TELKOMNIKA, Vol.17, No.5, October 2019, pp.2481~2485
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v17i5.12684

A low cost electromagnetic sensor for detecting holes in metallic sheet

Galang P. N. Hakim[1], Ahmad Firdausi[2], Mudrik Alaydrus*[3]
Department of Electrical Engineering, Universitas Mercu Buana,
Jalan Meruya Selatan, Jakarta, Indonesia
*Corresponding author, e-mail: macross.galang.pes@gmail.com[1],
ahmad.firdausi@ymail.com[2], mudrikalaydrus@mercubuana.ac.id[3]

Abstract

Unwanted hole in metal sheet that use for vehicle body or structure is proved dangerous situation. To prevent disaster this hole needs to be found before its installation, or other wise it will be time and money consuming once its found when already finished installation. Therefore, an inspection using sensor for metal sheet is recommended to prevent this problem. In this paper, we proposed a new sensor using radio wave propagation to detect holes in metal sheet. We propose to use RSSI methods to detect hole based on electromagnetic wave propagation signal strength. Using this method we success to detect 8 mm hole diameter in metal sheet with 1mm thickness. Using this method, we transmit electromagnetic wave energy at about 20 dBm, and we receive with average -27.53 dBm for iron sheet and -23.13 dBm for aluminum sheet.

Keywords: *electromagnetic wave, holey metallic sheet, sensor, shielding effectiveness*

1. Introduction

In modern time like this, metal material is one of the most important components that support human civilization. Almost every device has metal material inside. That metal material works either as electronic conductor because of their characteristic to deliver electron, or to become casing because of their strength and durability. Metal sheet as one of many form of metal material, played a vital role for most today application. Almost every vehicle and structure [1] has metal material to become support or become their body to cover and thus provide safety for passenger inside.

The strength and durability in metal sheet also had their flaw. Processing metal raw material to become metal sheet, sometimes make fatigue for metal sheet, and thus develop become holes [2]. This hole problem can develop become disaster that threaten life, and proved fatal in special vehicle that use metal sheet for its body cover (such as submarine and ships). Such disaster happen in 2008 when Russian spacecraft “Soyuz” experiencing the same problem [3]. The “Soyuz” has hole on its body with only two millimeters wide, but this hole causes oxygen to leak into space and thus pressure were dropping inside and threatening the life of astronouts. Therefore a manual inspection using human eye for metal sheet is a must to prevent this disaster from happen again [4]. But another problem arises when we are using human eye to inspect hole in metal sheet. It was unreliable inspection, because human eye sometimes misses to inspect a very small hole [5].

In this paper, a non-intrusive sensor based on electromagnetic wave is proposed to solve this problem. Several researches have been conducted for this problem, such as using RFID [6-8], using resonator and transformer [9-11], using microstrip and waveguide antenna [12,13]. Other unique methods would be the use of computer vision such as Otsu-Canny Edge Detection Algorithm [14]. Table 1 shows matrix related research. Unfortunately, using RFID system, we need additional readers to calculate RFID tag energy therefore it was costly with range $500 to $3000. Because it was expensive using RFID, therefore our works was not based on RFID, but rather using an electromagnetic wave propagation through material and signal measurement [15-17]. An electromagnetic wave is excited trough metal sheet and if there are hole, it can propagate trough hole. In this work a real time measurement of received signal strength is carried out, and by comparing with a calibration value, the shielding effectiveness of the structure is predicted.

