Casing inspection logs

Casing failure can be caused by:

- Deformation
- Physical wear
- Corrosion

Preventing such failures is critical to maintaining well production.

Contents

Casing inspection logs

There are four commonly used techniques for the inspection of casing:

- Cased-hole calipers
- Flux-leakage tools
- Electromagnetic phase-shift tools
- Ultrasonic tools

Ultrasonic radial-cement-evaluation (/Cement_bond_logs#Radial-cement_evaluation) devices and modified openhole-imaging devices are also used to evaluate casing for indications of[1][2][3][4]:

- Potential collapse
- Thinning
- Internal or external metal loss

Echo amplitude and travel time provide images of the condition of the inside casing surface (e.g., buildup, defects, and roughness such as pitting and gouges) (**Fig. 1**), and travel-time and resonant-frequency analysis provide casing thickness (**Fig. 2**).

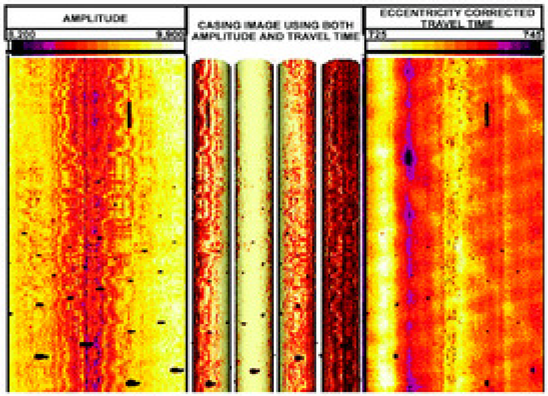

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Fig. 1 – Casing evaluation log display. Holes in the casing are visible in the series of ultrasonic images that are based on amplitude (left) and corrected travel time (right). The center 3D images show the pipe in 90° quadrants. The image shading is generated from the amplitude data[4] (courtesy of SPE).

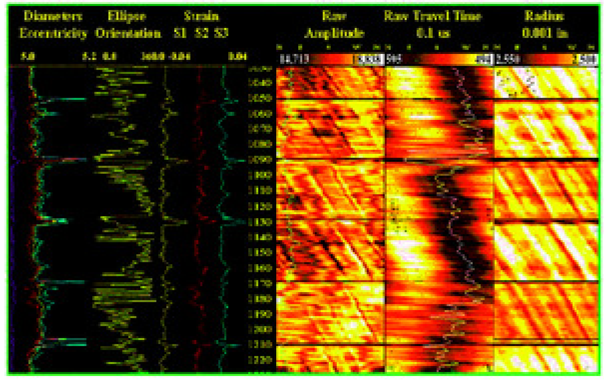

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Fig. 2 – Ultrasonic casing-evaluation display. In this example, casing radius and shape are presented as log curves and image maps and deformed casing is easily identified (courtesy of Baker Atlas).

The acoustic caliper generated from the pulse/echo travel time provides the casing inside diameter (an average of all transducers or a single circumferential scan). An estimate of casing ovality is obtained using only the maximum and minimum measurements. Then, if the nominal value of the outside casing diameter is assumed, changes in thickness can be calculated and internal defects identified. Frequency analysis determines the casing resonant frequency from the acoustic waveform; casing thickness is inversely related to the resonant frequency. By combining travel time and resonant-frequency measurements and using data from all available transducers (or a single scan), presentations showing casing cross sections are used to highlight casing damage such as (**Fig. 2**):

- Thinning
- Corrosion metal loss
- Collapse

Cased-hole calipers

Multifinger calipers are used to identify changes in casing diameter as indicators of wear and corrosion. They are also used to monitor casing deformation.[5] They can have up to 80 spring-loaded feelers or fingers, depending on the nominal casing diameter (**Fig. 1**). Different multifinger caliper tools can log casing sizes from 4 to 20 in. [100 to 500 mm]. Smaller tools are available for tubing inspection. Each hardened finger can measure the internal casing diameter with a radial resolution of a few thousandths of an inch and a vertical resolution of a few hundredths of an inch at a typical logging speed of 1800 ft/hr [550 m/h]. Measurements are taken many times per second for each finger, giving a typical spatial-sampling interval of approximately 0.15 in. [4 mm] as the tool travels up the borehole. A finger extends where it encounters a pit or hole and retracts where there is scale present or there has been partial collapse. A potential disadvantage is that the fingers can damage the casing, although modern electronic tools have a very low finger pressure to avoid this. The tool also indicates which finger is the one on the highest side of the well. Moreover, fingers can be grouped azimuthally. All these data can be combined with the measurements of diameter to produce a 3D picture of the casing, including cross-sectional distortions and changes in the trajectory of the well axis as small as 0.01°. The data can be either transmitted to the surface where the tool is run on a wireline or stored downhole where the tool is deployed on a slickline.

