In place detection of internal and external corrosion for underground steel casing pipes

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In-Place Detection of Internal and External Corrosion for Underground Casing Pipes

Jiming Yin[1]
J. Pineda de Gyves
Mi Lu[2]
Department of Electrical Engineering
Texas A&M University
College Station, TX 77843
U.S.A.

***Abstract*— Corrosion monitoring and early detection of pits and wall thinning is considerably important to the gas and petroleum industry. A new non-contact AC electromagnetic induction system has been developed for monitoring and detecting the corrosion in multi-string casing configuration. The system includes a sonde which has a transmitter coil and three receiver coils, with the transmitter circuit generating three low different frequencies at the same time. The multi-frequency AC current through the transmitter coil induces in the pipe wall a longitudinal alternating magnetic field which is sensed by three receiver coils located at different distances. The multiple transmitter frequencies and the multiple transmitter-receiver spacings can provide the maximum flexibility and the most extensive information in quantitatively determining the total wall thickness in single, dual, and three-string casing configuration.**

Due to the rigorous working conditions in underground casing pipes, the transmitter circuits are specially designed so that it can continuously work under high temperature of up to 175°C without having a "second break down". On the other side, since the dynamic range of received signal is very broad and the "road noise" is very severe, the high-stable high-accurate band pass filter and hard limiters are adopted in the receiver circuit and phase detect circuit. In order to discriminate the internal corrosion and external corrosion of casing pipes, an "electronic caliper" is incorporated in the new AC electromagnetic induction system to detect the average circumferential diameter of casing pipes. Therefore, the complete logging of the casing pipes can be accomplished with a single scan.

I. INTRODUCTION

Steel casing pipes used in underground gas storage or in oil fields are the subject of corrosion. The corrosion occurred frequently in casing pipes is pitting or wall thinning located at internal or external of casing pipes. More serious corrosion would form holes on the casing pipe and cause serious operational problems. Many oil wells or gas wells are required to be constructed by two or more concentric string pipes to protect the environment. Due to the constantly rising cost of well completion and more restrict regulations from the Environment Protection Agency (EPA), the corrosion monitoring and early detection of pits and wall thinning can bring considerable savings to the gas and petroleum industry.

The casing pipes of oil well or gas well are inspected by service companies which employ mechanical or electromagnetic logging instruments to probe the inside of pipes. A typical mechanical logging instrument is Multi-Finger Caliper (MFC). It is a contact-type instrument made through fingers (feelers) that are in physical contact with the internal surface of the casing pipes in the well. Apparently, the MFC is a reliable casing inspection instrument for detecting internal corrosion of casing pipes. The drawback of MFC is that it needs very intensive labor to maintain the proper operation and that any corrosion outside casing pipes is not detectable.

The electromagnetic casing inspection instruments are the most convenient and practical ones to use because of their high sensitivity to various types of defects, and their small size with light weight. In general, there are two types of electromagnetic instruments: Direct Current (DC) electromagnetic induction instrument and Alternative Current (AC) electromagnetic induction instrument.

The DC electromagnetic induction instrument is also a contact-type instrument. It uses a magnetic coil carrying the DC current to generate a stable magnetic field within and surrounding the casing wall and detects the field irregularity (or flux leakage) caused by the corrosion pits occurred inside or outside the casing wall. The sensor coils are located in housings (usually called pads or shoes), which are held against the casing wall as the instrument traverses the casing. The instrument requires a constant logging speed to maintain the accuracy of measurement. The advantage of DC electromagnetic induction instrument is that it is very sensitive to the small, isolated corrosion pits. However, it cannot accurately detect the "large area" corrosion and it has no response to the gradual casing wall thinning. In the multi-string well, only the very inner casing pipes can be inspected.

The AC electromagnetic induction instrument is a noncontact-type instrument. A transmitter coil is excited by the low frequency AC current, which induces a longitudinal alternating magnetic field in the pipe wall. This alternating magnetic field induces a voltage signal across the receiver coil. The received signal is both attenuated and phase shifted though the casing wall, with the degree of phase shift in relationship to the wall thickness. Also, an "electronics" caliper is incorporated in the AC electromagnetic induction instrument. Unlike the DC electromagnetic induction instrument, the AC instrument does not require the constant logging speed. Generally, the AC electromagnetic induction instrument is used to detect changes on casing weight, casing wear (possibly caused by drill

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pipe), gradual wall thinning, as well as their location outside casing pipes in the multi-string well. However, it does not respond to the small, isolated corrosion pits and holes on the casing wall.

