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Beyond Steel Casing: Detecting Zonal Isolation in the Borehole Environment

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Motivation

Fiberglass composite pipes (zst.ru)

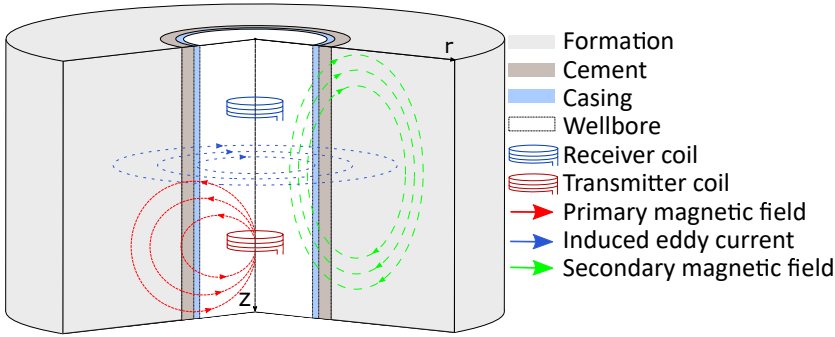
- Electrically resistive composite casing materials are being introduced to the oil and gas industry
- Composite tubulars are 4 times lighter than made of steel, withstand same pressure and load, resistant to corrosion and lasts more than twice longer
- The use of EM transparent casing materials requires the development of appropriate geophysical methods
- Presence of conductive particles in the cement allows to increase its displacement and check its quality using EM
- We use magnetic sensors to verify quality of the cement behind casing

Magnetic susceptibility logging, borehole environment

- Borehole environment is magnetized by a low frequency induction tool
- Measurements can be made by coils or sensors (Flux gate magnetometers)
- Alternating magnetic field provides necessary noise immunity of logging measurements and excludes the influence of the geomagnetic field

Magnetic susceptibility logging

- Transmitter coil generates magnetic field, that produces eddy current in the formation
- The secondary magnetic field is registered by receiver coil
- Only vertical component of magnetic field is considered - H_z



Magnetic susceptibility logging

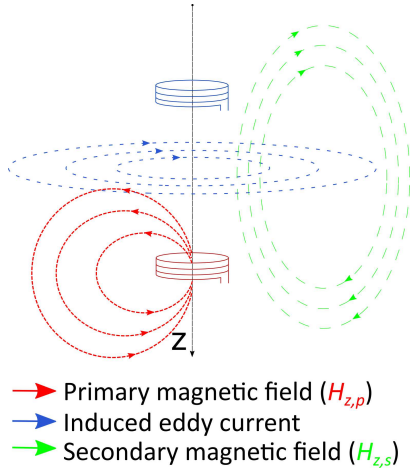
- Primary and secondary magnetic fields induce an electromotive force in the receiver coil
- Primary magnetic field is much stronger than secondary one
- Magnetic susceptibility tool is calibrated by response measurement in the air and its exclusion from the measured signal
- There is no secondary magnetic field in the air

Tool response measurement

$$H_{z,m} = H_{z,p} + H_{z,s} \qquad (1)$$

$$H_{z,s} = H_{z,m} - H_{z,p} \qquad (2)$$

$H_{z,m}$ - measured magnetic field,
$H_{z,p}$ - primary magnetic field,
$H_{z,s}$ - secondary magnetic field

