Smart Coil Tubing Inspection Technology (SCIT) Using Smart Sensors, Image Processing & Artificial Intelligence (AI)

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ABSTRACT-
In this project, we propose Online Coiled Tubing (CT) Inspection via Smart Sensors & AI concept. Fatigue life measurements appear to be a statistical phenomenon, which makes the measurement of the fatigue life of the Coiled Tubing (CT) string to be only just an estimation. Most common tubing failures are microcracks, Strain due to repeated bend cycling of CT string, 3rd party failure, Metal loss, Ovality, External damages, Dent, Gouge & physical failure at weld joints etc.

Index Terms- Oil & Gas, Coil Tubing (CT), Inspection, NDT, Magnetic Flux Leakage, Ultrasound Technique, IR sensors, Artificial Intelligence (AI), Image Processing, Displacement Sensor & Velocity/Distance Measuring System.

I. INTRODUCTION

Wireless Tubing **transports the oil and gas from deep in the well to the surface** – the third phase of the wellbore. Oil and gas occasionally rise to the surface on their own; usually, pumps are needed to bring the fluids to the surface. The oil and gas flows through coil tubing into the ground and enters the gathering pipeline & transported for further processing.

In other words, coiled tubing refers to **a very long metal pipe, normally 1 to 3.25 in (25 to 83 mm) in diameter which is supplied spooled on a large reel**. It is used for interventions in oil and gas wells and sometimes as production tubing in depleted gas wells.

Coiled tubing has also been used as a cheaper version of work-over operations. It is used to perform open hole drilling and milling operations. Common coiled tubing steels have yield strengths ranging from 55,000 PSI to 120,000 PSI so it can also be used to fracture the reservoir, a process where fluid is pressurized to thousands of psi on a specific point in a well to break the rock apart and allow the flow of trapped product. Coil tubing can perform almost any operation for oil well operations if used correctly.

Since CT utilized under harsh environment including high pressure, high temperature, aggressive chemicals, high H_2S for long time durations, before/during/after operations, CT associates with Integrity Challenges including bending strains, metal loss, ovality, hairline cracks, physical failures, external damages, dent & gouges etc., Therefore, reliable online inspection is required to validate integrity of CT before/during/after operations.

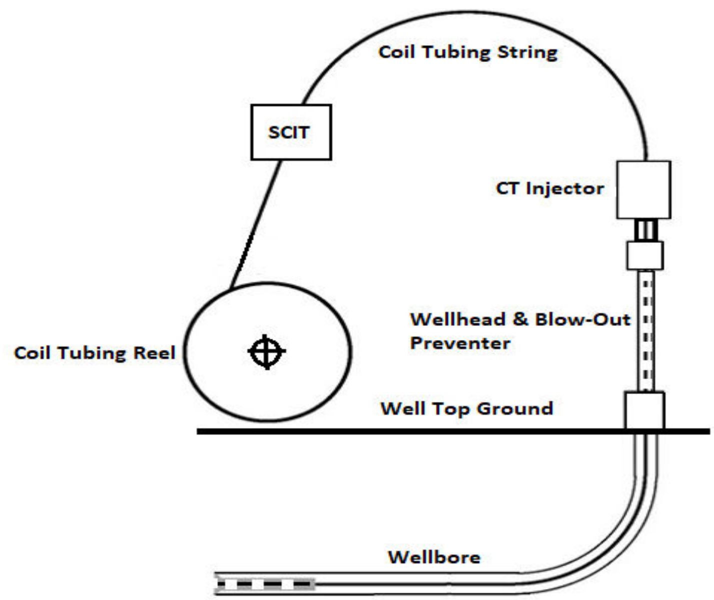

Figure 1. Overview of Well Vs. Coil Tubing Vs. SCIT Setup

Depth and Velocity

The depth/length is determined from the readings of the ODO unit. It consists of three friction wheels at 120 degrees spacing the circumference of the CT string. The wheels are rotated as the CT passes through the ODO unit. Three encoders linked to these friction wheels converts the motion of the CT into three depth/length readings. Out of these three depth/length readings a true meter depth/length is generated. Malfunction of the ODO unit can be detected automatically using the two-backup depth/length readings. The measured depth/length is decreased when the CT is pulling out of the well. The CT velocity (running speed) was calculated from two successive depth/length measurements.

