

**THE DESIGN, CONSTRUCTION AND TESTING OF AN INTELLIGENT
DEVICE FOR COATING FLAWS AND CRACK DETECTION IN PIPELINES**

Abstract: *The major pollutant induced by pipeline failure in Oil and Gas industry has been mitigated over the years using non-destructive techniques like liquid penetrant, magnetic particles, radiographic, ultrasound and eddy current testing. The eddy current technique's advantage over the other testing devices remains the best suitable in the design and construction of the devices due to the nature of the pipeline materials. For this present work, a pre-test-post-test experimental design was used to test devices on a defect free pipe and a pipe with machined defects of known dimensions and different orientation (longitudinal and axial) after construction. The defect detection was done using electromagnetic technique of eddy current by exciting a coil with power supply and placed close to the tested pipe surface, as a micro-controller was used to track the irregularities on the material surface by computer systems. The device set up for the test was a coil with a power supply of a DC battery connected with micro-controller of a quantization level of 4.88mV. For visual display, result obtained indicates no variation in the amplitude of the pulse as demonstrated by a pipe with no defect while variations (deeps) occurred in the pipe with defects as the coil was traversed over the defect. The orientation had no significant effects on the sensitivity and effectiveness of the device. Results validation was done using a non-destructive technique by visual inspection. Thus, device has shown its effectiveness in detecting defects irrespective of the orientation. Similarly, the size of the defects is a determinant in the amplitude variation of the pulse displayed which implies at higher sensitivity, a high frequency is required.*

Key-words: Eddy Current; DC Battery; Micro Controller; Crack Detection; Pipeline Failure; Pipeline Testing; Non-Destructive Technique; Quantization Level.

1.0 INTRODUCTION

1.1 Background of the Study

It has been established that pipelines happened to be about the safest and most economical (in terms of energy usage) means for transporting products over any distance [1]. A high range of products from non-hazardous products like water to highly inflammable products like petroleum products are transported with pipelines [2]. The safety and integrity of pipelines are a matter of principal importance due to the highly inflammable nature of some of its transported substances [3]. Should a pipeline fail, the transported content can cause extensive environmental damage and also affect the population living and working by the pipeline. Furthermore, pipeline failure is linked with repair and excavation costs, cleaning costs, and loss of content [4]. The suspected origin of pipe failure was usually detected using a non-destructive technique, stress corrosion cracking (SCC) were observed on the failed pipe [5]. Thus, this project entails the instigation of failure in pipelines as caused by flaws by adopting a suitable technique like eddy current non-destructive testing approach.

1.2 The Eddy Current Testing

Eddy current testing (ECT) technique is a widely applied non-destructive test (NDT) to detect defects and assess structural reliability in pipelines materials [6]. The testing technique has nearly been perfected to

42 detect cracks, sub-surface and coating flaws [7] using the electromagnetic principle. The range of
43 thickness that ECT can handle is usually from the level of micrometres to the level of millimetres. The
44 changes in the properties of the coil in conductivity and permeability condition when in contact with the
45 material are detected by the eddy current testing device [8]. The substitution of the probes with the ring of
46 coils will enable the detection of possible surface defects without pipeline obstructions [9]. The choice of
47 check parameters should be done with a deep understanding of the nature and technique of flaws. The
48 device can handle a wide range of flaws such as coating flaws, cracks and so on. The in-depth
49 understanding of this mentioned flaws gave birth to the non-destructive techniques, which is useful in the
50 detection and identification of defects [10]. Thus, the present work design construct and test intelligent
51 device with options for visual display benchmarking against existing non-destructive techniques for
52 testing flaws, identified and implemented algorithms to detect coating flaws and cracks in pipeline
53 structures in the intelligent device [11].

54 **1.3 Crack Induced due to Stress Corrosion**

55 Early detection of cracks induced by stress corrosion cracking and coating flaws will mitigate against the
56 disastrous and sudden failure of pipelines [12]. Most oil and gas industries have been plagued in the
57 recent years with spillage which has caused grave environmental pollution over the year which is
58 estimated to have cost about \$614billion and may span through a period of about 30years to clean up the
59 affected environment [13].

60 This proposed device is unlike the existing intelligent pig which is cumbersome, requires high level of
61 technical know-how and needs to be deployed in the pipe to flow with the fluid content of the pipe hereby
62 obstructing operation of the pipe [14]. This has several advantages ranging from portability, affordability
63 and versatility while it does not require high level of technical know-how to interpret the results. In a
64 country like Nigeria with a pipeline network of length 4226km (approximately) for just crude oil and
65 natural gas alone spanning through most part of the country it is essential to develop a device to help in
66 the regular inspection of this pipeline network [15].

67 **1.4 Non-Destructive Test Techniques for Pipelines**

68 The non-destructive techniques are majorly used for research in mechanics of materials and maintenance
69 check in the industry, this technique doesn't in any way affect the structure of the material [16]. The most
70 widely used non-destructive techniques that would be reviewed in the paper are electromagnetic,
71 ultrasonic and liquid penetrant testing [17]. One of the conventional electromagnetic methods utilized for
72 the inspection of conductive materials like copper, aluminium or steel is eddy current non-destructive
73 testing which as shown in this work to be the most versatile and effective techniques of all the other
74 techniques used for pipeline inspection.

