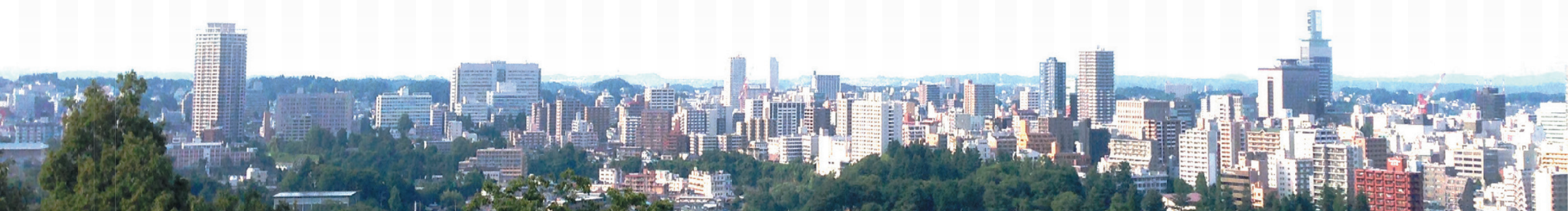
The 20th International Workshop on Electromagnetic Nondestructive Evaluation (ENDE2015)

Origin, Legacy, and Future Directions of ENDE

September 21-23, 2015
Sendai, Japan



PROGRAM

Preface

It is our great honor to hold The Twentieth International Workshop on Electromagnetic Non-Destructive Evaluation, ENDE. The former ENDEs have been held in UK, Japan, France, USA, Hungary, Germany, South Korea, Poland, India, Brazil, Slovakia, and China. It is not too much to say that ENDE is regarded as one of the most important academic forums for exchanging ideas and discussing recent developments of the application of electromagnetics to the non-destructive testing and evaluation.

The Twentieth International Workshop on Electromagnetic Non-Destructive Evaluation, ENDE2015, is held from September 21st to 23rd in Katahira Sakura Hall, Tohoku University, Sendai, Japan. The major topics of the workshop include, but not limited to, advanced sensors, analytical and numerical modelling, inverse problems and signal processing, material characterization, monitoring and diagnoses of mechanical structure, biomedical applications, and innovative industrial applications. Since this is the commemorable twentieth workshop, several special sessions are arranged with a theme of 'Origin, Legacy, and Future Directions of ENDE'.

There are two keynote lectures, one invited lecture, and 84 contributions to be presented in ENDE2015. The contributions are categorized into and presented in seven oral sessions, one poster session, and one special session named 'Student Session'. The contributions presented will be peer-reviewed for a possible publication in a volume of IOS book series "Studies in Applied Electromagnetics and Mechanics".

ENDE2015 is organized by ENDE2015 Organizing Committee, co-organized by School of Engineering, Tohoku University, Institute of Fluid Science, Tohoku University, and Japan Society of Maintenology, and sponsored by Intelligent Cosmos Research Institute, Sendai Tourism, Convention and International Association, The Kajima Foundation. ENDE2015 Organizing Committee would like to express sincere gratitude to all the members of the international standing committee members, participants, and the sponsors for their contributions and supports.

Sendai, September, 2015
Co-chairmen of ENDE2015
Noritaka Yusa
Tetsuya Uchimoto
Hiroaki Kikuchi

Student Session (Chair: D. Zhou and J. Wang)

SS01 A FOURTH STAGE KOCH CURVE EXCITING COIL PLANAR EDDY CURRENT PROBE FUNDAMENTALS, SIMULATION AND EXPERIMENT

G. Chen[1], W. Zhang[1], W. Pang[1], F. Qin[1], Y. Guo[1]

[1] School of Mechanical Engineering, Beijing Institute of Technology, China

SS02 LOW FREQUENCY MAGNETIC FIELD MEASUREMENT TO MONITOR PIPE WALL THINNING USING MI SENSOR ARRAYS

N. Tajima[1], K. Sasaki[1], N. Yusa[1], H. Hashizume[1], T. Uchimoto[2], T. Takagi[2], K, Tanji[3]

[1] Department of Quantum Science and Energy Engineering, Graduate School of Engineering, Tohoku University, Japan

