щей в пересечении четырехпроводной электрической линии, поставлена задача определения связи преобразования Кларка (α-β-0) и Фортескью (1-2-0). На основании анализа последовательности расчета составляющих прямой, обратной и нулевой последовательностей в общем случае и для каждой из фаз отдельно, и сопоставление с преобразованием Кларка для отдельных последовательностей, получены аналитические соотношения, которые позволяют определить составляющие прямой и обратной последовательностей в области α-β-0. Такой способ представления составляющих тока и напряжения позволяет выполнить декомпозицию мгновенной мощности при использовании *p*-*q*-теории. Выполнен численный расчет составляющих тока и напряжения, а также мощности по *p*-*q*-теории, который подтвердил полученные аналитические выражения.

Результаты. Аналитически обоснована связь прямого и обратного преобразования напряжений (токов) в области 1-2-0 (преобразование Фортескью) с напряжениями (токами) в области α-β-0 (преобразование Кларка), что позволяет в последней отделить составляющие, вызванные действием прямой и обратной последовательностей.

Научная новизна. Предложено аналитическое определение составляющих прямой, обратной последовательностей в области α-β для использования этих составляющих при расчете мгновенной мощности по *p*-*q*-теории для четырехпроводных линий.

Практическая значимость. Полученные результаты являются составляющей анализа компонент мощности электрической энергии в электрических четырехпроводных сетях при несимметричных параметрах режима и могут быть использованы для сетей с несинусоидальными напряжениями и токами.

Ключевые слова: *четырехпроводная линия, силовой активный фильтр, прямая, обратная, нулевая последовательности, преобразования Фортескью, преобразования Кларка, p-q-теория мгновенной мощности*

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A TRIGGER METHOD BASED ON MAGNETIC INDUCTION IN METAL-ENCLOSED SPACE

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ПУСКОВИЙ МЕТОД НА ОСНОВІ МАГНІТНОЇ ІНДУКЦІЇ В МЕТАЛОЗАМКНЕНОМУ ПРОСТОРІ

Purpose. As the application environment of storage test technology is getting worse and worse, the trigger signal with the function of wake becomes the key to the success of the test. In this paper, a new method that induces changes of the intensity of magnetization to implement trigger is proposed. This method is very useful for solving the harsh environment of metal-enclosed space.

Methodology. We design a kind of thin film coils which are placed inside the metal shell. It can induct the slight changes in the magnetic field, and output corresponding induction electromotive force which will be amplified to meet requirements of the trigger signal.

Findings. By theoretical and experimental analysis, this method can be used to realize the trigger with the metal-enclosed space. Moreover, it can improve the reliability of the trigger by several times to generate the trigger signal.

Originality. We designed a controlled variable magnetic field, a flexible thin-film coil and a signal processing unit. These can achieve the metal confined space of the trigger problem. The research on this aspect has not been found at present.

Practical value. We also increase the reliability of the trigger design, and the optimization of the system can be used to achieve the best form of trigger. This provides a certain way and method to extend the application field of storage test technology.

Keywords: *storage test, metal-enclosed space, thin film coil, electromagnetic induction, magnetic induction, trigger signal*

Introduction. Trigger technology is one of the key technologies to obtain the signal effectively, especially in the process of storage test and distributed multi parameter acquisition. The trigger module is an essential part of the system. In order to ensure the accuracy of signal value [1–3], it is essential [3–4] to realize synchronous triggering of multipoint signal in distributed multi parameter acquisition, such as Wireless Sensor Networks. The storage test is the only effective means to dynamic parameter in harsh environment. Being battery powered, this test method increases the energy consumption management. So, this system needs a trigger signal, i.e. they are even more dependent on the trigger signal. As a result, to choose the correct trigger signal is the key of success on the design of a stored test system [5].