Received October 27, 2018; Revised March 19, 2019; Accepted April 22, 2019

Table 1. Matrix of Related Research

Publication	Application	Device
R. Zoughi & S. Kharkovsky [12]	Microwave and millimetre wave sensors for crack detection	Waveguide Antenna
B. Zhou & J. Zhang [15]	Potential Measurement in ECT System	Capacitance Electrode
P. Lopato & M. Herbko [16]	Microwave Structural Health Monitoring Sensor for Deformation Measurement of Bended Steel	Microstrip Antenna
M. Lisowski & T.Uhl [17]	Wireless passive RFID-based sensor for crack detection	RFID Printed Sheet
This work	A Low Cost Electromagnetic Sensor for Detecting Holes in Metallic Sheet	ESP8266

2. Measurement Method

The metallic sheet under test is located between the transmitter and receiver, as illustrated in Figure 1. The transmitter generates the electromagnetic signal with the frequency 2.4 GHz, which is transmitted by the antenna and propagates towards the metallic sheet. A receiver captures the electromagnetic signals penetrating through the hole. The received power can reveal the dimension of the holes under certain calibration.

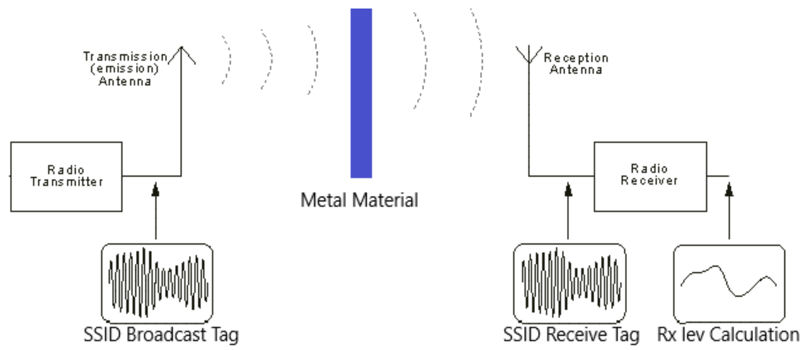


Figure 1. Measurement Method

The designed electromagnetic sensor consists of the transmitter and receiver block. The transmitter generates an electromagnetic wave which we tag with “SSID Metal Check”. The receiver catches the electromagnetic wave signal, and using Arduino IDE Serial Monitor calculates the received signal strength. To keep the interference to the minimal level, we placed the transmitter block inside a 0.5 mm thick metallic case and the receiver block on a plastic case. The microcontroller Wemos (esp8266 based) is used as an electromagnetic wave signal transmitter and also as receiver. The microcontroller Wemos is a popular IoT node, which is low cost and has compact size. It is a programmable microcontroller with L106 32-bit RISC microprocessor core based on the Tensilica Xtensa Diamond Standard 106 Micro running at 80 MHz. This microprocessor has also a WiFi capability with an integrated TR switch, balun, LNA, power amplifier and matching network.

The microcontroller wemos is powered by Li-Po battery; the battery charger and boost converter for recharging the battery and powering the entire system; see Figure 2. The transmitter circuit consists of four blockes, microcontroller wemos (A), the battery (B), battery charger and boost converter (C) and the on/off switch (D), as given in the left side of Figure 2. For the transmitter it is essential to set the equivalent isotrop radiated power (EIRP) in order to be able to provide detectable received level behind the hole. The EIRP of the transmitter consists of the transmit power (P_{TX}) and the gain of the transmitting antenna (G_{TX}):

$$EIRP = P_{TX} + G_{TX} \tag{1}$$

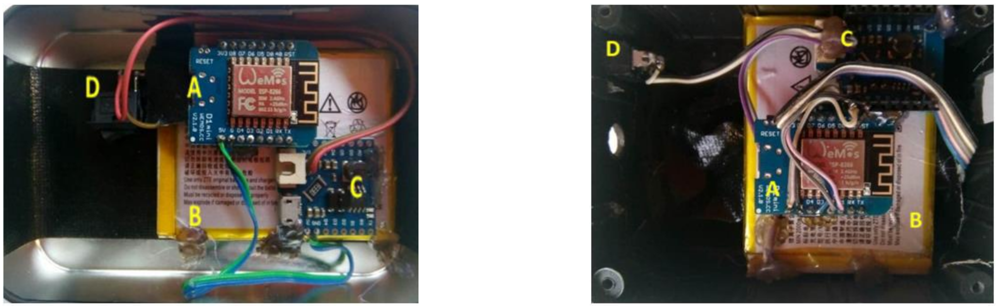
P_{TX} = transmit power (17dBm)
G_{TX} = gain of the antenna (3 dBi)

The EIRP becomes 17 dBm + 3 dBi = 20 dBm or 100 mW.