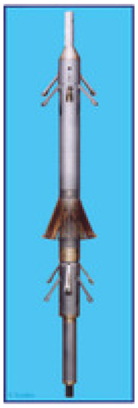

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Fig. 1 – Multifingered caliper tool for development as a memory tool on slickline or as a surface-readout tool on monoconductor cable. This tool has 60 fingers, a 4-in. [100-mm] diameter, and a measurement range of 4.4 to 9.625 in. [114 to 245 mm]. It has a radial resolution of 0.005 in. [0.13 mm], a radial accuracy of ± 0.03 in. [0.75 mm], and a vertical resolution of 0.23 in. [5.84 mm] at a logging speed of 3,000 ft/hr [914 m/hr]. Pressure and temperature ratings are 15,000 psi [103 MPa] and 350°F [177°C], respectively. Note the tool centralizers. (Courtesy of Sondex.)

There are two types of multifinger calipers, mechanical and electronic, although the distinction is misleading because all such calipers are mechanical in their deployment. The difference is in the way in which data are recorded. Older calipers were truly mechanical in that they were operated on a slickline and used a scribe chart for downhole data recording. These mechanical calipers have high temperature ratings because they are not limited by the ratings of downhole electronics [e.g., 600°F (315°C) for the Kinley caliper offered by the Expro Group]. Modern tools convert the mechanical data into electronic information for downhole memory storage or for transmittal uphole for real-time data display. Operating temperatures for these electronic tools are typically up to 350°F [177°C].

Multifinger tools contain an inclinometer so that tool deviation and orientation can be recorded. If these brmeters are known, the high-quality output from modern multifinger calipers allows several image-based products to be generated. Deliverables include digital "maps" of the ovality of the casing and its internal diameter. The logs can be run and displayed in time-lapse mode to quantify the rates of corrosion or scale buildup. A digital image of variations in the inner diameter of the casing is the principal tool for identifying corrosion. In its basic form, this is an electronic version of what one might see using a downhole video camera; however, the electronic image can be rotated and inspected from any angle. Artificial colors are used to bring out anomalies.

Another processed product is the 3D shape of downhole tubulars to map the trajectory of the wellbore and to quantify casing deformation. An interesting example of the use of multifinger-caliper data to evaluate casing deformation in primary heavy-oil production in northeastern Alberta has been described by Wagg *et al.*[6] (**Fig. 2**). Several postulates for formation movement were modeled and compared with the observed casing deformations. In the end, it was concluded that sand production from an elongated disturbed zone caused reservoir shortening to an extent that could account for the wellbore observations. The use of casing-deformation logs as a tool in reservoir geomechanics leads to an improved knowledge base for well design.

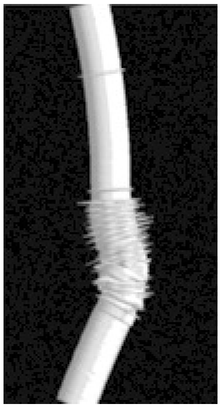

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Fig. 2 – Digital image of casing deformation based on multifingered caliper data processed with C-FER Technologies' CalTran™ software. The "spikes" are indications of casing connections or perforations.[6]

Although they are intended for cased-hole application, it is possible to use multifingered calipers in open hole. The results are much more detailed than with a standard openhole caliper, and the output can be displayed as images similar to those obtainable with ultrasonic imaging tools.

Flux-leakage tools

Flux leakage is a semiquantitative method that uses a strong magnetic field to identify and, to a certain extent, quantify localized corrosion on both the inner and the outer surfaces of the casing. A downhole electromagnet that fits snugly within the casing creates a low-frequency or a direct-current magnetic field. This can be a permanent magnet so it is possible to use this tool on a memory string for which battery power is at a premium. Magnetic flux is concentrated within the casing, which is close to magnetic saturation. The tool contains spring-loaded, coil-type, pad-mounted sensors that are pushed close to the casing during logging. Where casing corrosion is encountered, the lines of flux "bulge out" from the casing as though they were leaking from it. The primary sensors pass through this excluded flux and measure the induced voltage. The amplitude and spatial extent of the sensor response is related to the volume and shape of the corrosion metal loss, thereby allowing an estimate of the size of the defect. Because the primary measurement cannot distinguish between internal and external casing defects, many tools use an additional higher-frequency eddy-current measurement. This is a shallower measurement that responds only to casing flaws on the inner wall. It uses a separate transmitter coil. The flux-leakage and eddy-current signals are distinguished using frequency filters.

