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# Flat/Film Infinity Coils and Backside Defect Searching

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**Abstract**. Previously, we have proposed an infinity coil as a high sensibility ECT sensor. This paper has evaluated a possibility of the backside defect searching by the low frequency excitation of a modified infinity coil whose exciting coils are the flat/film shape to adapt to the curverved test targets.

In the present paper, we have elucidated the liftoff characteristics of the backside defect searching when employing the low frequency excitation to our flat/film shape infinity coil.

## 1 Introduction

The modern mass transportation vehicles, e.g. air plane, high-speed train, carrying a large number of people are required the ultimate highest safety as well as reliability.

To keep the highest safety and reliability, nondestructive testing is one of the most important key maintenance technologies, because most of the frame materials are composed of metallic materials.

Operating principle of ECT is fundamentally based on the detection of magnetic field distribution change due to the defect in the targets. To realize this principle, we have two methodologies. One detects the defect in the target as a change of input impedance of the exciting coil. This is because the magnetic field distribution is changed by the detour eddy currents flowing around the defect in the target which corresponds to the secondary circuit of a single phase transformer [1-3]. The other ECT sensor equips a sensing coil in addition to the exciting coils for detecting the magnetic field change caused by the detour eddy currents flowing around the defect. The former and latter are called the impedance sensing and sensing coil types, respectively.

The sensing coil type is further classified into two variations. Most popular sensing coil type employs a spatial differential coil, and also the other type whose surface of the sensing coil is perpendicularly installed to those of the exciting coil. As is well known the spatial differential coil detects the uniformity of the magnetic field distribution. Similarly the other type whose surface of sensing coil is perpendicularly installed to those of exciting coil detects only the magnetic fields caused by the detour eddy currents due to the defect in the target.Our developed flat/film shape infinity coil is one of the these types. A key idea of our flat/film shape infinity coil is that the sensing coil wound around a ferrite bar is installed at the lowest magnetic field intensity region between the north and south poles of exciting coils [1].

This paper tries to clarify the liftoff characteristics of the backside defect searching when employing a low frequency excitation to the flat/film shape infinity coil. As a result, it is revealed that the low frequency excited flat/film shape infinity coil is capable of detecting the backside defects over 1mm liftoff

## 2 Experiments


Fig. 1 Reference ECT signal processor "ET-5002" produced by EMIC Co. LTD.

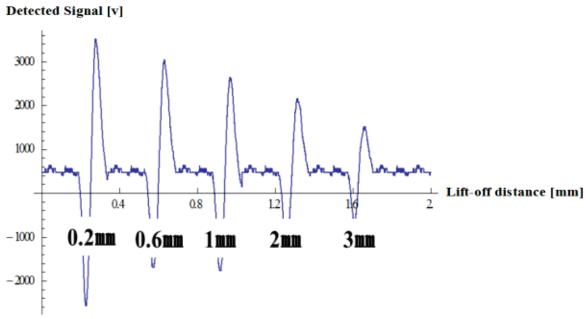


Fig. 2 Detected signal vs. Liftoff characteristic

In our experiments, we have employed the two laminated copper plates as a test target, the upper is the normal copper plate having 2mm thickness, 10cm length, 2cm width, and the backside is composed of 2 independent plates contructing a line crack having a 1mm depth and 2mm width.

Consideration of the skin depth, the absolute sensibility and higher frequency noise signals accompanying the practical measurements have led to employ the 2kHz as the best excitation frequency.

We measured the signals due to the backside defect by means of the commercial based signal processing device "ET-5002" shown in Fig1 while the flat/film shape infinity coil was scanned along a test target surface. Operating principle of the ET-5002 is that the equilibrium balanced condition of the bridge circuit picks up only the discontinuity of signals when the sensor scans over the defect. Liftoff distance was changed from 0.2mm to 3mm. The gain 60dB and 10Hz-256kHz band pass filter were set up to the ET-5002 for the backside defect searching.