[2] Institute of Fluid Science, Tohoku University, Japan

[3] Tohoku Electric Power, Co., Inc., Japan

SS03 GENERALIZED FREQUENCY FLUCTUATION ANALYSIS OF THE GEOMAGNETIC FIELDS

M. Iida[1], K. Kikuchi[1], I. Marinova[2], Y. Saito[1]

[1] Department of Electrical and Electronic Engineering, Hosei University, Japan

[2] Technical University of Sofia, Bulgaria

SS04 ENHANCE THE FLAT ∞ COIL SENSIBILITY BY MULTI-FREQUENCY CONVOLUTION STRATEGY

S. Hamanaka[1], I. Marinova[2], Y. Saito[1], M. Ohuch[3], T. Kojima[3]

[1] Graduate School of Electrical and Electronic Engineering, Hosei University, Japan

[2] Technical University of Sofia, Bulgaria

[3] Denshijiki Industry Co., Ltd, Japan

SS05 APPLICATION OF FIELD SIGNATURE METHOD IN A GAS FIELD IN CHINA

G. Fangji[1], W. Zhengjun[1], L. Yuting[1], L. Junbi[1]

[1] School of Manufacturing Science and Engineering, Sichuan University, China

SS06 APPLICATION OF BP NEURAL NETWORK TO QUANTITATIVE IDENTIFICATION IN PULSED EDDY CURRENT THERMOGRAPHY

G. Xumei[1,2], X. Changhang[1,2], X. Jing[1,2], Z. Naiwang[1,2]

[1] College of mechanical and electrical engineering, China University of Petroleum, China.

[2] Centre for Offshore Engineering and Safety Technology in China University of Petroleum, China

SS07 COIL DESIGN OF THE SEMI-CIUCULAR ∞ COILS FOR PRACTICAL USE

T. Hyuga[1], N. Ishikawa[1], I. Marinova[2], Y. Saito[1], M. Ohuch[3], T. Kojima[3]

[1] Graduate School of Electrical and Electronic Engineering, Hosei University, Japan

[2] Technical University of Sofia, Bulgaria

[3] Denshijiki (EMIC) Industry Co., Ltd, Japan

SS08 AN SVM APPROACH WITH ALTERNATING CURRENT POTENTIAL DROP TECHNIQUE TO CLASSIFY PIT AND CRACK OF METAL PLATE

Y Li[1], Z. Wan[1], F. Gan[1], J. Liao[1]

[1] School of Manufacturing Science and Engineering, Sichuan University, China.

SS09 RESONANT FREQUENCY CONTROL OF THE RESONAT TYPE EDDY CURRENT SENSOR UTLIZING AN INGENEOUSLY COIL CONNECTION BY CHANGING THE COIL TWISTING PITCHES

K. Okuda[1], I. Marinova[2], Y. Saito[1]

[1] Graduate School of Electrical and Electronic Engineering, Hosei University, Japan

[2] Technical University of Sofia, Bulgaria

SS10 A NOVEL METHOD TO REDUCE THE LIFT OFF EFFECT USING EMAT

B. Hui[1], P. Yi[1], K. Zhang[1]

[1] School of Mechanical Science & Engineering, Huazhong University of Science & Technology, China

SS11 DEVELOPMENT OF MAGNETIC PHASE MAP FOR ANALYZING THE INTERNAL STRUCTURE OF SPOT WELDING

S. Nannan[1], K. Shiga[1], K. Sakai[1], T. Kiwa[1], K. Tsukada[1]

[1] Graduate School of Natural Science and Technology, Okayama University, Japan

SS12 MAGNETO OPTICAL IMAGING WITH MAGNETOPHOTONIC CRYSTAL FOR ESTIMATION OF DEFECT DEPTH

R. Hashimoto[1], H. Takagi[1], T. Goto[1], H. Endo[2], M. Inoue[1]

[1] Department of Electrical and Electronic Information Engineering, Toyohashi University of Technology, Japan