The major advantage of flux-leakage tools is that they can identify localized casing defects such as corrosion patches, pits, and holes as small as 0.2 in. [5 mm] on both the inside and the outside of the pipe. A disadvantage is that the tool does not detect large areas of corrosion. It does not see nonmagnetic scale, which can degrade the sensor response. The tool is affected by changes in the electromagnetic properties of the casing. It is limited in three ways:

- Accuracy
- Coverage
- Resolution

The coil-sensor response is sensitive to logging speed, and this sensitivity makes quantitative interpretation more difficult.

Electromagnetic phase-shift tools

The electromagnetic phase-shift technique provides an estimate of casing thickness across approximately 1 ft [300 mm] of casing length, so its spatial resolution is weaker than that of the first two methods. Electromagnetic phase-shift tools make measurements that are averages around the circumference of the pipe. They lack the localized investigative capability of flux-leakage tools and are best used to investigate larger-scale corrosion. Essentially, a transmitter coil generates a low-frequency alternating magnetic field, which couples to a receiver coil. It also induces eddy currents in the surrounding casing and formation. These eddy currents generate their own magnetic field, which is phase-shifted by the presence of casing. The phase-shifted field is superimposed on the transmitted field. This total field is detected by a receiver coil. The phase shift between the transmitted and received signals is related to the thickness, electrical conductivity, and magnetic permeability of the casing. If the last two are known, the casing thickness can be determined. Higher phase shifts indicate a higher casing thickness, all other things being equal. In practice, the electromagnetic properties of the casing can vary with composition, aging, and stress. To overcome this problem, modern tools comprise multiple sensor coils, which allow variations in the electromagnetic properties of the casing to be factored into the computation of casing thickness. Advantages are that the method is sensitive to large areas of corrosion and to gradual thinning of the casing. The sensors do not need to be in close proximity to the casing, so a single tool can examine a range of casing sizes. Disadvantages are the low spatial resolution and the lack of response to nonmagnetic scale. Moreover, the alternating-current magnet requires a relatively high power, which makes the tool difficult to deploy in memory mode.

Ultrasonic tools

The ultrasonic method provides a full quantitative record of casing radius and thickness. The first ultrasonic casing-inspection tools were the borehole televiewers, but these only "saw" the inner casing surface and their use is now mainly in open hole (see Acoustic Imaging (/Borehole_imaging#Acoustic_Imaging)). Later tools had fixed ultrasonic transducers, but these were principally directed at cement evaluation, and they provided an incomplete coverage of casing-thickness measurements. This problem was overcome by a rotating ultrasonic transducer that was initially directed at cement evaluation (see Cement-Evaluation Logs (/Cement_bond_logs#Cement-Evaluation_Logs)).

More recently, tools have been designed for a better spatial resolution.[7] Schlumberger's Ultrasonic Corrosion Imager (UCI™) was designed with a short-pulse 2-MHz transducer, 0.5 in. [12.5 mm] in diameter, focused at a distance of 2 in. [50 mm] from its front face. The higher-frequency measurement sharpened the spatial resolution so that internal pits of diameter 0.16 in. [4 mm] could be defined quantitatively. The velocity of sound in the borehole fluid is measured using a built-in reflector at a known offset while running into the hole. The wellsite computer calculates the internal radius from internal echo time and the measured fluid velocity. Downhole processing extracts the time difference between the internal and external echoes for an improved determination of casing thickness using the velocity of sound in steel. This information allows external casing defects to be identified. Azimuthal sampling interval is 2°. Vertical sampling interval in high-resolution mode is 0.2 in. [5 mm] at a logging speed of 425 ft/hr [130 m/hr]. The signal is attenuated by the borehole fluid. Best results are achieved with brine, oil, or very light drilling muds. **Fig. 3** shows UCI images of 2D percentage metal loss and 3D views of casing integrity in a 5.5-in. [140-mm] saltwater-injection casing in Canada.[7]

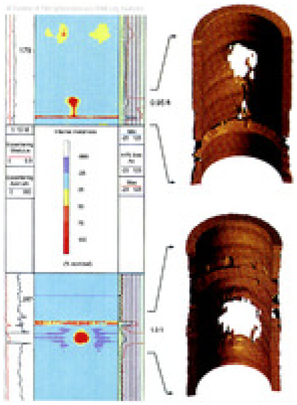

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Fig. 3 – Example of casing inspection using the Ultrasonic Corrosion Imager (UCI™). The presentation includes digital 2D images of percentage metal loss, with good casing shown in light blue and holes indicated in red, together with 3D views of casing integrity. There are two holes in the 5.5-in. [140 –mm] casing, each with a diameter of approximately 2 in. [50 mm]. In the upper image, note the deep groove from casing hole down to the casing collar.[7] [Courtesy of the Soc. of Petrophysicists and Well Log Analysts (SPWLA)].