In our consideration, the DC electromagnetic induction instrument and AC electromagnetic induction instrument can be supplemental to each other for casing inspection. The very early AC induction instrument was designed to use line power (117VAC/60Hz) to excite the transmitter coil [1] directly. It had a drawback that the metal penetration was very limited, i.e., it was sensitive to the single string pipe only and the outside string pipes could not be clearly detected. Later the design was improved and the frequency of transmitter current was lowered to 16Hz so that the second outside string pipe could be detected [2]. Though the improved instrument has better penetration for detecting the outside string pipe, its sensitivity for detecting single string was low.

A new AC induction system for electromagnetic casing inspection was developed which uses three different low frequencies and three receiver coils located at different distances. Since the higher frequency has better sensitivity than the lower frequency on the single string casing and the lower frequency has better penetration on the multi-string casing, our Multi-Frequency Multi-Spacing (MFMS) detecting system can provide maximum flexibility in quantitatively determining the wall thickness in single, dual, and three-string casing configuration.

The rest of the paper is organized as follows. The general description of the system is given in Section 2. The circuit of MFMS detecting system is presented in Section 3. Section 4 provides applications aspects of the system, and Section 5 summarizes the system development.

II. GENERAL DESCRIPTION OF SYSTEM

The MFMS detecting system is composed of an electronics module and a sonde section. All the electronic printed circuit boards (PCB) are mounted on a special backbone chassis which is housed inside a slick pressure housing made of stainless steel alloy. The sonde section consists of all the sensor coils mounted on the fibergrass mandrel including one transmitter coil, three receiver coils, one circumferential caliper coil and some auxiliary coils. The transmitter coil and three receiver coils are used to measure the wall thickness of casing pipes.

Fig. 1 illustrates the theory of measuring casing wall thickness using a transmitter coil with a single receiver coil. It also allows the use of multiple receiver coils for a single transmitter. Notice that there is no contact between the coils and the casing wall. The low frequency alternating current through the transmitter coil induces a longitudinal alternating magnetic field in the pipe wall. This alternating magnetic field is sensed by the annular receiver coil. The signal voltage measured at the terminals of receiver coil is affected by the mass of steel near the receiver and transmitter coils. Variations in average wall thickness or wall thinning caused by corrosion produces changes in both amplitude and phase shift of receiver coil voltage. Those changes are measured by the sensing circuit to detect the corrosion pitting and wall thinning. The measured data are interpreted by the interpretation charts to estimate the depth of corrosion and wall thickness.

In order to discriminate the internal corrosion and external corrosion of casing pipes, an "electronic caliper" is incorporated in the system to detect the average circumferential diameter of casing pipes. Fig. 2 illustrates the principle of the electronic circumferential caliper. The sensor coil paralleled with a selected capacitor is excited by such a high frequency that only the variation of the distance between the coil and the internal casing wall changes the impedance of the coil system. Such impedance changes are measured by a peak detector and rectified into a DC voltage. The variation of the DC voltage is translated into the internal diameter (ID) of the pipe by the surface computer program. By interpreting the combination of the phase shift signal (low frequency for measuring the wall thickness) and the circumferential caliper signal (high frequency for measuring the ID), the corrosion occurred at external or internal of the wall of casing pipes can be discriminated.

The electronics module and sonde section, as mentioned early in this section are linked by a mechanical-electrical joint called *quick change* shown in Fig. 3. The electronics module is located on the top part of the linkage connected by the multiconductor logging cable. To perform the casing inspection, the electronics module and sonde are lowered down through casing pipes by a well-logging truck, which has all necessary mechanical equipment, a diesel power generator and a computer logging system (CLS). During the casing inspection, the electronics module is controlled by CLS to perform the signal processing, data acquisition and data transmission. The logging data would be transmitted, recorded, and plotted by the CLS in "real time mode". The ID of a casing pipe can be read directly on the logging chart. The selected phase shift and amplitude can also be plotted on the logging chart. However, the phase shift is the preferred indicator of the casing wall thickness because of its linearity. The casing wall thickness can be determined using provided interpretation curves as shown in Fig. 4.

