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Material Transition Detection in Drilling Using Data Analytics

McBrayer, K.L.

Sandia National Laboratories, Albuquerque, NM, USA

Su, J.C.

Sandia National Laboratories, Albuquerque, NM, USA

U.S. DEPARTMENT OF ENERGY NNSA

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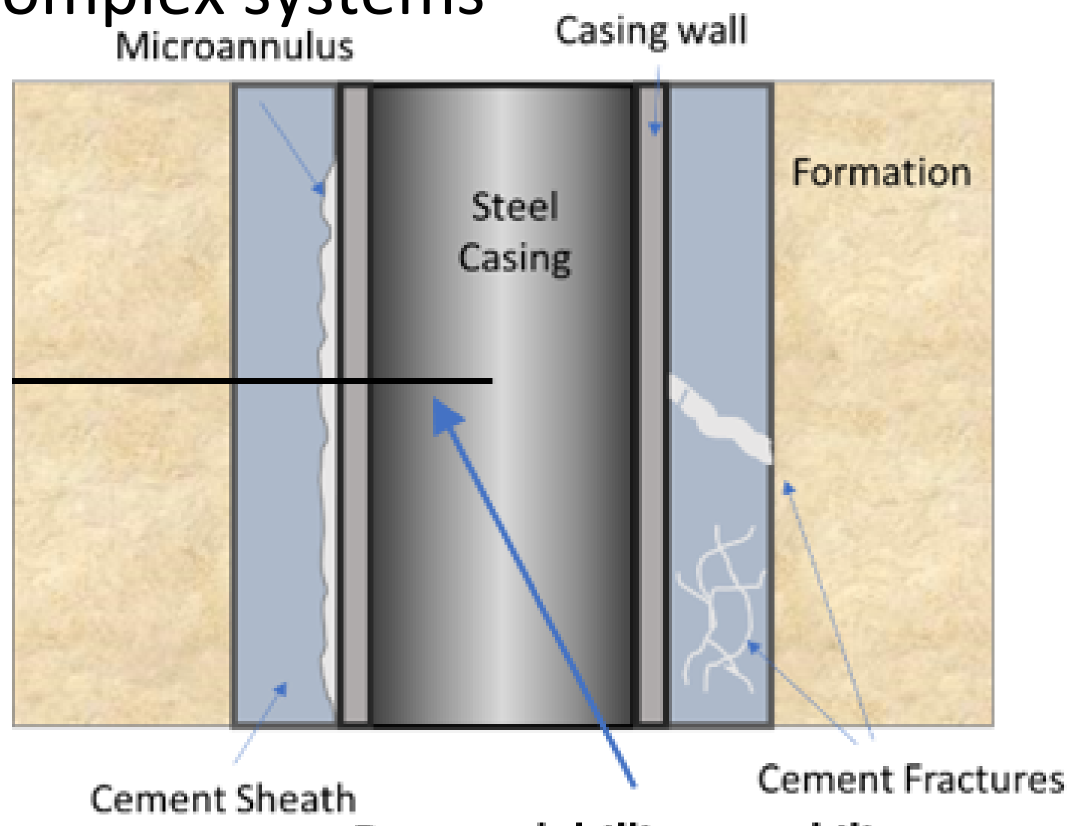
Introduction

- Sandia is investing internal funds through the lab directed research and development (LDRD) program to support sensor emplacement through precision drilling.
- The goal is to help support the aging wellbore infrastructure by providing a means of targeted sensor emplacement to detect leaks or other wellbore integrity issues. The LDRD is focused on several aspects of this including drilling to the formation from within the confines of wellbore, leak detection analysis, and long-term sensor emplacement.
- The work being presented supports the drilling effort by helping to detect material and material transitions (e.g. casing to cement, cement to formation) to precisely drill for sensor placement when deploying from within the wellbore.
- Wellbore Integrity is a significant environmental and energy security problem for our nation
- 30% of the 4 million wells worldwide show signs of integrity issues (Davies et al., 2014)
- Current industry paradigms for well design include using cement as a barrier, however many cementing problems go undetected (Yakimov, 2012)
- The ability to detect material transitions has far-reaching applications that extend beyond wellbore sensor emplacement. Potential applications include utilities installation and other access-limited drilling environments.