[2] Hitachi Research Laboratory, Hitachi Ltd., Japan

SS13 FLAW DEPTH ESTIMATION OF STRESS CORROSION CRACKING AND THERMAL FATIGUE CRACKING BY USING AN EDDY CURRENT Θ PROBE

T. Hongu[1], K. Koyama[2]

[1] Graduate School, Nihon University, Japan
[2] College of Industrial Technology, Nihon University, Japan

SS14 EDDY CURRENT TESTING OF UNIDIRECTIONAL CARBON FIBRE REINFORCED POLYMER COMPOSITES USING ADVANCED PROBE

K. N. Antin[1], T. Santos[2], P. Vilaça[1]

[1] Department of Engineering, Design and Production, School of Engineering, Aalto University, Finland

[2] Department of Mechanical and Industrial Engineering, Faculty of Science and Technology, Portugal

SS15 EXPERIMENTAL STUDY OF PARTICLE BASED FILMS' CURE PROCESS BY HF EDDY CURRENT

I. Patsora[1], I. Kharabet[1], H. Heuer[1,2], M. Schulze[2], S. Hillmann[2], D. Joneit[2], D. Tatarchuk[3], Y. Didenko[3]

[1] Electronics Packaging Lab (IAVT), Faculty of Electrical and Computer Engineering, Technische Universität Dresden, Germany

[2] Fraunhofer Institute for Ceramic Technologies and Systems, Germany

[3] Microelectronics Department, Faculty of Electronics, National Technical University of Ukraine "Kiyv Polytechnic Institut", Ukraine

SS16 DESIGN STUDY OF PROBE FOR QUANTITATIVE EVALUATION OF PIPE WALL THINNING BY EXCITATION CONTROL EDDY CURRENT TESTING

K. Nakajima[1], R. Urayama[2], T. Uchimoto[2], T. Takagi[2]

[1] Graduate School of Engineering, Tohoku University, Japan

[2] Institute of Fluid Science, Tohoku University, Japan

SS17 INVESTIGATION OF PERMEABILITY AT HIGHER TEMPERATURE FOR DEVELOPMENT OF HEAT-RESISTANT MAGNETIC SENSOR

K. Honmyo[1], H. Kikuchi[1]

[1] Faculty of Engineering, Iwate University, Japan

SS18 DEVELOPMENT OF INSPECTION OF DEFECTS IN THERMOREACTOR TUBE IN PETRO-CHEMICAL INDUSTRY

Y. Nishimura[1], T. Suzuki[1], K. Fukuda[2], E. Ikeda[2], G. Uchibe[2]

[1] National Institute of Advanced Industrial Science and Technology, Japan

[2] National Institute of Technology, Tokyo-college, Japan

ENHANCE THE FLAT ∞ COIL SENSIBILITY BY MULTI-FREQUENCY CONVOLUTION STRATEGY

Shunichi HAMANAKA[1*], Iliana MARINOVA[2], Yoshifuru SAITO[1]
Manabu OHUCH[3] and Takaharu KOJIMA[3]

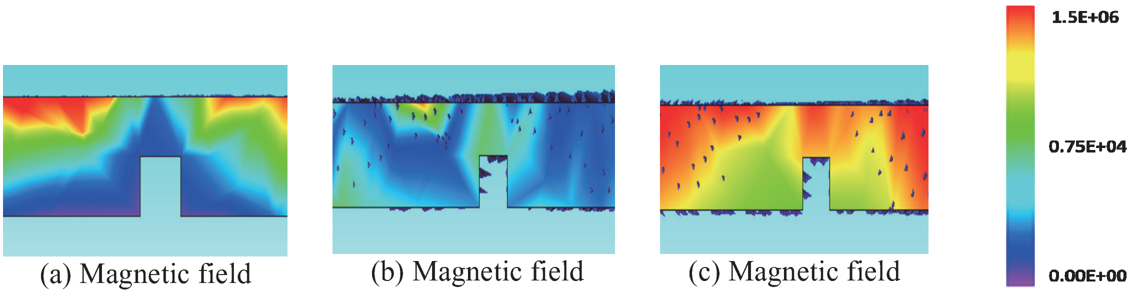
[1] Graduate School of Electrical and Electronic Engineering, Hosei University, 3-7-2, Kajino Koganei, Tokyo, 184-8584, Japan
[2] Technical University of Sofia 1756, Sofia, Bulgaria
[3] Denshijiki Industry Co, Ltd, 115-0051, Tokyo, Japan

