ENHANCEMENT OF EDDY CURRENT TESTING PROBE FOR CRACK DETECTION AND LIFT-OFF COMPENSATION

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DOCTOR OF PHILOSOPHY

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Saluran paip tertakluk kepada kecacatan dan kakisan yang seterusnya boleh menyebabkan kebocoran dan kerosakan persekitaran. Pengujian semasa eddy telah terbukti menjadi teknik yang berkesan untuk mengesan kecacatan yang berlaku di dinding paip. Dalam dua dekad yang lalu, beberapa jenis pemeriksaan arus eddy telah dibangunkan untuk pemeriksaan paip yang termasuk prob gegelung bobbin, prob berputar dan prob susun-atur, tetapi setiap prob ini masih mempunyai batasannya sendiri. Di antara jenis ini, prob bobbin digunakan secara meluas dalam industri untuk memeriksa tiub dan saluran paip. Untuk mendapatkan kedalaman penembusan yang lebih dalam, frekuensi pengujaan yang lebih rendah harus digunakan kerana kedalaman penetrasi berkadar dengan akar kuadrat frekuensi pengujaan. Walau bagaimanapun, dalam prob bobbin arus eddy konvensional, penurunan nisbah isyarat-ke-bunyi (SNR) diperhatikan berlaku pada frekuensi yang lebih rendah, serta meningkatkan kesan yang mengurangkan pengesanan ketepatan siasatan. Untuk menangani masalah ini, tesis ini membentangkan reka bentuk penyelidikan baru untuk mengesan retak dengan pengukuran kecacatan dalam yang lebih tepat. Gegelung bobbin yang digunakan dalam magnetisasi paip menggunakan isyarat pengujaan 30 kHz dan pelbagai sensor GMR digunakan sebagai pengesan untuk mengukur kebocoran medan dari retak paip (paksi dan lubang). Metodologi permukaan tindak balas (RSM) telah digunakan untuk mengoptimumkan parameter reka bentuk penyelidikan yang dicadangkan untuk meningkatkan kebarangkalian pengesanan kecacatan dalam paip keluli karbon berdiameter 55 mm. Selain itu, teknik pampasan pintar berdasarkan logik kabur telah digunakan untuk mengatasi pengaruh pengangkatan untuk pengukuran kecacatan yang tepat. Metodologi permukaan tindak balas menunjukkan bahawa nilai keinginan tertinggi 0.679 dengan parameter optimum bagi penyelidikan yang dicadangkan adalah 6 sensor GMR, pengangkatan 2 mm dan ketinggian gegelung 10 mm yang meningkatkan kadar pengesanan kecacatan. Keputusan eksperimen menunjukkan bahawa ketepatan pemeriksaan reka bentuk siasatan adalah 100% untuk kecacatan paksi dan lubang menggunakan jumlah minimum 6 sensor GMR. Berbanding dengan reka bentuk projek sebelumnya menggunakan 6 sensor GMR menunjukkan bahawa kadar pengesanan kecacatan adalah 80%. Di samping itu, teknik pampasan kesilapan yang dicadangkan mengesahkan bahawa terdapat pengurangan kesan pengaliran dan juga Berjaya meningkatkan ketepatan prestasi siasatan secara keseluruhan. Pengesahan bagi prob yang dicadangkan melalui perbandingan dengan prob komersial dengan jelas menunjukkan bahawa reka bentuk prob yang dicadangkan dapat dengan ketara meminimalkan kesan pengangkatan dalam ujian arus eddy dalam 7.2% kesilapan untuk setiap 1 mm lift-off. Selain itu, keputusan eksperimen menunjukkan apabila dibandingkan dengan teknik pampasan yang sebelumnya didapati kesilapan yang disebabkan oleh 2 mm lif off berada pada 14.3% dan 18.3%, untuk teknik yang dicadangkan dan teknik pampasan sebelumnya. Siasatan yang dicadangkan dapat mengesan kedua-dua lubang dan kecacatan aksial, dan menawarkan kepekaan yang tinggi terhadap pelbagai frekuensi, serta berpotensi memberikan kadar pengesanan kecacatan yang sangat tinggi, di samping meningkatkan ketepatan pengukuran kecacatan kedalaman.