OUTER DIAMETER

The outer diameter measurements are undertaken with the CAL unit. The CAL unit uses twelve caliper sensors placed around the CT circumference qt 30 degrees spacing and determines six outer diameter measurements. Out of these six outer diameters the minimum, maximum and average outer diameter is identified.

OVALITY

The ovality of the coil tubing is calculated from the measured minimum and maximum outer diameter of the CT by the following formula,

$$\text{Ovality} = \frac{(OD_{max} - OD_{min})}{0.5 \times (OD_{max} + OD_{min})} \times 100\%$$

DETECTION OF METAL LOSS

The detection of the metal loss is carried out with the MFL unit. This unit consists of there magnetic circuits and 45/54 degrees sensors placed on three carriers around the CT string. The CT string is axially magnetized into saturation by the three magnetic circuits. In the normal conditions (no flaws) the magnetic flux can travel undisturbed through the CT. In the presence of internal and/or external metal loss the flux can travel of the CT and is detected by the sensors. Depending on OD of the CT, SCIT setup required 45sensors for smaller or equal to 1” and 54 sensors for greater or equal to 2” coil tubing.

WALL THICKNESS

The determination of the CT wall thickness is based on the readings of the MFL unit taking the physical relation between thickness and magnetization of ferromagnetic material into account. The magnetization of the CT is dependent on the magnetic properties of the CT steel. Different types of steel have slightly different magnetics properties. Therefore, this method alone will provide a relative measurement only.