Fig.2 shows detected signals by the flat/film infinity coil when scanning a surface of the target piece having a backside defect. Observe the detected signals makes it possible to find the 5 distinct peaks in each of the liftoff positions. Each of the detected signals at the five different liftoff positions suggests the existence of backside defect in the target piece. Also, it is found that the amplitude of the detected signals is inversely proportional to the lift-off distances.

## 3 Conclusion

In the present paper, we have employed the low frequency excitation of flat/film shape infinity coil to search for the backside defect of the metallic target when changing the liftoff distances from 0.2mm to 3mm. As a result, it has been clarified that the low frequency excitation of flat/film shape infinity coil makes it possible to search for the backside defects along with the signal processing device ET-5002 enhancing the S/N ratio.

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# Ingeniously Coil Connection and its Application to the Tesla Coils

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**Abstract**. This paper proposes a simple method to get the stabilized discharging characteristics by the Tesla coil without additional electronic circuits. Also, it is revealed that an ingenious coil connection changes the Tesla coil into a dramatically stable high voltage dischargeable source.

## 1. Introduction

Stable discharging is essential to the discharge machining, lighting, metal welding connection, and so on. The Tesla coil may be the oldest method generating high voltage source for discharging [1]. Further the Tesla coil may be regarded as one of the coreless transformer whose secondary induced voltage is extremely high. Apply a primal input source having one of the resonant frequencies of secondary coil makes it possible to generate a high secondary voltage. This secondary high voltage discharges from an externally attached electrode working as a resonant capacitor. However, its discharging characteristic is intermittently and not so stable. Thereby, this requires equipping the other electronics to obtain the stable and continuous discharge.

This paper proposes a simple method to get the stable discharging characteristics by the Tesla coil without additional electronic circuits, i.e., a simple ingenious connection of secondary circuits changes the Tesla coil into a dramatically stable discharge generator [2].

## 2. Resonant Tesla Coils

A typical conventional Tesla coil which is composed of the two coaxial finite length solenoid coils. The number of the outer primal and inner secondary coils are small and extremely large, respectively. Thereby, the Tesla coil is one of the coreless transformer whose transform ratio $a=N_1/N_2$ are extremely small, where $N_1$ and $N_2$ denote the number of turns of primal and secondary coils, respectively.

When a coupling between the primal and secondary coils through a common magnetic flux is high, it is possible to obtain a high secondary induced voltage. However, their coupling is very small so that the Tesla coil could not use as a normal voltage boost up transformer.

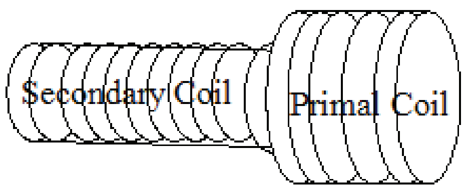


Fig.1 A typical Tesla coil

Fig. 2 shows a frequency characteristic of the secondary coil. Obviously, the secondary coil has the multiple resonant frequencies between the stray capacitance and leakage inductance. Thereby, it is essential to attach an external capacitor to fix a particular resonant frequency. After attaching the capacitor, it is possible to remove the effect of secondary leakage flux by the capacitor, i.e., a resonant phenomena, when supplying the resonant frequency to the primal coil. This leads to the desired high voltage determined by transformer ratio *a*.

On the other side, a resonant connection utilizing a capacitance between the inner and outer layer coils of the secondary winding exhibits a single resonant frequency characteristic as shown in Fig.2 [2]. A major resonant frequency in Fig. 2 is nearly 20MHz. On the contrary the single resonant frequency in Fig. 3 is nearly 30KHz. Difference between them is quite large frequency so that an ingeniously connection of the coils never requires an external resonant capacitor and creates the reasonable single resonant frequency characteristic.

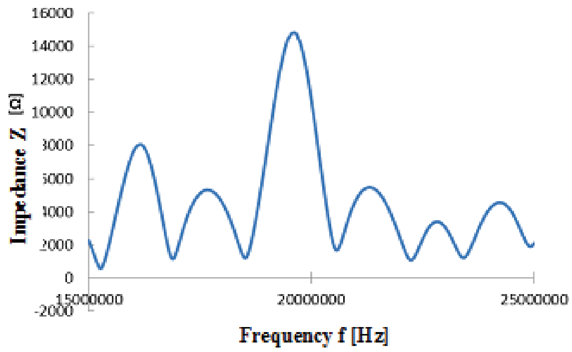


Fig.2 Frequency characteristic of the secondary coil.

