EVALUATION OF SLIT PARAMETER OF FERROMAGNETIC MATERIAL BASED ON MAGNETIC FLUX LEAKAGE

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DECLARATION

I declared that this project entitled "Evaluation of slit parameter of ferromagnetic material based on magnetic flux leakage" is the result of my own work except as cited in the references.

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature :

Name : Siti Norbaya binti Sahadan

Date : 26th August 2020

DEDICATION

To my beloved parents, family members and friends who have been with me throughout an incredible journey of this 23 years of life.

ABSTRACT

Evaluation and testing the quality of materials are vital importance in order to maintain the productivity of materials, which could have an impact on safety and reliability of the material used. Nondestructive testing (NDT) method, which is a process of evaluating the defects on material without destroying or harming the system is used in this project due to their advantages of retaining the material's properties without causing damage. To promote the evaluation of defects on ferromagnetic materials, magnetic flux leakage (MFL) method is commonly used, which is reliable for crack detection. However, the requirement of magnetizing objects in traditional MFL method limits their applications in some condition. Hence, metal magnetic memory (MMM) method which is recently proposed by the researchers is chosen in this experiment because of their advantages of easy to operate and is more sensitive to stress. MMM method is highly effective in assessing the extent of early damages such as fatigue cracks in the ferromagnetic components because of the existence of stress concentration zone. The main purpose of this project is to evaluate the slit parameter of ferromagnetic material based on MFL. For this project, SAE 1045 carbon steel is used as the specimen due to its good machinability and offers lower cost compared to the other materials. The 3D view of the specimen models, with different slit depth and slit length are drawn by using SolidWorks software and then finite element analysis is applied to the models of the specimen. During the analysis, 100 N of tensile force is applied to the right end of the models to get the distribution of stress concentration on the models. Then, the results of stress concentration and Von Misses stress acting on the models is tabulated and graphically presented. From the results obtained, the stress concentration will increase when the slit length and slit depth increase. However, the results proved that the slit depth gives more influence to the stress concentration than the slit length. For examples at the

same length (5 mm) but with different depth, the value of the Von Mises stress increase much higher from 1.544×10^6 N/m² to 1.724×10^6 N/m² at 1 mm and 1.5 mm depth respectively. In contrast, at the same depth (1 mm) with different length of the slit, there are just a small increment in the value of the Von Misses stress which is from 1.544×10^6 N/m² to 1.555×10^6 N/m² at 5 mm and 10 mm length respectively. Then, comparative study is conducted to study and compare the results obtained from the finite element analysis with the previous study. From the comparative study, it is validated that the results of the finite element analysis are similar with the existed experimental results from previous study. Therefore, the coincidence confirms that the MFL method can be used in the evaluation of the slit parameters of ferromagnetic material.

ABSTRAK

Penilaian dan pengujian kualiti bahan sangat penting untuk menjaga produktiviti bahan, yang dapat mempengaruhi keselamatan dan kebolehpercayaan bahan yang digunakan. Kaedah Nondestructive testing (NDT), yang merupakan proses menilai kecacatan pada bahan tanpa merosakkan atau merosakkan sistem digunakan dalam projek ini kerana kelebihan mereka mengekalkan sifat bahan tanpa menyebabkan kerosakan. Untuk mempromosikan penilaian kecacatan pada bahan feromagnetik, kaedah kebocoran fluks magnetik (MFL) biasanya digunakan, yang dapat dipercayai untuk pengesanan retakan. Walau bagaimanapun, keperluan objek magnet dalam kaedah MFL tradisional menghadkan aplikasinya dalam beberapa keadaan. Oleh itu, kaedah memori magnetik logam (MMM) yang baru-baru ini dicadangkan oleh penyelidik dipilih dalam eksperimen ini kerana kelebihannya senang dikendalikan dan lebih sensitif terhadap tekanan. Kaedah MMM sangat berkesan dalam menilai sejauh mana kerosakan awal seperti keretakan keletihan pada komponen feromagnetik kerana adanya zon penumpuan tekanan. Tujuan utama projek ini adalah untuk menilai parameter slit dari bahan feromagnetik berdasarkan MFL. Untuk projek ini, keluli karbon SAE 1045 digunakan sebagai spesimen kerana kebolehkerjaannya yang baik dan menawarkan kos yang lebih rendah berbanding dengan bahan lain. Tampilan 3D model spesimen, dengan kedalaman celah yang berbeza dan panjang celah dilukis dengan menggunakan perisian SolidWorks dan kemudian analisis elemen hingga diterapkan pada model spesimen. Semasa analisis, daya tegangan 100 N digunakan pada hujung kanan model untuk mendapatkan taburan kepekatan tegasan pada model. Kemudian, hasil penekanan tekanan dan tekanan Von Misses yang bertindak pada model-model tersebut dijadualkan dan ditunjukkan secara grafik. Dari hasil yang diperoleh, kepekatan tekanan akan meningkat apabila panjang celah dan kedalaman celah meningkat. Walau bagaimanapun,