Challenges and Approach

- Wellbore integrity assessment relies on a combination of indirect measurements (through casing) and models to assess these very complex systems



Proposed drilling capability

- We propose a new capability to drill precision holes (at depth) through the sidewall casing
- These small diameter holes would enable direct, precise measurements in the cement that indicate potential failures

Current methodologies

- Existing methods require fiber optic or sensor placement during well construction
  - Expensive, technically challenging, could introduce fluid leaks
  - Applies only to NEW wellbore installation—does not address aging wells that may be failing

- Our approach would entail intentionally breaching the casing in a controlled manner to enable precise assessment
  - Enables the future development of smarter, effective, remediation techniques/materials that are tailored to the wellbore flaw, reducing risk to the entire well

Focus

- Simulate wellbore drilling using benchtop set-up and wellbore material sandwich samples

- Data analysis to characterize mechanisms of micro-drilling in wellbore material (shale, cement, steel)
  - Develop ability to predict properties and transitions ahead of drilling
  - Enables optimization of drilling conditions to suit wellbore formation
  - Enables precise placement of sensor package for long term monitoring

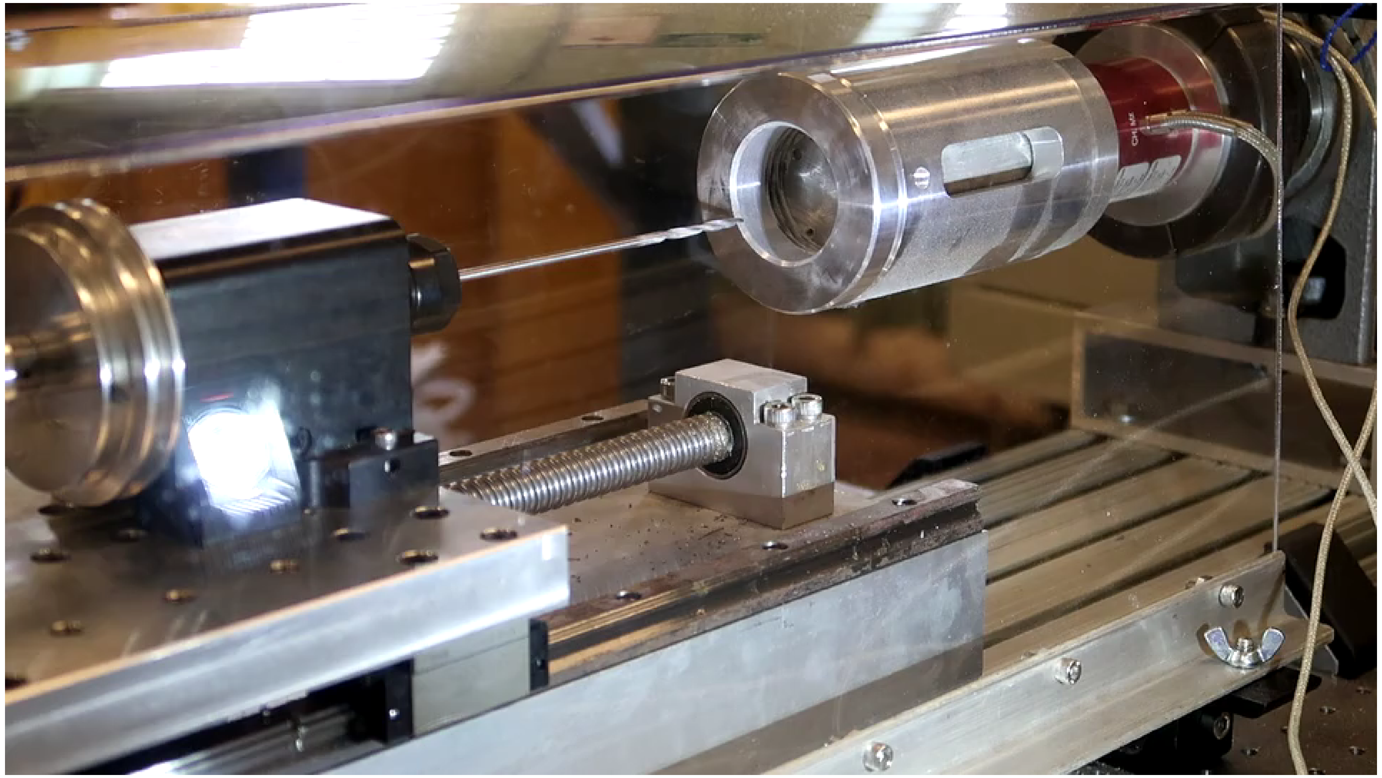
- Detect active material transitions while drilling using real time temporal kurtosis

