Design of Permanent Magnetic Yoke for Subsurface Defect Detection with Magnetic Particle Inspection Methode

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Abstract: The development of magnetic particle inspection testing is not only focused on testing materials placed indoors, where the need for electrical resources is the main thing. The increasing number of requests to carry out Non-Destructive Test (NDT) testing with the magnetic particle inspection method makes inspectors unable to speculate whether in open areas such as mining areas there is a power source available. To reduce the speculation of inspectors about the limited electrical resources in the open area, a permanent magnetic yoke was designed. Permanent magnetic yoke is an NDT testing tool with a magnetic particle inspection method that does not use an electric power source but uses permanent magnets. Yoke material used is Al6061 with a thickness of 50mm. The magnet used is a Neodymium type permanent magnet. The working principle of a permanent magnetic yoke uses the properties of permanent magnetism with the magnetic particle inspection method in areas where there is no power source Based on the results of the comparison test between Permanent Magnetic Yoke and DC Yoke through the same treatment, the level of accuracy of reading subsurface defects on welding joints of steel material with dimensions of 300 x 150 x 10 mm with 3G position SMAW welding process using permanent magnetic yoke is 96.78%.

1 INTRODUCTION

The development of manufacturing is currently increasingly advanced, especially in welding technology or engineering because it has an important role in metal engineering and repairing. The manufacturing process for metal in modern times currently involves many elements of welding, especially in the fields of design. In the welding process, not all the results of the metal connection are good. There must be a defect and discontinuity in the metal resulting from the connection. Some of these defects include defects that are on the surface (surface defect) and defects below the surface (subsurface defect). When welding doesn't pay attention to the guidelines contained in the Welding Procedure Specification (WPS) and Procedure Qualification Record (PQR) documents, generally the product will experience defects in welding.

Defects in the welding process will affect the material strength of a product. This is very vulnerable and it is the responsibility of a WI (Welding Inspector) to maintain in order to minimize and even eliminate defects, namely starting from theemergence of porosity clusters which result in repairs in the welding process (Warman, 2017).

In the process of welding work equipment from excavators, such as parts of the excavator boom, which use thick steel plate material, it is necessary to use special welding techniques. This technique is used to avoid defects that often occur in the boom joint welding process of excavators. Defects can be detected and identified using non-destructive testing with one of the methods, namely magnetic particle inspection (Pardede and Hendroprasetyo, 2015).

Several research have begun to use magnets as a defect identification with NDT (Non Destructive Test) using the Magnetic Particle Inspection method. In the research that has been done, it can be concluded that the effectiveness of reading using Magnetic Particle Inspection will decrease along with the increase in the thickness of the nonconductive coating from the actual crack size. while in particle magnetic examination, magnetization can use an electromagnet yoke (AC current) and permanent magnet. Permanent magnet yoke has different sensitivity with AC yoke in detecting surface defects. AC yoke is good at detecting surface cracks while permanent magnet

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yoke is better at detecting cracks on the subsurface (Dyatmika and Akbar Putra, 2012)

1.1 Magnet

$$\mu_r = \mu_{material} / \mu_o \quad (1)$$

with: μ_r : Relative permeability of a material Any text or material outside the aforementioned $\mu_{material}$: Material Permeability margins will not be printed.

Magnets are metals that can attract iron or steel and have a magnetic field. The word of "magnet" is thought to have come from the word "magnesia" which is the name of an area in minor of Asia, where magnets were first thought to have been discovered by humans. In the Magnesia area, rocks that can attract iron and steel were first found, which in turn were called magnets (Puspita and Rohima, 2009). Magnets always have two poles, a north pole and a south pole. The basic concept of magnetic poles is shown in Figure 1.

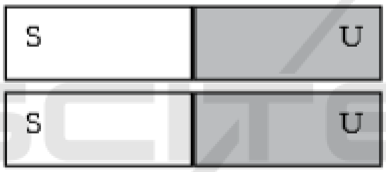

Figure 1: Magnetic Poles (Puspita and Rohima, 2009).

