Alternate Method of Determining the Speed of Sound for Acoustic Fluid Measurements

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Fluid Level Determination

- Reflected pressure pulses have long been used in the industry to measure fluid level (i.e. Echometer)

- Fluid Distance = \( \frac{1}{2} \times [\text{Round Trip Time}] \times [\text{Speed of Sound}] \)

- Fluid accuracy depends on accuracy of measuring:
  - Round-trip time
  - Speed of Sound

Capturing reflected signals with Echometer product
Round-Trip Time Accuracy

- Round trip time can usually be measured to better than 1 msec. That accuracy represents a fluid level error of roughly 0.5 ft. (or less)
- This timing accuracy is sufficient for most fluid monitoring applications
- For more demanding applications, timing resolution can be increased through increased data acquisition frequency and higher frequency response pressure sensors.
- Time accuracy isn’t the problem.

Timing accuracy is already pretty accurate and consistent.
Speed of Sound Accuracy

- Speed of sound in gas is hard to measure...
- Speed of sound changes with gas composition, temperature, and pressure
- In a casing, it will be different at different depths
- Goal is to measure the “average” speed of sound in the casing
- If the speed of sound is off by 1%, the fluid level will be off by 1%.

**Fluid Level**

\[ \text{Fluid Level} = \frac{1}{2} \times (\text{speed of sound}) \times (\text{round-trip time}) \]

If speed of sound = 1200 ft/s and Round-trip time = 10.0 s

\[ \text{Fluid level} = \frac{1}{2} \times (1200) \times (10.0) = 6000 \text{ ft.} \]

If speed of sound = 1212 ft/s (a 1% difference) and Round-trip time = 10.0 s

\[ \text{Fluid level} = \frac{1}{2} \times (1212) \times (10.0) = 6060 \text{ ft.} \]

Speed of sound accuracy is directly proportional to fluid level accuracy.
How is Speed of Sound Measured?

- Three methods:
  - Collar/Joint Counting
  - Marker identification
  - Pump off identification

- All three methods are prone to errors.
Collar/Joint Counting

- Most frequently used method
- An inherently difficult measurement to make
- Pressure pulse width is often greater than the actual joint spacing
- Overlap of reflected signals greatly reduces signal visibility
- Requires extensive filtering of signal (which can cause artifacts)
- Need to accurately know (and enter) the joint spacing for all joints
- What if you don’t have joints?

This is proportionally what a 30ms pulse looks like…
Marker Location

• Only measures the average speed of sound to the “marker” (not the average speed in the full well)

• Requires that the marker location be known/recorded accurately

• Requires information to be entered by the user

• Not useful when fluid is above marker

• Many wells have no marker
Pump Off Identification

- Most accurate method for measuring average speed of sound in casing
- Must be certain, however, that the well is pumped off
- Must be certain of pump depth values and fluid location associated with well being pumped off
- Cannot use this technique when fluid is over pump
- Not suitable for many pumps (i.e. PC)
Testing Collar Counting Accuracy

- 1500 ft. test well fabricated with 17 joints:
  - First 500 ft had 0 joints.
  - Second 500 ft had 17 joints.
  - Last 500 ft had 0 joints.

- Environment known:
  - Acoustic velocity: 1127 ft/s.
  - Well depth: 1507 ft.
  - Pressure: 0 PSig
  - Temperature: ~22°C
  - Joint Spacing: 32.0 ft.

- Fluid level measured with an Echometer
Results

- 10 measurements made
- Echometer detected:
  - Between 23 and 39 joints
  - Speed of sound between 1107 ft/s and 1122 ft/s (a 2% error)
  - Well distance determined to be between 1485 and 1505 ft. (a 2% error)
  - Round trip time was always the same
- A 2% error at 10,000 ft is 200 ft.
- This test had no noise and the joint spacing was known precisely
- Very easy to see how actual well conditions could easily have 3-4% error or fluctuation in measured fluid levels
“Ghost Joints” Look Real (but aren’t)
• Why were 39 collars detected when only 17 were present?

• Most likely due to over-filtering…

• Signal is small, so frequency filtering must be very aggressive

• But too much filtering causes artifacts/ringing at filtered frequency

• Over-filtering can result in a “self-fulfilling” prophesy

• These inherent problems limit the achievable accuracy of collar/joint counting techniques to a few %

Example of Filtering Artifacts…
An Alternate Approach…

- Accidentally stumbled across a new method for acoustic distance measurement…
- A very fast pressure impulse is emitted into casing annulus
- The pressure pulse is made up of many different frequencies
- These frequencies travel through casing gas at slightly different speeds
- The result is that the narrow pulse widens the further the pulse travels
- This is called “pulse dispersion”

Example of Pulse Dispersion…
Early Test Results…

- Tested the degree of pulse dispersion at different distances for different gases (ranging from CO$_2$ to He)
- Found that the speed of sound of the gas did not impact the amount of pulse dispersion…
- Amount of pulse dispersion was only dependent on actual distance traveled
- Ergo, pulse dispersion measures distance to fluid independent of the speed of sound
- Testing on artificial well shows that technique can consistently determine distance to ±1 ft at 8000 ft.
Pulse dispersion is a differential effect. For varied casing gas compositions it appears to be independent of the actual speed of sound.
Comparison with Collar Counting...

Using Collar Counting

Using Pulse Dispersion
Benefits...

- Allows fluid depth to be determined very accurately and completely eliminates need to make difficult speed of sound measurement.
- Removes #1 cause of variability in fluid level measurements.
- Could be used to precisely determine average speed of sound in well (samples total gas column).
- Can be used with wells with continuous/coiled tubing or no tubing.
- Does not require collar/joint spacing to be known or entered (one less step).
- Can be easily incorporated into existing products.

Coiled Tubing
Summary...

- Current methods of speed of sound measurement are inadequate
- New “pulse dispersion” technique greatly improves the accuracy with which fluid levels can be determined
- Patent app submitted and technique is currently undergoing field trials
- Dispersion in gases is a complex phenomena. Extensive testing and modeling still needed...
- Field trial data to be released next year...

MaxPro5000 product currently being upgraded to incorporate new pulse dispersion technique.
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