hasilnya membuktikan bahawa kedalaman celah memberi lebih banyak pengaruh terhadap kepekatan tegangan daripada panjang celah. Sebagai contoh pada panjang yang sama (5 mm) tetapi dengan kedalaman yang berbeza, nilai tegangan Von Mises meningkat jauh lebih tinggi dari $1.544\text{x}10^6$ N / m² menjadi $1.724\text{x}10^6$ N / m² pada kedalaman 1 mm dan 1.5 mm. Sebaliknya, pada kedalaman yang sama (1 mm) dengan panjang celah yang berbeza, hanya terdapat sedikit kenaikan dalam nilai tegangan Von Misses yang dari $1,544\text{x}10^6$ N / m² hingga $1,55\text{x}10^6$ N / m² pada 5 mm dan Panjang masing-masing 10 mm. Kemudian, kajian perbandingan dilakukan untuk mengkaji dan membandingkan hasil yang diperoleh dari analisis elemen hingga dengan kajian sebelumnya. Dari kajian perbandingan, disahkan bahawa hasil analisis elemen hingga serupa dengan hasil eksperimen yang ada dari kajian sebelumnya. Oleh itu, kebetulan mengesahkan bahawa kaedah MFL dapat digunakan dalam penilaian parameter slit dari bahan feromagnetik.

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NDT	-	Nondestructive testing
MFL	-	Magnetic flux leakage
MMM	-	Metal magnetic memory
AC	-	Alternating current
DT	-	Destructive testing
SMFL	-	Self-magnetic flux leakage
3D	-	Three dimensions
2D	-	Two dimensions
1D	-	One dimension
SCZ	-	Stress concentration zone
EAC	-	Environmental assisted cracking
FEA	-	Finite element analysis
FEM	-	Finite element method

LIST OF SYMBOLS

q	-	Internal pressure
$H_{p(x)}$	-	Tangential SMFL component
$H_{p(y)}$	-	Normal SMFL component
σ_θ	-	Circumferential tension stress
σ	-	Stress
w	-	Defect location
y	-	Lift-off calue
b	-	Width
d	-	Depth
f	-	Frequency
R	-	Stress ratio
C	-	Carbon
Mn	-	Manganese
Cr	-	Cromium
Si	-	Silicon
p	-	Phosphorus
Ni	-	Nickel

Mo	-	Molybdenum
Cu	-	Copper
M	-	Magnetic domain

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Ferromagnetic materials are strongly magnetized when subjected to the external magnetic field and retain its magnetic moment even when the applied field is removed. Ferromagnetic materials do not only respond strongly to magnets, but they can also be magnetized, attracted to magnets and form permanent magnets. Ferromagnetism is the spontaneous magnetization phenomenon that exists in the ferromagnetic material in the absence of applied magnetic field. The examples of the ferromagnetic materials are transition metals such as ferum, nickel and cobalt (Wang et. al, 2013).

Nondestructive testing (NDT) is used during this project rather than destructive test because of their advantages that retain the properties of materials without causing damage. NDT is the process of evaluating and testing the defects of materials without destroying or harming the system. In other words, the part can still be used after it was tested (Gupta, 2018).however, destructive testing are destructive in nature and are conducted on the limited sample, rather than on the materials (Dwivedi, 2017). The traditional method of inspecting the quality of materials have several disadvantages such as results are not predicted immediately and destructive in nature. In addition, the traditional method which is destructive testing, are usually not appropriate for parts in operation. Therefore, several NDT methods have been developed to overcome the limitations.

Nowadays with the grows in technology, NDT is commonly applied in manufacturing and piping to inspect the materials and products integrity and reliability and to maintain the quality of materials (Usarek et. al, 2017). These methods have been drawn more attention due to the reliability and effectiveness of the testing process (Verma et. al, 2013). Eddy current, ultrasonic and magnetic flux leakage are among the types of NDT method that are commonly used for defect investigation. Eddy currents are generated by an electromagnetic induction system. Eddy currents testing is commonly used for the inspection of various type of defects such as surface crack detection, to measure the coating thickness and the determination of depth (Dwivedi, 2017). Ultrasonic technique is used to inspect or evaluate the internal flaws in sound-conducting materials, while the magnetic flux leakage is the most popular NDT method which uses a sensitive magnetic signal. Magnetic flux leakage (MFL) is used to detect crack, where the induced magnetic field will change with the existence of cracks in the specimen. This method of testing can measure the distribution of the magnetic field on the magnetized specimen and therefore has been applied in evaluating defects on specimens (Shi, 2015).