75 When selecting an NDT technique, the first issue to be addressed is the type and size of the defect(s) that
76 must be found as postulated in [18]. This was typically based on experience or, increasingly commonly,
77 on fracture mechanics calculations. Visual inspection by production or maintenance personnel is the most
78 widely applied NDT technique and is often used in conjunction with other methods. It frequently does not
79 involve the purchase of specific NDT equipment. Depicted in Table 1 below are the most commonly used
80 non-destructive techniques and a summary of their capabilities and demerits [19] as sourced from
81 Guriong, et al. [19].

83 **Table 1: Commonly used NDT Techniques**

Technique	Capabilities	Limitation
Visual inspection	Macroscopic surface flaws.	Small flaws are difficult to detect, no subsurface flaws.
Radiography	Subsurface flaws	Smallest defect detectable is 2% of the thickness; radiation protection. No subsurface flaws not for porous materials.
Dye penetration	Surface flaws	No subsurface flaws not for porous materials
Ultrasonic	Subsurface flaws	Material must be good conductor of sound.
Magnetic particles	Surface / near surface and layer flaws.	Limited subsurface capability, only for ferromagnetic materials.
Eddy current for metals	Surface and near surface flaws	Difficult to interpret in some applications; only for metals.

84

85 **Table 2: Showing the longitudinal, axial cracks and their dimensions machined on the galvanized pipe.**

S/N	Longitudinal cracks				Axial cracks				
	Sections	Length (mm)	depth (mm)	Width (mm)	Sections	Length (mm)	depth (mm)	Width (mm)	Sections
1	1	27	0.15	2	1	22	0.45	1.66	1
2		17	0.20	1.5		20	0.11	1.66	
3		27	0.22	1.5		22	0.32	1.86	
4	2	27	0.16	1	2	24	0.70	1.86	2
5		28	0.25	1		22	0.21	1.66	
6		26	0.45	1.8		24	0.21	1.86	
7		26	0.22	1		24	0.41	1.66	
8	3	15	0.58	2	3	23	0.47	1.66	3
9		15	0.16	1		23	0.35	1.68	
10		18	0.25	1		23	0.34	1.66	

86 **1.5 The Ultrasonic Testing for Pipeline Defects**

87 Defects can be detected using the principle of the propagation of sound waves in a material [20]. In the
88 case of ultrasonic testing which is a very competent and reliable non-destructive testing technique, ultra-
89 high-frequency sonic energy above the audible range is used in locating and identifying defects in
90 materials that are at any point in the pipeline materials [21].

91 Research have shown that most ultrasonic testing in pipelines are done within the range of 1 – 5 MHz, but
92 frequency range of 100MHz to 20KHz is used in specialist applications. Both shear and compression
93 waves are mostly used and they detect defects through the change in acoustic impedance produced
94 (product of density and speed of sound) in the path of the ultrasonic beam [17, 22].

95 Ultrasonic testing is commonly used in the industries because of its ease to use, accuracy and its ability
96 not to affect a material in any way for several purposes, one of which is quality control. It is also very
97 useful in testing the integrity of materials used in the formation of pipes [23]. Ultrasonic waves require a
98 medium to transmit its ultrasonic waves because it does not transmit well through air, solids or gels. It has
99 been discovered over the years that water or grease would conduct ultrasonic sounds effectively between
100 the transducer and the material to be tested [24]. Devices called pigs have been developed using
101 ultrasonic waves to detect defects in the in-service pipelines, this has overcome the problem of getting the
102 transducer into contact with an insulated pipe to be tested because it works from the inside of the pipe by
103 developing the device for assessing the inner walls of the underwater oil pipeline. Lamb waves which is
104 also an option of the waves that could be used for ultrasonic testing is preferred for a very thick material
105 just like the electromagnetic waves within a waveguide [25].

106 **1.5.1 Merits and Demerits of Ultrasonic Testing in Pipelines**

107 This can be deduced based on comparative or similar studies of ultrasonic testing and its application,
108 likewise that its versatility and flexibility avails it for use on a wide range of materials [21, 23]. It poses
109 no form of environmental hazard with very reliable, accurate and fast subsurface flaws detection when
110 compared to the others [26]. It is important to mention the demerits which could pose certain limitations
111 to the use of this device for defects detection on pipelines. A high level of expertise is required while
112 operating the device and cracks parallel to the direction of the wave travelling through the material would
113 not be detected [27]. It is a very expensive test which also requires couples (water or grease) as a medium
114 for the transducer to transmit and receive waves.

115 **1.6 Radiography Testing**

116 In Radiography Testing the material to be tested is placed between the radiation source and film or
117 detector [28]. Radiographic image formed is basically a two-dimensional shadow presentation of the
118 concentration of radiation passed through a material [29]. Defects of several forms such as a crack that
119 runs parallel to the beam of radiation reduces the absorption of radiation, this will be seen as a light area
120 in the image produced while an inclusion of higher density than the parent material will appear darker
121 [30]. Radiography tests can be carried out in several different forms and each has its specific applications.
122 Below are different radiography tests. This includes the conventional radiograph which is the most
123 appropriate for when the materials to be tested are not too dense or too thin. These types of radiography
124 are useful in detecting large voids, inclusions, trans-laminar cracks, non-uniform fiber distribution, and
125 fiber mis-orientation such as fiber wrinkles or weld lines [31]. The gamma ray radiography test which is
126 good for dense materials because the gamma rays have shorter wavelengths and the penetrant-enhanced

127 radiography which is employed specifically to detect small matrix cracks and delamination in the material
128 to be tested [32].

