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A Design of Magnetic Memory Sensor of Oil Well Casing Damage Detection

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Abstract: Subjected to effect of complex working conditions, oil production well casing will produce different degrees of stress concentration during the long-term service process. This kind of stress concentration can cause casing damage accident very easily, inflicting huge economic losses. As the advantage of the magnetic memory testing technology in metal damage prediction, a kind of magnetic memory sensor which has high sensitivity and good temperature resistance is invented, then make it sealed and insulating. The detection in laboratory and field test proved that this kind of sensor has good temperature-pressure resistance and sealed property, it also makes the detecting different form of the casing deficiency with high sensitivity realized and can provides theory basis for casing life prediction and safety evaluation.

Key words: Casing, magnetic memory, sensor, detection

INTRODUCTION

Casing is a very important infrastructure in the oil field production process, however with the increase of the using years of casing for oil and gas field in the world, most of the casing exist damage, which are directly affect the output value of oil and gas filed and its economic benefit (Chen, 2012). So, casing damage is a serious problem to be solved. In general, casing damage were caused by geological tectonic stress factors, engineering technique factors and corrosion factors during the oil production (Yong, 2009) and the form mainly includes collapse, deformation, corrosion, fracture, joint dislocation, faults etc. (Da Silva *et al*., 1990; Zhou *et al*., 2010). Every year, only in China, the economic loss due to casing damage has reached tens of billions of Chinese Yuan recently (Han, 2001; Hu *et al*., 2003; Liu, 2006; Peng *et al*., 2007). But then the problems keep increasing year by year in Chinese Oilfields. Once damaged, most casings are difficult to repair in practice. Therefore, the most effective way to ensure the regular production of oil wells is to prevent casing damage, requiring periodic detection for casing pipes.

At present, there are several methods to examine the casing damage, including mechanical caliper logging technology, electromagnetic detection technology, ultrasonic detection technology and down hole video detection technology, etc. (Brill *et al*., 2011; Xu *et al*., 2013). But all these damage detection methods apply only to test the existing damage, cannot detect the potential damage caused by stress concentration (Ren *et al*., 2010). If there is a way can detect the potential damage, remedial measures can be taken in advance to prevent the relevant accidents. Fortunately, in 1997, a new non-destructive testing technology which named Metal Magnetic Memory (MMM) testing was presented (Doubov, 1997). This new technology is based on the analysis of self-magnetic leakage field distribution on the surfaces of components in order to detect stress concentration zones, defects and structure inhomogeneities of the metal (Doubov, 1999; Vlasov and Dubov, 2004; Dubov *et al*., 2003) and the residual lifetime of the components made of ferromag-netic materials could be predicted (Shi *et al*., 2010).

The basic rationale is that: Under the effect of the geomagnetic field and mechanical load, abnormal magnetic signals will be generated in the metal material work piece stress concentration zones, the tangential component of the signal magnetic flux leakage, appears with a maximum value, while the normal component, changes polarity and has a zero value (Wilson *et al*., 2007). By measuring the value of the leakage magnetic field can determine the degree of damage and the result of the injury degree can be used for work piece life span prediction. At present, this approach has already been applied to early diagnose power machinery components (Roskosz *et al*., 2010), welded joints of pipeline (Dubov and Kolokolnikov, 2010) and other ferromagnetic components. Surprisingly, there is a dearth of research on casing damage detection by using

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MMM technology and there is not any mature inspection product based on the technology in the world. The metal magnetic memory sensor for down hole working is even less. So, this kind of sensor is exactly the theme the study study at.

