IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Crack Detection in Pipelines Using Capacitive Sensors

J.Senthil Kumar[*1], M.Manivannan[2], Y.John Durai Singh[3]

[*1,2,3] Department of Electronics and Communication Engineering, MepcoSchlenk Engineering College, Sivakasi, Tamil Nadu, India

senthilkumarj@mepcoeng.ac.in

Abstract

Detection of cracks in pipes which are buried under the ground at greater depths is difficult and time consuming task. Humans can’t be utilized to detect cracks in buried pipelines. So we propose a Robot that navigates through a pipeline and detect cracks in such buried pipelines using capacitive sensors.Capacitive sensors that used here for detecting cracks are efficient,economic, reliable and compact.

Another purpose of using this method is, for an unknown crack in pipeline, in which the diameter is small, has to be analysed in a more significant manner. It is harder to find the exact location of cracks as humans can’t be used there and also the devices should be smaller and compact. Hence in order to detect the exact location of cracks in such pipes we need to dig the entire soil and check the crackmanually. This leads to waste of money and time, which can be overcome by the proposed method of crack detection.

Keywords: BuriedPipeline, Cracks,Crack detection,capacitive sensor, Navigation, Microcontroller.

Introduction

Pipelines are being used in all household and industrial applications. Pipeline Transport is the common term used in application where pipes are used to deliver products from one place to another. Most commonly, liquids and gases are sent, but pneumatic tubes using compressed air can also As for gases and liquids, any chemically stable substance can be sent through a pipeline. Therefore sewage, slurry, water, or even beer pipelines exist; but arguably the most valuable are those transporting crude petroleum and refined petroleum product including fuels: oil (oleo duct),natural gas (gas grid), and bio fuels.Thesepipelines will be damaged as days roll due to corrosion,stress etc.The impact of these cracks on the atmosphere depends on the type of product that particular pipeline is transporting.If the pipeline is transporting a hazardous gas then a minor crack has greater impact on the society.So cracks should be identified as soon as possible to avoid its impact on the society.

The Nature of Crack Detection

Every crack, regardless of its type or origin, weakens the structural integrity of your pipeline. There are many types of cracks, including Stress Corrosion Cracking (SCC), fatigue, hydrogen-induced cracking (HIC) and sulfide corrosion. They occur in the base material of the pipe, in welds and in heat-affected zones, and can develop from dents or other defects. Since each type exhibits distinct attributes and growth characteristics, accurate and timely crack detection is a major challenge. Specialized inspection capabilities are essential in order to identify and accurately describe cracks, and PII Pipeline Solutions, a GE Oil & Gas and Al Shaheen joint venture, offers four proven crack detection services for this critical task. Some tools use advanced ultrasonic and magnetic technologies to obtain precise descriptions in the widest range of pipe diameters and wall thicknesses for gas and liquid pipelines. Also experienced analysts, backed by sophisticated software tools and the industry’s largest database of pipeline anomalies, produce reports that are clear, accurate and actionable

Analysis of Alternatives

A large number of studies have been carried out on conventional (dye penetrant, magnetic particle induction, ultrasonic, etc.) and modern approaches to non-destructive testing and evaluation. The conventional methods have been well developed, implemented in widely marketed equipment, and accepted by industry and regulatory agencies as practically applicable non-destructive evaluation (NDE) methods. The modern NDE methods are still under development, implemented in a limited manner in some equipment and not fully accepted by the industry and regulatory agencies as practicably applicable NDE methods. One of these modern methods is the vibration-based inspection methodology.

A comprehensive survey of available literature on damaged structures was carried out by Richardson [9], to determine the current state of the crack detection technology. The paper discussed the various methods used for structural integrity monitoring of nuclear power plants, large civil engineering structures, rotating machinery, etc. A more comprehensive survey was presented later by Doebling et al.[10]. This survey reviewed the numerous technical literatures available on detection, sizing and location of structural damage via vibration-based testing. It categorized the various methods available for crack detection according to the measured data and analysis techniques.