- Foundational step towards the development of fully autonomous well drilling that could automatically adjust drilling parameters to minimize or avoid drilling dysfunctions

Bench Top Testing Set-up

- Simulates micro-drilling into a wellbore casing

- Consists of:
  - Carriage mounted spindle actuated using servo driven ball
  - Linear rail guides
  - Plastic shield for protection
  - LabView data acquisition system
  - Bi-axial load cell coupled to test samples via test carrier—measures force and torque



Test Samples

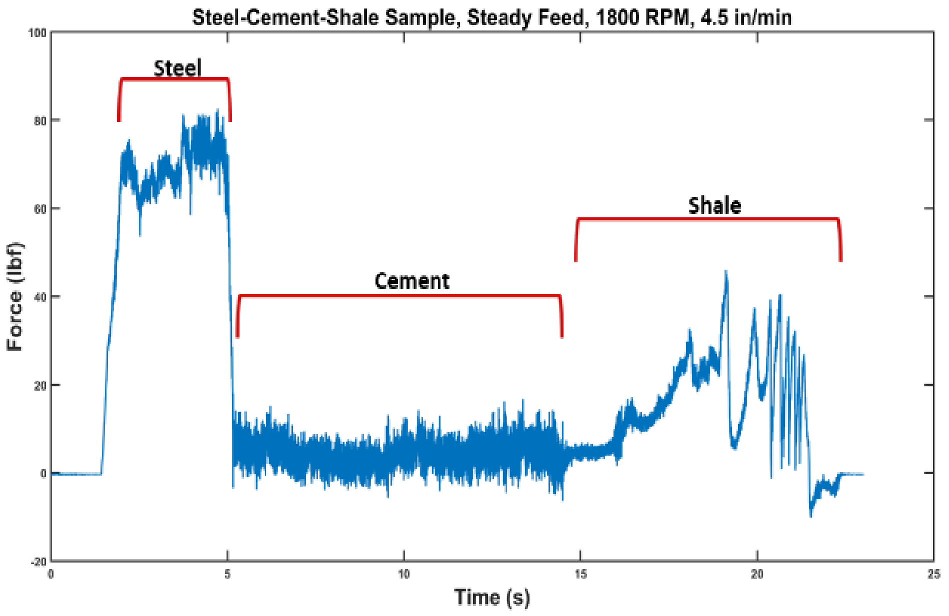
- Simulates materials in a wellbore—shale, cement, and 1018 steel
- Bonded together with epoxy
- Samples were made with the materials in different orders and separately
  - Allows better understanding of the force interaction between the drill and the individual material