Previously, we have developed a new flat eddy current testing sensor named the flat ∞ (infinity) coil whose operating principle is based on the following fact. A zero magnetic field region between the two exciting coils composing the north and south magnetic poles becomes not zero magnetic fields due to the detour eddy currents caused by defect of a target test piece[1].

According to this operating principle, our flat ∞ coil never depends on the operating frequencies so that low frequency drive of the flat ∞ coil is a very effective and useful to detect the backside defect of a target test piece because of large skin depth [2].

In the present paper, we employ the multi-frequency excitations along with convolution signal processing technology.

As shown in Fig.1, changing the exciting frequencies changes the penetration depth of the eddy currents.



(a) Magnetic field vectors at 100kHz

(b) Magnetic field vectors at 10kHz

(c) Magnetic field vectors at 2kHz

(d) Color bar [A/m^2]

Figure. 1 Magnetic fields and eddy currents distributions by the 3D FEM simulations. Color bar denotes the magnitude of eddy currents. Magnitude and direction of the magnetic field vectors are shown by the colors and triangular symbols, respectively

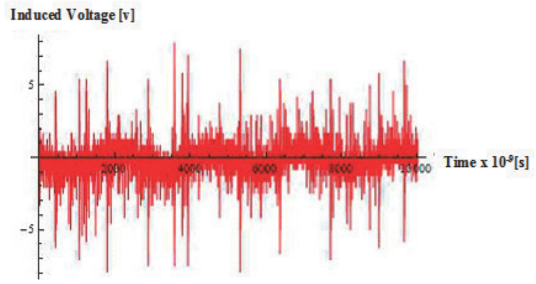
Even though the low frequency excitation is superior in sensibility of the backside defect searching, amplitude of the detected signals becomes small in value, and is contaminated by the environmental higher frequency noise signals. On the other side, higher frequency excitation yields a low amplitude detected signal not contaminated by the environmental noise signals. Therefore, selection of the excitation frequency is one of the difficult tasks when carrying out the backside defect searching.

Principal purpose of this paper is to remove this frequency selection difficulty in the backside defect searching by means of the combination approach of the multi-frequency excitation and signal convolution strategy.

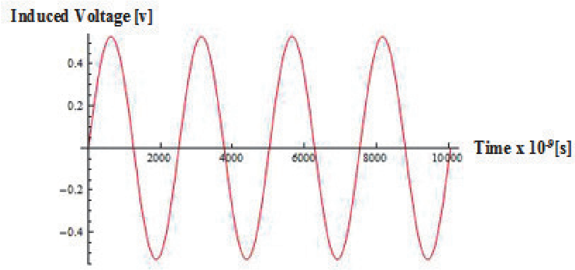
* Corresponding author. *Phone & Fax: +81 42 387 6200, E-mail address: shunichi.hamanaka.jc@stu.hosei.ac.jp*

Our strategy is composed of the four-steps. At first, to extract the exact signal frequency, apply the Fourier transform to the detected signals makes it possible to extract only the same frequency component to the exciting frequency as the exact detected signals. Figures 2(a) and 2(b) show the typical examples of the original and exact detected signal by Fourier transform. Second, we arrange the peak maximum induced voltages (similar to the signals shown in Fig.2(b)) along with the test piece positions as shown in Fig. 2(c). Third, the peak induced voltage distribution along the target piece surface (Fig.2(c)) is normalized between the values of 0 to 1. The sequential processes from the 1st to 3rd steps are repeated to each of the entire detected signals obtained by changing the exciting frequencies. Finally, an entire normalized detected signals processed by 1st to 3rd steps to each of the different exciting frequencies is convolved by the multiplications among the normalized values taking the same test piece positions. Since the value in each of the normalized detected signals takes a value between 0 and 1, then this convolution extracts only the common signals over the entire signals.