The magnetic poles are the ends of the magnet that have the greatest power to attract iron particles compared to other parts of the magnet. Every magnet has two poles, namely a south pole and a north pole. The straight line connecting these two poles is called the magnetic axis. If we hang a magnet and hold it still, the longitudinal direction of the magnet always points in a north-south direction. For a while, if a magnet is cut, each piece will still have two poles and become a new magnet (Puspita and Rohima, 2009).

Magnetic permeability is the degree of magnetization of a material in responding linearly to a magnetic field. According to international units, the permeability of the vacuum has a value of 4π×10-7 TmA-1 or 12.57×10-7 TmA-1 (Serway and Jewett, 2004). The value of the permeability of a magnetic material is not constant, which largely depends on the magnitude of the magnetizing force applied to it. The permeability of a magnetic material is always compared to the permeability of a vacuum, where this comparison is called relative permeability (Lusyana, Toifur, and Rohman, 2014). Relative permeability is defined by equation 2.3 as follows (Lusyana, Toifur, and Rohman, 2014). The relative permeability of a material can be calculated by the equation 1.

μ_o : Vacuum Permeability.

1.2 Magnetic Properties

According to their properties, magnets can be divided into:

1. Temporary Magnet

Temporary magnets are magnets whose elementary magnetic arrangement easily returns to irregularity after the magnetic material is used as a magnet (Puspita and Rohima, 2009).

2. Permanent Magnet

Permanent magnets are magnets whose elementary magnetic arrangement is difficult to be disorganized again so that they have a relatively long durability to become a magnet (Widodo et al, 2009). At this time there are many kinds of permanent magnets that are often used based on the material, including Barium ferrite, and Neodymium Iron Boron (NdFeB) Magnets (Irasari and Idayanti, 2009).

a. Barium Ferrite Magnet ($BaFe_{12}O_{19}$)

Barium ferrite magnets began to be developed in the early 1960s, as an alternative to the use of metal magnets. This magnet belongs to the classification of hard magnetic ceramic materials that have a hexagonal structure (BaFe12O19) (Irasari and Idayanti, 2009).

The advantage is that the price is cheaper when compared to other permanent magnets, causing barium ferrite magnets to be very preferred to be applied as permanent magnets (Irasari and Idayanti, 2009).

b. Neodymium Iron Boron (NdFeB)

In 1980, Neodymium Iron Boron (NdFeB) magnets were discovered with high strength, and they have been commercialized since November 1984. NdFeB is a rare earth type permanent magnetic material, because it is formed by 2 atoms of a rare earth element neodymium (Nd), 14 atoms of iron (Fe) and 1 atom of boron (B), so the molecular formula formed is Nd2Fe14B (Irasari and Idayanti, 2009).

The magnetic characteristics of NdFeB are better than other permanent magnets. Because it has better and higher magnetic characteristics than other magnets, in its application NdFeB magnets have small dimensions and volume. The application of NdFeB magnets is quite a lot, such as in electronic equipment, electric motors, generators, sensors, automotive industry, petrochemical industry and medical equipment products (Irasari and Idayanti, 2009).

The drawback is that it cannot be applied at high temperatures, which is only a maximum range of up to 200 ^{0}C. In addition, these magnets are quite expensive and have low corrosion resistance, so that in their application a surface treatment is required, such as being coated with nickel, zinc or gold (Irasari and Idayanti, 2009).

Non-destructive testing or non-destructive testing is defined as an inspection, test or evaluation applied to a material to determine the structure or components in the material in order to maintain the quality of the material use process (Ministry of Transportation, 2016). In NDT testing, it can determine the condition of the material and can detect any defects or damage to the material.