III. THE CIRCUIT OF MFMS DETECTING SYSTEM

Fig. 5 presents the circuit block diagram of the MFMS detecting system. The transmitter signals (8Hz, 16Hz and 32Hz sine wave) are generated by a crystal oscillator. These signals are added together by a summing circuit. Then the composed signals are amplified to 100-105Vpp to excite the transmitter coil. The induced signals from the receiver coil are amplified and conditioned so that other noises would be suppressed. The received signal of each frequency is separated by the band pass filters (BPF). The amplitude of signal is sensed by a peak detector and is converted into a DC voltage. The phase shift of signals is obtained from the phase detector circuit which compares the received signal with transmitter signal and gives the corresponding phase count. The circumferential signal is also sensed by a peak detector and is converted into a DC voltage. All of the signals are sent to the processing circuit. According to the command from the CLS on surface, the micro-processor in the processing circuit invokes the analog-to-digital converter (ADC) to digitize the signals individually, stores the data in the random access memory (RAM), and then sends the data to the

CLS via logging cable.

The underground temperature is increased as the logging depth increases, and the temperature measured in a well of 20000 feet depth can be as high as 175°C. The transmitter power amplifier has to provide adequate power (100-105Vpp) to excite the transmitter coil in such environment and to sustain its continuous working condition without the problem of "second breaking down". On the other side, the power amplifier itself generates a lot of heat while constantly working, which would make the situation worse. The local temperature around the power amplifier could be as high as 200°C. To ensure the power amplifier working properly at such high temperature, differential amplifier input stages are adopted. Each stage of the power amplifier is biased by a mirror constant current source to keep a stable working condition. The output stage is an A-B class push-pull amplifier composed of a paralleled power transistors mounted on a large heat sink. These measures guaranteed the proper operation of power amplifier at the temperature as high as 175°C.

The receiver circuit is required to work at very broad dynamic range since the amplitude of signal from the receiver coil is attenuated exponentially as the wall thickness increases. The experiments results show that the range of signal amplitude can be in volts when the sonde section is suspended in air and can be in micro-volts when the sonde is inside two string casing. When the signal strength becomes extremely weak, the "road noises", which is generated when the sonde section is traversing through the casing pipe during logging, would affect the correct phase shift measurement severely. In order to keep the correct phase measurement, a pre-amplifier amplifies the received signal, suppressing the high frequency noises. The amplified signal is then sent to three high stable BPFs to separate the 32Hz, 16Hz and 8Hz signals. Each of BPFs is tuned accurately at its resonant frequency when the BPF is checked out. The conditioned signal is branched into two circuits: amplitude circuit and phase detection circuit. The amplitude signal is obtained by a peak detector which converts the 8Hz, 16Hz or 32Hz AC signal into a DC voltage sent to the processing circuits. The phase detection circuit is composed of the hard limiter and pulse converter. It detects the zero-crossing of the signal and converts the crossing point into corresponding pulse. The pulses from the received signal are used to control phase shift counters. The advantage of this circuit is that the count is proportional to the phase shift and the counted data can be interfaced directly to the micro-processor.

There are three auxiliary coils on the sonde section which are used to detect the anomaly of casing pipes. These coils are also called "Differential Anomaly Indicator" (DAI) coils. The DAI circuit will produce a signal when the DAI coils on the sonde pass a casing collar or an anomaly in the casings. The DAI circuit consists of two portions: transmitter circuit and receiver circuit. In the transmitter circuit, the Wien oscillator is composed of an Op-Amp and R-C components to generate a 200Hz sine wave. This sine wave is amplified by a push-pull amplifier to drive the DAI transmitter coil.

The two DAI receiver coils have exactly the same winding and are mounted on each side of the DAI transmitter coil with equal distances. These two receiver coils are connected out-of-phase so that the received signals from each coil cancel each other if the coils are in the air or inside the casing without any anomaly. When the DAI coils on the sonde pass the casing collar or any anomaly during logging, the balance between the two receiver coils is disturbed and a peak-detector will sense the change. The conditioning circuit is used to process the changing signal and suppress noises. The conditioned signal is also sent to the processing circuits.

The processing circuit is controlled by the commands from the CLS on surface. The micro-processor in the circuit is configured as an "interrupt driven mode" to perform the data acquisition and data transmission.

IV. APPLICATIONS OF MFMS DETECTING SYSTEM

The MFMS detecting system responds to the metal loss, especially in the situation of multi-string casings. It can be operated in all type of well fluids. Paraffin or scale build-up does not affect the logging response. The primary applications of the MFMS detecting system in fields are as follows:

A. Locate casing joints with different weight and wall thickness in mixed casing strings. It can also detect casing collars and other casing hardware (up to three string casing pipes).

B. Locate the evidence of casing erosion and identify it as external or internal. It also can locate larger pitting areas and large holes on the casing wall.