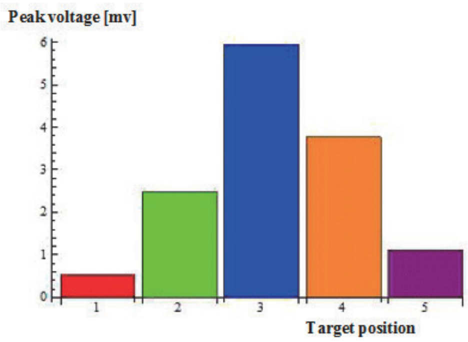
Thus, it is possible to obtain the highly reliable defect signals even if the backside defect searching. Figure 2(d) shows a typical result of our multi-frequency convolution strategy. The reliable detected signal means the enhancement of the sensibility of ECT testing.



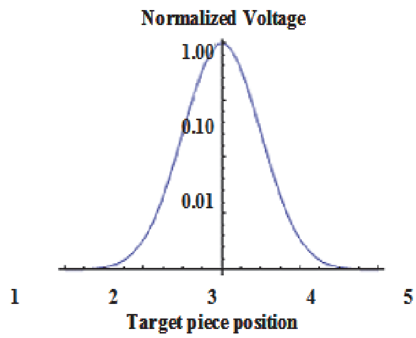
(a) Original detected signal



(b) Exact detected signal



(c) Peak induced voltages along with the target position



(d) Convolved detected signal distribution

Figure. 2 Explanation diagrams of the multi-frequency convolution strategy

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[1] Kouki Maruyama, Iliana Marinova and Yoshifuru Saito, Developments of Flat ∞ Coil for Defect Searching in the Curved Surfaces, E-Journal of Advanced Maintenance, in printing (Japan Society of Maintenology).

[2] Shunichi Hamanaka, Yoshifuru Saito, Iliana Marinova, Manabu Ohuch, Hideo Mogi and Yoshiro Oikawa," Backside Defect Searching by Means of the Low Frequency ∞ Coil Excitation" SIELA 2014 18th International Symposium, 29-31 May 2014, published by IEEE.

COIL DESIGN OF THE SEMI-CIUCULAR ∞ COILS FOR PRACTICAL USE

Takahiro HYUGA[1]*, Naoto ISHIKAWA[1], Iliana MARINOVA[2], Yoshifuru SAITO[1]
Manabu OHUCH[3] and Takaharu KOJIMA[3]

[1]Graduate School of Electrical and Electronic Engineering, Hosei University,
3-7-2, Kajino Koganei, Tokyo 184-8584, Japan
[2]Technical University of Sofia 1756, Sofia, Bulgaria
[3]Denshijiki (EMIC) Industry Co, Ltd, Tokyo 115-0051, Japan

Eddy current testing (ECT) is one of the most representative nondestructive testing methods for metallic materials, parts, structures and so on. Operating principle of ECT is based on two major properties of the magnetic fields. One is that alternating magnetic field induces eddy current in conducting materials. Thereby, an input impedance of the magnetic field source, i.e., electric source, depends on the eddy current path. Second is that the magnetic field distribution depends not only on the exciting current but also on the reactive magnetic fields caused by the eddy currents in targets. Former and latter are the impedance sensing and leakage magnetic flux sensing types, respectively [1].

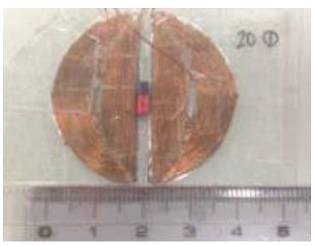
Previously we have succeeded in exploiting a new high sensibility eddy current testing sensor called the flat infinite (∞) coil [2]. Operating principle of the flat ∞ coil is that two adjacent coils constructing the north and south poles alternatively set a zero magnetic field region and keep this zero magnetic fields situation when eddy currents are flowing along the paths in parallel to the exciting coils. If the eddy currents could not flow the paths in parallel to the exciting coil due to the defect of a specimen, then a zero magnetic field region between the two exciting coil moves toward the other position. This means that a sensing coil located at a mid point position of two exciting coil is possible to detect the disturbed magnetic fields, i.e., the defect in the specimen could be detected by the sensing coil signal.