All these methods are efficient depending on the application. In buried small diameter Pipelines these techniques can't be implemented. Also these type of testing will be very costly compared to our sensor based crack detection.NDT using ultrasonic can be used only by industries because of its high cost.

In this paper, an attempt has been made to detect the presence of a crack in pipeline using cost effective, compact capacitive sensors.

Capacitive Sensors

In electrical engineering, capacitive sensing is a technology, based on capacitive coupling that takes human body capacitance as input. Capacitive sensors detect anything that is conductive or has a dielectric different from that of air.

Many types of sensors use capacitive sensing, including sensors to detect and measure proximity, position or displacement, humidity, fluid level, and acceleration. Human interface devices based on capacitive sensing, such as track pads can replace the computer mouse. Digital audio players, mobile phones, and tablet computers use capacitive sensing touch screens as input devices. Capacitive sensors can also replace mechanical buttons.

As for gases and liquids, any chemically stable substance can be sent through a pipeline. Therefore sewage, slurry, water, or even beer pipelines exist; but arguably the most valuable are those transporting crude petroleum and refined petroleum product including fuels: oil (oleo duct),natural gas (gas grid), and bio fuels.Thesepipelines will be damaged as days roll due to corrosion,stress etc.The impact of these cracks on the atmosphere depends on the type of product that particular pipeline is transporting.If the pipeline is transporting a hazardous gas then a minor crack has greater impact on the society.So cracks should be identified as soon as possible to avoid its impact on the society.

The Nature of Crack Detection

Every crack, regardless of its type or origin, weakens the structural integrity of your pipeline. There are many types of cracks, including Stress Corrosion Cracking (SCC), fatigue, hydrogen-induced cracking (HIC) and sulfide corrosion. They occur in the base material of the pipe, in welds and in heat-affected zones, and can develop from dents or other defects. Since each type exhibits distinct attributes and growth characteristics, accurate and timely crack detection is a major challenge. Specialized inspection capabilities are essential in order to identify and accurately describe cracks, and PII Pipeline Solutions, a GE Oil & Gas and Al Shaheen joint venture, offers four proven crack detection services for this critical task. Some tools use advanced ultrasonic and magnetic technologies to obtain precise descriptions in the widest range of pipe diameters and wall thicknesses for gas and liquid pipelines. Also experienced analysts, backed by sophisticated software tools and the industry's largest database of pipeline anomalies, produce reports that are clear, accurate and actionable

Analysis of Alternatives

A large number of studies have been carried out on conventional (dye penetrant, magnetic particle induction, ultrasonic, etc.) and modern approaches to non-destructive testing and evaluation. The conventional methods have been well developed, implemented in widely marketed equipment, and accepted by industry and regulatory agencies as practically applicable non-destructive evaluation (NDE) methods. The modern NDE methods are still under development, implemented in a limited manner in some equipment and not fully accepted by the industry and regulatory agencies as practicably applicable NDE methods. One of these modern methods is the vibration-based inspection methodology.

A comprehensive survey of available literature on damaged structures was carried out by Richardson [9], to determine the current state of the

 ISSN: 2277-9655

crack detection technology. The paper discussed the various methods used for structural integrity monitoring of nuclear power plants, large civil engineering structures, rotating machinery, etc. A more comprehensive survey was presented later by Doebling et al.[10]. This survey reviewed the numerous technical literatures available on detection, sizing and location of structural damage via vibration-based testing. It categorized the various methods available for crack detection according to the measured data and analysis techniques.

All these methods are efficient depending on the application. In buried small diameter Pipelines these techniques can't be implemented. Also these type of testing will be very costly compared to our sensor based crack detection.NDT using ultrasonic can be used only by industries because of its high cost.

In this paper, an attempt has been made to detect the presence of a crack in pipeline using cost effective, compact capacitive sensors.