Due to the complexity and particularity of the testing process, it is necessary to design an appropriate trigger method in the testing process of different requirements to achieve the effective and reliable trigger signal. A kind of trigger method in literature [5] is to compare the value of the sample signal to judge whether the value has reached the threshold value. It is achieved by an external interrupt control circuit which consists of two resistors in series. A kind of trigger method in literature [6] uses the trigger signal source which is constituted by the semiconductor laser, the fan-shaped screens and the retro-reflector to provide the start signal for the high speed photography system and measure the velocity of moving objects. Another trigger method in literature [7] uses the ECG signals associated with the pulsed magnetic field as the trigger signal. Among the current triggering methods, some use the electric signal as the trigger signal, and some use the optical signal as the trigger signal. But in some tests, the test object is placed in the metal-enclosed space, the optical signal and the electrical signal, which is produced by the external interrupt and the bus protocol, cannot be input to the closed space to realize the trigger. Wireless energy is transmitted based on magnetic field resonance, as shown in [8–10]. The question at issue is: is it possible to receive the magnetic pulse signals in a metal tank without any holes? Our research shows that the magnetic pulse signal can be received by the coil inside the metal tank and act as a trigger signal. The magnetic pulse signal is produced by a magnetic relay outside the metal tank.

Aiming at the storage test for parameters of metal-enclosed space, a new trigger method by changing magnetic field to transfer the trigger signal is presented in this paper. After dealing with the non-contact trigger signals, the test circuit can be triggered in a confined space to ensure the test is normal and effective.

Trigger principle and analysis. When the electromagnetic wave reaches the interface between the air and the shield body, the discontinuous impedance will produce radiation to the incident wave so as to reduce the electromagnetic wave energy. A part of the energy into the shielding body will result in heat loss. According to the shielding theory of the Schelkunoff, the total shielding effectiveness is the sum of the absorption loss and the multiple reflection loss [7]. The larger the thickness of the shielding body is, the more significant the shielding effect is.

The traditional triggering method is realized by signal transmission. The signal should be received completely which can be triggered after identifying and judging correctly. However, the closed space has a certain performance of electromagnetic shielding, which will attenuate the signal and cause the receiver to be unable to recognize it, so that the circuit cannot be triggered. Combined with the characteristics of closed structure, the traditional signal trigger mode can be changed through changes in the magnetic flux to trigger the circuit. This kind of method is similar to analog signal transmission, which does not have the rollover threshold limit like the traditional trigger signal and can amplify the trigger signal to make it recognizable.

Principle of inductive triggering. The thin film coil is sensitive to the change of the magnetic flux which can be placed in the receiving end. The thin film coil is also known as the multi-turn coil, which is a closed coil winding, and the principle of it is the change rate of magnetic flux.

According to the law of electromagnetic induction, the induction electromotive force E by the coil is

$$E = -n\frac{\Delta\varphi}{\Delta t}, \quad (1)$$

where n is the turn of coil; $\Delta\varphi$ is the change of magnetic flux; Δt is the time of duration.

When the magnetic flux changes, there will occur induction of EMF E. The larger the change is, the greater the electromotive force value is. However, if the electric potential is relatively weak, the value can be increased through the level of amplification circuit, and become the trigger signal of the memory test circuit.

Simulation analysis. The trigger method of the thin film coil induced by the varying magnetic field is simulated by using the Ansoft maxwell simulation software. The specified volume of the metal-enclosed space model is 40 × 60 × 55 mm, it is hollow inside with manganese steel shell wall thickness of 5 mm. The varying magnetic field is generated by the electromagnet which consists of the electromagnet core and copper coils. The number of turns is set to 300.

We increase square wave excitation current in the coil cross-section to 1.5 A. The distance between the electromagnet and the shell is 10 mm. The simulation time L is 5 s. According to the above conditions, we get cloud simulation and related data through simulation. To solve the magnetic field strength of the space inner and outer walls, the corresponding cloud and values are required as shown in Fig. 1, 2.

A small amount of alternating magnetic signal to pass through the metal-enclosed space into the interior of the space can be seen in Fig. 3. As long as the alternating magnetic signal passes through the metal-enclosed shell, the film coil generates an output signal, which is the trigger signal of the circuit through processing.