According to the intensive 3D FEM simulations as well as experiments, the two key design policies are found. One is the shape of exciting coils, which enlarges the zero magnetic field region between the two adjacent coils constructing the north and south poles alternatively. The other is the shape of flat exciting coils whether each of the coils should be fully wound until no space or not fully wound remaining some space, i.e., each of the exciting coil surfaces does not has any area otherwise has a space enclosed by an exciting coil.

Principal purpose of this paper is to carry out the latter designing policy, i.e., how to design the shape of flat exciting coils for some particular line defect.

At first, we have carried out the 3D FEM simulations as well as experiments to the 10 turns coil (a) having a space and the 20 turns coil (b) having no space as shown in Fig. 1.

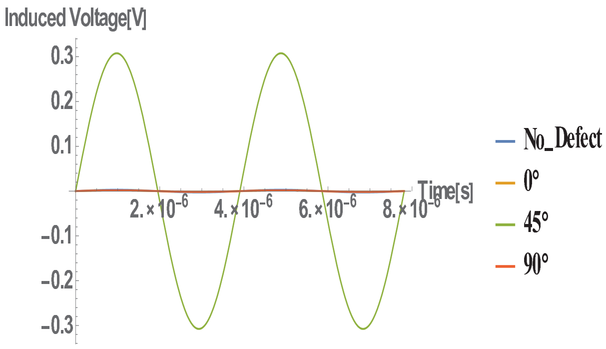
(a) 10 Turns



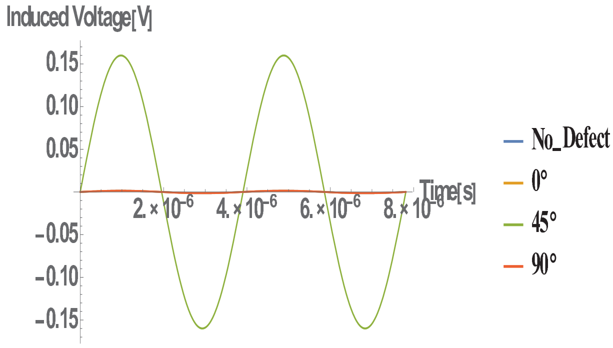
(b) 20 Turns

Figure 1. The first prototype flat ∞ coils

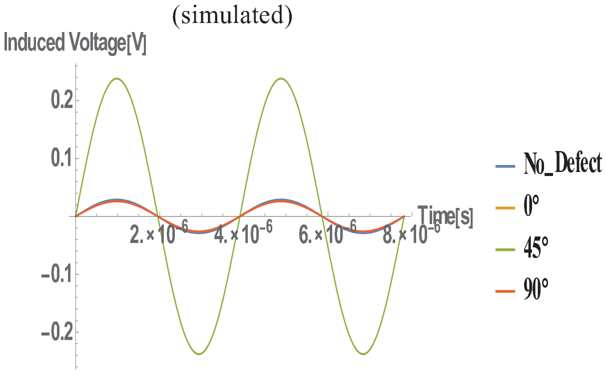
* Corresponding author. *Phone & Fax: +81 42 387 6200, E-mail address:takahiro.hyuga.8k@stu.hosei.ac.jp*



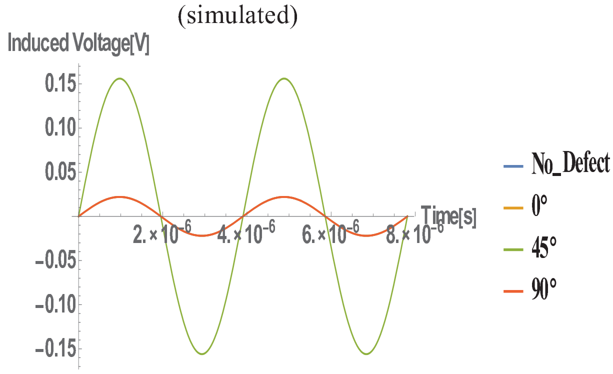
(a) 10 Turns, sensor output signal (simulated)