Capacitive Sensors

In electrical engineering, capacitive sensing is a technology, based on capacitive coupling that takes human body capacitance as input. Capacitive sensors detect anything that is conductive or has a dielectric different from that of air.

Many types of sensors use capacitive sensing, including sensors to detect and measure proximity, position or displacement, humidity, fluid level, and acceleration. Human interface devices based on capacitive sensing, such as track pads can replace the computer mouse. Digital audio players, mobile phones, and tablet computers use capacitive sensing touch screens as input devices. Capacitive sensors can also replace mechanical buttons.

Design of Capacitive Sensor

Capacitive sensors are constructed from many different media, such as copper, Indium tin oxide (ITO) and printed ink. Copper capacitive sensors can be implemented on standard FR4 PCBs as well as on flexible material. ITO allows the capacitive sensor to be up to 90% transparent (for one layer solutions, such as touch phone screens). Size and spacing of the capacitive sensor are both very important to the sensor's performance. In addition to the size of the sensor, and its spacing relative to the ground plane, the type of ground plane used is very important. Since the parasitic capacitance of the sensor is related to the electric field's (e-field) path to ground, it is important to choose a ground plane that limits the concentration of e-field lines with no conductive object present.

Designing a capacitance sensing system requires first picking the type of sensing material (FR4, Flex, ITO, etc.). One also needs to understand the environment the device will operate in, such as the full operating temperature range, what radio frequencies are present and how the user will interact with the interface.

Operating Principle

Capacitive sensors can function, contact free and non-reactively and can detect both metallic as well as non-metallic targets. A decisive factor in their functioning is their capacitor-like design with two plates between which an electronic charge can be stored. The change in this charge quantity – the capacity – is used for metrological measurement purposes. It can result from a change in the plate distance, the effective plate surface or the dielectric. With non-conducting materials, the change in the dielectric has the effect that the plates are formed on the one hand by a probe and, on the other hand, by the surroundings. With conducting materials, the change in material functions like the change in the plate distance.

The active element is formed by two metallic electrodes positioned much like an "opened" capacitor (Fig 1).
Electrodes A and B are placed in a feedback loop of a high frequency oscillator.

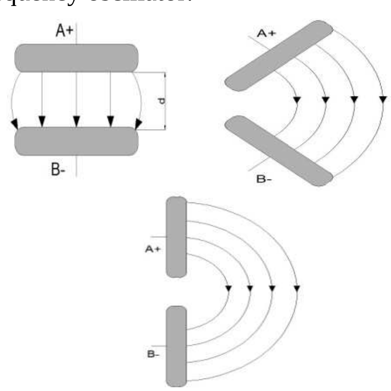

Fig1.Position of electrodes and the field between the electrodes

Capacitance is a function of surface area of eitherelectrodes(A or B), the distance between the electrodes (d),and the dielectric constant of the material (ε) between the electrodes (Fig 1)

Capacitive sensors are constructed from many different media, such as copper, Indium tin oxide (ITO) and printed ink. Copper capacitive sensors can be implemented on standard FR4 PCBs as well as on flexible material. ITO allows the capacitive sensor to be up to 90% transparent (for one layer solutions, such as touch phone screens). Size and spacing of the capacitive sensor are both very important to the sensor's performance. In addition to the size of the sensor, and its spacing relative to the ground plane, the type of ground plane used is very important. Since the parasitic capacitance of the sensor is related to the electric field's (e-field) path to ground, it is important to choose a ground plane that limits the concentration of e-field lines with no conductive object present.

Designing a capacitance sensing system requires first picking the type of sensing material (FR4, Flex, ITO, etc.). One also needs to understand the environment the device will operate in, such as the full operating temperature range, what radio frequencies are present and how the user will interact with the interface.