C. Indicate the casing mechanical defects such as internal casing wear, possibly caused by drill pipe. Also, it can detect if there is a casing failure, such as vertical separation or split, which requires remedial work.

D. Detect the bottom of outside casing strings and locate the collars of the outside casing strings.

E. Locate severe anomalies on outside string of pipe when running in combination with other corrosion detection instruments, such as DC electromagnetic induction instrument.

F. Monitor the progress of corrosion or mechanical wear through periodic surveys.

It is recommended to use centralizers on both top and bottom to ensure that the instrument follows the casing's centerline during operation so that the best logging results can be obtained.

V. SUMMARY

A new non-contact AC electromagnetic induction system has been developed for detecting the corrosion in multi-string casing configuration. The system utilizes digital communications to simultaneously transmit all the measurements to the surface for recording and plotting. The system includes a single transmitter coil and three receiver coils for measuring the circumferential average wall thickness of downhole casing pipes. The multiple transmitter frequencies and transmitter-receiver spacings provide maximum flexibility in quantitatively determining the wall thickness in single, dual, and three string casing configuration. The detecting system also detects changes of the average circumferential internal diameter of the interior string, and to discriminate whether the corrosion occurs at the internal or external of casing pipes. In addition, its differential anomaly indicator (DAI) also responds to small defects on the inside wall of the interior casing string.

In comparison with other detecting systems, which either operate on single frequency or need to change the frequency during the logging operation, our detecting system can complete the casing pipe inspection with a single scan. Considerable details regarding the condition of the internal wall of the interior casing string can be provided for both single and multiple casing strings. The corrosion occurred at the internal or external of casing pipes can be discriminated.

VI. REFERENCES

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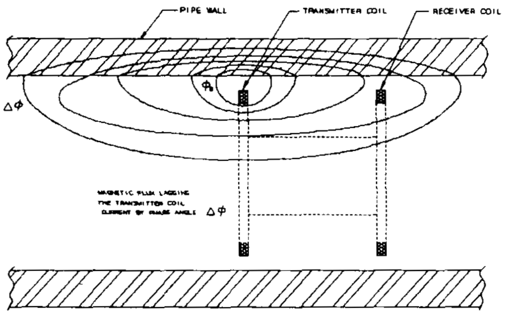