129

130 **1.6.1 Varieties of Radiographic Testing Method and Applications**

131 There are varieties of radiographic testing methods for different applications. These methods are film
132 radiography, computed radiography [28], computed tomography [9], and digital radiography [3]. X-ray
133 Computed Tomography (XCT) is a non-destructive technique for visualizing interior features within solid
134 objects, and for obtaining digital information on their 3-D geometries and properties. The great advantage
135 of XCT in comparison with the projection radiology is the 3-D visualized image of the structure while in
136 projection radiology the image is only 2-D. Therefore, the XCT data is readable quickly and simply. XCT
137 will modify the scale of observation from macroscopic to microscopic scale so the results of the XCT
138 method are very reliable [7]. The major disadvantage of radiography is the health hazard posed by
139 radiation [. It is expedient to know that radiation imaging method of NDE enjoys an advantage over many
140 other NDE methods in that it is inherently pictorial and interpretation is to some extent intuitive [21].
141 Analyzing and interpreting the images requires skill and experience but the casual user of radiation
142 imaging services can easily recognize the item being imaged and can often recognize discontinuities
143 without expert interpretation. Also, X-ray NDE is not as limited to the type of material it can study, unlike
144 other NDE methods [4]. Radiation methods are suitable for sensing changes in elemental composition. It
145 is especially applicable to finding voids, inclusions and open cracks and is often the method of choice for
146 verification of internal assembly details [20]. Radiation is dangerous and also high voltage is needed to
147 generate most X-rays can be dangerous as well as the difficulty in using heavy shielding materials. Also,
148 radiography is limited in utility for detecting cracks [18]. For a crack to affect the transmission of
149 radiation there must be an opening resulting in a local absence of material. A closed crack is not
150 detectable using radiation. In addition, even when the crack has a finite opening, it will generally only be
151 detectable in a radiograph at certain orientations [3]. Ideally the long dimension of the crack is parallel to
152 the direction of radiation travel, i.e., this maximizes the radiation-crack interaction. Surface defects are
153 often hard to distinguish with 2-D radiography [31]. Finally, they are very expensive and time consuming
154 and require the use of highly trained safety conscious engineers, scientists or technicians.

155 **1.6.2 Other Crack Testing Methods in Pipelines**

156 Several other defect testing methods in pipelines include the use of liquid penetrants for detecting flaws
157 has been validated in several literatures. The penetrant is usually applied by an aerosol and is drawn into
158 small openings by capillary action. Following a dwell time, excess penetrant is removed from the surface
159 and a developer in liquid or powder form is applied in Stander, et. al., [37]. This developer absorbs
160 penetrant drawn from discontinuities. Liquid penetrant inspection is used for testing critical parts and
161 articles in aircraft building, ship building, power and agricultural machine building, in railway transport,
162 and in other branches of industry. The merit and demerits of this method is that Penetrant testing is a
163 simple, inexpensive, and sensitive non-destructive testing method [19]. It allows the inspection of a large
164 variety of materials, component parts, and systems for discontinuities that are open to the surface. Liquid
165 penetrant is portable, it is often used in remote locations.it has been observed that it does not require high
166 level of expertise compared to some other NDT methods, even though careful attention to cleanliness,
167 procedures, and processing time is needed, and also comprehensive knowledge of types of discontinuities
168 that may occur in the parts to be tested.

169 1.7 The Eddy Current Testing Principle

170 This testing uses the fact that when an alternating current coil induces an electromagnetic field into a
171 conductive test piece, a small current is created around the magnetic flux field; much like a magnetic field
172 is generated around an electric current. The principle of eddy current is based on electromagnetic
173 induction; this is best captured using the Maxwell equations.

$$174 \qquad \qquad \qquad D = \epsilon E \qquad \qquad \qquad (1)$$

$$175 \qquad \qquad \qquad B = \mu H \qquad \qquad \qquad (2)$$

$$176 \qquad \qquad \qquad J = \sigma E \qquad \qquad \qquad (3)$$

177 The complex parameters in the above equations 1 to 3 are D, B, E, H and J and they represent electric flux
178 density, magnetic flux density, electric field, magnetic field strength and current density respectively with
179 ρ as electric charge density. With additional parameters of ϵ , μ and σ which are electric permittivity,
180 magnetic permeability and electric conductivity. The flow pattern of this secondary current, called an
181 "eddy" current, will be affected when it encounters a discontinuity in the test piece, and the change in the
182 eddy current density can be detected and used to characterize the discontinuity causing that change [36].

183 2.0 EXPERIMENTAL PROCEDURE

184 2.1 Materials and Methods

185 The extensive steps used in the design and the several tests used for calibration of an intelligent device
186 examined on a carbon steel pipe would be discussed in this chapter. As stated earlier, the primary goal of
187 this present work is to detect coating flaws and surface cracks on pipelines. The system model Figure 3
188 presents a diagram of the basic probe-flaw interaction. There are some parameters, including the magnetic
189 field range, the operating frequency band and sensor dimensions that permit the selection of the most
190 suitable sensor type for eddy current testing. After the broad discussion of the five most commonly used
191 non- destructive techniques, Eddy current proved to be the most appropriate considering the property of
192 the availed test material and the nature of the test to be conducted on it. For effective research and
193 analysis, the system is divided into three modules, namely power source, microcontroller and data
194 acquisition. In addition, the application of the eddy current technique in the device design, the
195 experimental design for the test of the intelligent device and its procedures is well highlighted. The
196 concluding part of this work focused on the signal processing of the output data for a good result.