In the periodic inspection of non-destructive testing, the Magnetic Particle Inspection method has standard tests that must be carried out so that a construction is declared safe. The standard contains Acceptance Criteria so that a construction is declared safe to use, it must go through a testing process based on applicable standards. The recognized standards of Magnetic Particle Inspection testing and evaluation are:

- Legislation No. 1 of 1970 concerning Work Safety.
- Legislation No. 13 of 2003 concerning Manpower.
- ASME (American Society of Mechanical Engineering) Sec.V Article 7
- ASTM (American Standart for Testing Material) E3024,709 8

2 MATERIALS AND METHODS

2.1 Materials

Making this research requires several tools and materials as a support in the process of making these tools. The tools and materials used are as follows:

2.1.1 CNC Milling/Milling Machine

In the research, the CNC Milling machine used type Brother S500XI for making magnetic grip frames on Permanent Magnetic Yoke.

2.1.2 Aluminium Al6061

In the research, the material used for the manufacture of the design / frame of the handle is mild steel type Al6061

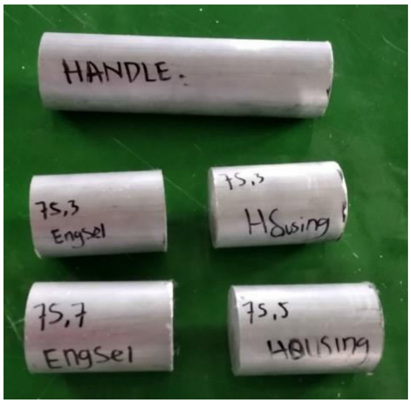

Figure 2: Materials Al6061.

2.1.3 Neodymium Magnets

Neodymium magnets are used for the magnetization process of the workpiece to be inspected so that it can find out the existing defects.

Figure 3: Neodymium Magnet.

2.1.4 Calibration Metal (18.2 Kg)

Calibration metal weighing 18.2 kg (40 lb) was used for the calibration of the Permanent Magnetic Yoke before being applied for the inspection stage to the workpiece.

2.1.5 Magnetic Yoke AC/DC

The AC/DC magnetic yoke in Figure 3 is used as a comparison of the test results of the permanent magnet yoke.

Figure 4: Magnetic Yoke AC/DC.

2.2 Methods

In the manufacturing process, the workpiece design process goes through the CAD (Computer Aided Design) process. CAD (Computer Aided Design) is a computer program for designing a product. The CAD process is very necessary as an initial design before making a product using the manufacturing process. Basically, CAD can be in the form of 2-dimensional or 3-dimensional technical drawings with detailed drawing descriptions to make it easier for the next processing. In the process of making this research design using Solidworks.

This permanent magnetic yoke design is based on 3 main parts, Handle Yoke, Link Yoke, and Housing Magnet Yoke, where all manufacturing processes are carried out with 3 axis CNC Milling. The geometric shape of each part of the permanent magnetic yoke is as follows. Figure 5 has shown handle yoke and link yoke design.

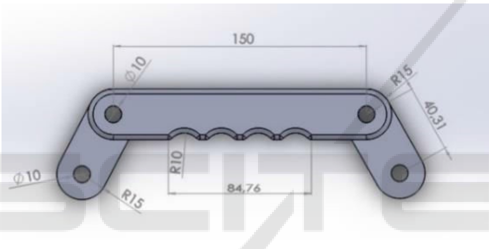

Figure 5: Handle Yoke and Link Yoke.

Yoke handle serves as the holder of the permanent magnetic yoke test equipment. The design of the handle yoke design follows the morphology of the inspector's fingers so that it does not cause work accidents on the fingers during the testing process. The link Yoke functions to adjust the length and shortness of the test area so that the effectiveness of the performance of the magnet during testing becomes better. Magnet housing has shown on Figure 6.

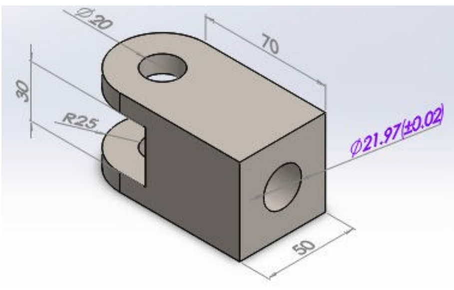

Figure 6: Housing Magnet.

The housing magnet serves as a place for the Neodymium permanent magnet to be implanted. The size of the housing magnet hole is made using a fitting adjustment tolerance, so that the magnet insertion is carried out with the help of heating on the housing. Permanent Magnetic Yoke design has shown on Figure 7.

