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Crack Detection of Power Line Based on Metal Magnetic Memory Non-destructive

Niu Fenglian
School of Mechatronics Engineering / Ningbo Dahongying University,
No. 1, Xueyuan Road, Yinzhou District, Ningbo city, China
E-mail: nfl1979@126.com

Abstract

Visual inspection method using helicopter equipped with infrared and ultraviolet camera is often employed to check the transmission status of power line, but it is so expensive and unsafe relative to using power line robot to implement crack detection of power line. In this paper a new measuring method is proposed using metal magnetic memory non-destructive (MMMNDT) to to automatically detect defects or abnormal conditions based on a completely autonomous mobile platform capable of a meaningful payload for signal data processing. In this work one kind of brand-new mechanical structure has been designed for inspection robot, and some important parts of the mechanical structure have been fully explained. At the same time, a detection system of the robot has been designed based on MMMNDT. The results of experiments about the crack detection of power line show that the robot can satisfactorily span obstacles automatically and fulfill the specified inspection tasks, experiment results of the detection system verified that this diagnosis system is feasible and can be applied to power line detection.

Keywords: *power line robot, mechanical structure, metal magnetic memory, magnetic elasticity effect, non-destructive testing*

1. Introduction

Safety detection of power line is important in power transmission when the power line are exposed for a long time, some damage such as break, abrasion and corrosion is often produced by suffering from sustaining mechanical tension, the material aging. If repair and replacement are not prompt, the original small breakage and flaw will expand or even cause serious accidents with big area power cut which will bring enormous economic loss and serious social influence. Therefore, we must inspect the transmission line regularly in order to monitor the working situation of the transmission line as well as the changing of environment, discover and eliminate the hidden danger promptly, prevent accident occurrence and guarantee the power supply security.

In recent years, researchers have been working on designing all kinds of mobile robots to partly or fully perform the inspection tasks of power transmission lines [1-2]. Power line robot is effective and safe tools along the transmission line to perform part of power line inspection tasks, and the research on high-voltage transmission line inspection robot began in the late 1980 such as the research institutions of Japan, Canada, American and China have developed different kinds of robot successively [3]. There are two kinds of robots which have been developed so far: One has the function of spanning obstacles, but large structure size and weight causes poor practicability, and most of them are under laboratory conditions. The other robot of power line can only inspect between two pole towers, that is, it can't span obstacles, which limits inspection work scope. In china, the research on high-voltage transmission line began in the late 1990's, such as Wuhan University, Shandong University, the Shenyang Institute of Automation of the Chinese Academy of Science, the Automation institute of the Chinese Academy of Science and other the scientific research units also developed the power transmission line inspection robots.

In the research on power line robot, there are some urgent problems needed to be solved. Inspection robot must plan its behavior to negotiate obstacles. A navigation system is needed to recognize and locate the obstacles with its sensors, and then the control system of inspection robot will plan its motions according to the obstacle information to negotiate these

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obstacles autonomously. At present, the inspection robot was equipped with different sensors to recognize the obstacle and navigate their inspection robot to avoid the collision against the obstacle, such as ultrasonic sensor, contacting sensor and camera [4]. The limitation of the battery capacity, most inspection robots are powered by Li battery packs. The robot can't work continuously for a long outime and requires periodical maintenance, so continuous long period working ability of robot becomes one of the vital difficulties before putting it into practical applications [5-6]. To solve this problem, on-line power supply system is needed.

The important function of power line robot needs to have the ability to detect the cracking of power line, while different methods for detecting insulator faults exist, e.g. visual inspection or electro technical measurement. In this paper we present a novel recognition method using metal magnetic memory non-destructive sensors to recognize the faults of power line, which can be used complementary with other methods and especially for identifying mechanical damage and flashover marks. However, there is no inspection method or measurement device that is able to detect all possible insulator faults.