197 2.2 Coil and Power Source

198 The power of this system was sourced from a direct current 12V battery which controls supply channel
199 for the individual components. The advantages of using coils as sensors for the eddy currents are the
200 simplicity of their construction, the huge dynamic range and the possibility of focusing the sensor which
201 is confirmed by De Haan, et al., [11]. The coils used as the probe sensor is made of copper wires and
202 circular in design. Special profile encircling probes are designed for researchers and manufacturers to
203 control surface and sub-surface defects in products with special profiles and shapes. The four coils in total
204 are homogenous in dimensions and properties, these coils are connected in series to form a chain round
205 the pipe for easy and complete testing of the pipe. The inner and external diameters of the coils stand at
206 5mm and 15mm respectively. The length of each of the coils are 110mm with resistance of 40 Ω and
207 excitation current of 50mA. All this was done to achieve the required sensitivity of the probe which is
208 vital in flaw detection. Tian, et al. [38] took the relationship between coil size and sensitivity into account

209 and proposed a method for reconstructing the flaw in order to determine the crack's depth. The coil had
210 600 number of turns and are connected to the microprocessor where the change in impedance experienced
211 in the coil is filtered to leave only useful signal for processing as shown in Fig. 2 below.

212 The calibration of the device was done to ensure that the coils were sensitive enough to detect defects and
213 to ascertain if the micro controller was able to take the change of the impedance on the coil from analogue
214 to digital for visual display which eases interpretation of the result.

215 2.3.1 The Micro-Controller

216 The micro controller chip was used to receive the analogue signals from the coil and remove noisy signals
217 (through the use of common mode rejection ratio), process and concurrently send signals to the computer
218 system for visual display. Its major constituency is the analogue to digital converter. The two important
219 steps taken by this chip to perform its function includes:

220 • **Signal quantization:** This step took the output voltage signal from the coil and the discretized it
221 into resolution signals of 4.88mV. Thus, this can be mathematically shown

$$222 \text{Quantization level} = \frac{V_{max} - V_{min}}{2^L} \quad (4)$$

223 Where L (Number of analogues to digital converter bits) = 10

224 Maximum voltage (V_{max}) = 5V

225 Minimum voltage (V_{min}) = 0V

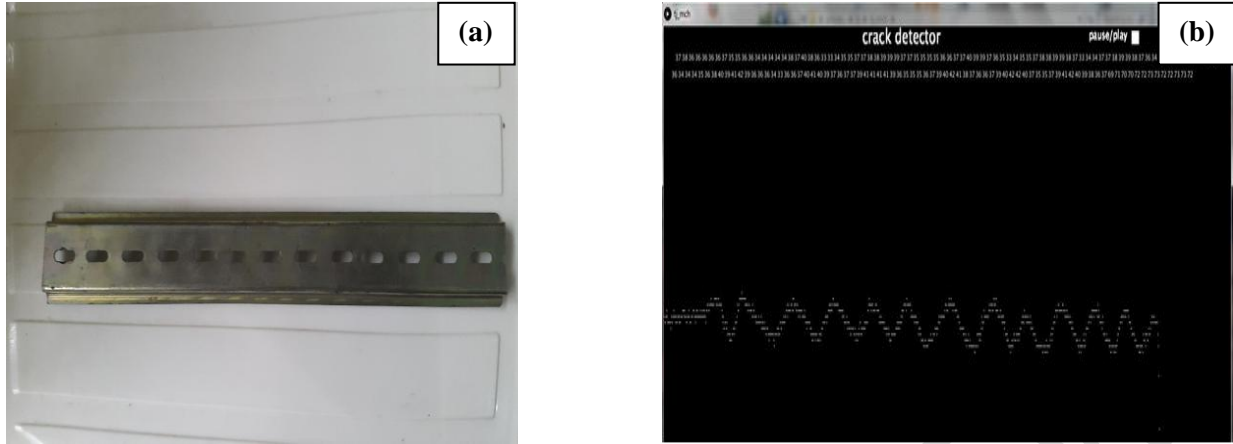
226 • **Encoding:** This involves the conversion of resolution signals of 4.88mV into digital resolution.
227 This was done with the use of the Arduino Nano device connected via a USB port to aid the
228 transfer of the digital representation of the signal to the computer system for further review and
229 analysis.

230 2.3.2 Visual Display

231 Several eddy current instruments are available with computer connections that vastly increase their
232 capabilities to search, visualize and analyze eddy current inspection data [34, 35]. Computers systems can
233 receive data from multiple channels and also with real-time processes of the inputs it gets. Some authors,
234 such as Rao et al., [24], Fahmy et al., [31], and Stander et al., [32], have published papers relating to
235 computer-controlled eddy current systems. Interpretation of the test was done with the use of an eddy
236 current device, made simple through an explicit graphical display aided by the Processing 3 software,
237 flexible software in a visual context. This displayed a pulse signal which has a baseline of the value of
238 4.88mV but could change in amplitude for every increase or decrease in the value of the of the baseline
239 signal.