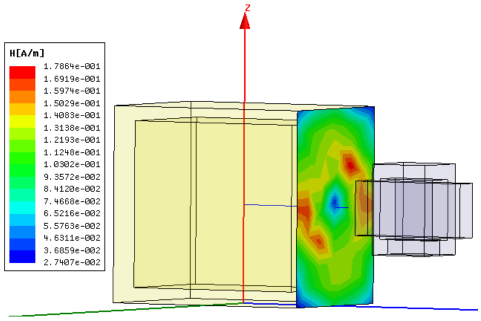

Fig. 1. Magnetic field intensity distribution of the outer wall of the shell

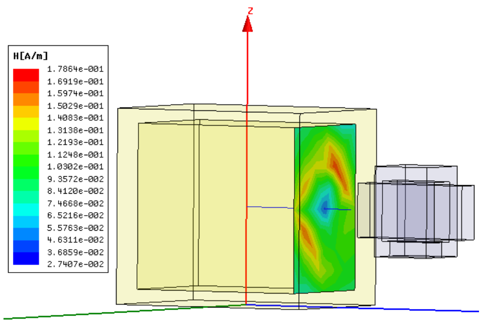

Fig. 2. Magnetic field intensity distribution of the inner wall of the shell

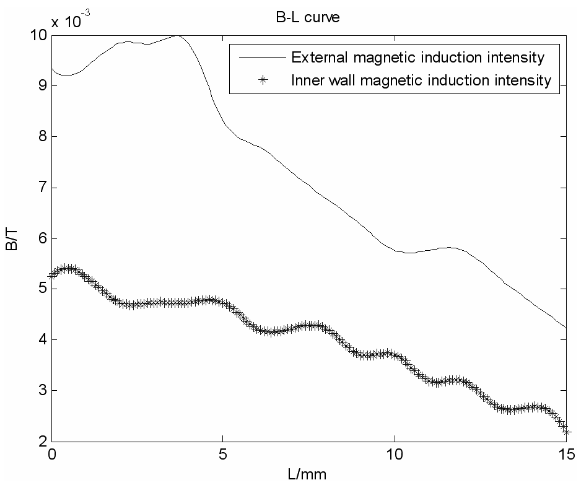

Fig. 3. The distribution of magnetic induction intensity on the inner and outer walls

Fig. 3 shows the relationship between the change in the metal inner and outer walls of the space confined by magnetic flux density according to the position. Abscissa zero is located in the central position of the inner and outer wall. As it can be seen from this Figure, with increasing distance from the centred position, the magnetic induction intensity is gradually reducing. The inner and outer wall strength values are different due to the shielding of the metal shell; compared with the outer wall, the inner wall has a great attenuation.

According to the (1), the induction electromotive force produced by the thin film coil is related to the number of turns and the change of the magnetic flux. The type of metal materials and thickness of the metal-enclosed space, the external magnet field value are also closely related to the electromotive force E.

The simulation analysis result shows that: the magnetic field strength is proportional to the conductivity of the space material and other factors; the distance between the electromagnets and the shell is inversely proportional to the magnetic field strength when the thin film coil contacts with shell inner side.

For a specific application, the number of turns of the coil, the material, the thickness and the conductivity of the metal-enclosed shell are all fixed values.

In order to neutralize the influence of the shell on the magnetic field (as shown in Fig. 3),we can increase the current value of the electromagnet, increase the rate of change of the magnetic flux, shorten the distance between the electromagnets and the shell to generate the desired trigger signal.

The trigger signal that we needed is a transient signal, thus, the easiest way to generate the transient magnetic field is by controlling the electromagnet power supply on and off.

Therefore, in the experiment which using a specific type of metal-enclosed shell, the influence of the adjustable factors of the electromotive force E involves only the electric current value of the electromagnet and the distance between the electromagnets and the shell.

Experimental verification. The trigger and a receiving device being designed on the basis of simulation analysis, the thin film coil induces a weak magnetic signal; thus, trigger circuit implementation feasibility is verified by experiment.

The trigger module is mainly composed of a trigger control unit circuit which is arranged outside the metal-enclosed space, and a trigger circuit which is arranged in the metal-enclosed space, as shown in Fig. 4. The triggering control unit circuit is composed of a trigger control unit, a relay, an electromagnet and a power management. Its main function is to receive the test start signal of the system, and control the relay to the solenoid to generate a varying magnetic field at the same time.