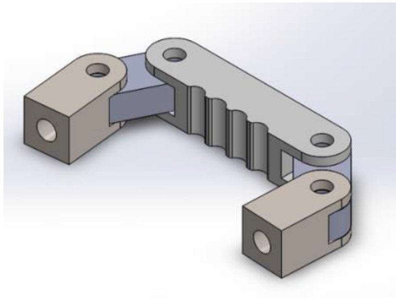

Figure 7: Permanent Magnetic Yoke Design.

Furthermore, the CAD softcopy of the three-part design will be imported into the CAM software for CAM programming to be made before being executed on the CNC Milling machine. CAM programming has shown on Figure 8.

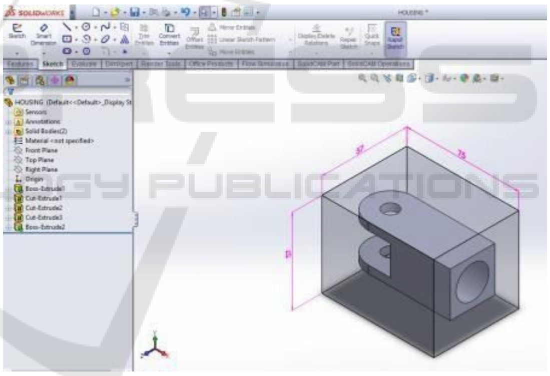

Figure 8: CAM Programming.

Making the CAM program still refers to the appropriate parameters for machining raw materials. The examples of G-Code simulation programs above and their explanations has shown on Table 1.

Before being executed on a CNC machine, it is necessary to verify in the form of a toolpath simulation from the CAM program that has been created. One form of the simulation has shown on Figure 9.

Table 1: G-Code program for Housing.

No	G – Code	Penjelasan
1.	M06 T8	Penggantian Jenis pahat posisi di turret no. 8 (pahat jenis en mill diameter 16)
2.	G00 G54 G90 X-9.6	Gerakan pahat menuju retract point X dengan work coordinate G54
3.	S1000 M03	Kecepatan Spindle 1000 Rpm searah jarum jam
4.	M08	Coolant on
5.	G01 Z-0.5 F33.	Gerakan lurus pahat memakan benda kerja kedalaman 0.5 mm dengan pemakanan 33 mm/min
7.	X84.6 F500.	Gerakan pahat menuju koordinat X 84.6 dan pemakanan 500 mm/min
8.	Y44.1427 F1000.	Gerakan pahat menuju koordinat Y 44.1427 dan pemakanan 1000 mm/min
9.	X-9.6 F500.	Gerakan pahat menuju koordinat X – 9.6 dan pemakanan 500 mm/min
10.	Y33.7142 F1000.	Gerakan pahat menuju koordinat Y 33.7142 dan pemakanan 1000 mm/min
11.	X84.6 F500.	Gerakan pahat menuju koordinat X 84.6 dan pemakanan 500 mm/min
12.	Y23.2858 F1000.	Gerakan pahat menuju koordinat Y 23.2858 dan pemakanan 1000 mm/min

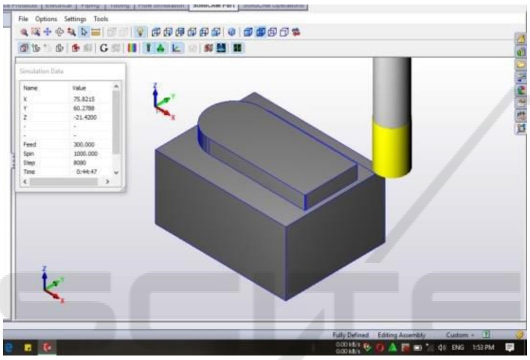

Figure 9: *Toolpath* CAM simulation.