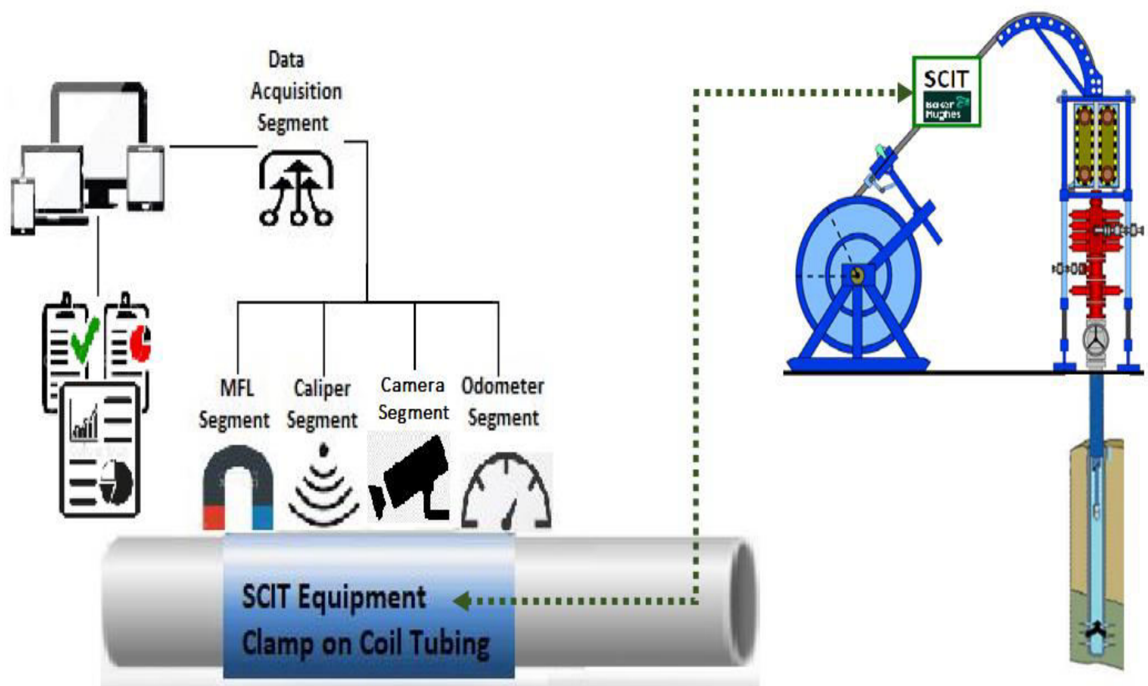

Figure 2. Detailed SCIT Setup Depicting Sensors

SCIT setup comprise of following items

MFL unit: Measuring metal loss/wall thickness

CAL & UT unit: Measuring ovality and outer diameter

Camera Unit: Real Time photos for AI purpose

ODO meter: Measuring velocity and inspection depth

To obtain an absolute value for the CT wall thickness the relative measurements of the MFL unit shall be converted to wall thickness readings by comparison with absolute UT measurements.

CT Failure Statistics Globally

Within one major service company, all failures that occur are analyzed for the root cause(s) of failure. This results in the identification of corrective actions to avoid their recurrence. Statistical data is kept observing trends on failure causes.

Several technical publications show that approximately 80% – 90% of CT string failures within the period of 1995 to 2006 were associated with corrosion, mechanical damage, human error, and string manufacturing problems, depicted in below pie diagrams. Three main categories, Material, Manufacturer & Process related.

Actions taken in the last two decades by the CT services companies, and constant improvement implemented by CT manufacturers have reduced the influence of some of these causes. However, work in ever-more challenging well conditions (such as higher pressures, temperatures, and depths), the need to use larger-diameter and higher-strength CT, and the use of recycled fluids for the interventions, have created new issues and introduced new CT failure mechanisms. The new mechanisms within the industry include microbiologically influenced corrosion (MIC), premature fatigue failures on bias welds of high-strength grades, and mechanical damage associated with pipe slippages.

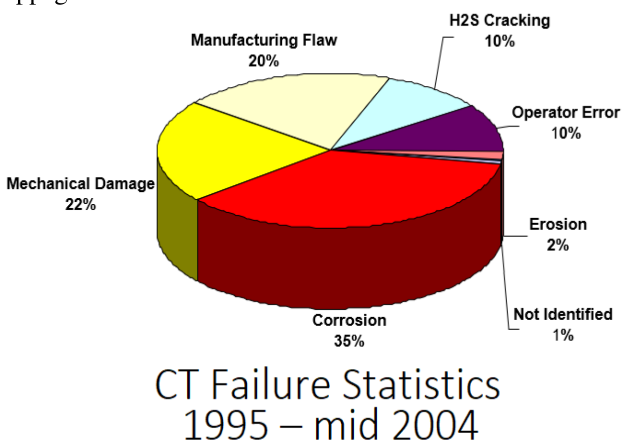

Figure 3. CT Failure Statistics 1995 – Mid 2004

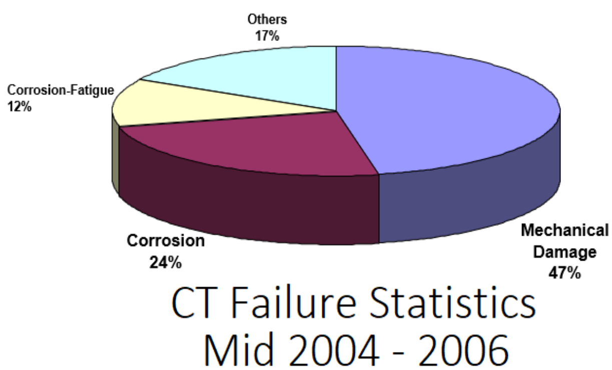

Figure 4. CT Failure Statistics Mid 2004 – 2006

CT Integrity Challenges & Most Common Failures

- Strain
- Physical Failure at Weld Joints
- Ovality
- Metal Loss
- External Damage
- Hairline Crack
- Dent, Gouge & etc.,

All above failure scenarios stored in database of Artificial Intelligence for active comparison with real time captured photos from SCIT.