Operating Principle

Capacitive sensors can function, contact free and non-reactively and can detect both metallic as well as non-metallic targets. A decisive factor in their functioning is their capacitor-like design with two plates between which an electronic charge can be stored. The change in this charge quantity – the capacity – is used for metrological measurement purposes. It can result from a change in the plate distance, the effective plate surface or the dielectric. With non-conducting materials, the change in the dielectric has the effect that the plates are formed on the one hand by a probe and, on the other hand, by the surroundings. With conducting materials, the change in material functions like the change in the plate distance.

The active element is formed by two metallic electrodes positioned much like an "opened" capacitor (Fig 1).

Electrodes A and B are placed in a feedback loop of a high frequency oscillator.

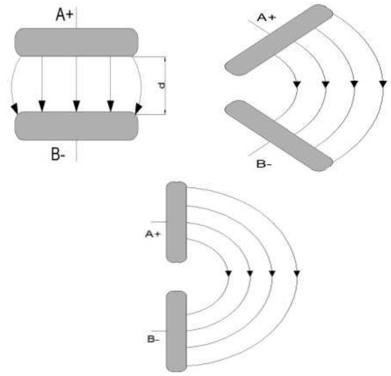

Fig1.Position of electrodes and the field between the electrodes

Capacitance is a function of surface area of eitherelectrodes(A or B), the distance between the electrodes (d),and the dielectric constant of the material (ε) between the electrodes (Fig 1).

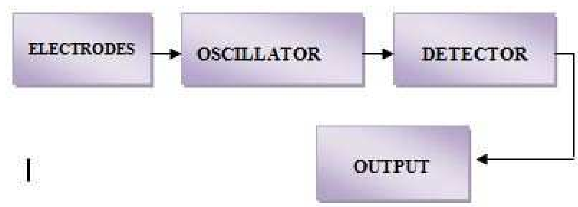

Fig2.Internal blocks in capacitive sensors

When no target is present, the sensor's capacitance is low; therefore the oscillation amplitude is small. When a target approaches the face of the sensor, it increases the capacitance. This increase in capacitance results in an increased amplitude of oscillation(Fig 2). The amplitude of oscillation is measured by an evaluating circuit that generates a signal to turn on or off the output
C = capacitance of sensor
A = surface area of either electrode
d = distance between two electrodes
ε = dielectric constant of material between the electrodes

$$C = \frac{\varepsilon \text{ X } A}{d}$$

When a Conductive Target enters the sensor's field, it forms a counter electrode to the active face of the sensor, thus decreasing the distance between the electrodes (d) and increasing their average surface area (Fig 3). The capacitance with a metal target present is always greater than the capacitance of the circuit in the absence of the target.

Reduction factors for different metals are not a consideration when using capacitive sensors.

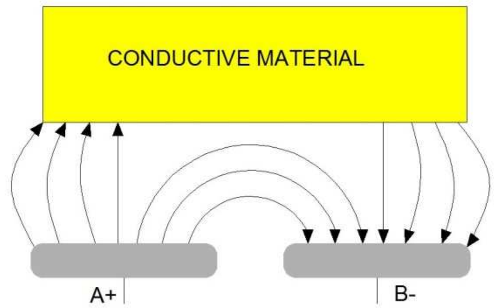

Fig3.Fields between electrodes when a conducting material is sensed

When a Non-Conductive Target enters the sensor's field, it acts as an electrical insulator between electrodes AandB(Fig 4).The dielectric constant of the material (ε) is a measure of its insulation properties. All liquids and solids have a greater dielectric constant than air (air = 1). Therefore, the capacitance with a non-metallic target presentisalways greater than the capacitance of the circuit in the absence of the target.

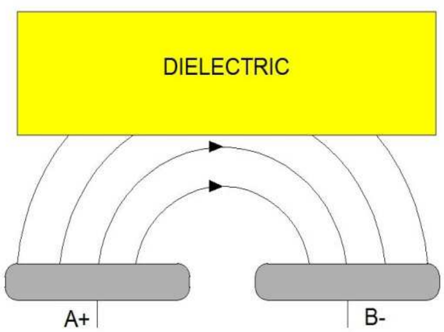

Fig4.Fields when a dielectric is placed

Sensitivity Adjustment

These capacitive sensors can be adjusted for sensitivity.They can be used as embeddable devices and non embeddabledevices.Thispaper is based on non-embeddable device having sensitivity of about 20-40mm.