Crack is a major concern in ensuring the durability, safety and serviceability of structures. This is because the presence of crack can cause the reduction in the effective loading area which lead to the increase of stress and subsequently failure of the materials or structures. Cracking seems unavoidable and appears in wide variety of structures such as concrete wall, beam and brick walls. Various types of defects also can be found in pipeline applications (Agbainor, 2014). Slit and crack are the examples of defects that commonly found especially in the ferromagnetic materials. The presence of defects will affect the reliability, safety and the consistency of materials' quality. Therefore, it is crucial to test and evaluate the materials or structure to detect cracking for the safety and health of the structure. The presence of such cracks can be detected by using various types of NDT.

However, these methods or techniques have their own advantages and limitations depends on their use and applications (Gholizadeh, 2016). NDT plays a vital role to identify the existence of defects that enables the early planning for the structure replacement from the results of testing or evaluation (Verma et. al, 2013). Combination of different NDT is a good way to inspect the defect and abnormalities of the structures. In many cases, more than one NDT method is use in the process of defect inspection. To ensure the effectiveness of the inspection process, more understanding on the backgrounds, advantages and limitations of each NDT technique is necessary. Understanding one nondestructive method alone may not be enough to obtain the accurate results from the testing process (Dwivedi, 2018). Therefore, analysis of signals is very important before conducting inspections because the combination of different methods is necessary when there is not enough information provided from a single test method.

1.2 PROBLEM STATEMENT

Evaluation and testing the quality of material are very important during the life of a material (Verma, 2013). To maintain the productivity of the materials, proper inspection techniques are required for infrastructure deterioration. NDT is an important method for the inspection of surface and subsurface flaws which could have an impact on safety and reliability of the material used**.** The issue of inspection is important especially during the production stages. Factors such as economics, safety and the use of constructive designs come into play when product quality is of concern.

Based on the recent studies, there are various type of defect that could affect the productivity of materials. The purposed of this project is to characterize the slit parameter of ferromagnetic material based on MFL. Slit and crack are the examples of defects that commonly found in the ferromagnetic materials. The presence of these types of defects will give an impact to the consistency of the materials quality and directly will affect the reliability and safety of materials. For a better understanding, crack is either a stress corrosion crack or a fatigue crack which is artificially produced or formed naturally. In other hand, defect is commonly used to refer a crack, slit or other abnormalities such as corrosion (Yusa, 2009).

With the current development in technology, there are many types of NDT method that available to detect crack. Liquid penetrant testing is one of the basic methods which can be used for defects or cracks detection. During this method of testing, liquid dye penetrant is applied to the material surface and then drawn into any surface with cracks or slits, highlighting the detected cracks on the materials. Other than that, eddy current testing is capable in detection of surface crack. Eddy current testing utilizing low frequency of electromagnetic fields which induces eddy currents inside the test materials. This method with high speed and sensitivity of inspection for surface cracks offers a suitable inspection method especially for surface cracks (Yusa, 2009). However, this method is basically used for conductive materials and more difficult to determine the defects that embedded in the specimen. Theoretically, phase measured signal can be used to characterize the defect depth. However, it is complicated to evaluate the phase of signals in reality (Yusa, 2010).

Therefore, instead of using eddy current to characterize the slit parameter of ferromagnetic material, it is more preferable to use metal magnetic memory (MMM) due to the numbers of significant advantages compared to other methods for the inspection of ferromagnetic materials (Wang, 2009). MMM is a newly developed NDT method which is capable to detect early failure such as fatigue damage, micro crack and stress concentration of material. One of the advantages of MMM method is that the model does not require special magnetizing equipment as the magnetization unit phenomenon is used in this operation. Other than that, this method with small-sized instruments will ease the inspection and testing process, besides having self-contained power supply (Ning, 2017).

1.3 OBJECTIVES

The objectives of this project are :

1.3.1 To characterize the slit parameter of ferromagnetic material based on magnetic flux leakage.

1.3.2 To study the distribution of stress concentration based on different approaches.

1.3.3 To validate the MMM method with different methods of NDT.

1.4 SCOPE OF PROJECT

The scopes of the project are:

1.4.1 This study is conducted by using FEA.

1.4.2 The sample of this project is made of SAE 1045 carbon steel.

1.4.3 Crack imitation(slit) is used in this project, rather than the actual crack.