DESIGN THE METAL MAGNETIC MEMORY SENSOR

Design requirements: Most of the depth for casing wells is between 10,000-60,000 m. Besides the leakage magnetic field on the surface of casing is very faint and the underground environment is also very harsh. Moreover, the under-well temperature and pressure increase as the depth increases. The max temperature value could reach 120°C and the bottom hole pressure could exceed 50 MPa, in addition, there are also corrosive substances. These factors is a huge challenge for the design of down hole sensor. In order to overcome these difficulties, the following conditions must be met:

- The magneto sensor must have these properties, wide range of detection magnetic field, high sensitivity and good tolerance of temperature
- The size of the sensor should be as small as possible with fewer wires
- The sensor should be dealt with insulating and sealing

Selection of magneto sensors: At present, there are generally three kinds of magneto sensors which can apply to the weak magnetic field: HALL, Anisotropic Magneto-resistance (AMR) (Bartok *et al*., 2013) and Giant magneto-resistance (GMR) (Liu *et al*., 2013). Features of three different magneto sensors are shown in Table 1. The detection principles vary and the detection effective range of the magnetic field is quite different. The one with the widest detection effective range is GMR which also has high sensitivity, temperature stability and simple detective circuits. Consider of the underground working environment, the stability of temperature is a very important property for the sensor and it can greatly reduce the difficulty of the down hole sensor package, if the detection circuit of the GMR is simple enough. To sum up, for the down hole complicated environment, GMR is the best choice.

Circuit design of sensor and encapsulation: The magneto sensors output signal cannot be directly used for processing and analysis Because of weakness of it and the existing of interference from common-mode voltage signal and all kinds of common-mode. So, it must be filtered and amplified by an instrumentation amplifier. And the amplifier are required to be high efficiency, high linearity, low temperature drift, low noise, super high Common-Mode Rejection Ratio (CMRR), high input impedance, high integration, wide gain bandwidth etc. Therefore, wide supply range, rail-to-rail output instrumentation amplifier are selected to well meet the requirements. And the amplifier gain demand by only setting one external resistor. In order to improve the sensor loading capacity, an extra voltage follower with isolation and buffer needs to be added. The circuit diagram is shown in Fig. 1.

Although, the magnetic memory sensor can realize non-contact and nondestructive testing, the distance between the sensor and the work piece cannot be too far away. The magnetic memory sensor must be fixed, sealed and insulated to guarantee the down hole working safety and stability. So, according to the characteristics of the magnetic memory detection, the material of the protective device should be a kind of non-magnetic metal which has good wear resistance and corrosion-resistant function etc. In condition of these factors, a non-magnetic stainless steel is chosen as the material for the protective device. After the sensor is fixed, the seal and insulation should be carried out. Insulation material is a two-component sealant

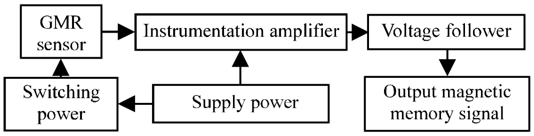

Fig. 1: Circuit diagram

Table 1: Features of 3 different magnetic sensors

	Magneto sensor		
Characters	Hall element	AMR	GMR
Detection principle	Hall effect	Magnetoresistance effect	Giant magnetoresistance
Detection range (Gs)	0.1-1000	10^{-6}-10	10^{-6}-106
Sensitivity	7μ V/V/Gs	0.8-4 mV/ V/Gs	0.3-18 mV/ V/Gs
Frequency response range	0-100 KHz	0-5 MHz	0-1 MHz
Temperature stability	Low	Medium	High
Detective circuits	Temperature-compensation	Set/reset circuits	Simple

with high strength, good hydrolysis-resistant and good corrosion resistant; another important property of insulating materials is a good adhesion of the sensor circuit and protection device, which can efficiently prevent down hole fluid to enter the sensor and then induce the sensor damage.

TESTED THE PERFORMANCE OF SENSOR

Temperature testing: Though the GMR operating temperature range is from minus 50°C to plus 120°C, the temperature characteristic of the whole sensor system is uncertain. So, a temperature resistant measurement test was designed. Put both the magnetic memory sensor and a temperature sensor into an airtight electric thermostatic drier. Their signal wires were connected to a data acquisition card outside the drier. With the constant magnetic field (geomagnetic field) in the airtight electric thermostatic drier, the test curves could be considered as the relation between the sensor output signal and the temperature variation under the constant magnetic field conditions. The curves of output voltage values with the temperature were obtained (as shown in Fig. 2). It can be seen from the Fig. 2, that when the temperature is less than 120°C, the output voltage is approximately linear with the temperature. When the temperature is above 120°C, the output voltage values hardly change with the temperatures and remain constant. In conclusion, if the bottom-hole temperature is below 120°C, the measurement signal of the sensor can be calibrated by temperature compensation.