3 RESULTS

Testing of the permanent magnetic yoke is carried out by referring to the ASME Sec standard code. VIII Mandatory Appendix 6 of 2009 with criteria for acceptance of defects in the Magnetic Particle Examination testing method. An indication of a defect is evidence of the imperfection of a material caused by certain things. Only indications having dimensions (dimensions) greater than 1/16 inch (1.5mm) will be considered. Evaluation of indications according to ASME Sec.VIII Mandatory Appendix 6:

a. A linear indication is one having a length greater than three times the width
b. A rounded indication is one of circular or elliptical shape with a length equal to or less than three times its width.
c. Any questionable or doubtful indications shall be reexamined to determine whether or not they are relevant.

These acceptance standards shall apply unless other more restrictive standards are specified for specific materials or applications within this Division. All surfaces to be examined shall be free of:

a. relevant linear indications;
b. relevant rounded indications greater than 3/16 in. (4.8 mm);
c. four or more relevant rounded indications in a line separated by 1/16 in. (1.6 mm) or less, edge to edge.

Based on SEC ASME standards. 5 article 7 regarding Magnetic Particle Inspection, the AC Yoke testing procedure is different from the Permanent magnet yoke. However, for the evaluation and analysis of defects that occur in the material, it still refers to the ASME Sec. VIII Mandatory appendix 6.

3.1 Equipment and Material Used

Equipment Used:

a. duster
b. AC Yoke
c. Lighting
d. Iron Brush
e. Light Meter (Lux Meter)
f. Ruler Material Used:

a. Cleaner
b. White Contrast (WCP-2)
c. Wet Pacticle (7HF)

3.2 Procedure Test

a. Prepare tools and electrical resources, then test the strength of the AC yoke first (Power Lifting of Yoke) based on ASME section V Article 6 (T-773, 2), namely for AC current the yoke must be able to lift a load of 4.5 kg (10 lbs). If the yoke can still lift the required load, then the yoke is still suitable for use. This lifting power test is usually carried out once a year.
b. Clean the surface of the test specimen from oil, and other impurities in the form of rust, grease, paint, and other impurities with a cleaner
c. Spray the test specimen with White Contrast Paint (WCP 2) evenly.
d. Wait for the white contrast paint to dry (dwell time).
e. Arrange the yoke in such a way that it can magnetize the test specimen properly and during the process of magnetizing the test specimen the yoke is placed in different positions so that all discontinuities in the test material are visible, both cracks on the surface and subsurface.
f. When the yoke is magnetized, the test specimen is sprayed with wet particle so that the defects in the test material appear.

g. Observing discontinuities and defects.
h. Demagnetization or removal of magnetic residue on the specimen after evaluation.
i. Post Cleaning

4 DISCUSSION

The level of accuracy in the process of reading and measuring defects is very necessary in determining whether the workpiece is suitable for use or not. Basically, precise measurement and calibration of precision measuring instruments can support the success rate in data analysis.

To determine the performance of the permanent magnetic yoke test equipment, a welding defect detection test was carried out on the test specimen in the form of steel with a 3G connection type SMAW welding process. The test also uses a DC yoke as a comparison. The following are the results of welding specimen testing, has shown on Figure 10 and Figure 11.

Figure 10: Permanent Magnetic Yoke testing.

Figure 11: Comparison with Yoke AC/DC.

Identification of defects in the weld metal of the test specimen can be seen in the following Figure 12.

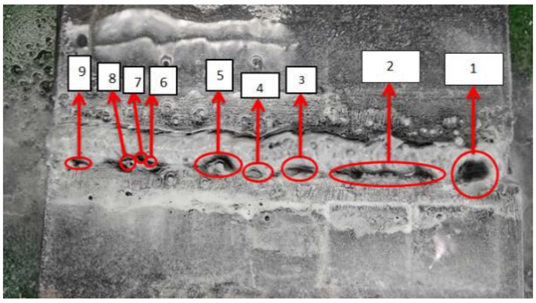

Figure 12: Specimen Test Results with Permanent Magnetic Yoke.

Figure 13: Test Specimen Defect Measurement.

Measurement of defect readings on test specimens can be seen in the following Figure 13:

Table 2 is the test result data and analysis of the accuracy of Permanent Magnetic Yoke and DC Yoke readings.