The power line using non-destructive detection (NDT) is an interdisciplinary field dealing with non-invasive inspection of component and product structure and integrity. It plays a critical role in assuring that structural components and systems perform their function in a reliable and cost effective fashion. Metal Magnetic Memory Non-destructive testing as one of the NDT was first introduced by the author in 1994. In recent years metal magnetic memory (MMM) has been a newly developing technique to effectively diagnose early defect of ferromagnetic items [7-9].Traditional methods of diagnostics such as ultrasonic inspection, magnetic particle inspection, X-ray are oriented to detect the already existing defects, but cannot predict sudden fatigue damages of equipment, which are the main reasons of failures and sources of maintenance staff traumatism. In our early research, parallel port based sampling system is adopted to sample magnetic signals; However, it is inconvenient relative to USB based sampling system, so on the base of earlier research, a new based-USB data acquisition system is developed and applied to crack detection of power line.

2. Robot Mechanism Design

The high-voltage transmission line inspection robot is a complex electromechanical system which involves many different fields, and the overall system is based on the mechanical structure, which should fulfill the functions that walking steadily along the line, spanning obstacles automatically, pose balance and so on. The power line robot is composed of five components: power source and controlling, flexible arm, braking device, driving device, opening and closing device, and detecting system, the 3D structure is shown in Figure 1.

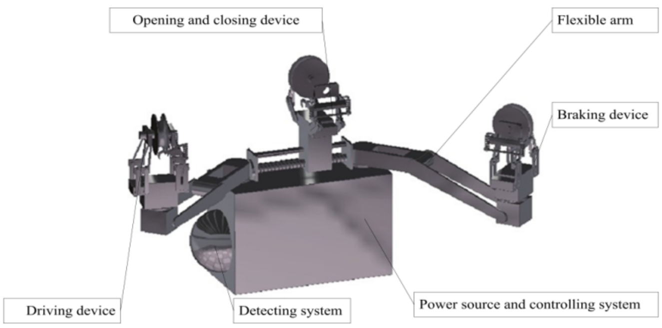

Figure 1. Structure of Power Line Robot

2.1. Flexible Arm Design

Before the robot walks on the line, the power line should be placed at the bottom of the wheel and guarantee the robot walking properly, so the two rotating joints is needed to meet with the above requirements. There are four degrees of freedom for this robot, wherein the robot determines the position of the first two, the two arms of the gesture determined to finalize its structure as shown in Figure 2.

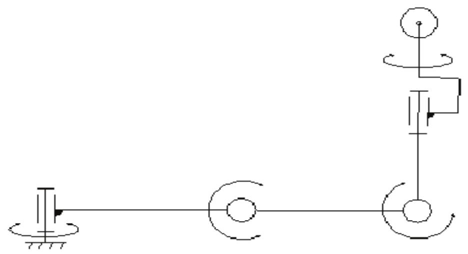

Figure 2. Flexible Arm Structure

Flexible arm is composed of the shoulder, base, arm, forearm, elbow, and the end of the actuator components, which has four degrees of freedom in order to realize the big arm swing, pitching arm, and down turn of the wrist rotation. Shoulder and elbow consist of the reducer and turntable. Motor is driven to achieve vertical and horizontal movement of the arm direction by reducer rotating turntable. The rigidity of the flexible arm can be achieved smooth conversion to adapt the robot across the turn, the position and attitude of the jumper requirements by controlling the braking device of the motor. The inspection robot manipulator motion parameters are set as follows: The length of big arm, Wrist and arm respectively is 250mm, 72mm and 400mm. the long end of the actuator is 344mm, and each joint rotation range are:

Joint 1: ± 90 ° joint 2: ± 90 ° Joint 3: ± 90 ° joint 4: ± 90 °

2.2. Driving Mechanism Design

The wheel walking mechanism consists of the driving wheels, the hanging arms, the main driving motor, the main transmission shaft, the transmission chains, and some crew gears. The main driving motor drives the main transmission shaft to rotate by the first level transmission chain, and three gears are installed on the main transmission shaft fixedly, meanwhile the three gears severally mesh with three screw gears which are at the end of the hanging-arm, therefore the screw gears can be driven to rotate, then steady walking of the robot is realized. In order to realize the robot speed regulating, direct current motor is adopted as the main driving motor to facilitate the PWM speed regulating. Moreover, the wedge type profile wheels have been adopted as driving wheels, also each wheel is made by the high polymer nylon rubber material to increase the coefficient of adhesion between walking wheel and the line. The whole driving mechanism can steadily run along the high-voltage transmission line that the slope angle does not surpass 30°.

Drive means to drive the robot reaches the specific position of each joint. Currently there are three main drivers used: pneumatic, hydraulic and motor drive. Comparing stepper driver and DC servo driving, stepper motor drive control system is simple and low-cost advantages, but the open-loop stepper motor control with a low controlling accuracy, DC servo motor using closed-loop control could acquire high position precision. Travel agencies using wheeled mobile robots realize the robot walking. When the slope is small, the friction wheels allow the robot moving, the robot uses wheel drive mechanism. When the line steep, difficult to achieve friction drive wheels when walking robot, the robot grab three brake lines, and with the screw spiral vice composition crawling mechanism means carry crawling drive.

The hanging-arm inspection robot for high-voltage transmission line walks along high-voltage transmission line, and the types of obstacles on high-voltage transmission line are varied, moreover the relative position of the high-voltage transmission line and the obstacles, the robot posture are not extremely fixed, so the robot has many uncertain factors in actual works. Regarding those special working conditions, the robot has been requested to have two workings that independent movement control and remote control, and the robot has the ability of reliable work in the adverse circumstance.

3. Detection Systems Setting Up

The detection system is employed to measure the faults of the power line, which is installed in the front of the robot. The magnetic effect principle is used to analyze the defect of power line, which is different with the vision detection method.

3.1. Detection Principle

When power line with ferromagnetic property work in the conditions of alternating load, irreversible reorientation of the magnetic domain textures for magneto-striction will take place under the action of working load, as well as strain concentration zones is formed. The relation between leakage magnetic H_p and stress change of ferromagnetic construction $\Delta\sigma$ can be expressed,

$$H_p = \frac{\lambda^H}{u_0}\Delta\sigma \tag{1}$$

Here λ^H is the irreversible component of magnetic-elastic effect which is decided by stress, outer magnetic attitude and ambient temperature, u_0 is the vacuum permeability.

The magnetic field $H_p(\mathrm{x})$, $H_p(\mathrm{x})$ respectively has its maximum value and zero value in the tangent component and normal component. This magnetic field condition will be kept after the working load is removed, so the stress concentration position can be deduced by measuring the normal component of the leakage magnetic field. The criteria is to find maximum gradient value and zero value of leakage magnetic normal component of ferromagnetic construction's surface, and calculate the normal component which should equal the ratio value between the difference and minimum values, the difference is equal to the maximum value minus the minimum. Therefore the life and safety parameter could be estimated by gradient value K,

$$K = \frac{dP_H(y)}{d} \tag{2}$$

The scheme of magneto-elastic effect action is shown in Figure 3. If a cyclic load or acts in some area of the power line, the residual induction and residual magnetization growth occurs in the action of external field.

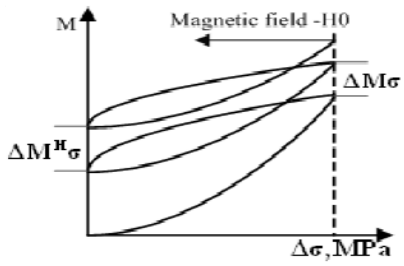

Figure 3. Scheme of Magneto-elastic Effect Action

3.2. USB-based Hardware and Software System Design

The Universal Serial Bus (USB) is a standard for connecting PCs to peripheral devices such as printers, monitors, modems and data acquisition devices. USB offers several advantages over conventional serial and parallel connections, including higher bandwidth (up to 12 Mbits/s) and the ability to provide power to the peripheral device. USB is ideal for data acquisition applications. Since USB connections supply power, only one cable is required to link the data acquisition device to the PC, which most likely has at least one USB port. Figure 4 shows the principal diagram of USB-based metal magnetic memory diagnosis system.