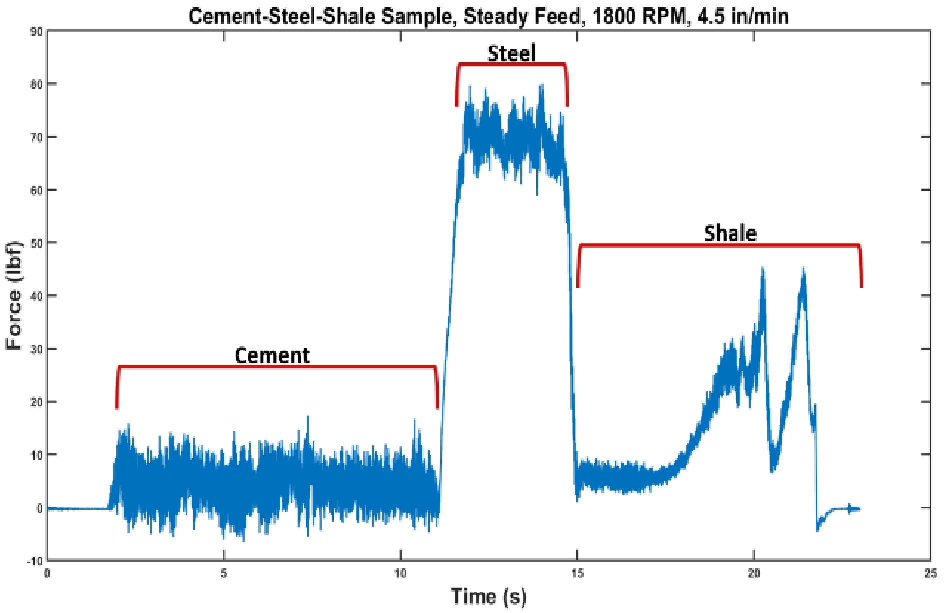
Drilling Data Analysis

- “Standard” data was collected at 1800 RPM with a 4.5 in/min feed rate using a 1/8 inch drill bit
- Force and torque data were collected from the bi-axial load cell—highly correlated
- Chose to focus on force data
  - Focusing on fewer measurements better simulates real world applications and makes it easier to scale-up diagnostic tool later
  - Early indications show that the force data has a higher SNR than the torque data which allows for easier statistical analysis

Drilling Data Analysis—Material Sandwich

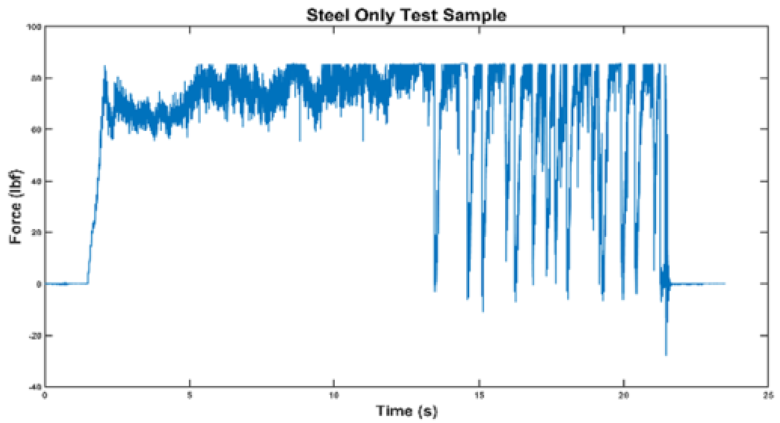
- Drill through 3 wellbore materials in succession, but in different order for each sample
- Shows unique force signature for each given material (steel, cement, shale) independent of drilling order