Whereas as illustrated in the right side of Figure 2, the receiver is also composed of microcontroller wemos (A), the battery (B), battery charger and boost converter (C) and the on/off switch (D). The received power can be calculated by (2):

$$P_{RX} = EIRP - PL \geq P_{RX,min} \quad (2)$$

P_{RX} = Received Power (dBm)
PL = Path loss (dB)
$P_{RX,min}$ = minimal received power/sensitivity of the receiver (-98 dBm)



(a) (b)

Figure 2. (a) Transmitter and (b) receiver circuitry

In path loss we include the geometrical power decrease, all possible disturbances along the propagation path and the gain of the receiving antenna. By this occasion, the effect of the hole in metallic sheets can be described in the penetration of the fields through the hole. The additional loss due to the hole is calculated in a simple way by comparing the received power in the presence of the hole to the case without the hole. As long as, the value of the received power is higher than the minimal detectable received power, we can measure meaningful received power.

Moreover, there is a shielding characteristics due to the presence of the holey sheet [18], which can be quantified by its shielding effectiveness. For a circular hole in a metallic sheet, a simple equation is available as given in [19]:

$$SE = 20\log\left(\frac{\lambda_o}{2d}\right) \quad (3)$$

λ_o is the wavelength in the free space and d is the diameter of the hole.

In this work, we can calculate the shielding effectiveness simply by taking the difference between the received power without and with the holey sheets:

$$SE = P_{RX,Without} - P_{RX,with} \quad (4)$$

3. Metallic Sheets under Test

In this work, we use two different metal specimens; the aluminum sheet and iron sheet. Aluminum is a strong and light weight metal that can be found in everyday life such as food wrapping, furniture, panel [20] etc. More importantly, aluminum is used in most aircraft [21], use for shielding against lightning strike [22], also because its metal feature provides durability against weather (corrosion resistant) [23] and has good thermal conductivity [24]. Meanwhile, the iron can easily be found in a heavy duty application such as bridges [25], roads, and others. In this experiment, we use iron and aluminum metal sheets with 1 mm thickness and the dimension 10 cm x 15 cm. Each aluminum and iron metal sheet we built consist of a hole with diameters of 2 mm, 4 mm, 6 mm and 8 mm, as given in Figure 3.

4. Measurement

A real time measurement is carried out to validate whether this sensor can detect a hole in the metal sheet. In order to do that, at first we are going to measure the received power without metal sheet. This measurement becomes a basis for calibration purposes for other measurements. Any variation of the received power means disturbances in the propagation path, which in this work is a metallic sheet with a hole with different diameter. Table 2 shows the measured received signal strength for free space condition (without metal) and for the case metallic sheets with different hole diameters. Based on the measured received power in Table 2, the shielding effectiveness of holey iron and aluminum sheet is calculated with (4), and for comparison purposes we use also the analytic equation in (3). The results are given in Figure 4.

Figure 4 reveals that iron shows bigger shielding effectiveness than aluminum sheet has. As the hole diameter increases, the value of shielding effectiveness decreases, as also given by the simple analytical expression. We see the order of the measured values is the same like given in the analytical approach.

