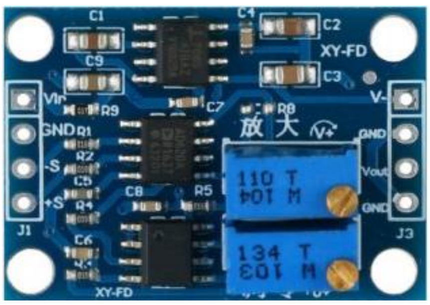
- Microcontroller ATmega328
- Operating Voltage 5V
- Input Voltage (recommended) 7-12V
- Input Voltage (limits) 6-20V
- Digital I/O Pins 14 (of which 6 provide PWM output)
- Analog Input Pins 6
- DC Current per I/O Pin 40 mA
- DC Current for 3.3V Pin 50 mA
- Flash Memory 32 KB (ATmega328)
- SRAM 2 KB (ATmega328)
- EEPROM 1 KB (ATmega328)
- Clock Speed 16 MHz

L293d motor driver:



- Two connections for 5V 'hobby' servos connected to the Arduino's high-resolution dedicated timer - no jitter!
- Up to 4 bi-directional DC motors with individual 8-bit speed selection (so, about 0.5% resolution)
- Up to 2 stepper motors (unipolar or bipolar) with single coil, double coil, interleaved or micro-stepping.
- 4 H-Bridges: L293D chipset provides 0.6A per bridge (1.2A peak) with thermal shutdown protection, 4.5V to 25V
- Pull down resistors keep motors disabled during power-up
- Big terminal block connectors to easily hook up wires (10-22AWG) and power
- Arduino reset button brought up top
- 2-pin terminal block to connect external power, for separate logic/motor supplies.

AD620 instrument amplifier:



1. Easy to use

- Gain set with one external resistor (Gain range 1 to 10,000)
- Wide power supply range (±2.3 V to ±18 V)
- Higher performance than 3 op amp IA designs
- Available in 8-lead DIP and SOIC packaging
- Low power, 1.3 mA max supply current

2. Excellent dc performance (B grade)

- 50 µV max, input offset voltage
- 0.6 µV/°C max, input offset drift
- nA max, input bias current

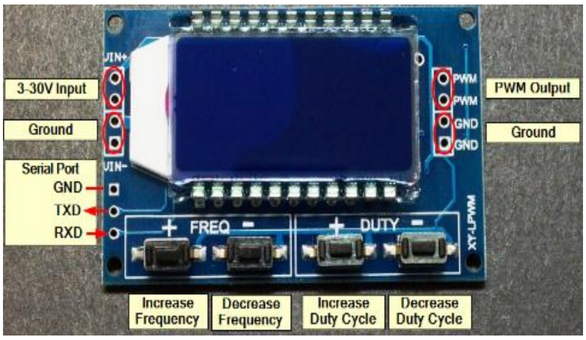
- 100 dB min common-mode rejection ratio (G = 10)

3. Low noise

- 9 nV/√Hz @ 1 kHz, input voltage noise
- 0.28 µV p-p noise (0.1 Hz to 10 Hz)
- Excellent ac specifications
- 120 kHz bandwidth (G = 100)
- 15 µs settling time to 0.01%

PWM generator:

- Operating Voltage: 3.3 - 30 VDC
- Frequency Range: 1Hz – 150 KHz
- Frequency Accuracy: the accuracy in each range is about 2%
- Signal Load Capacity: 5 - 30 mA
- Output Amplitude: PWM Amplitude Equal to the Supply Voltage
- Operating Temperature: -20 - +70 Celsius
- Dimensions: 52 x 32 x 10 mm



Power supply ps1502d+:

- The power input: we can do 110V, 220V, 230V, 240V AC
- Electric current: 0.6-2A0-500mA
- Output voltage: 0-15 VDC
- The test voltage: 0 to 49.9V
- Have 9v voltage output function
- Power input: 220V AC
- Maximum power: 35w max.
- Working temperature: 40oC-70oC
- Vacuum bring to exhaust: <0.25W

Hantek 1008c:

Model	Hantek1008
Vertical System	

Analog Channel	8
Input Impedance	Resistance: 1MΩ
Input Sensitivity	10mV/div to 5V/div
Input Coupling	DC
Resolution	12 bits
Horizontal System	
Memory Depth	4K
Max. Input	400V (DC+AC Peak)
Real-Time Sampling Rate	2.4MSa/s
Time BaseRange	1ns/div to 20000s/div(1-2-5sequences)
Time Base Precision	±50ppm
Trigger System	
Time Base Range	1ns/div to 20000s/div(1-2-5sequences)
Time Base Precision	±50ppm
Trigger Source	CH1, CH2,CH3,CH4, CH5, CH6,CH7,CH8
Trigger Mode	Edge
X-Y Mode	
X-Axis Input	CH1
Y-Axis Input	CH2
Cursors and Measurement	
Voltage Measurement	Vpp, Vamp, Vmax, Vmin, Vtop, Vmid, Vbase,Vavg, Vrms, Vcrms, Preshoot, Overshoot
Time Measurement	Frequency, Period, Rise Time, Fall Time, Positive Width, Negative Width, Duty Cycle
Cursors Measurement	Horizontal ,Vertical, Track, Auto Measure Modes
Waveform Signal Process	+,- , x,÷, FFT, Invert
Voltage Range	10mV to 5V/div @ x 1 probe 100mV to 50V/div @ x 10 probe 10V to 5000V/div @ x 1000 probe 100V to 50000V/div @ x 10000 probe 200mV to 100V/div @ 20:1
Current Range	100mA to50.0A/div @ CC65(20A) 1000mA to500.0A/div @ CC65(65A) 1A to100.0A/div @ CC650(60A) 1A to200.0A/div @CC1100(100A) 10A to2000.0A/div @CC1100(1100A)
FFT	Rectangular, Hanning, Hamming, Blackman Window
Math	Addition, subtraction, multiplication, division
Programmable Generator	
Channel	8
Output Level	LVTTL
Frequency Range	0-250kHz
Interface	USB 2.0
Power	No need extra power supply
Size & Weight	185 x 150 x 27 (mm); 0.35kg

Table 2 Hantek 1008c specs [24]

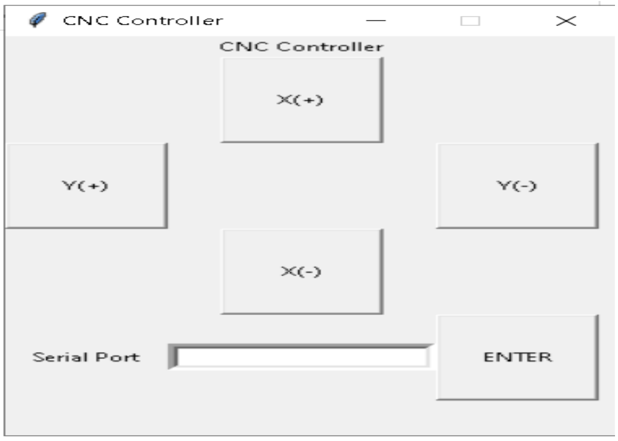
Annex

Arduino code:

```
#include <AFMotor.h>

const int stepsPerRevolution = 200;

const int stepsPerRevolution1 = 200;

AF_Stepper motorY(stepsPerRevolution, 1);

AF_Stepper motorX(stepsPerRevolution1, 2);

void setup() {

  Serial.begin(9600);

  Serial.println("Stepper test!");

  motorX.setSpeed(150);

  motorY.setSpeed(150);

}

void loop() {

  while(Serial.available()<0){}

  ordr=Serial.read();

  if (ordr == "x+"){

    motorX.step(47, FORWARD, MICROSTEP);

  }

  if (ordr == "x-"){

    motorX.step(47,BACKWARD, MICROSTEP);

  }

  if (ordr == "y-"){

    motorY.step(47,BACKWARD, MICROSTEP);

  }

  if (ordr == "y+"){

    motorY.step(47,FORWARD, MICROSTEP);

  }

}
```

Annex

Python code (software program):




```
import tkinter as tk

import serial

window = tk.Tk()

window.geometry("300x400")

window.resizable(width=False,height=False)

window.title('CNC Controller')

def getport():

   port=entry.get()

   ser = "serial.Serial(port,9800,timeout=1)"

def Xplus():

   if len(port) < 0:

      tk.tkMessageBox.showinfo("Entre Serial Port!")

   else:

      ser.write(b'x+')

def Xminus():

   if len(port)< 0:

      tk.tkMessageBox.showinfo("Entre Serial Port!")

   else:

      ser.write(b'x-')

def Yplus():

   if len(port)< 0:

      tk.tkMessageBox.showinfo("Entre Serial Port!")
```

```
    else:
        ser.write(b'y+')
def Yminus():
    if len(port)< 0:
        tk.tkMessageBox.showinfo("Entre Serial Port!")
    else:
        ser.write(b'y-')
Xp = tk.Button(window, text="X(+)",height=5,width=10)
Xm = tk.Button(window, text="X(-)",height=5,width=10)
Yp = tk.Button(window, text="Y(+)",height=5,width=10)
Ym = tk.Button(window, text="Y(-)",height=5,width=10)
ok = tk.Button(window, text="ENTER",height=5,width=10)
label1 = tk.Label(window, text="Serial Port")
label1.grid(row=4,column=0)
entry = tk.Entry(window,bd=5)
entry.grid(row=4,column=1)
label = tk.Label(window, text="CNC Controller")
label.grid(row=0,column=1)
Xp.grid(row=1,column=1)
Xm.grid(row=3,column=1)
Yp.grid(row=2,column=0)
Ym.grid(row=2,column=2)
ok.grid(row=4,column=2)
window.mainloop()
```