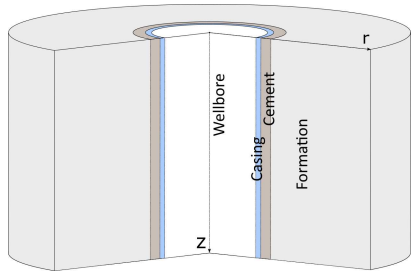


Formulation of the problem

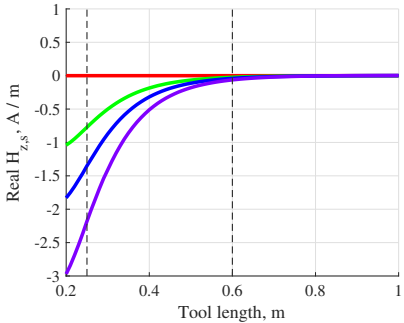
1. All layers are isotropic and homogeneous
2. Media consists of cylindrical layers with constant electrical parameters in the direction parallel to Z axis
3. Wellbore is an infinite column of liquid, its axis coincides with the axes of all layers
4. Coils axes coincides with the axis of the wellbore
5. Compared with the size of the tool coils are considered to be point dipoles

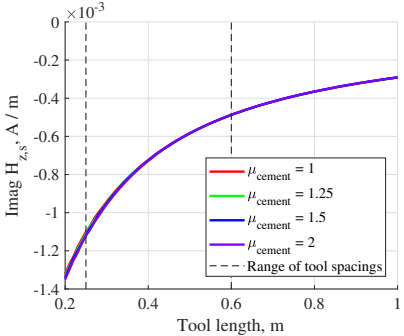
Geoelectric table

Parameter	Wellbore	Casing	Cement	Formation
Radius, m	0.07	0.10	0.15	
Resistivity, $\Omega \cdot m$	2	10^8	1 - 1000	50
Magnetic permeability	1	1	1, 1.25, 1.5, 2	1



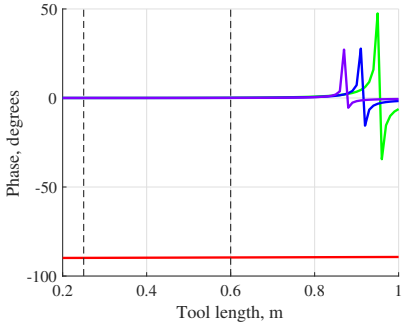
Amount of magnetic powder in the cement, frequency = 1 kHz

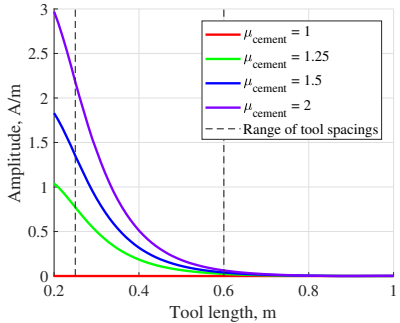




- $H_{z,s}$ is strongly influenced by amount of magnetic powder
- For magnetic cement quality logging it is better to use tools from 0.25 to 0.6 meters
- Imaginary part of $H_{z,s}$ is weakly influenced by amount of magnetic powder in the cement

Induction logging signals, frequency = 1 kHz

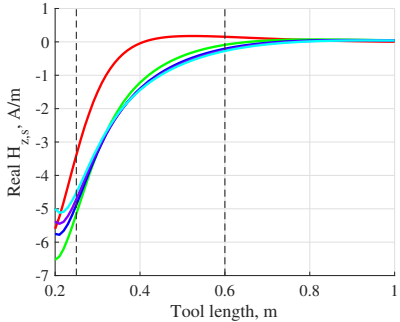


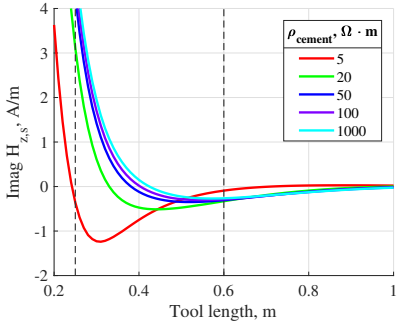


$$a = Re(H_z), b = Im(H_z); \qquad \varphi_m = \arctan\left(\frac{b}{a}\right); \qquad A_m = \sqrt{a^2 + b^2} \tag{3}$$

φ_m - signal phase, A_m - signal amplitude, a and b - real and imaginary parts of H_z