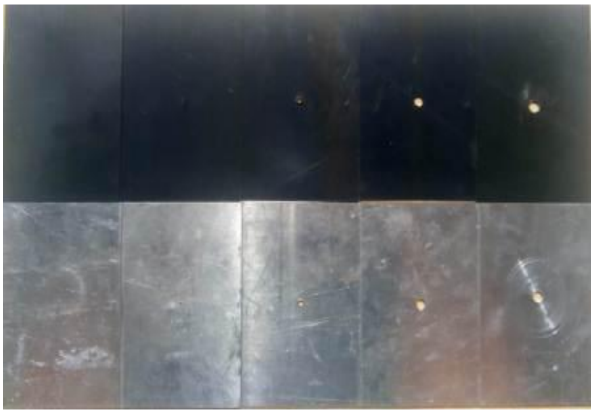


Figure 3. Aluminum & iron metal sheet specimens, from left to right (hole with a diameter of 2 mm, 4 mm, 6 mm and 8 mm)

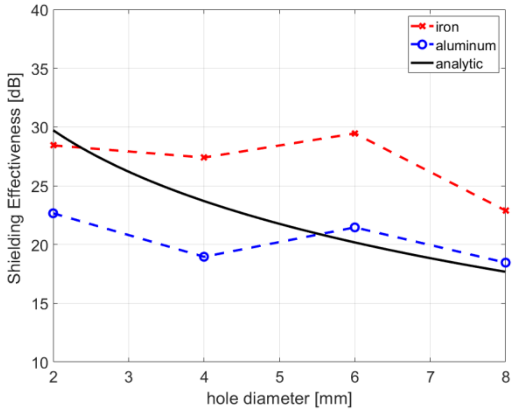


Figure 4. Shielding effectiveness of holey iron and aluminum sheets

Table 2. RSSI Measurement obtained for several metallic sheets (values in dBm)

Spesimens	Without Metal	Metal with hole, diameter			
		2 mm	4 mm	6 mm	8 mm
Iron	-4.6	-33.1	-32.0	-34.1	-27.5
Aluminum	-4.6	-27.3	-23.6	-26.1	-23.1

5. Conclusion

In this research we proposed a low cost electromagnetic wave based sensor for hole detection in metal sheet. This sensor only cost about $37.8 dollar more cheaper compare with RFID system based sensor. Using RSSI method to simplify the real time measurement, we success to detect 8 mm hole in diameter in 1 mm thickness metal sheet. The transmitted signal strength was 20 dBm and the received signal strength at average -27.53 dBm for iron sheet and -23.13 dBm for aluminum sheet. We were also able to predict the shielding effectiveness of the holes with different diameters and compared the result with those found by analytical expression.

Acknowledgements

The authors would like to thank Kemenristek Dikti for the financial support of this research for the period 2019.

References

[1] Shiraiwa T, Enoki M. Fatigue Crack Length Measurement of Sputtered Metal Film for RFID-based Smart Stress Memory Patch. *ISIJ International*. 2011; 51(9): 1480–1486.

[2] Lammi CJ, Lados DA. Effects of Processing Residual Stresses on Fatigue Crack Growth Behavior of Structural Materials: Experimental Approaches and Microstructural Mechanisms. *Metallurgical and Materials Transaction A*. 2012; 43(1): 87–107.

[3] OSMA Assesements Team. *NASA astronauts on Soyuz: experience and lessons for the future*. NASA. Report number: NASA/SP–2010–578. 2010.

[4] Martínez-Castro RE, Jang S, Nicholas J, Bansal R. Experimental assessment of an RFID-based crack sensor for steel structures. *Smart Materials and Structures*. 2017; 26(8): 85035.

[5] Yi X, Cho C, Wang Y, Cook B, Tentzeris MM, Leon RT. *Crack propagation measurement using a battery-free slotted patch antenna sensor*. 7th European Workshop on Structural Health Monitoring (EWSHM). Nantes. 2014.

[6] Yi X, Cho C, Cooper J, Wang Y, Tentzeris MM, Leon RT. Passive wireless antenna sensor for strain and crack sensing electromagnetic modeling, simulation, and testing. *Smart Materials and Structures*. 2013; 22(8): 085009.

[7] Marindra AMJ, Tian GY. Chipless RFID Sensor Tag for Metal Crack Detection and Characterization. *IEEE Transaction on Microwave Theory and Techniques*. 2018; 66(5): 2452–2462.