Capacitive sensors can be adjusted two ways in order to sense a target consistently.

1. Physical adjustment - moving the sensor towards or away from the target is the preferred method of adjustingsensitivity when the sensor is not in direct contact with the target. This allows materials to be moved into or out ofrange while leaving the sensor at the factory setting or after re-calibration to the nominal operating distance.

2. Adjustment of the potentiometer - turning the potentiometer in a clockwise direction increases the sensitivity of thesensor. The potentiometer is factory-set for an operating distance of 0.7 to 0.8 cm to a grounded standard target. It should be adjusted in increments of no greater than a quarter-turn. Increasing the sensitivityresults in a greater operating distance to both conductive and non-conductive targets.

Taking the advantage of capacitive sensors and moving further into its characteristics, it is evident that they cab be effectively used in crack detection in pipeline

Proposed Crack Detection Method

This paper, as from the beginning, insists on finding cracks in underground buried pipelines. How to go beneath 100 ft or more is a question striking in everyone's mind.Robot in small size is the only solution for that query.

This paper deals with three major steps in crack detection

1. Detection of cracks in pipeline
2. Calculating the distance at which the crack is detected
3. Sending the intimation and distance to the base station.

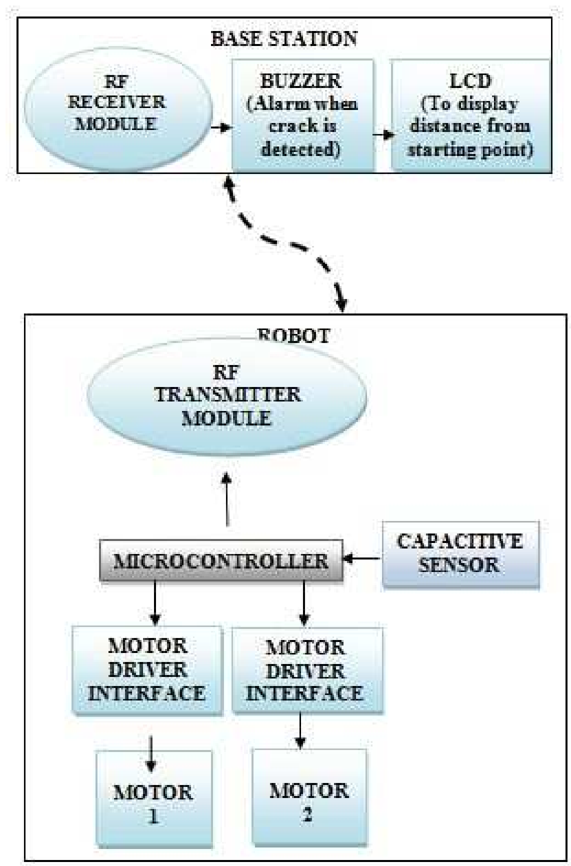

Fig 5: Physical Components and its interconnections of the proposed crack detection methodology

Required Components

- Capacitive sensors
- RF transmitter and receiver
- RF wireless camera
- Micro controller
- Stepper motor with sufficient torque

RF Transmitter and Receiver

Radio Frequency transmitter and receiver is used in the remote controlling of movement of the robot and also for signal intimation. Radio frequency is a rate of oscillation in the range ofabout 3 kHz to 300 GHz,which corresponds to the frequency of radio waves, and the alternating currents which carry radio signals. RF usually refers to electrical rather than mechanical oscillations; however, mechanical RF systems do exist. Frequency at which the RFpair(Transmitter and Receiver) operates is of major concern. Depending on the distance that is to be investigated and the material to be investigated frequency should be selected.