(b) 20 Turns, sensor output signal (simulated)



(c) 10 Turns, sensor output signal (experimented)



(d) 20 Turns, sensor output signal (experimented)

Figure 2. Sensor output signals, where the green and red are denoting the exact and noise signals, respectively

Even though the differences between the simulated and experimented values have been observed, the output signals of 10 turns coil is much larger than that of 20 turns coil. Fundamental difference between the simulated and experimented signals is the noise shown by the red lines in Fig.2. This difference may be caused by the hand making of the coils so that it is possible to reduce this difference by the skilful line constructing processes in the factory.

Thus, it has been elucidated that increasing the number of turns never increases the output signal and optimum number of turns concerning on the exciting coils of the flat ∞ coil design should be decided depending on the shapes of target defect.

As described above, this paper has clarified the designing policy of the flat ∞ coil having semi-circular exciting coils, i.e., how to design the shape of flat exciting coils for some particular line defect, by means of the 3D FEM simulations along with the experimental verifications.

References

[1] H. Kikuchihara et al, Development of a New High Sensitive Eddy Current Sensor, *Materials Science Forum Vol. 792* (2014), 98-103.

[2] K. Maruyama et al, Developments of Flat ∞ Coil for Defect Searching in the Curved Surfaces, *E-Journal of Advanced Maintenance,* in printing.

RESONANT FREQUENCY CONTROL OF THE RESONAT TYPE EDDY CURRENT SENSOR UTLIZING AN INGENEOUSLY COIL CONNECTION BY CHANGING THE COIL TWISTING PITCHES

Kazuya OKUDA[1*], Iliana MARINOVA[2] and Yoshifuru SAITO[1]

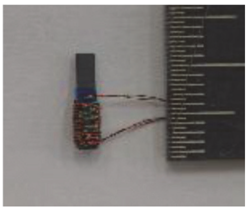
[1]Graduate School of Electrical and Electronic Engineering, Hosei University, 3-7-2, Kajino Koganei, Tokyo 184-8584, Japan
[2]Technical University of Sofia 1756, Sofia, Bulgaria

The eddy current sensor is classified into two major types. One is the coil impedance sensing type without any sensing coils and the other is the magnetic flux sensing type composed of the exciting as well as independent sensing coils to detect the leakage magnetic flux caused by detour eddy currents due to the defect of target. Former coil impedance sensing type is further classified into two types. One is the simple coil impedance sensing type detecting an input impedance depending on the target whether no defect or defect. The other is the impedance sensing type operating only at the resonant frequency.

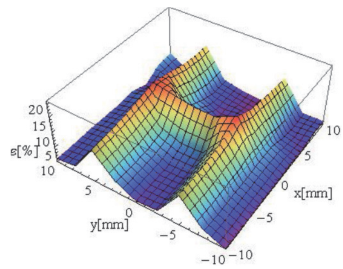
Previously, we have proposed a new resonant type eddy current sensor by means of an ingeniously coil connection [1]. This new sensor does not need any external capacitor for keeping a stable resonant situation and has an extremely high sensibility, but it is suffered a higher operating resonant frequency.

To overcome this higher operating resonant frequency problem, we have attached to an external capacitor in parallel to the ingeniously coil connection [2]. Attach the external capacitor in parallel to the original resonant type eddy current sensor makes it possible to reduce the resonant frequency and to enhance the sensibility. Figure 1 shows an example of coil twisting, an example of the resonant type eddy current sensor utilizing the ingeniously coil connection using a ferrite bar as axis, and demonstrates the high sensible capability of the resonant type eddy current sensor attaching an external capacitor to detect a H shape slits artificially made by discharging machining.

(a) Coil Twisting



(b) An example of the resonant type eddy current sensor



(c) A detected H shape defect

Figure 1. The coil twisting, an example of the resonant type eddy current sensor and a detected H shape defect. (a) Show a typical two coils twisting. (b) An example the resonant type eddy current sensor utilizing the ingeniously coil connection using a ferrite bar as an axis. (c) A typical example of a H shape defect detection by the resonant type eddy current sensor utilizing the ingeniously coil connection with external capacitor, where x, y are denoting the positions in x-y plane, and ε is the deflection percentage to the reference impedance measured at the resonant frequency [2].