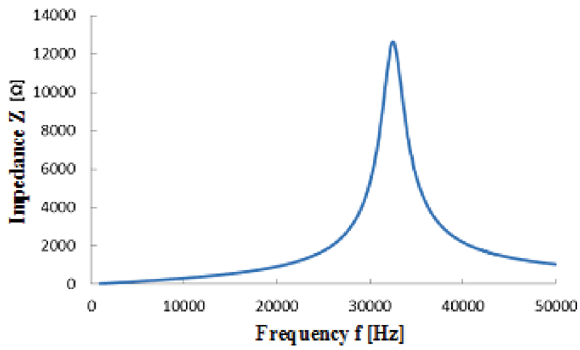


Fig.2 Frequency characteristic of the secondary coil when employing resonant connotation.

## 3. Conclusion

As shown above, we have succeeded in obtaining the single resonant frequency characteristic whose resonant frequency is relatively low. Thereby, it is possible to work out the devices, e.g., discharge machining, lighting, metal welding connection which require the stable discharging.

One of the innovative facts is that a simple ingeniously connection of the coils change the multi resonant into single resonant characteristics and removes the external electronic parts such as the external capacitor and high frequency processing elements.

## References

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# Design Strategy of The Practical Flat ∞ Coil

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**Abstract**. Previously, we had proposed an ∞ (infinity) coil for the high sensitive eddy current sensor and worked out several prototype of the ∞ coils. Because of the requirements of the practical environments, e.g.. defects searching in the tight slits and curved surfaces, we have further developed the flexible flat/film ∞ coils.
In the present paper, consideration to the practical use to the design of prototype the flat/film ∞ coil lead an employment of the two semi-circle exciting coils. Experimental and 3D FEM simulations verify the validity of our practical design direction of the flat/film ∞ coil..

## 1 Introduction

Since most of the human products as well as infrastructures are mechanically supported by the iron or its composites, then nondestructive testing of metallic materials is of paramount important work to keep our daily life.


Fig. 1 The First Prototype of The ∞ coil.

Previously we have succeeded in exploiting a new high sensibility eddy current testing (ECT) sensor called the ∞ coil [1]. Figure 1 shows one of the prototypes of our ∞ coil. Eventhogh the developmens of the first trototype design was carrying out, strorong requirements to use the defect searching between the tight slit spaces because of the searching for the defects after assembles, and for the curved surfaces such as pipes.

To respond this requirement, we had exploited a flat ∞ coil [2]. Remarkarbly this new flat ∞ coil displayed a versatile capabilities for the defect searching cauved serface and high sensibility compared with the old one as shown in Fig.1.

This paper is concerning to decide the degin direction of the flat ∞ coil, e.g., cicular or square closs-section shape and the flat excaiting coils shoud be wound remaing or not emaing the cetrers of flat excaiting coils.

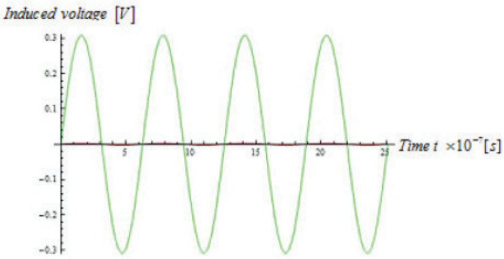
Finally, the first prototype degin direction of the flat ∞ coil is focused on the two key points, i,e, one is the shape of exciting coils, which enlarges the zero magnetic field region between the two adjacent coils constructing the north and south poles alternatively, and the second the shape of flat exciting coils whether each of the coils should be fully wound until no space or not fully wound remaining some space, namely each of the exciting coil surfaces does not has any area otherwise has a space enclosed by an exciting coil.