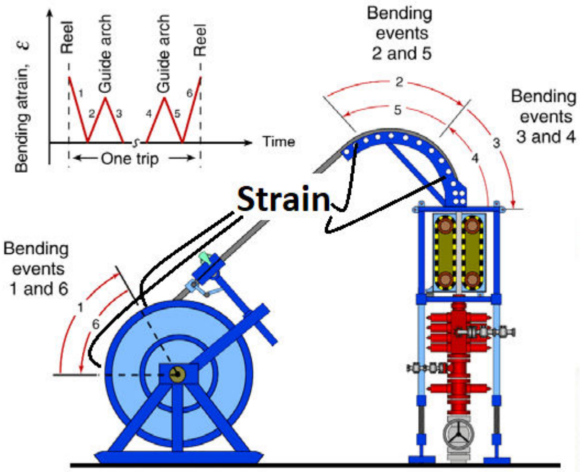

Figure 5. Failure due to Strain Effect

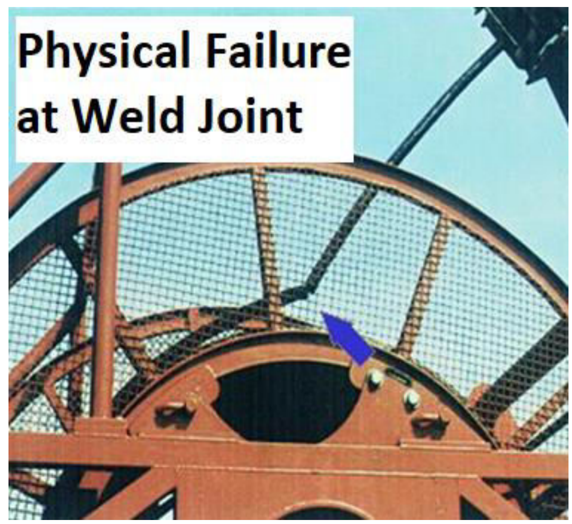

Figure 6. Failure due to Physical Failure at Weld Joint

Figure 7. Example of Ovality

Figure 8. Example of Metal Loss

Figure 9. Example of External Damage

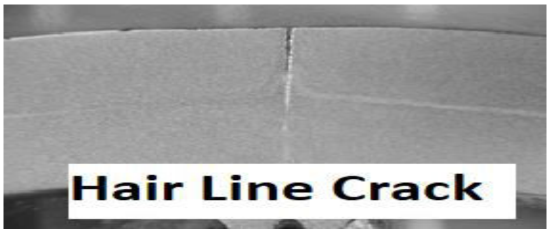

Figure 10. Example of Hair Line Crack

Figure 11. Example of Dent & Gouge

By service, the well intervention service segment is expected to make the largest contribution to the coiled tubing market during the forecast period.

Well intervention services include operations that are performed using coiled tubing units. The well intervention segment has been sub-segmented, by type, into well completions & mechanical operations and well cleaning & pumping operations. Well intervention services are done either through wireline or coiled tubing. Coiled tubing well intervention is the most popular as coiled tubing unit facilitates operations such as stimulation, re-perforation, fluid pumping, fishing, milling, sand control, and zonal isolation. The coiled tubing market is driven by rising well intervention operations demand.

SYSTEM DESIGN

System design comprises of all hardware & software part including Data acquisition, Smart Sensors, solid-state storage/memory, image processing etc.,

Data acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer. Data acquisition systems, abbreviated by the initialisms *DAS, DAQ,* or *DAU,* typically convert analog waveforms into digital values for processing. The components of data acquisition systems include:

- Sensors, to convert physical parameters to electrical signals.
- Signal conditioning circuitry, to convert sensor signals into a form that can be converted to digital values.
- Analog-to-digital converters, to convert conditioned sensor signals to digital values.