Table 2: Comparison of Yoke DC and Permanent Magnetic Yoke readings

UJI PARTIKEL MAGNETIK (*Magnetic Particle Test*)

Date : Rabu, 22 Juli 2020
Material : Weld SMAW Plat 3G
Reference : 1. ASME V article 6
2. ASME Sec. VIII appendix 6
3. ASME Sec V article 7

Equipment	✓ yoke DC	✓ Yoke Permanent	☐ coil	☐ SN:
Particle type	☐ dry	✓ wet	☐ fluorescent	☐ color contrast
Surface condition	✓ weld	☐ machine process	☐ grind	☐ ....
Range	☐ base metal		✓ weld part	
	☐ edge preparation		☐ repair weld	
	☐ back chipping		☐	

No	Part/Item	Size of defect (mm)				Result		Yoke Permanent Accracy	Remark (Weld Part)
		Yoke DC		Yoke Permanent		Accepted	Reject		
		P	L	P	L				
1	Plat SMAW 3G	9,57	6,6	9,5	6,47		✓	97.30%	REJECT
		33,37	3,2	33,57	3,1		✓	97.46%	
		7,67	4,07	7,37	4,03		✓	95.30%	
		8,93	3,2	8,67	3,07		✓	92.97%	
		4,8	3,47	4,67	3,43	✓		96.29%	
		2,4	1,2	2,33	1,2	✓		97.22%	
		3,2	2,6	3,2	2,56	✓		98.72%	
		2,9	1,23	2,9	1,2	✓		97.30%	
		6,53	1,83	6,43	1,83		✓	98.47%	

Based on the results of the permanent magnetic yoke test with a DC yoke comparison, the following results were obtained, has shown on Figure 14.

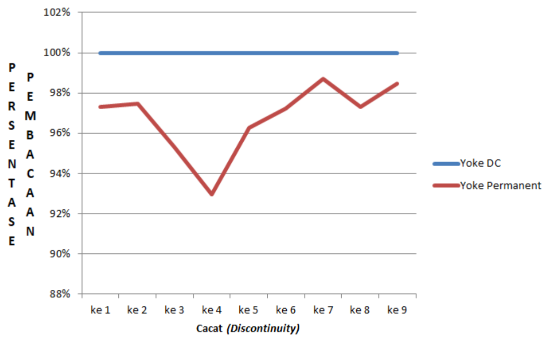

Figure 14: Defect Reading Comparison.

Based on the data in Figure 13, the Yoke DC reading is always 100% because the reference for comparison in this study is the "Magnaflux" brand DC Yoke which has been tested and calibrated with reference to the ASME BPVC, ASTM E1444, ASTM E709 standards.

For Permanent Magnetic Yoke readings, the average reading accuracy is 96.78% because at the time of making the permanent Yoke it was not calibrated to the standard applicable to the NDT test classification.

In the 4th defect indication, it was found that there was a significant decrease in the percentage due to several factors, one of which was an error in measurement due to the concave position of the defect and the irregular shape of the defect, so the measurement could not be precise with the original size of the defect (Nurachmandani, 2009).

5 CONCLUSION

After analyzing and collecting data using the Permanent Magnetic Yoke, it can be concluded as follows:

a. The percentage of accuracy in reading Permanent Magnetic Yoke defects is 96.78%. These results are obtained by reference to readings from Yoke DC Magnaflux which have been calibrated to international standards.
b. The increasing trend in the graph of the Permanent Magnetic Yoke test results shows that the effectiveness of the test equipment with the base material of Neodymium permanent magnets is reliable enough to be used in open areas such as mining and shipyards.

The suggestions that can be given for further development and research are as follows:

a. The results of several tests and data analysis, should be for accuracy in reading defects using a special specimen (test object) in the form of a measurable artificial defect.
b. Substitution in the selection of Permanent Magnetic Yoke material does not only pay attention to the light weight and ergonomics aspects, but the material characteristics also need to be considered. The basic nature of aluminum material turns out to be able to weaken the magnetic properties.

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