## 2 Practical Prototype Design of ∞ Coil

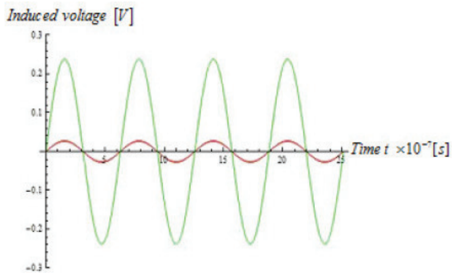
Operating principle of original flat ∞ coil is that two adjacent coils constructing the north and south poles alternatively set a zero magnetic field region and keep this zero magnetic fields situation when eddy currents are flowing along the paths in parallel to the exciting coils. If the eddy currents could not flow the paths in parallel to the exciting coil on the test 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 position of two exciting coil is possible to detect the disturbed magnetic fields, i.e., the defect in the test specimen could be detected from the sensing coil signal.

By means of the intensive 3D FEM simulation and experimental works, this paper reveals that the sensibility of the flat ∞ coil could be enhanced by enlarging the zero magnetic field region between the two adjacent exciting coils. This has been simply carried out by enlarging a two adjacent point to a two adjacent line. Effect of this exciting coil layout modification reflects on the output larger amplitude of sensing signals than those of conventional one. Also, we have carried out the 3D FEM simulations as well as experiments to the 10 turns coil having a space and the 20 turns having no space. Figure 2 shows the tested coils and their response signals to a straight line defects tilted 45 degree to the sensor coil of the ∞ coils.

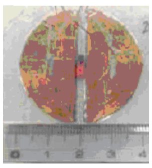
(a-1) 10 Turns




(a-2) 10 Tures (Simulated)

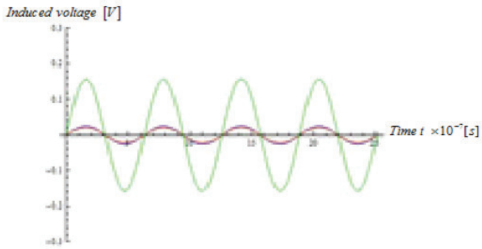



(a-3) 10 Tures (Experimented)



(b-1) 20 Turns


(b-2) 20 Tures (Simulated)




(b-3) 20 Tures (Experimented)

Fig. 2. The first tested flat ∞ coils.
The Green and Red lines are denoting the sensor output signals and noises, respectively.

As described above we have succeeded in decided to work out the first prototype design.

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# Frequency Fluctuation Signal Processing and Its Application to the Barkhausen Signals

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**Abstract**. Among a lot of signal processing methods, frequency fluctuation approach is rarely used. Only the 1/f frequency fluctuation is well known as a figure of healing activations. In the present paper, a generalized frequency fluctuation signal processing method is introduced to analyse the Barkhausen signals accompanying with the magnetization of the ferromagnetic materials. As a result, it is revealed that the situations of ferromagnetic materials under stressed or not are visualized in a three dimensional space.

## 1 Introduction

Barkhausen signal is observed in the ferromagnetic materials when they are magnetizing. It is well known that the Barkhausen signals are very sensitive to the physical external stress and radioactive damage to the ferromagnetic materials.

The iron and its composite ferromagnetic materials are widely used for main frame materials to support the mechanical structures in many artificial products and constructions. Because of their essential role, they are always got mechanical stress and they keep their past mechanical stress histories. Nondestructive detection of their mechanical stress as well as residual stress is of paramount importance for keeping the safety of the mechanical structures, since it is possible to see ahead of time what extent the mechanical structure will maintain their strength for further use.

The past researches concerning to a relationship between the Barkhausen signal and applied mechanical stress have revealed that Barkhausen signals are very sensitive to the mechanical stress and radioactive damage but any deterministic regularity has not been found [1,2]. Only a macroscopic regularity has been reported by means of a frequency fluctuation analysis approach [3]

This paper makes it possible to generalize $1^{st}$ order frequency fluctuation of the conventional analysis to the $n^{th}$ order frequency fluctuation analysis. As a result, it is succeed in visualizing the specimen's situations under stressed or not stressed from their Barkhausen signals.