ABSTRACT

Pipelines are subject to defect and corrosion which in turn can cause leakage and environmental damage. Eddy current testing has proved to be an effective technique to detect defects occurring in the pipe wall. In the past two decades, few types of eddy current probes were developed for pipe inspection that included bobbin coil probe, rotating probe and array probe but still, each of these probes have their own limitations. Among these types, the bobbin probes are widely used in industry to inspect tube and pipeline. In order to obtain deeper penetration depth, lower excitation frequencies must be used since penetration depth is inversely proportional to the square root of the excitation frequency. However, in conventional bobbin eddy current probes, a drop in the signal-to-noise ratio (SNR) was observed at lower frequencies, as well as lift off effects that reduced the accuracy detection of the probe. To address these problems, this thesis presents a new probe design for crack detection with accurate depth defect measurement. The bobbin coil used in the magnetization of pipe utilized a 30 kHz excitation signal and the GMR sensor array was used as a detector to pick up the field leakages from the pipe cracks (axial and hole). The response surface methodology (RSM) was utilized to optimize the proposed probe design parameters to increase the probability of defect detections in 55 mm diameter carbon steel pipe. Besides that, the intelligent compensation technique based on fuzzy logic was used to overcome the influence of lift-off for accurate defect measurement. The response surface methodology showed that the highest desirability value of 0.679 with optimum parameters of the proposed probe were 6 GMR sensors array, lift-off of 2 mm and height of coil of 10 mm that increased the rate of detection defects. The experimental result showed that the accuracy of the probe design inspection was 100 % for axial and hole defects using minimum number of 6 GMR sensors. Compared with the previous work design using 6 GMR sensor showed that the rate of defect detection was 80%. In addition, the proposed error compensation technique proved that there were reductions in the effect of lift-off and also enhanced the overall probe performance accuracy. Validation of the proposed probe through comparison with a commercial probe clearly indicated that the proposed probe can significantly minimized the effect of lift-off in eddy current testing within 7.2 % of error due for each 1 mm of lift-off. Moreover, the experimental results were compared with the previous compensation technique where the errors due to 2 mm of lift-off were within 14.3 % and 18.3%, for the proposed technique and previous compensation technique, respectively. The proposed probe can detect both hole and axial defects, offers a high sensitivity over a wide range of frequencies, can potentially provide extremely high rate defects detection and improve the accuracy of depth defect measurement.

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B	Magnetic field
MF	Membership Functions
T	Absolute temperature in Kelvins
Δf	The bandwidth of applied frequency in Hz
°C	Degree Celsius
μ	Conducting Material Permeability
I	Current
K	Kelvin
K_B	Boltzmann Constant in Joules per Kelvin
L	Inductance
R	Resistance
V	Voltage
N	Number of turns
X	Value of Design Variable
x_i	Design Parameter
Y	Vector of Observations
Θ	Angle
Σ	Conducting Material Conductivity
Ω	Angular Frequency
Δ	The penetration depth of eddy current
B_x	Magnetic field on the x-axis
B_y	Magnetic field on the y-axis
B_θ	Azimuth Magnetic Field
B_r	Radial Magnetic Field

LIST OF ABBREVIATIONS

AMR	Anisotropic Magnetoresistive
ANN	Artificial neural network
BP	Back propagation
CCD	Central composite design
CNC	Computer numerical control
Cr	Cuprum
CoA	Centre of area
DSP	Digital signal processing
DC	Direct current
ECTIS	Eddy current testing inspection system
ECT	Eddy current testing
ECP	Eddy current probe
ET	Electromagnetic testing
Fe	Ferum
FPGA	Field programmable gate array
FIS	Fuzzy Inference System
FEM	Finite element model
GMR	Giant magneto resistance
ID	inner diameter
IACS	International Annealed Copper Standard
MBE	Minimum bias estimator
MFL	Magnetic flux leakage
MRPC	Motorized rotating probe coil
MR	Magneto-resistive
MSE	Mean squared error
MT	Magnetic particle testing
MDO	Multidisciplinary design optimization
DT	Destructive testing
NDT	Non-destructive testing
NDE	Non-destructive evaluation
NCSF	Normalized crack signal fitting

OD	outer diameter
PEC	Pulsed eddy current
PT	Penetrant testing
PSI	Pounds per square inch
PVC	Poly vinyl chloride
RPC	Rotating pancake coil
PCB	Printed circuit board
PCA	Principle component analysis
RSM	Response surface methodology
RT	Radiographic testing
SNR	Signal to the noise ratio
USB	Universal serial bus
UT	Ultrasonic testing
VT	Visual testing

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