The whole hardware system is composed of five parts as shown in Figure 5, EZ-USB and peripheral circuit, FIFO and logical circuit, A/D converter circuit, Transducer circuit as shown in Figure 6, Analog signal output of multi-channel sensors. Considering functional requirements and power consumption, the following major devices have been chosen: EZ-USB (AN2131QC), FIFO (IDT7202), A 12-bit ADC (MAX197), linear hall sensors (3515). The peripheral circuit includes PC interface circuit and power circuit and its function is to guarantee the normal working of EZ-USB and communication with PC. A/D converter adapts 12-bit resolution MAX197. So when transmitting data to FIFO, high 8-bit data was transmitted and then low 4-bit.

Transducers sense physical phenomena and provide electrical signals that the DAQ system can measure. In this detecting system, Hall sensors convert magnetic signal system into an analog signal (voltage) that an ADC can measure. Other examples include strain gauges, flow transducers, and pressure transducers, which measure force, rate of flow, and pressure, respectively. In each case, the electrical signals produced are proportional to the physical parameters they are monitoring.

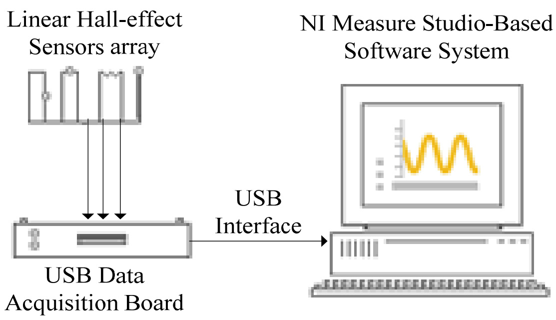

Figure 4. USB-based Metal Magnetic Memory Diagnosis System

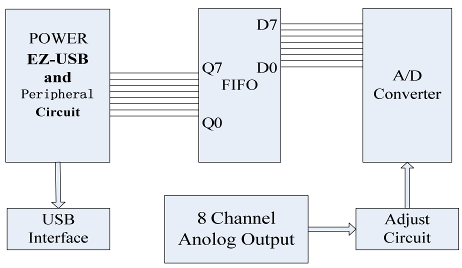

Figure 5. Data Acquisition Hardware Circuit

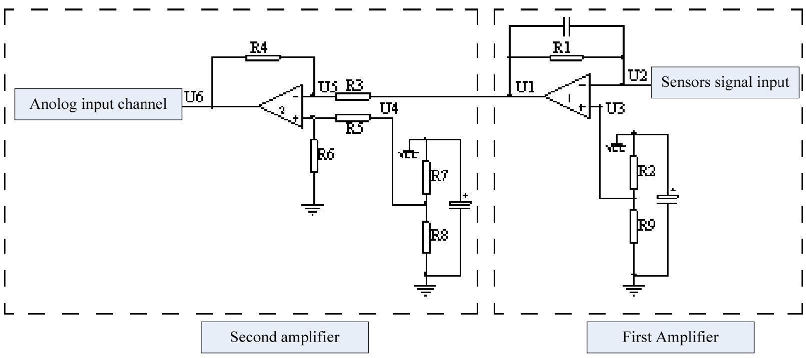

Figure 6. Transducer Circuit

Software transforms the PC and DAQ hardware into a complete DAQ, analysis, and display system. The majority of DAQ applications use driver software. Driver software is the layer of software that directly programs the registers of the DAQ hardware, managing its operation and its integration with the computer resources, such as processor interrupts, DMA, and memory. Driver software hides the low-level, complicated details of hardware programming, providing the user with an easy-to-understand interface.