Frequency Requirement

Operating frequency of the RF transmitter and receiver has significance in signal transmission. Penetration of RF signal through dense material depends on the frequency. RF frequency ranges from 3kHz to 300 GHz. Selecting higher frequency will provide higher penetration power. But there is a serious drawback in using high frequency signal. The higher frequency signal attenuates faster than the lower frequency signal and becomes too weak to be detected at the end of the receiver, located at larger distances. An RF power amplifier is used to amplify the power level of such a transmitter RF Signal, so that, it can travel up to larger distances with lesser attenuation.SoRf transmitter receiver pair with moderate operating frequency along with power amplifiers should be used.

Wireless Camera

Wireless camera is used for monitoring the movement of robot in underground pipeline that is to be detected.Wireless securitycameras are closed-circuit CCTV cameras that transmit a video and audio signal to a wireless receiver through a radio band. Many wireless security cameras require at least one cable or wire for power; "wireless" refers to the transmission of video/audio. However, some wireless security cameras are battery-powered, making the cameras truly wireless from top to bottom.Also larger cracks can be visualized by this camera and can be easily detected.

There are two major types of wireless camera.Analog, and Digital camera.Analog camera suits the crack detection application that we propose.Analog wireless is the transmission of audio and video signals using radio frequencies. Typically, analog wireless has a transmission range of around 300 feet (91 meters) in open space; walls, doors, and furniture will reduce this range

Controller Unit

Controller is used for controlling the motors used in locomotion.The output of the controller is given to a driver for amplification so that output from the controller can drive the motor.Most important purpose of controller here is to read the value from sensor and compare it with the programmed value(Fig 6).RF transmitter will be connected to the output pin of the controller.Once a output in produced ay the output pin in which RF transmitter is connected RF will transmit and the same is received at the base station.

Stepper Motor

In order to detect the crack at any point in the pipe the sensor is fitted to a stepper motor and it is rotated to cover the entire pipe circumference.Stepper motor used should have sufficiently high torque so that it can rotate with the given load (sensor and its mechanical design).Also the battery used to drive the stepper motor should have sufficient current rating so that load is driven by the motor.Using drivers is essential for providing the necessary current and voltage rating.The robot is moved along the pipe.At each instance the robot is stopped and the sensor fitted with the stepper motor is rotated 360 degree slowly.

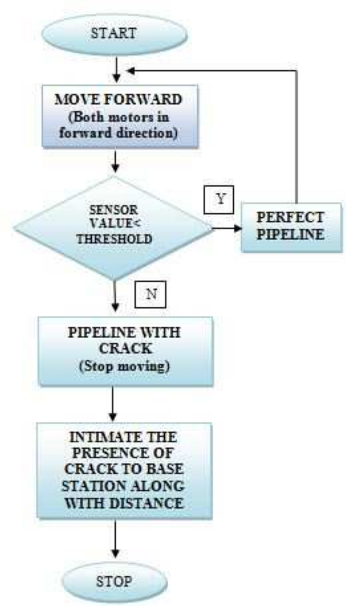

Fig 6:Flowchart interpretation of crack detecting module

Distance Measurement

The major aim of this paper is to detect the exact distance at which the crack is detected. Once a crack is detected a signal will be sent to the base station. Mere signal indication is not enough to find the location. Distance travelled by the robot can't be found directly using any meter as in case of automobiles. It can be determined indirectly only. First a counter should be implemented. Once the motor is moved forward using the controller the counter will increase, if it moves backward the counter will decrease. Before using the robot in the pipeline the robot is made to move in ground and the count value for certain distance (say 50m) is noted. The procedure is repeated for several times and the average in found. From the count value for say 50m it is possible to find the count value for 10m,20m and for any distance.