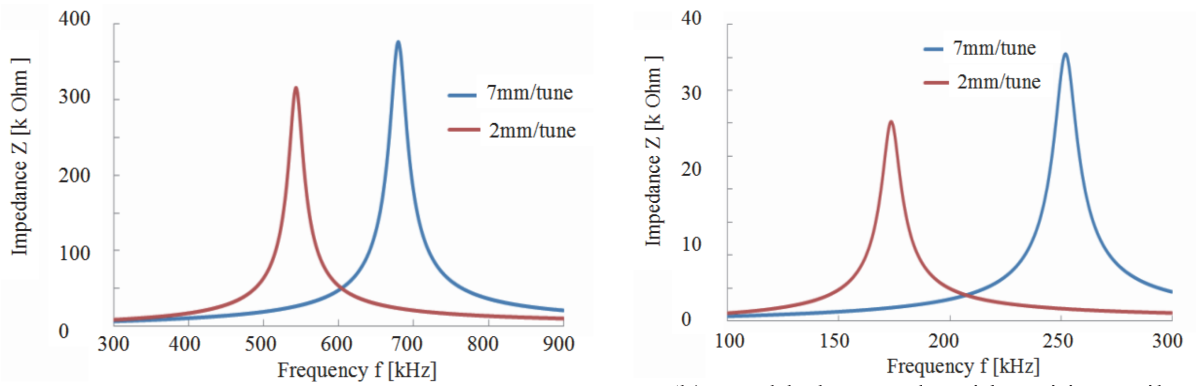
* Corresponding author. *Phone & Fax+81 42 387 6200, E-mail address: kazuya.okuda.2n@stu.hosei.ac.jp*

In the present paper, we propose a new resonant frequency control methodology without any external capacitor to the original resonant type eddy current sensor utilizing the ingeniously coil connection. A key innovative idea to control the resonant frequency of the eddy current sensor is an extremely simple procedure, i.e., only changing the twisting pitches.

Our resonant type eddy current sensor utilizing the ingeniously coil connection is intrinsically based on the utilization of stray capacitance among the conductors so that the control of stray capacitance by changing the twisting pitches may be considered as the best methodology.

Figure 2 shows the concrete examples of the controlled resonant frequencies by changing the twisting pitches.

tune-→turn



(a) Single layer solenoid exciting coil (b) Double layer solenoid exciting coil

Figure 2. The concrete examples of the controlled resonant frequencies by changing the twisting pitches. (a) Shows the controlled resonant frequencies of a single layer solenoid exciting coil whose resonant frequency is reduced from 680 to 543kHz by changing the twisting pitches from 7 to 2mm/turn. (b) Shows the controlled resonant frequencies of a double layer solenoid exciting coil whose resonant frequency is reduced from 253 to 173kHz by changing the twisting pitches from 7 to 2mm/turn. Both coils (a) and (b) are the cylindrical shape having the same dimensions 4.6cm length and 2cm diameter without any ferrite bar as the coil axes.

Thus, it is possible to control the resonant frequency of the ingeniously coil connection only by changing the twisting pitches. This means that the resonance type eddy current sensor could be used in a similar exciting frequency to those of normal impedance sensing type without any external capacitors.

Since a calculation of the stray capacitances among the multi-twisted conductors is an extremely difficult task even if the computer use, then we are now exploiting an empirical formula expressing the relations among the resonant frequency, twisting pitch, coil diameter, coil length and diameter of the finite length solenoid coil wound around a ferrite bar as an axis. Further details will be shown at the ENDE 2015 presentation and described in the full paper.

References

[1] H. Kikuchihara, I. Marinova and Y. Saito, Enhance the Sensibility of the Eddy Current Testing, *Journal of the Japan Society of Applied Electromagnetics and Mechanics*, Vol. 21, No.5, (2013), 356-361.

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