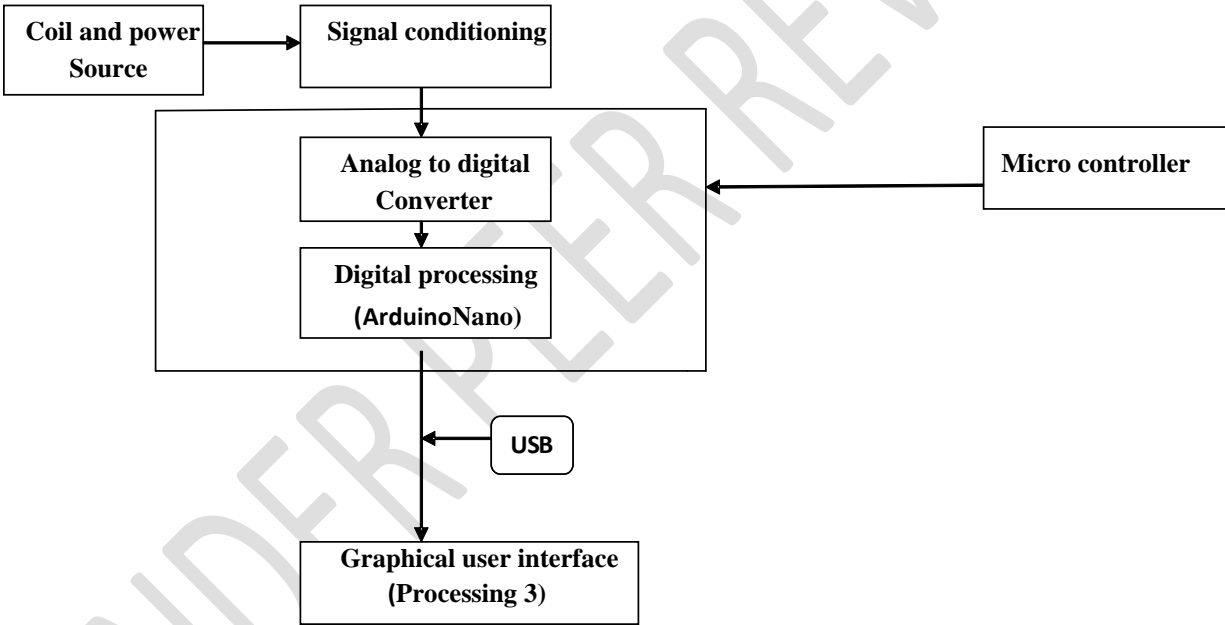
240 2.3.3 Experimental Design for Test

241 The device was initially calibrated with a steel plate 260mm by 35mm with 12 holes machined on it. The
242 holes have dimensions of 12mm by 4mm and are evenly spaced along the surface of the plate with
243 equidistance of 8mm. The display on the screen showed clearly the effect of the holes on the coil that is
244 been moved along the surface of the plate. The metal plate and also result from the calibration of the
245 device using the steel plate are depicted in Fig. 1 below.



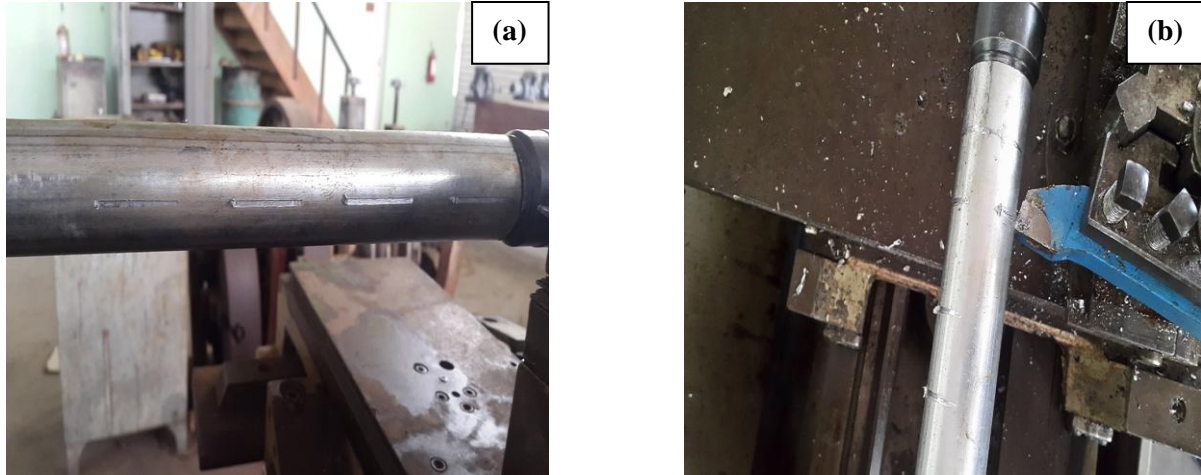
246
247 **Fig. 1(a):** The metal plate used to calibrate the device **(b)** Result showing the twelve holes on tested device