The trigger circuit is mainly composed of a multi turn coil and a differential amplifier circuit. Its main function is to induce the external magnetic field changes and provide a trigger signal for the activation of stored test instrument by signal processing.

In the experiment, the electromagnet uses 12 V power supply. According to the spatial structure characteristics of the metal-enclosed spaces and the volume of the storage test instruments, we designed a multi turn thin film coil with a line width of 6 mil. The thin film coil is a metal film sputtered on the insulating film with polyester amide substrate, using the advanced thin film processing technology, made of flexible thin-film multi-turn coil. Regarding the flexibility of thin film coil, it can be placed on any shape, and has a certain structural compatibility with the storage test instruments and the metal-enclosed space.

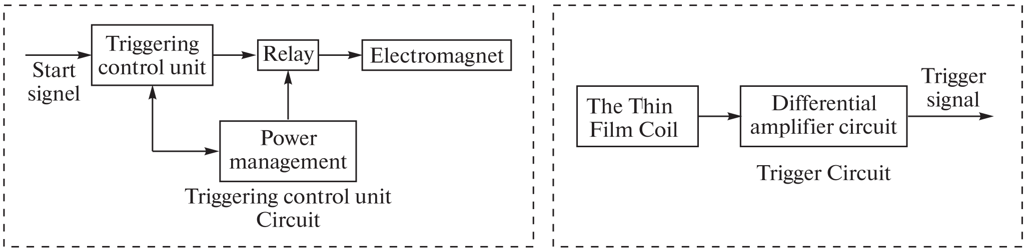

Fig. 4. The block diagram of the trigger module

The induction electromotive force of the coil is very weak, so the signal is amplified by a differential input instrumentation amplifier with a magnification of about 450 times, to meet the requirements of the trigger level value.

The trigger module is constructed according to Fig. 4, "start signal" in Fig. 4 of the power control solenoid generates a changing magnetic field.

In the trigger circuit, the output signal of the thin film coil is enlarged.

The constructed trigger module has the storage test instruments attached and the simulation experiment is carried out on the shell. In the experiment, the thin film coil is mounted in a metal-enclosed metal casing, which is attached to the insulator and is wound into a circular (or rectangular).The normal of the film coil is parallel to the iron core in the alternating electromagnetic field generating device, namely, the plane of the multi-turn coil is perpendicular to the axial changes in the electromagnetic field generated in the device core.

The stored test circuit is connected with the thin film coil to be placed in a metal cylinder, and the external electromagnet is controlled by a trigger switch (Fig. 5). Fig. 6 shows the signal waveform, which is the output of the thin film coil inside the metal cylinder.

As shown in Fig. 6, the output signal of the thin film coil is about 1ms delayed compared with the input signal which controlled electromagnets.

However, this delay time is characteristic of the system and has a constant value. This delay time has little effect on the speed of operation of the device, since the output signal is used to activate the device. The correct timestamp in the data can be obtained with the known system delay time.

The distance between the electromagnets and the shell is a key factor in this operation mode. The test results show that the longest distance between the two is about 3 cm, with the electromagnet current of 0.6 A at 12 V.

Discussion and conclusion. The dynamic parameter test of metal-enclosed space is realized by stored test, which is necessary to solve the problem of trigger of testing circuit, in order to ensure activation of the circuit reliably. Through simulation, the Variable Magnetic Field is induced by the thin film coil to produce the feasibility and impact factors of a trigger signal: Induced electromotive force generated by the thin film coil, is related to the number of turns, the electric current of the electromagnet, the conductivity of the casing material and other factors, and increases according to the values of these factors. The induced electromotive force produced by the thin film coil is inversely proportional to the distance between the coil and the shell. According to this method, the trigger module is designed to produce, receive and process the magnetic field. The feasibility of this method is verified by simulation experiments, which can provide effective ways and methods to solve the problem of the metal-enclosed space.