Working of the Robot

The robot is sent inside the buried pipeline. Wireless camera is used to monitor the movement of robot inside the pipeline. The robot is moved and paused at certain points of inspection .The sensor will be rotated over the entire circumference of the pipe with the help of stepper motor. Sensors's output voltage will decrease when there is a crack. The output voltage of sensor in case of crack and crack less pipe will be found already .The threshold will be determined and programmed in microcontroller. If the output voltage fall below the threshold value, intimation will be given to base station using RF transmitter and receiver pair. Along with intimation, distance at which the crack is present is also Transmitted.

Modelled Crack Detecting Robot

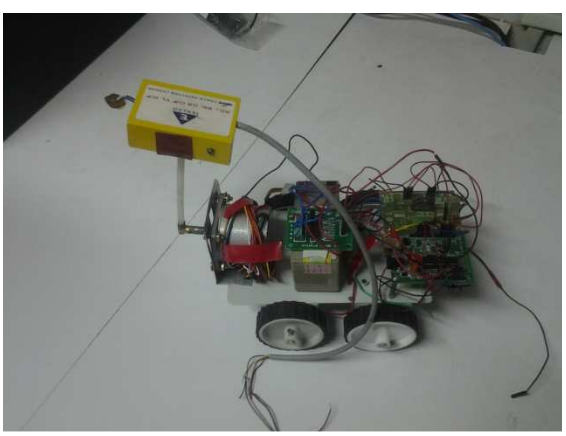

Fig 7: Robot with rotating capacitive sensor

The system as a whole will look like Fig 7.Capacitive sensor is fitted with the stepper motor and it is placed in front of the robot. As the robot moves the stepper motor will start rotating around the circumference of the pipeline to be investigated.Once a crack is detected the stepper motor will be stopped and signal intimation will be sent to the base station.

References

[1]. FerranReverter and Òscar Casas, Member, IEEE," Interfacing Differential Capacitive Sensors to Microcontrollers: A Direct Approach", IEEE transactions on instrumentation and measurement, vol. 59, no. 10, october 2010

[2]. HoonSohn and Seuno Bum Kim, "Development of Dual PZT Transducers for Reference-Free Crack Detection in Thin Plate Structures",IEEE Transactions on Ultrasonic, Ferroelectrics, and Frequency Control, vol. 57, No.1, January 2010

[3]. Fengtian Han, Qiuping Wu, Rong Zhang, and Jingxin Dong, Member, IEEE,"Capacitive Sensor Interface for an Electrostatically Levitated Micromotor",IEEEtransactions on instrumentation and measurement, vol. 58, no. 10, october 2009.

[4]. F. Reverter and Ò. Casas, "Interfacing differential resistive sensors to microcontrollers:A direct approach," IEEE Trans. Instrum. Meas., vol. 58,no. 10, pp. 3405–3410, Oct. 2009.

[5]. Reza K. Amineh , Maryam Ravan_, S. H. HesamedinSadeghi_, and RouzbehMoini,"Removal of Probe Liftoff Effects on Crack Detection and Sizing in Metals

[6]. by the AC Field Measurement Technique",IEEEtransactions on magnetics, vol. 44, no. 8, august 2008

[7]. F. Reverter and Ò. Casas, "Direct interface circuit for differential capacitive sensors," in Proc. IEEE Int. Instrum.Meas. Technol. Conf., Victoria,BC, Canada, 2008, pp. 1609–1612.

[8]. M. Ravan, S. H. H. Sadeghi, and R. Moini, "Using a wavelet network for reconstruction of fatigue crack depth profile from AC field,"NDT&E Int., vol. 40, no. 7, pp. 537–544, Oct. 2007.

[9]. M.H. Richardson, "Detection of damage in structures from changes in their dynamic (modal) properties, A Survey", NUREG/CR-1431, US, Nuclear Regulatory Commission, Washington, DC, 1980.

[10]. S.W. Doebling, C.R. Farrar, M.B. Prime, P.W. Shevitz, Damage identification, Health monitoring of structural, and mechanical systems from changes in their vibration characteristics, A Literature Review, Los Alamos National Laboratory, Los Alamos, New Mexico, 1996, 100pp.