248 **2.4 Designs for Eddy Current Testing Device**



259 **Fig. 2:** Flow diagram denotes principal for Eddy Current Testing Device

262 The result from the calibration was validated by doing a visual inspection of the metal plate, this was followed by
 263 testing the device on a pipe. Two Galvanized test pipes were purchased and cut into smaller lengths of 300mm with
 264 internal diameter of 30mm and external diameter of 31.72mm. These measurements were done with a ruler and
 265 digital Vernier caliper respectively while the abrasions machined using the lathe machine. This is done to imitate a
 266 pipeline with cracks on it for the device to detect. The galvanized steel pipes were chosen because of its close
 267 similarity to the pipeline in terms of the material which is steel with resistivity of $1.43 \times 10^{-7} \rho$ ($\Omega \cdot m$) and
 268 conductivity of $6.99 \times 10^6 \sigma$ (s/m). Below are the two orientations of cracks (longitudinal and axial cracks) with their
 269 dimensions and also the machining processing that was done on each of the pipes as shown in Fig. 3 below.



270
271 **Fig. 3:** Different side view of the tested cracked device (a) Longitudinal (b) Axial

272 **3.0 RESULTS AND DISCUSSION**

273 This present work was done using an indigenous design for a compact and effective eddy current device
274 and connecting coils in series for outer surface of pipe inspection using eddy current testing device.
275 The non-destructive technique of eddy current testing was the basic principle on which this intelligent
276 testing device was designed and constructed [36, 37]. The device was able to induce eddy current on the
277 pipe (test material) through a coil and also give a visual display of the result from the change in
278 impedance on the coil on computer system software (Processing 3) through a micro controller connected
279 to it. The set up for the device constructed is shown below. This device does not only detect defects but
280 will also help in monitoring and evaluating defects on pipes.

281
282 **3.1 Defects in Conductive Materials**

283 The presence of a defect in a conductive material implies a region where electrical conductivity is null. If
284 electrical currents are generated in the conductive material, in these regions they do not exist and paths
285 are disturbed. In an open surface defect eddy currents can go around it, moving at the same horizontal
286 plane, or can even immerse, passing underneath the crack [38]. Each of these behavioural occurrences
287 depends on the crack length, on the crack depth and on the standard depth of penetration determined by
288 the operating frequency and the electrical conductivity [39]. In this present work, experimental tests were
289 performed on the test pipes containing machined axial and longitudinal defects with the setup in scanning
290 an area over the crack. An operating frequency of 100 Hz was imposed to the excitation coil.

291 **3.2 Eddy Current Testing Device**

292 The device is basically made up of a circular coil with parameters as earlier stated in the methodology
293 which is powered by a direct current battery and also a micro controller that converts the analogue signals
294 to digital and filters noisy signals [40]. This is connected to a computer system software (Processing 3)
295 which displays the effect of the surface of the pipe on the coils. The complete set up of the eddy current
296 device as shown in Fig. 4 below.

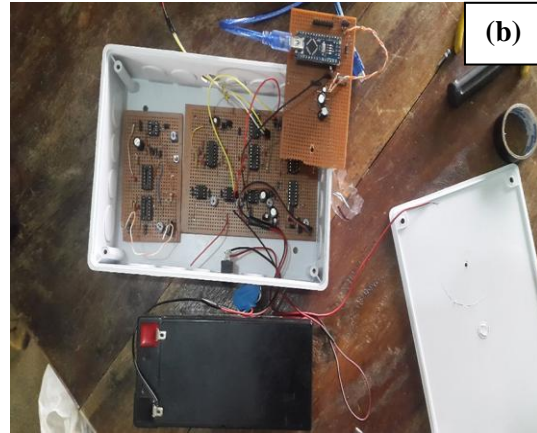


Fig. 4: (a) Complete set-up of an eddy current test device (b) The Micro-controller

297
298

3.3 Experimental Test Design

300 A pre-test and post-test experimental design was employed in the testing of galvanized steel pipes. The
 301 pre-test was done on the galvanized pipe after which the post-test was done on a galvanized pipe with
 302 machined defects of both axial and longitudinal orientations as developed in the models. First, the result
 303 of the pre-test on a defect free pipe is presented showing the response of the coil to the impedance
 304 encountered on the pipe. Second, the result of the post-test on the pipe with both the longitudinally and
 305 axially machined defects showing the response of the coil to the impedance caused by the defects. Then
 306 lastly the test result from a half-coated pipe is also presented. All the cases mentioned involves scanning
 307 the surface of the pipe with the coils. A very strong algorithm was also developed to filter, magnify output
 308 response and also visually display an easy to interpret result. Validation was carried out using a Non-
 309 destructive technique.

3.3.1 Test on Defect Free Galvanized Steel Pipe

311 This test shows the response of the coil on a defect free pipe. At the start of the test lift off caused a little
 312 change in the pulse signal but as the test progressed it was eliminated by maintaining a constant distance
 313 between the coil and the pipe. The relatively straight pulse signal shown on the screen of the computer
 314 system was expected as the impedance on the coil was relatively constant and was not and altered in
 315 anyway due to absence of any form of defect on the test pipe. Shown below in Fig. 5 and Fig. 6 are the
 316 visual display of the test conducted using the Processing 3 software on a computer system. The numbers
 317 at the top of the screen is just to show the numerical values of the nverse of the change in impedance on
 318 the coil which is in line with the pulse signal displayed.