The software system mainly consists of PC-based data analysis software, Firmware design and USB driver software. Firmware software is developed under the development environment "u-Vision" and firmware code frame of EZ-USB developing packing. Equipment driver program provide the interface between cooperation system and hardware. EZ-USB developing tool has offered a universal driver program. According requirement of user the program can be modified to be the data acquisition in windows DDK. Application software is developed in the environment Visual C++.NET and NI Measure Studio which offer many active tool to do data analysis.

In detecting the magnetic signal, linear hall sensor was adapted because of its high stability to temperature and high sensitivity. The parameter to be measured has converted to voltage signal, which must be processed to satisfy the second instrument show, save, transmission and converter. So the signal transducer is the interface of the sensors and continual analog circuit. Its function is to amplify, process, noise suppressor and make it satisfy requirement of the second instrument. MAX197 is fit to accept high lever current (4-20mA)or voltage (0-±10V). Since the sampling signal is very weak, so it is important to amply to send signal to high resolution AD converter. The following calibration experiment gets the relation about stress and voltage.

(1) Experiment ambient temperature is $30^0 C$ and surface of power line isn't disposed;

(2) One segment of power line has been experimented in seven kinds of force according following Table 1.

Experiment items is the used power line which diameter and material is respectivelyф10.5mm and Al, the relation about voltage and position as Fig 7 shows. From the Fig7, we know the curve of big load items has passed zero point, but front and back curve of zero point is very flat, we can reason that the pull force is very small, so the stress concentration zone is very small. From the Figure 8, we can see that the curve passed zero and the front and back curve of zero point is very sloped relative to above two items.

The above-described data acquisition system (interface board and software program) has been implemented and installed in a modern PC. The system has been initially tested to perform to detect the stress concentration zones. The obtained result is consistent with that previously reported for similar diffract to meters.

Table 1. Seven Tensile Force of Power Line

Item N.O	1	2	3	4	5	6	7
Pulling force (KN)	5.80	13.04	16.25	20.77	25.27	33.88	34.92

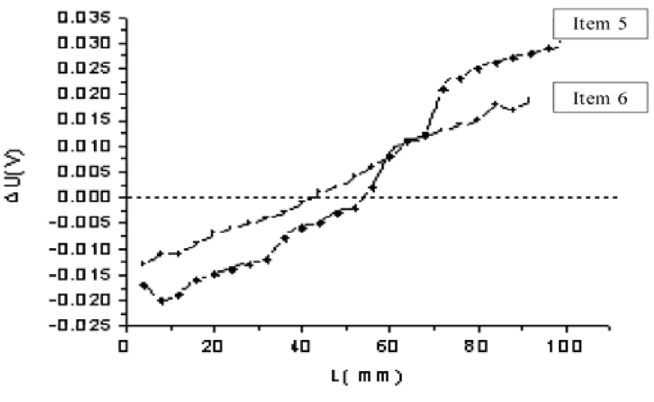

Figure 7. Item 5, 6 Sampling Signal

4. Experiment Result and Analysis

Figure 8. Sample of Power Line

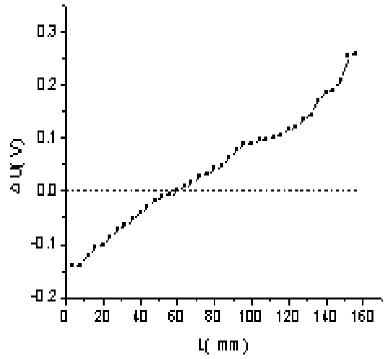

Figure 9. Sampling Signal of Power Line

In the experiment, we make use of eight channels linear hall effect sensors to detect the same items, the sample of item as Figure 8 shows, three detection positions of item are as three different benchmarks. One is center point, the other two are positioned at the two sides of center point and the distance between the two detecting point is 20mm. As Figure 9 shows, in the center of item, the signals pass the zero point. According the theory of distribution of the magnetic leakage field of stress concentration zone, magnetic memory effect on the stress concentration zone of the ferromagnetic material will result in maximum horizontal and zero vertical component of magnetic leakage field. Thus, we can accurately predict the defect zones by measuring vertical magnetic leakage. Figure 10 and Figure 11 respectively shows the change of magnetic signal near the defect zones.