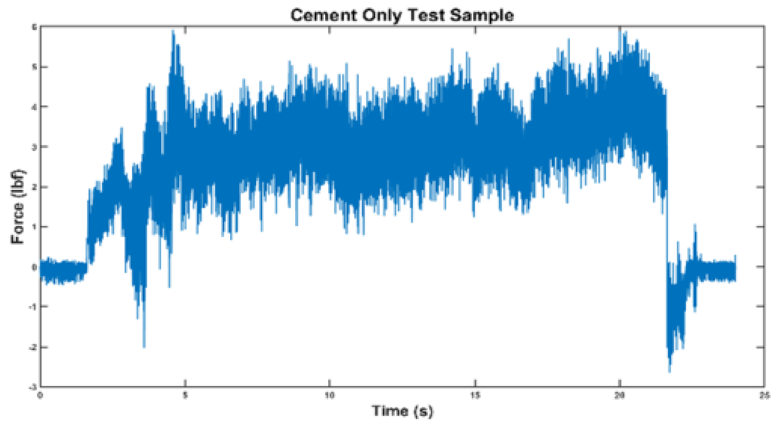


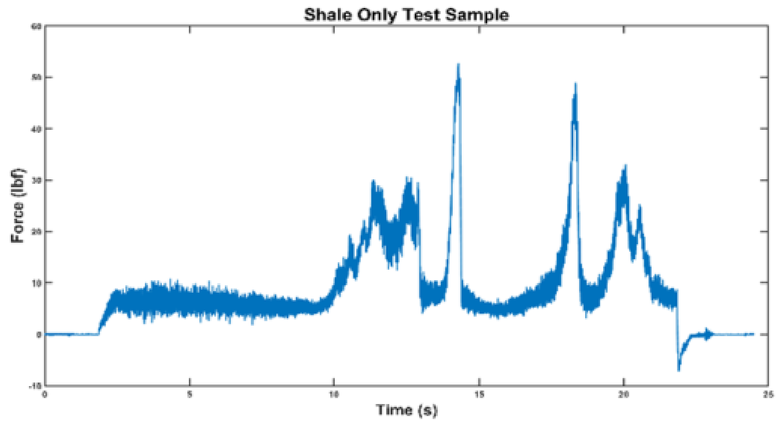


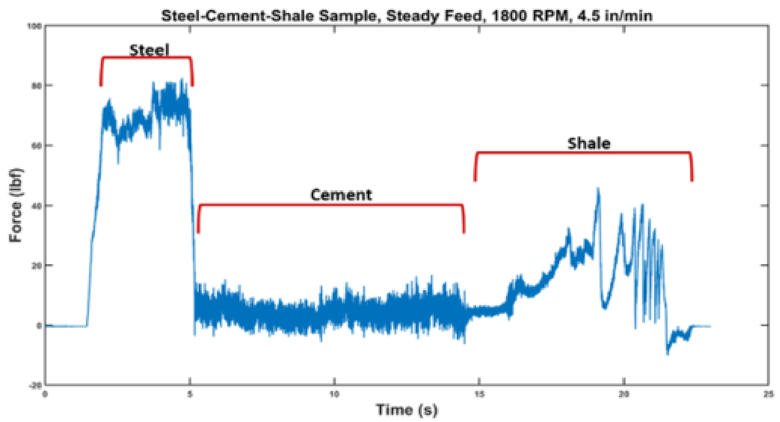
Drilling Data Analysis-Individual Material