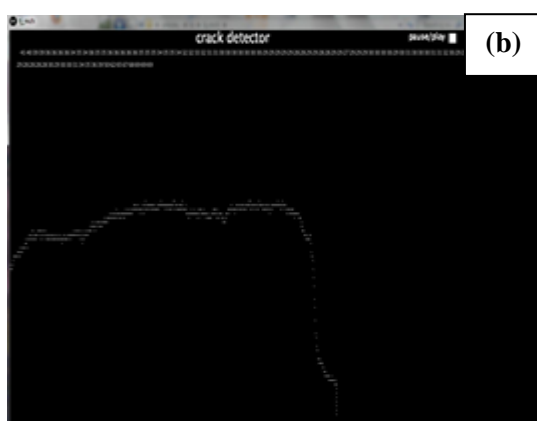
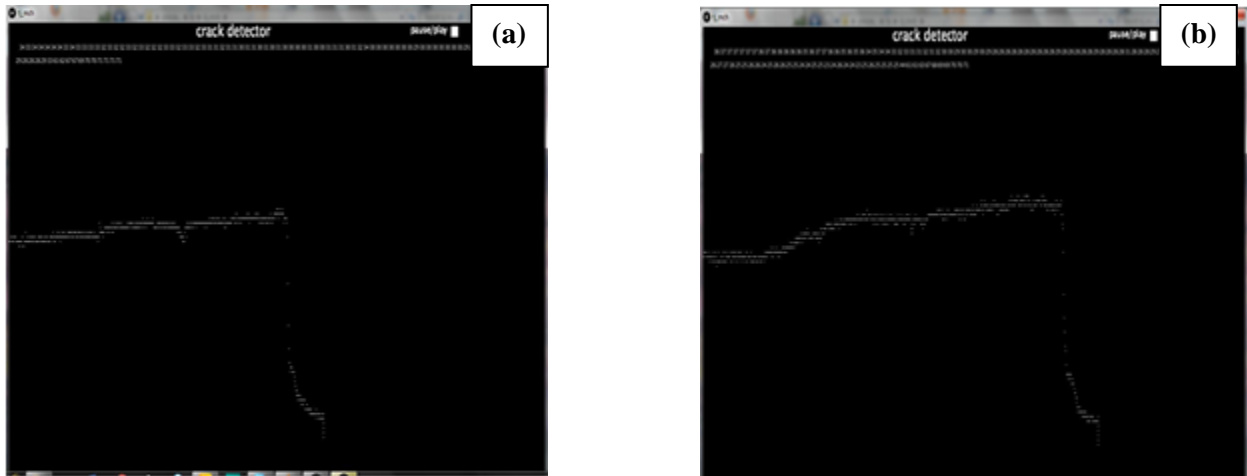


Fig. 5: Result from the tested done galvanized pipe (a) without defects (b) with longitudinal defects in section 1

319
320



321
 322 **Fig. 6:** Result from tested devices done galvanized pipe with longitudinal defects in (a) section 2 (b) section 3

323 **3.3.2 Test on axial Cracks on a Galvanized steel pipe**

324 During the post-test carried out on the galvanized steel pipe at the first section lift off was completely
 325 eliminated which gave a more regular pulse signal compared to the longitudinal defects test. Pulse signal
 326 showed significant low amplitude at the points where the coil encountered defects which was a strong
 327 indication. The test on the second section showed also complete elimination of lift off with the pulse
 328 signal regular till defects were encountered by the coil. This was indicated distinctively by the low
 329 amplitude that was seen on the display. The third test carried out in the third section of the pipe also
 330 showed no visible lift off on the display. The pulse signal showed the expected low amplitude at the
 331 points of defects. The visual display of the results can be seen from Fig. 7 below, also showing the
 332 numerical values at the top of each of the display which is the inverse of the impedance on the coil as the
 333 test was been carried on and it is in line with the pulse signal displayed.



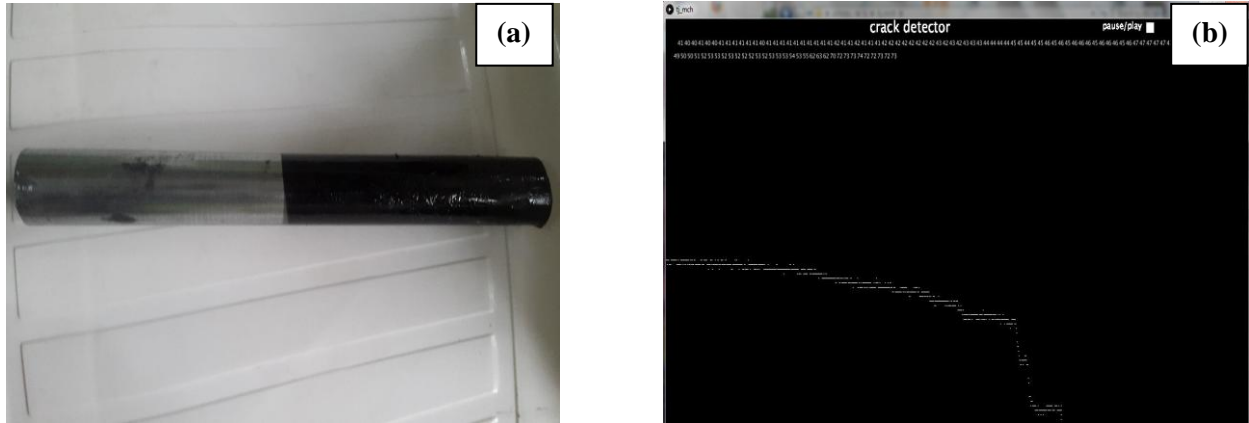
334
 335 **Fig. 7:** Result from tested devices done galvanized pipe with axial defects in (a) section 1 (b) section 2 (c) section 3