Fig. 1. Theory of casing wall thickness measurement

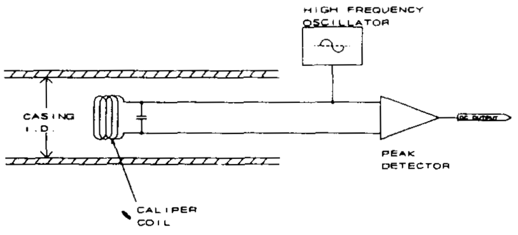

Fig. 2. Principle of electronic caliper

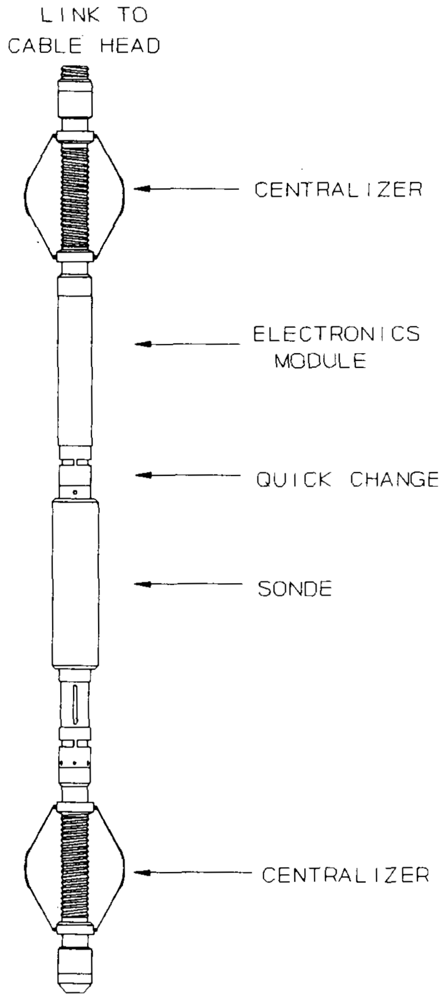

Fig. 3. Perspective of MFMS detecting system

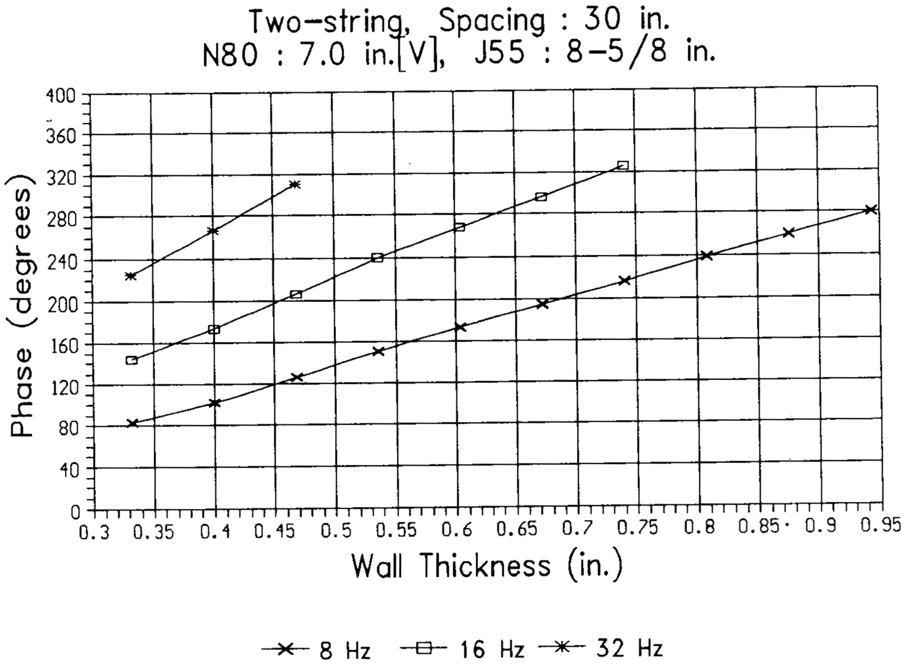

Fig. 4. Phase shift interpretation chart. The 7.0-in casing is inside 8-5/8-in casing. All three frequencies are recorded at the long-spacing coil.

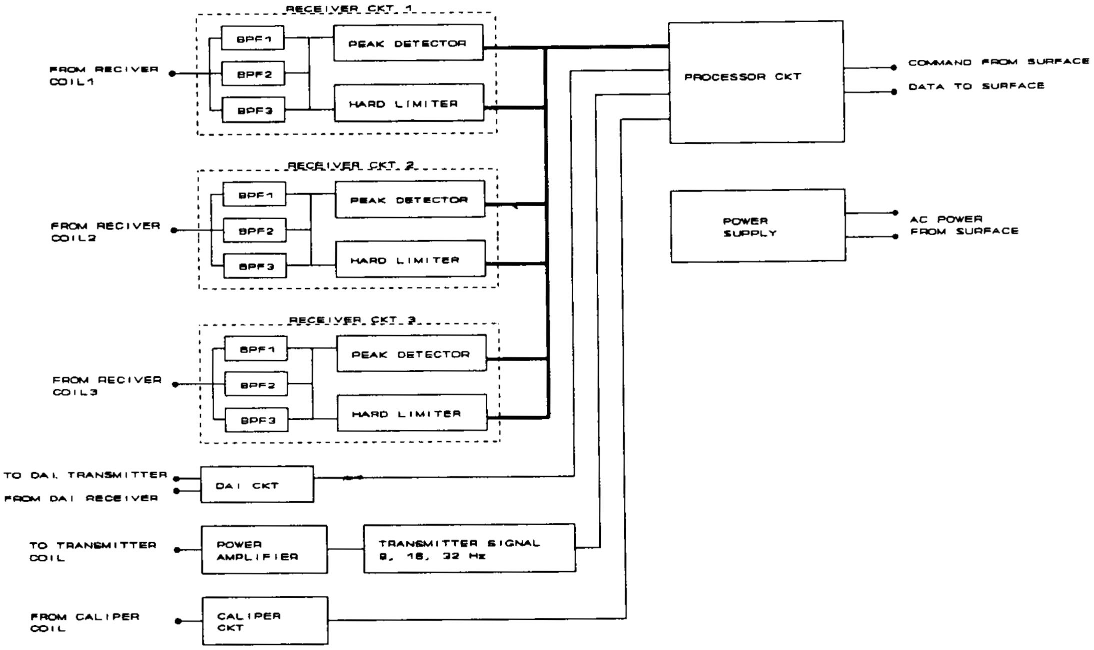

Fig. 5. Circuit block diagram