- Also shows unique force signature for each material



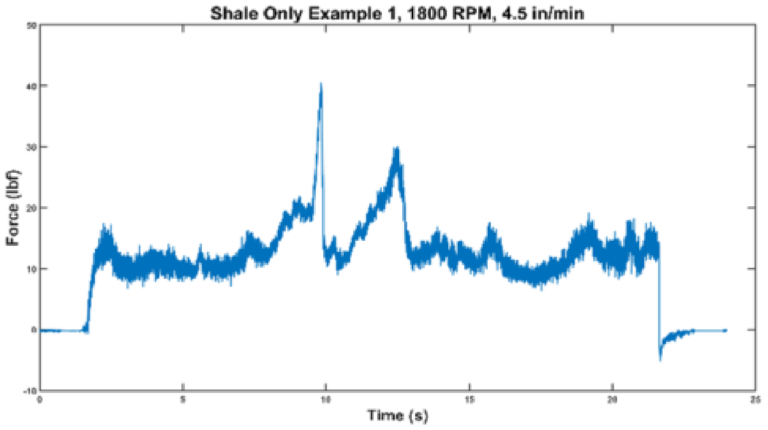


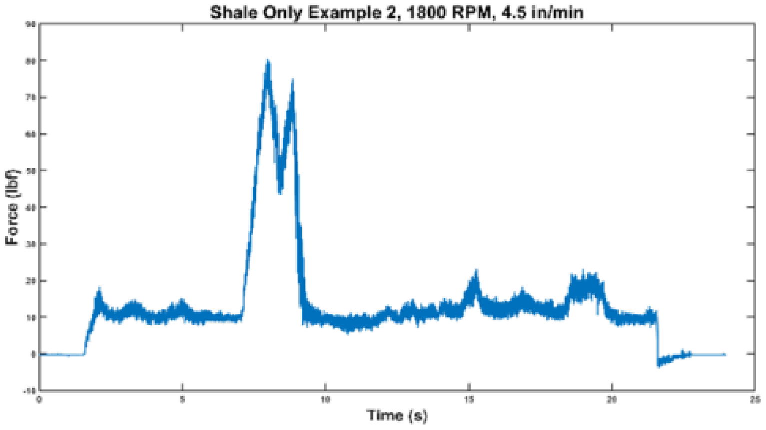


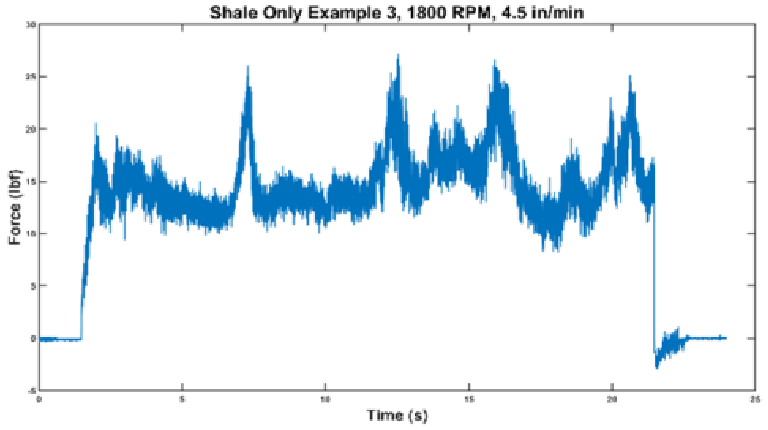


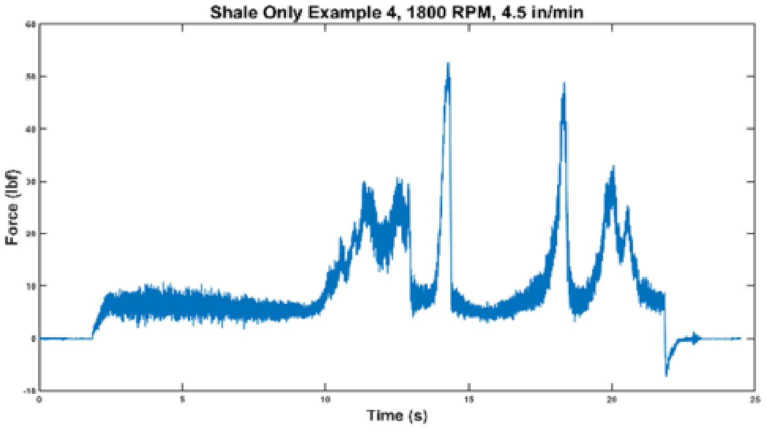
Drilling Data Analysis—Shale

- Nonhomogeneous composition that could cause unexpected force variability from sample to sample









Drilling Data Analysis—Temporal Kurtosis

- Shows the extreme values of either tail of a distribution representing the "tailedness" of the distribution (Decarlo, 1997, Song and Cha, 2016)

$$TK = \frac{\frac{1}{N}\sum_{i=1}^{N}(\mu_i - \mu)^4}{\left(\frac{1}{N}\sum_{i=1}^{N}(\mu_i - \mu)^2\right)^2}$$

- Identify any rapid changes in the force data which we hypothesize to be related to the drill's transition between materials in real time

- Temporal kurtosis was chosen for a variety of reasons:
  - Variance alone proved to not be a reliable statistical measurement so we decided to look at higher order statistics
  - Simple measurement that could be performed quickly in real time and used as a feedback to our control system

Drilling Data Analysis—Shale Cement Comparison

- Greatest Similarity observed between shale and cement materials
- Noticeable difference between variance observed in force data between the shale and cement materials
- Compared temporal variance between cement and shale materials
- Highlights inhomogeneous nature of the shale material versus the cement material

Shale Test #	Temporal Variance	Cement Test #	Temporal Variance
Shale 1	0.5773	Cement 1	0.2278
Shale 2	1.2759	Cement 2	0.2117
Shale 3	1.6078	Cement 3	0.2199
Shale 4	0.9323	Cement 4	0.2326
Shale 5	1.3284	Cement 5	0.2114
Shale 6	1.2656	Cement 6	0.2316
Shale 7	3.6535	Cement 7	0.2186
Shale 8	4.0809	Cement 8	0.2232
Shale 9	0.8130	Cement 9	0.2694

Algorithm/Benchtop Set-up Integration

- Kurtosis analysis was modified for real time analysis and integrated into the benchtop drilling software
  - Integrated using a built-in LabView moving average function with a mean window size of 10