[8] Sunny AI, Tian GY, Zhang J, Pal M. Low frequency (LF) RFID sensors and selective transient feature extraction for corrosion characterisation. *Sensors Actuators, A Physical*. 2016; 241: 34–43.

[9] Albishi A, Ramahi OM. Detection of surface and subsurface cracks in metallic and non-metallic materials using a complementary split-ring resonator. *Sensors*. 2014; 14(10): 19354–19370.

[10] Alahnomi RA, Zakaria Z, Yussof ZM, Sutikno T, Alhegazi A, Abu-Khadrah AI. Enhanced Symmetrical split ring resonator (SSRR) for metallic surface crack detection. *TELKOMNIKA Telecommunication Computing Electronics and Control*. 2019; 17(4): 2107–2115.

[11] Zhou J, Xu Y, Zhang T. A wireless monitoring system for cracks on the surface of reactor containment buildings. *Sensors*. 2016; 16(6): 1–13.

[12] Zoughi R, Kharkovsky S. Microwave and millimetre wave sensors for crack detection. *Fatigue and Fracture of Engineering Materials and Structure*. 2008; 31(8): 695–713.

[13] Liu Z, Chen K, Li Z, Jiang X. Crack Monitoring Method for an FRP-Strengthened Steel Structure Based on an Antenna Sensor. *Sensors*. 2017; 17(10): 2394.

[14] Othman Z, Abdullah A, Kasmin F, Sakinah S, Ahmad SSS. Road Crack Detection using Adaptive Multi Resolution Thresholding Techniques. *TELKOMNIKA Telecommunication Computing Electronics and Control*. 2019; 17(4).

[15] Zhou B, Zhang J. Potential measurement in ECT system. *Journal of Electrostatics*. 2009; 67(1): 27–36.

[16] Lopato P, Herbko M. Microwave Structural Health Monitoring Sensor for Deformation Measurement of Bended Steel Structures: Influence of Curvature Effect. *Radioengineering*. 2017; 26(4): 1060–1066.

[17] Lisowski M, Uhl T. Wireless Passive RFID-Based Sensor for Crack Detection-Second Stage of Investigations. *Key Engineering Materials*. 2013; 588: 352–359.

[18] Wardoyo AS, Alaydrus M. Degradation of Shielding Performance of Metallic Sheet due to Aperture Configuration and Dimension at 2.4 GHz. *J Elektron dan Telekomun*. 2018; 18(1): 9–14.

[19] Celozzi S, Araneo R, Lovat G. Electromagnetic Shielding. In: Chang K. *Editor*. Encyclopedia of RF and Microwave Engineering. Wiley Interscience. 2018.

[20] Prayitno D, Irsyad M. Effect Of Ratio Of Surface Area On The Corrosion Rate. *SINERGI*. 2018; 22(1): 7-12. ISSN 24601217.

[21] Yashpal, Jawalkar CS, Kant S. A Review on use of Aluminium Alloys in Aircraft Components. *i-Manager's Journal of Material Science*. 2015; 3(3): 33–38.

[22] Permata D, Gurning MC, Martin Y, Sitorus HBH, Muda MA, Sinaga HH. Electromagnetic interference shielding in unmanned aerial vehicle against lightning strike. *TELKOMNIKA Telecommunication Computing Electronics and Control*. 2019; 17(2): 915–919.

[23] Haque MM, Limon SA, Moniruzzaman M, Bepari MM. Corrosion Comparison Of Galvanized Steel And Aluminum In Aqueous Environments. *International Journal of Automotive and Mechanical Engineering (IJAME)*. 2014; 9: 1758-1767.

[24] Majid ZAA, Razak AA, Ruslan MH, Sopian K. Characteristics Of Solar Thermal Absorber Materials For Cross Absorber Design In Solar Air Collector. *International Journal of Automotive and Mechanical Engineering (IJAME)*. 2015; 11: 2582-2590.

[25] Lantz G. Crack detection using a passive wireless strain sensor. MSC Thesis. Georgia Institute of Technology. 2011.