Tested the insulation and sealing performance: The insulation and sealing performance was tested to the processed sensor. The experimental apparatus was designed by the laboratory, which includes a pressure test pump, a pressure bucket and a suit of data acquisition system. Before the experiment, the sensor was placed into the pressure bucket and the wires were connected to the data acquisition system by a multi pin feed thru electrical connector. At the beginning of the test, the pressure test pump started to increase pressure in the pressure bucket. When the pressure reached 50 MPa, the pump stopped pressure increasing and kept constant pressure for half hour. During the process, the data acquisition recorded the electric current value every 5 min. The current curve is presented in Fig. 3 and as can be seen, the current remains constant (4 mA). It can proved that the sensor was not crushed by the hydrostatic pressure and has excellent resistance to water seal and electrical insulation.

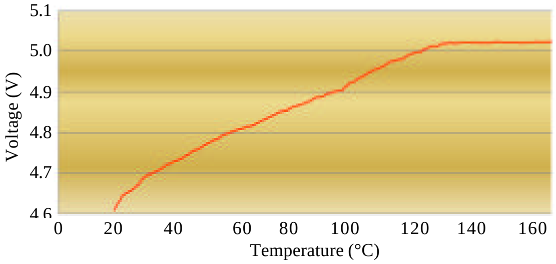

Fig. 2: Heat resistance test curve

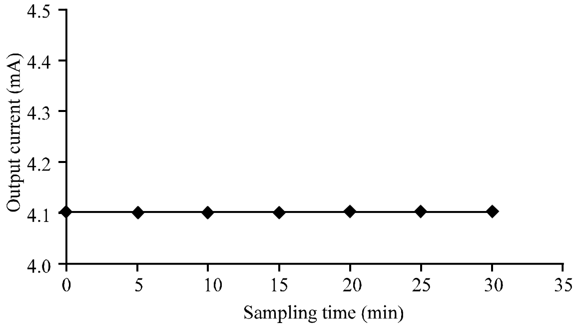

Fig. 3: Current curve

LABORATORY TEST

A section of perforated casing was selected to detect for the laboratory test and dug four parallel rows of round holes in the non-perforation area. The specification diameter of these holes includes: 8, 9, 10 and 12 mm. The casing is shown in Fig. 4. A strip of paper which was divided into 90 equal portions by lines (as shown in Fig. 4) was pasted to one end of the casing. The experiment equipment includes a magnetic memory sensor, a high precision electronic control translation stage, a control system, a high-precision data acquisition system and other auxiliary systems. The sensor was fixed on an adjustable trestle table that can move with the electronically controlled translation stage and the trestle table was set on the translations stage. The distance (2 mm) between the sensor and the outside of the casing surface can be kept constant by adjusting the trestle table. Before the experiment began, the speed of the translation stage was set to 16 mm sec^{-1}, the sampling frequency of the data acquisition was set to 960 S sec^{-1}. The sensor traveled in straight lines during the detection and recorded the inspection results. By the end, the data acquisition had gathered the 90 groups of data comply with this method.

The noise data which will affect the assessment of the holes; state must be eliminated from the test result;