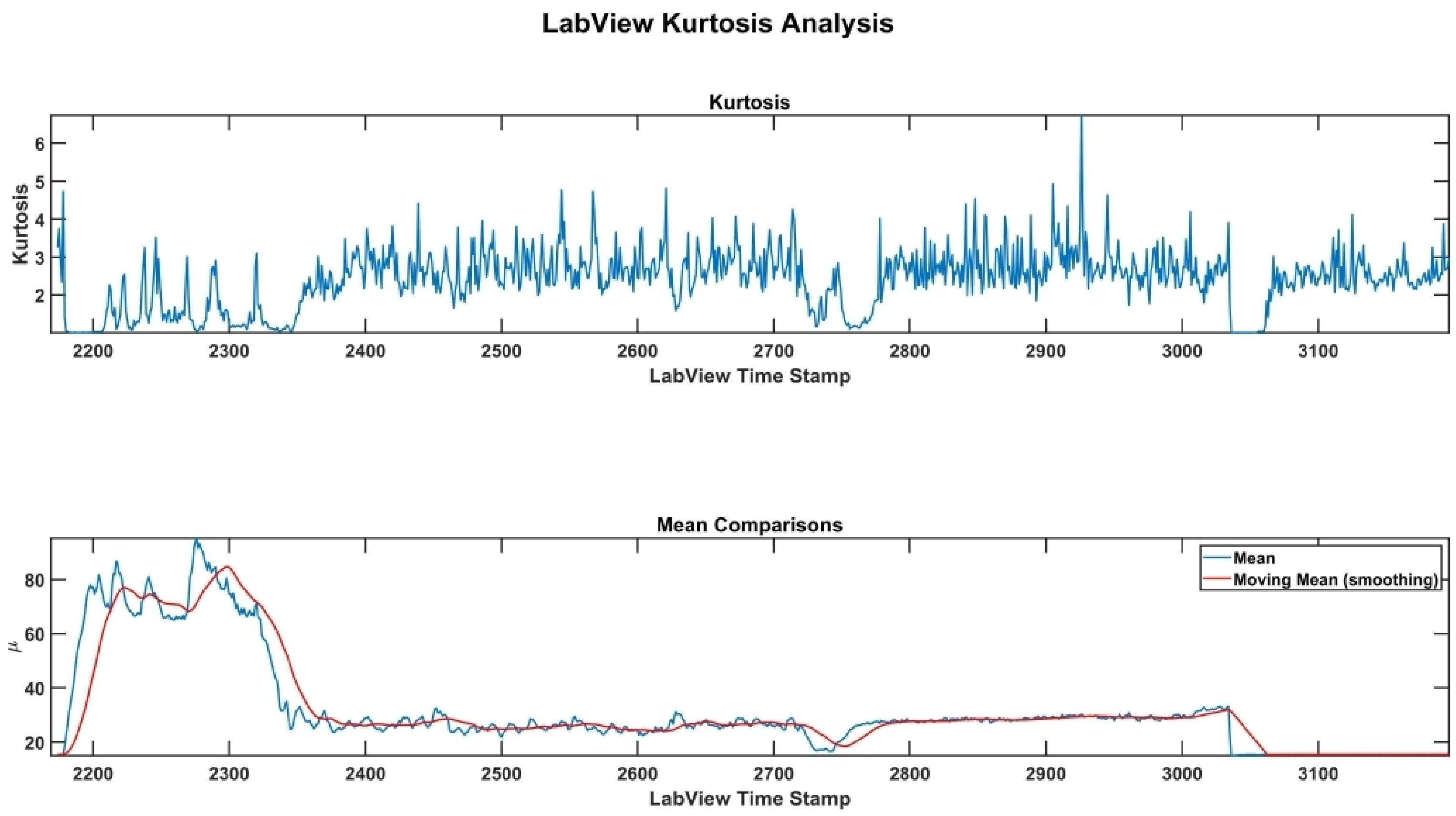
$$TK = \frac{\frac{1}{N}\sum_{i=1}^{N}(\mu_i - \mu)^4}{\left(\frac{1}{N}\sum_{i=1}^{N}(\mu_i - \mu)^2\right)^2} \longrightarrow \text{LabVIEW}$$

- ***Hypothesis*—**a kurtosis value that varies far from a Gaussian distribution of 3 will indicate the drill is actively transitioning between materials