Figure 12. Well Intervention Services Large Contribution to Coil Tubing Market

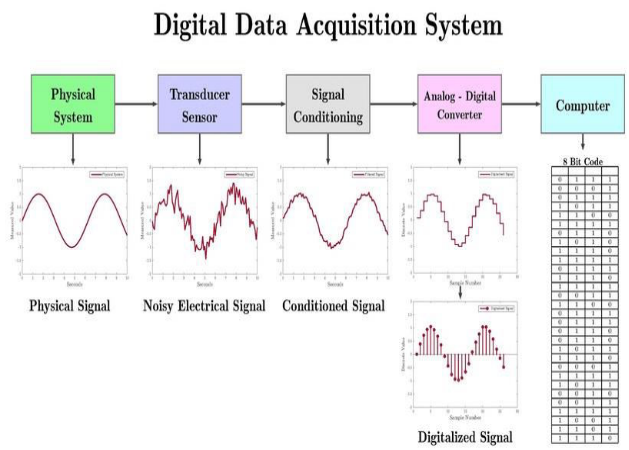

Figure 13. Digital Data Acquisition System

Smart Sensors are special & specific sensors design for application in harsh environment like Oil & Gas sector. In subject project following sensors are utilized

MFL Sensors, Caliper Sensors, Advance Camera & ODO-meter Sensors.

MFL Sensors, Magnetic Flux Leakage (MFL) Inspection techniques have been widely used in the NDT oil field inspection industry for verification/validation/examination of pipeline, structures, coil tubing and casing.

Due to the fact, this flux is very reluctant to travel in air unless it is forced to do so by the lack of another suitable medium. For the purposes of this application, a magnetic circuit is utilized to introduce as near a saturation of flux as is possible in the inspection material between the poles of the magnetic circuit. Any significant flaw, dent, bent or reduction in the thickness of the coil tubing will result in some of the magnetic flux being forced into the air around the area of reduction. Sensors which can detect these flux leakages are placed between the poles of the magnetic circuit as depicted below.

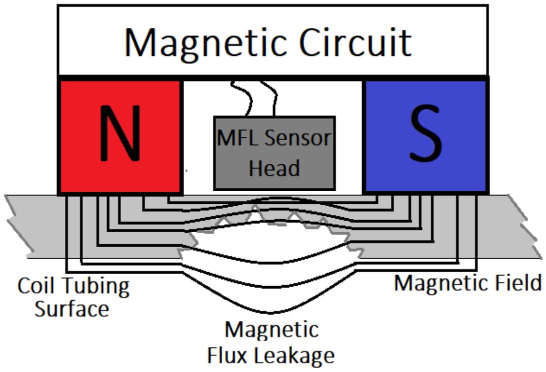

Figure 14. Magnetic Flux Leakage Principle

Coils are passive devices and follow Faraday's Law in the presence of a magnetic field. As a coil is passed through a magnetic field, a voltage is generated in the coil and the level of this voltage is dependent on the number of turns in the coil and the rate of change of the flux leakage. From this, it's clear that speed will have some influence on the signals obtained from this type of sensor.

Caliper Sensors, potentiometric Linear Transducer CLP13 is used as displacement sensor in space-saving design & front guided push rod for 13mm to 100mm strokes. CLP13 is almost infinite resolution, space saving, compact design, robust with long lifetime ideal application in harsh environment such as Oil & Gas industries.

Figure 15. Potentiometer used as Caliper Sensor

ADVANCE CAMERA, USB 3.0 INDUSTRIAL CAMERAS

Excellent Image Quality & Great Performance. The Imaging Source USB 3.0 industrial cameras are best known for their excellent image quality, great performance and extremely competitive price. The USB 3.0 industrial cameras ship with very sensitive CCD or CMOS sensors from Sony which provide outstanding image quality and accuracy in color reproduction, even under the harshest lighting conditions. They feature a variety of input, output, strobe, and trigger options via an external Hirose port. With their high-speed interface, the USB 3.0 industrial cameras deliver up to 120 images per second. Thanks to the integrated binning feature, the USB 3.0 industrial cameras merge pixels together to increase sensitivity. They output only a region of interest (ROI) and thus achieve a very high frame rate. The Imaging Source USB 3.0 industrial cameras the perfect solution for small device construction and the most demanding applications.