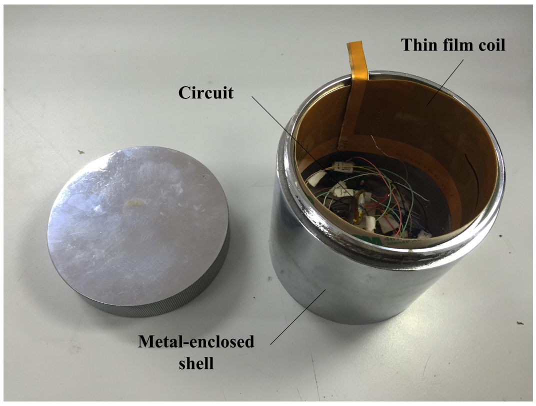

Fig. 5. Simulated closed shell and a thin film coil

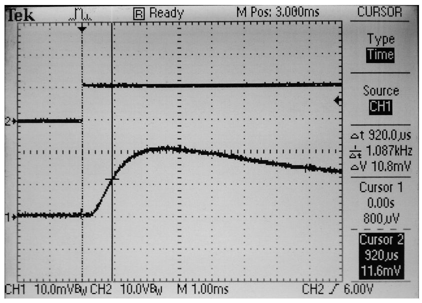

Fig. 6. Output signal of a thin film coil

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Мета. У міру того як прикладне середовище технології тестування пам’яті стає все гірше й гірше, пусковий сигнал з функцією пробудження стає ключем до успіху тестування. У даній роботі запропоновано новий метод, що викликає зміни інтенсивності намагнічування для реалізації пуску. Цей метод дуже корисний для рішення жорстких умов металозамкненого простору.

Методика. Ми проектуємо вид тонкоплівкових котушок, що знаходяться всередині металевої оболонки. Вони можуть індукувати невеликі зміни в магнітному полі, вихідний сигнал відповідає індуктивній електрорушійній силі, що буде посилена для задоволення вимог пускового сигналу.

Результати. Теоретичний та експериментальний аналіз підтверджує, що цей метод може бути використаний для реалізації пуску в металозамкненому просторі. Крім того, він може підвищити надійність пуску в декілька разів, генеруючи пусковий сигнал.

Наукова новизна. Розроблене кероване перемінне магнітне поле, гнучка тонкоплівкова котушка та блок обробки сигналів. Це дозволяє досягти рішення проблеми запуску в металозамкненому просторі.

Практична значимість. Підвищена надійність конструкції пускового приладу. Оптимізація системи може бути використана для досягнення оптимальної форми тріггера.

Ключові слова: *тест зберігання, металозамкнений простір, тонкоплівкова котушка, електромагнітна індукція, магнітна індукція, пусковий сигнал*

Цель. По мере того как прикладная среда технологии тестирования памяти становится все хуже и хуже, пусковой сигнал с функцией пробуждения становится ключом к успеху тестирования. В данной работе предложен новый метод, который вызывает изменения интенсивности намагничивания для реализации пуска. Этот метод очень полезен для решения жестких условий металлозамкнутого пространства.

Методика. Мы проектируем вид тонкопленочных катушек, которые находятся внутри металлической оболочки. Они могут индуктировать небольшие изменения в магнитном поле, выходной сигнал соответствует индукционной электродвижущей силе, которая будет усилена для удовлетворения требований пускового сигнала.

Результаты. Теоретический и экспериментальный анализ подтверждает, что этот метод может быть использован для реализации пуска в металлозамкнутом пространстве. Кроме того, он может повысить надежность пуска в несколько раз, генерируя пусковой сигнал.

Научная новизна. Разработано управляемое переменное магнитное поле, гибкая тонкопленочная катушка и блок обработки сигналов. Это позволяет достичь решения проблемы запуска в металлозамкнутом пространстве.

Практическая значимость. Повышена надежность конструкции пускового устройства. Оптимизация системы может быть использована для достижения оптимальной формы триггера.

Ключевые слова: *тест хранения, металлозамкнутое пространство, тонкопленочная катушка, электромагнитная индукция, магнитная индукция, пусковой сигнал*

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