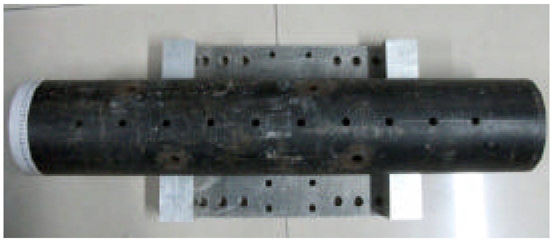

Fig. 4: Perforated casing

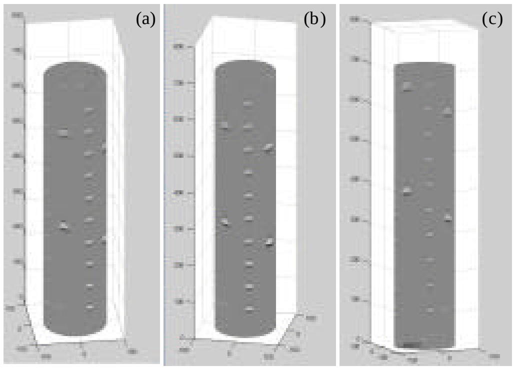

Fig. 5: Gray image

the Wavelet soft-threshold denoising method was used to analysis the original data information and then solved the signal gradient. The author reconstructed the casing three-dimension gray image by using the signal gradient. The gray image is shown in Fig. 5. The light grey areas represent the holes, the size and morphology of the holes can be obviously seen from the gray image. The distribution of the light gray areas on the image is very similar with the holes on the casing. This fully shows that the sensor has good ability to distinguish the casing deformation holes.

FIELD TEST

The laboratory developed a set of 18-arms lantern casing damage detector by using the packaged metal magnetic memory sensor. In order to evaluate this detector, Perforated casing testing experiment was carried out in Daqing oilfield. A new perforated casing well was selected as the experiment well, the fundamental parameters of this well is shown in Table 2. As can be seen, the temperature and pressure of bottom-hole are all within the sensor applicable scope. Therefore, the whole measurement system can work well here. At the beginning of the logging, the detector relied on weight to reach the target logging horizon. And then the logging data was recorded and solved in the ascension process.

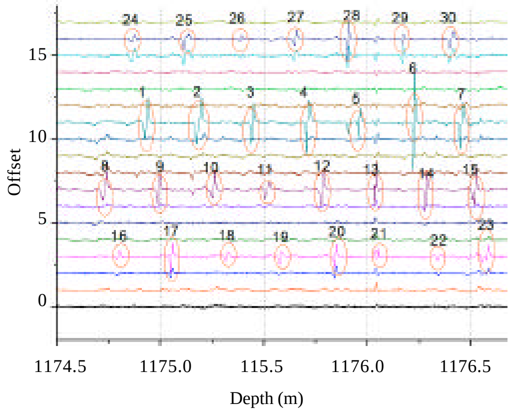

Fig. 6: Color waterfall plot graphic

Table 2: Well parameters

Main categories	Parameters
Well depth (m)	1245.0
Size of casing (mm)	ϕ139.7
Casing material	J55
Casing wall thickness (mm)	6.2~7.72
Bottom-hole pressure (MPa)	15
Bottom-hole temprature (°C)	30

Table 3: Second layer parameters

Second layer	Position (m)	Hole density (hole m^{-1})	Perforating No.
Parameters	1176.7-1174.8	16	30

After the test, the wavelet filtering method was applied to the filtered 18-channel data acquisition of field experiments and then solved the signal gradient. This paper drew the signal gradient figure by using the ORIGIN LAB. Because of the large size of image, this paper only selected the most representative part of the second layer figure. The borehole parameters are shown in Table 3. As can be seen, this layer has 30 perforated holes which are all located between 1174.8 and 1176.7 m. The color waterfall plot graphic is shown in Fig. 6, as can be seen from Fig. 6, that the signal amplitude change is very regular and the number of amplitude jumps is 30, same with the perforations. There are 16 amplitude jumps within 1m, correspond with the perforation density. All these two phenomenon can strongly prove that this detector have good inspection to the casing perforation.

CONCLUSION

The metal magnetic memory method is a non-destructivetesting method with a great potential and it is perfect for many applications. This study have discussed three magnetic sensor elements and then GMR sensor was chosen as sensing element. GMR sensors are designed to detect the leakage magnetic field on the surface of casing with high sensitivity and low noise.

Through the Laboratory experiments show that the GMR sensors are completely meeting the need of the early detection of casing damages. After sealing and isolation treatment, the sensor satisfies the detection demand under the well and has a good capability to discriminate the casing perforation. The field experiment shows that the casing damage detection device using the metal magnetic memory has a favorable application foreground in the field of casing damage measurement.

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