Figure 16. USB Camera

ODO-Meter Sensors, A Hall effect sensor is a type of sensor which detects the presence and magnitude of a magnetic field using the Hall effect principle. The output voltage of a Hall sensor is directly proportional to the strength of the magnetic field.

Non-contact magnetic sensors that measure the distortion of magnetic field created by a ferrous target. These sensors provide very precise measurements of movement even at zero speed which makes them ideal for speed measurements or indirect depth/length measurement of Coil Tubing as well. These sensors provide digital output with constant amplitude signal regardless of variation of the speed.

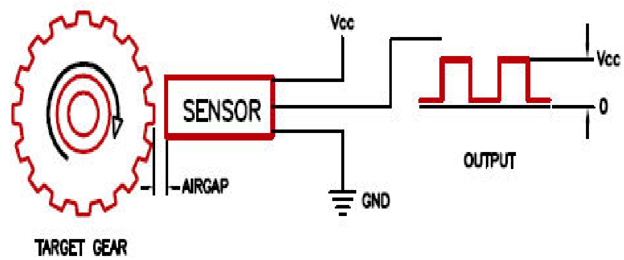

Figure 17. Non-Contact Magnetic Hall Sensor

Crack Detection Using Image Processing, the basic architecture for the crack detection using the image processing technique depicted below in Fig. 18. The main advantage of the image-based processing analysis of the crack detection is that by using image processing technique it provides accurate result compared to the conventional manual methods. The processing difficulty of crack detection completely depends on the size of the image. Recent digital cameras have the image resolution beyond 50 megapixels with 1622FPS. This increase in resolution enables the acquisition of the detailed images of concrete surfaces. By using the trendy cameras of commercial purpose, big range of a concrete surface can be acquired in a single shot. For inexpensive applications, a wide range image can be used for the practical crack detection.

Below general architecture for crack detection based on the image processing. The blocks in the image processing technique are as shown below,

- Collection of images of coil tubing will be subject to crack detection.

- Collected images are pre=processed within which the methodologies like segmentation are done thereby making it an efficient one for the image processing.
- Special techniques are utilized to process the detected image sample.
- Crack detection will be highlighted on structure using the result of the processed image.
- Crack feature extraction where cracks are separated based on width, depth & direction of propagation of the crack.

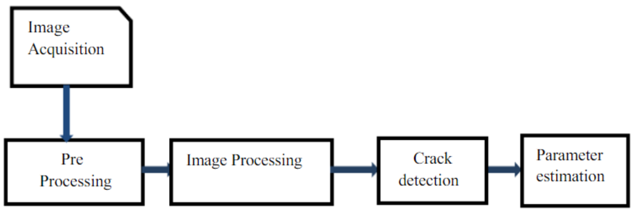

Figure 18. Software Architecture of Image Processing Based Crack Detection

Figure shows general architecture for crack detection based on the image processing. The steps in the image processing technique are as follows: (1) initially collect the image of the structure which will be subjected to the crack detection process using the camera or any sources. (2) After the image acquisition, the collected images are pre-processed within which the methodologies like segmentation are done.

CONCLUSION

- Magnetic Flux Leakage is a qualitative, not quantitative inspection tool and is a reliable detector of corrosion on coil tubing.
- Truly quantitative results can only be obtained using a combination of Ultrasonic testing and Magnetic Flux Leakage.
- In most cases, visual techniques are perfectly adequate for this purpose, that why high-resolution Camera's utilized.
- Crack detection by means of Image processing yield high resolution results with less processing time due to AI technique.

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