336 **3.3.3 Test on Coating Flaws on a Galvanized Steel Pipe**

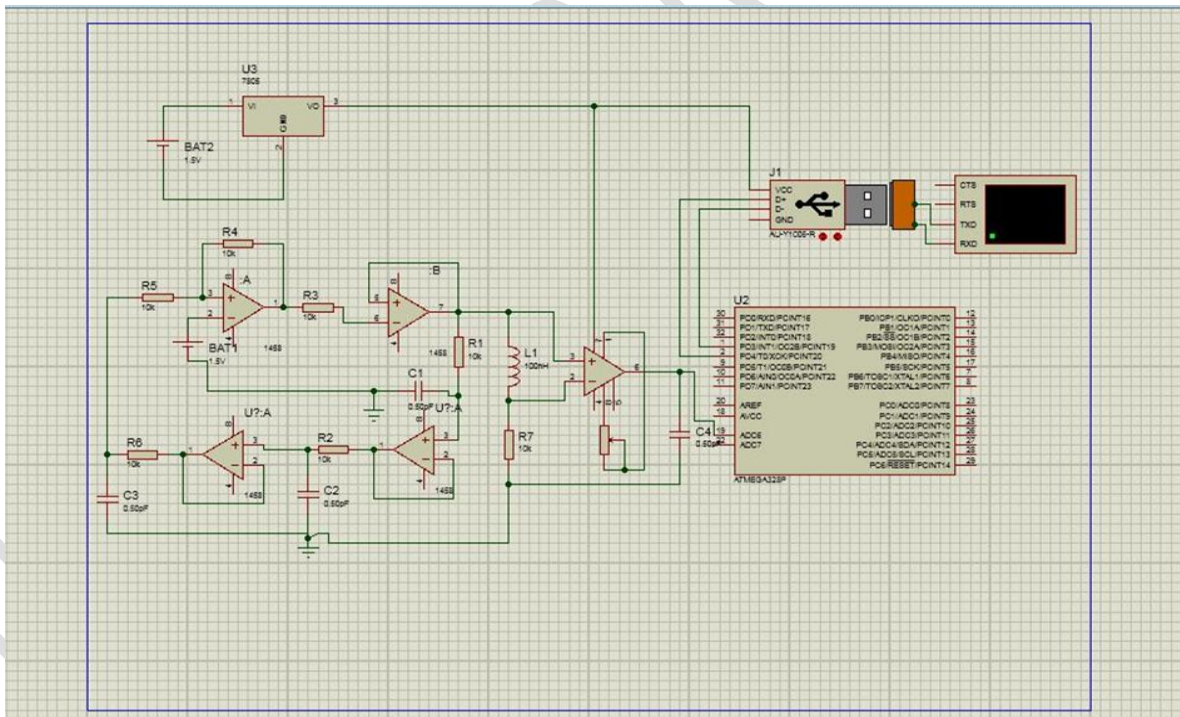
337 Coating flaws which is function of the variation in the thickness of coats on a pipe to keep it from rusting
 338 was also detected by testing the device on a pipe that was half coated with gloss paint as shown in Fig.
 339 8(a) and the result from this test can be seen in the displayed in Fig. 8(b) below. There was no lift off
 340 experienced during the test and the test was done from the part not coated to the part coated. The gradual
 341 low amplitude on the pulse signal was an indication of gradual increase in the impedance which is as a
 342 result of the increase in thickness of the area covered by the coil as it moves on the surface of the pipe.

343 **3.4 Validate of Test Device**

344 All the result of the defects tested for on the galvanized pipe as depicted in was validated by using a non-
345 destructive test of visual inspection and it was validated that though the change in pulse signal was not
346 relative to the size of the defects being detected due to low sensitivity of the coil but it was effective in
347 detection.



348
349 **Fig. 8(a):** Showing a half-coated pipe tested for coating flaws **(b)** Result of test galvanized pipe with coating flaws



350
351 **Fig. 9:** Showing the circuit diagram for the micro controller

352 **4.0 CONCLUSION**

353 This present study gives a solution from the experimental test result that was done on pipelines with
354 longitudinal defects, axial defects and coating flaws. The results confirmed that the designed and
355 constructed intelligent device is able to detect these types of defect or flaws.

356 From the present experimental investigation, the following conclusions can be made:

- 357 • The detection rate for this device on these types of defect is relatively high and reliable. This
358 indicates the proposed intelligent device is sensitive for different defect orientations and nature.
- 359 • Detailed analysis on the signals for coating flaws, axial and longitudinal defects shows that the
360 indicating change in amplitude of the pulse signal is not affected by the orientation or nature of
361 the defect.
- 362 • Comparing the result from the calibration to that of the test it can be deduced that different sizes
363 of defect generate different pulse signal response, which is useful for defect classification.
- 364 • The experimental design validated by the visual inspection method of non-destructive techniques
365 shows the effectiveness of the device.

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