Solidification of the cement spotted at frequency = 200 MHz

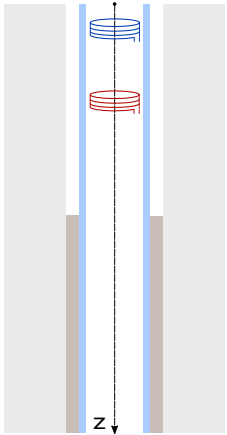


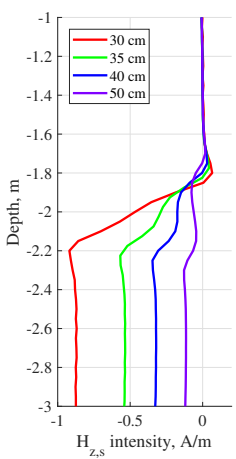


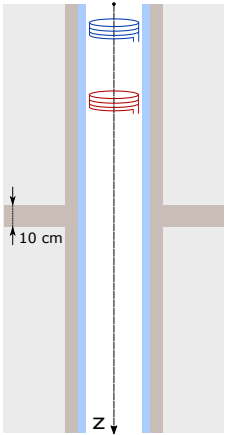
- Electrical resistance of cement depends on the degree of its solidification
- The harder the cement the higher its resistivity
- Soft cement can be detected at high frequency