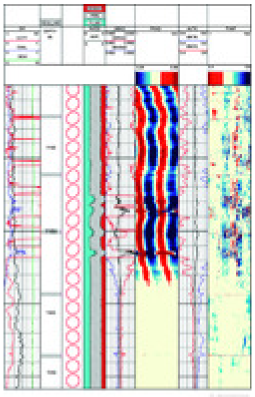
Frisch and Mandal[1] described a "new generation of ultrasonic tools" for use in large-diameter casings. Their (Halliburton) tool uses two ultrasonic transducers, one of which rotates while the other is fixed for real-time measurements of borehole-fluid velocity. The tool operates in image mode or cased-hole mode. In image mode, the tool can be operated in open hole or in cased hole, where it examines only the inner casing surface. In cased-hole mode, it determines the inner radius and the casing thickness, so that defects on the outer casing can be discerned. Waveform processing allows the evaluation of cement bonding (/Cement_bond_logs) from the same logging run.

Simultaneous casing inspection and cement evaluation

Ultrasonic tools can be operated to address two objectives concurrently: casing integrity and cement evaluation. A further example is Halliburton's Circumferential Acoustic Scanning Tool—Visualization version (CAST-V™), which allows separate or simultaneous casing inspection and cement evaluation.[5] The tool can operate in two modes:

- Image mode, whereby the scanner evaluates only the inner surface of the casing.
- The cased-hole mode, whereby circumferential maps of casing thickness and acoustic impedance are used to assure casing integrity and to distinguish between fluids and cement in the annulus.

Figs. 11 and 12 show examples of CAST-V data displays. This tool can also operate in open hole as a formation imager (see Borehole imaging (/Borehole_imaging)).



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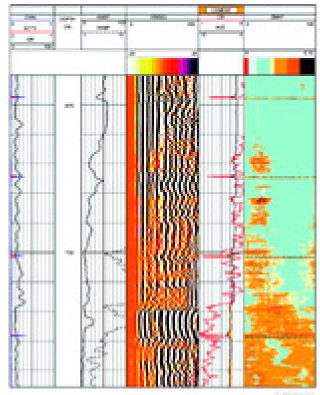

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Fig. 4 – Example of casing inspection using the visualization version of the Circumferential Acoustic Scanning Tool (CAST-V™). The casing-evaluation presentation includes casing ovality, eccentricity, hole deviation, and gamma ray in Track 1. In this case, the eccentricity comprises both tool and casing eccentricity resulting from formation movement (salt flow). Track 2 shows a cross-sectional presentation of the pipe shape. Track 3 shows a cross section of the pipe wall. Track 4 provides the average, minimum, and maximum values of the pipe radius that is shown in Track 5. Track 6 provides the average, minimum, and maximum values of the pipe thickness that is the image shown in Track 7, where red indicates pipe thinning and blue indicates pipe thickening. (Courtesy of Halliburton.)

Fig. 5 – Example of cement evaluation using the visualization of the Circumferential Acoustic Scanning Tool (CAST-V™). The data relate to an interval that overlaps with the conventional CBL shown in Fig. 6. The cement-evaluation presentation includes casing ovality and tool eccentricity in Track 1. The conventional CBL output is shown in Tracks 2 and 3 as per Fig. 6. Data from CAST-V are shown in Tracks 4 and 5. The image in Track 5 is an acoustic-impedance map from 0 to 360° (left to right) with 0° representing the high side of the hole. Track 4 contains the average impedance of the image in Track 5 and a cement-bond index (CBI) as a quick indication of the degree of bonding. Tracks 4 and 5 impart clarity to the interpretation of Fig. 6 by more clearly showing no cement above X80 depth units, good cement below Y20 depth units and questionable bonding in between. (Courtesy of Halliburton.)

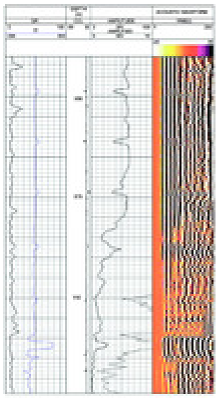

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Fig. 6 –Example of CBL. Track 1 contains the gamma ray (for correlation) and acoustic travel time (for quality control). Track 2 contains the amplitude curve and amplified amplitude, which indicates cement-to-casing bond. Track 3 contains the CBL waveform, which indicates cement-to-casing bond as well as cement-to-formation bond. Straight lines in the CBL waveform, along with high amplitude readings, indicate poor cement-to-casing bond. There is nearly free pipe above an apparent top of cement at a depth of approximately X80 depth units. At greater depths, the pipe is well bonded. (Courtesy of Halliburton.)

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