## 2 Generalized frequency fluctuation analysis

Conventional 1/f frequency analysis is that application of the 1st order least squares to the both Fourier power spectrum and frequency extracts the 1st order frequency fluctuation, i.e., Log of Fourier power spectrum is approximated by Log of $a_0 + a_1 f$, yields a $1^{st}$ order frequency fluctuation characteristic, where $a_0$ and $a_1$ are the $0^{th}$ and a $1^{st}$ order frequency fluctuation terms, respectively. If the frequency fluctuation term $a_1$ takes $a_1=1$, then we have the 1/f frequency fluctuation. One of the most famous frequency fluctuations is the 1/f frequency fluctuation, which can be observed in most of the natural phenomena such as natural wind, sea water waves, river flow sound and so on gives a healing effect to the mentalities via human sensibilities [4].

On the other side, we generalize this conventional *1st* order frequency fluctuation to the *nth* order frequency fluctuation characteristics, i.e., Log of Fourier power spectrum is approximated by a Log of $a_0 + a_1 f + a_2 f_2 + ... + a_n f^n$, where $a_0, a_1, a_2, ...., a_n$ are the $0^{th}$, $1^{st}$ $2^{nd}$, ... ,$n^{th}$ order frequency fluctuation terms, respectively. Careful examination of the coefficients $a_0, a_1, a_2, ...., a_n$ leads to the precise frequency fluctuation characteristic of the Barkhausen signals.

According to our experimental results, all of the frequency fluctuation characteristics are sufficiently represented up to the $4^{th}$ order terms. Fig.1 shows a typical relationship between the frequency characteristic and $4^{th}$ order least squares curve.

Let the normalized $1^{st}$, $2^{nd}$, $3^{rd}$, $4^{th}$ order frequency fluctuation coefficients be respectively the coordinate values on the x-, y-, z-axes, and point shade color, then up to the $4^{th}$ order frequency fluctuation characteristics locate the three dimensional space coordinate position and point shade color.

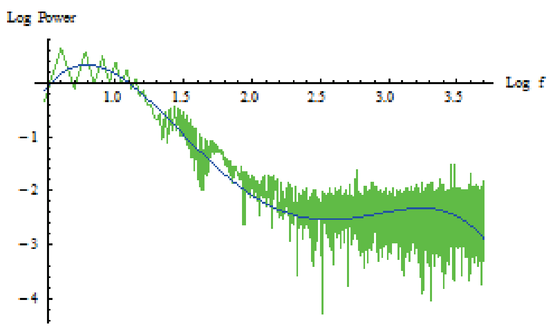


Fig. 1 A typical relationship between the frequency characteristic and 4th order least squares curve.

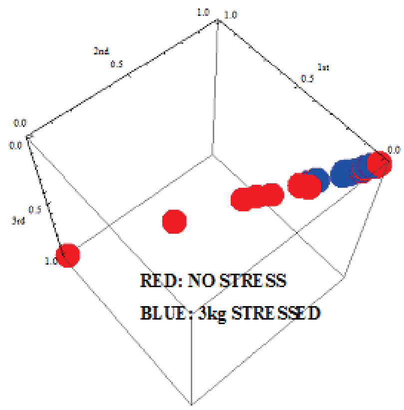


Fig. 2 The visualized stress situations by the 4th order frequency fluctuation analysis to the 30 specimens.

To check the validity of our approach, we have carried out the frequency fluctuation analysis to the 30 silicon steel sheet specimens when they are stressed and not stressed. Fig.2 shows the stress situations to the 30 silicon steel specimens. In Fig.2, the normalized $1^{st}$, $2^{nd}$, $3^{rd}$, $4^{th}$ order frequency fluctuation coefficients are respectively the coordinate values on the x-, y-, z-axes, and point shade color. Comparison among the different specimens of this diagram visualizes an each of the distinct characteristics depending on their mechanical stress conditions.

## 3 Conclusion

As shown above, we have succeed in visualizing the stress situations of the silicon steel sheets in the 3 dimensional space whose coordinates are composed of the terms representing the higher order frequency fluctuation of their Barkhausen signals.

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