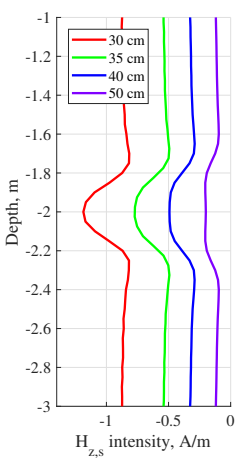
Magnetic cement logging

Incomplete cement lift and fracture filled with cement can be detected



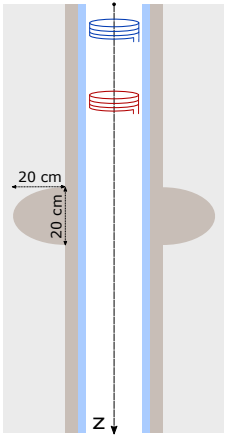


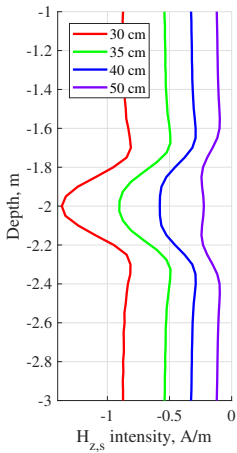


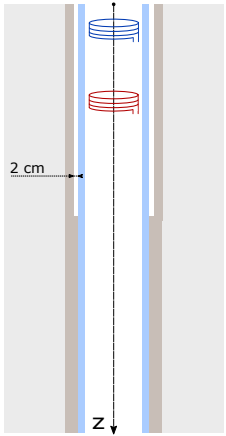


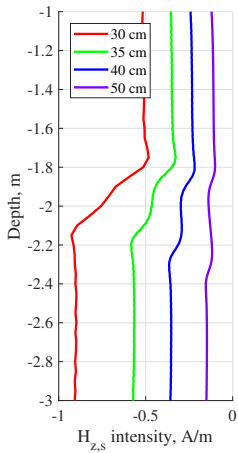
Magnetic cement logging

Cavity filled with cement and 2 cm cement debonding can be detected







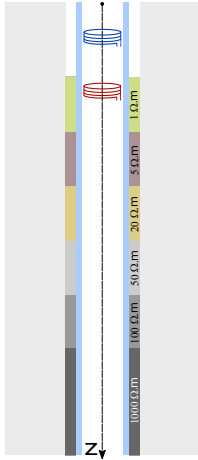


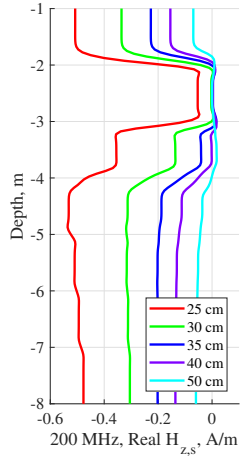
Cement hardening logging

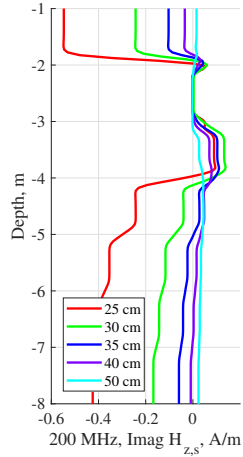
A stair-step change of the real and imaginary part can be observed

Magnetic field magnitude changes while logging through different layers

Soft cement can be distinguished from hard one





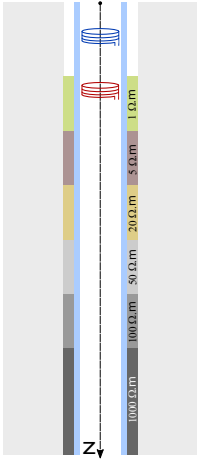


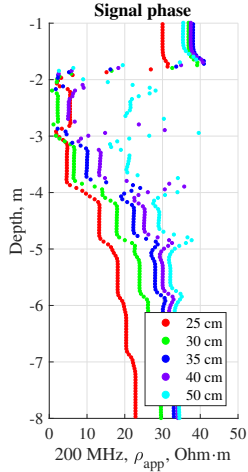
Cement hardening logging, apparent resistivity

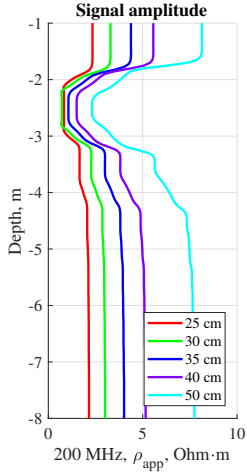
Apparent resistivity is calculated from logging signals using homogeneous medium approximation

Resistivity obtained from signal phase is more sensitive to cement resistivity

Singularities can be observed when cross different layers

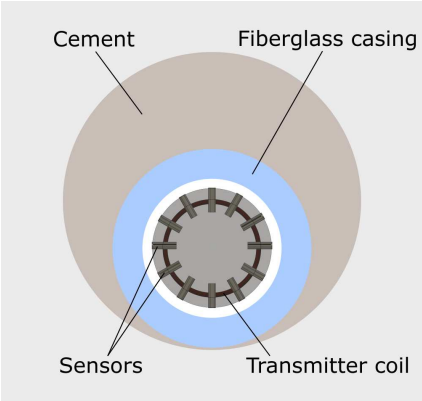


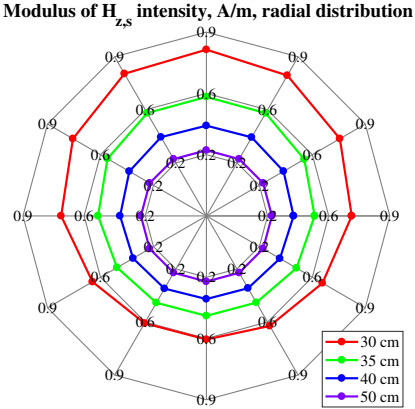




Eccentricity of the cement

The eccentricity of cement can be determined using a magnetic sensor tool





Summary

- Tools with lengths from 0.25 to 0.6 meters are the most sensitive to the cement properties
- Real part of the $H_{z,s}$ for the frequency range from 0.1 kHz to 10 kHz is more sensitive to the magnetic cement
- Inhomogeneities filled with cement are visible on the logs
- The absence of cement causes a sharp decrease of magnitude of the secondary magnetic field
- 200 MHz induction tool can be used for cement solidification detection
- The proposed method can determine poor-quality cementation through a non-conductive casing