Above detecting data are acquired by measuring on the surface of ferromagnetic item. In practice, the detecting probe is near the surface of ferromagnetic item because of the work-piece may be covered with such layers of insulating material as paint, so that it may be impossible that detecting probe is close to the surface of metal surface. The following experiment would testify the effect of “Lift-Off” Effect. In the experiment, the distance of “Lift-off” is 15mm. From the acquired data, amplitude value of signal decreased by more than 10% relative to on the surface. This phenomenon can be explained in this principal: when the detecting probe lifts off the surface, distribution of magnetic lines of force decrease and the magnetic signal detected would turn weak. So a conclusion can be gotten that a certain lift-off distance has no obvious effect on stress concentration zones.

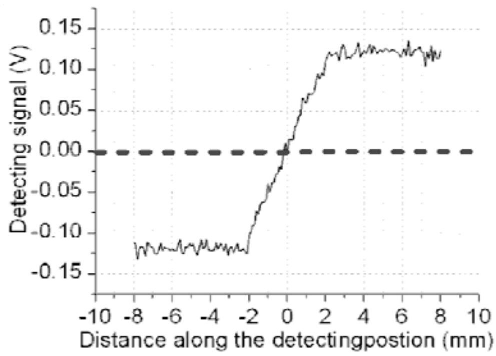

Figure 10. Detecting Signal of Defect Zone

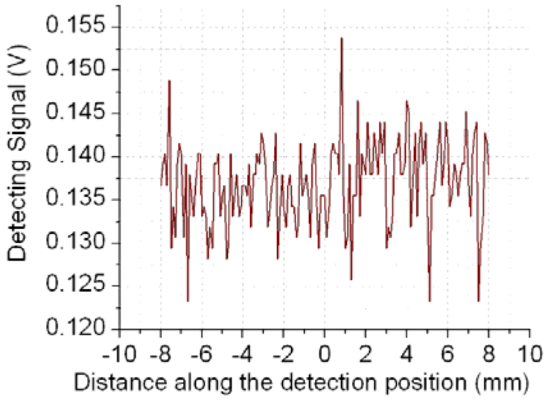

Figure 11. Sampling Signal on the Left Side of SC

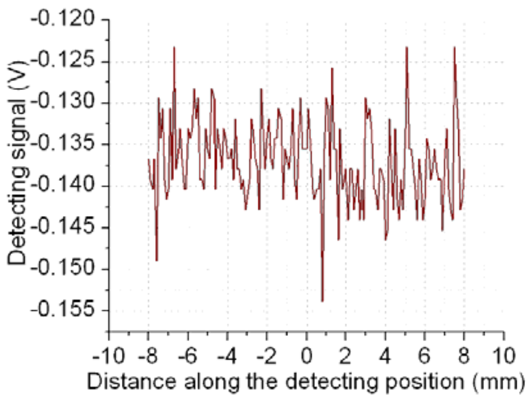

Figure 12. Sampling Signal on the Right Side of SC

7. Conclusion

This paper presents a novel method using metal magnetic memory to detect crack of power line based on pipe line robot. During the experiment on items and used power line about tensile process, we can conclude that the inherent magnetic property of power line items is changing with the different tension force and USB-based multi-channel diagnosis system is feasible to acquire magnetic signal in ability of diagnosis software system and apply the detecting system to flaw estimation of power line in the help of robot.

Acknowledgements

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