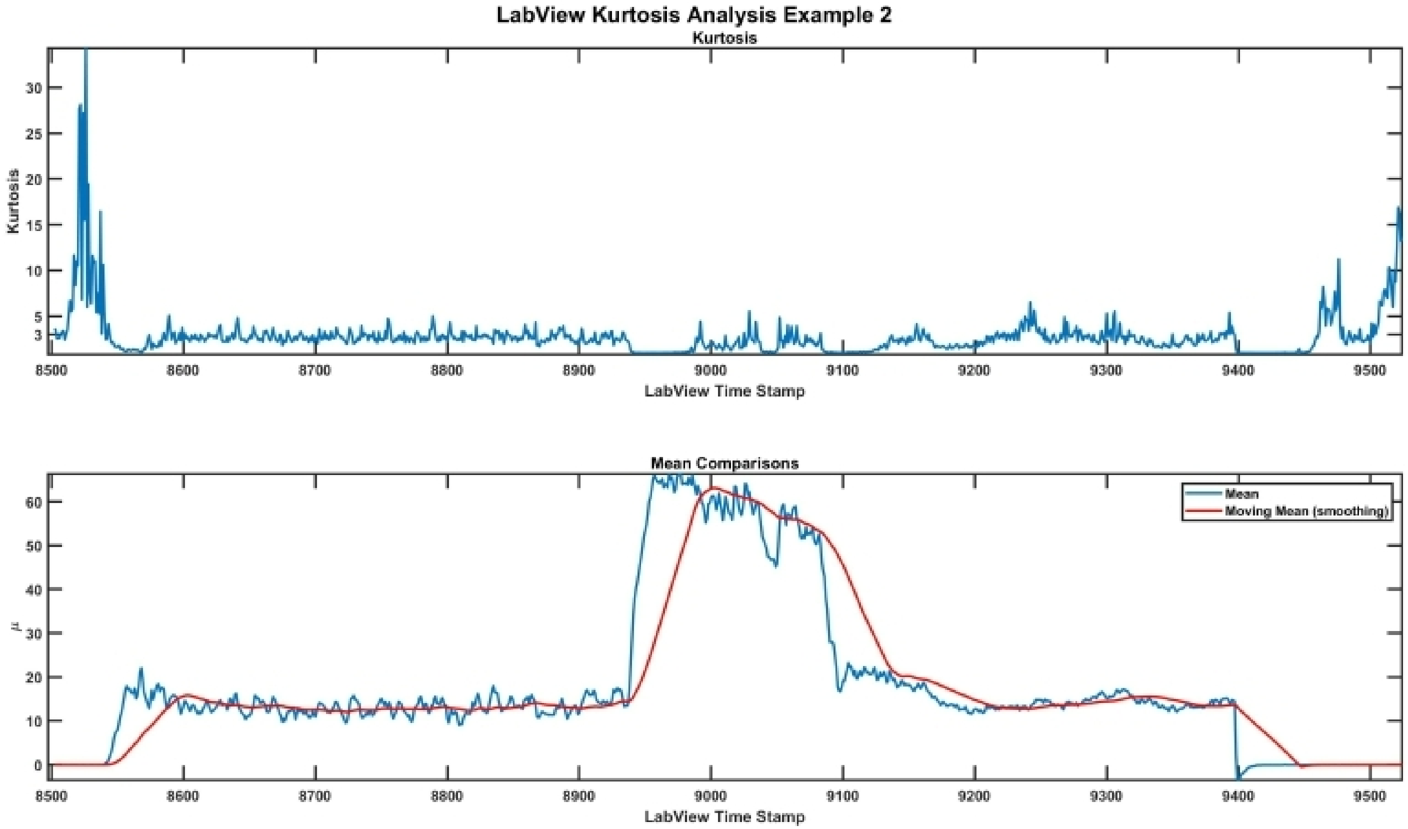
Algorithm/Benchtop Set-up Integration Conclusions

- A kurtosis value of around 3 is observed when drilling in a constant material
- When the drill actively transitions between materials a dip in the kurtosis value to around 1 is observed
- Kurtosis computation can be used in a real time capacity to determine active material transitions

Algorithm/Benchtop Set-up Integration Results Example 1



Algorithm/Benchtop Set-up Integration Results Example 2



Future Work

- Develop thresholding algorithm to help distinguish what material the drill is currently drilling through
  - Leverage SNR and variance data
- Consider using torque data to further analyze and develop algorithm
- Determine whether there is a frequency dependence with variance

References

1. 1. McBrayer, K.L., Su, J.C. 2020. Material Transition Detection in Drilling Using Data Analytics, American Rock Mechanics Association
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Technical Paper PPT Requirements

- **Presentations will be 20 minutes total, including Q&A (ex. 15 minute presentation and 5 minute Q&A)**
- All technical presentations must be designed using PowerPoint.
- 16:9 aspect ratio (widescreen)
- Minimum Font size 12 pt.
- Use page numbers on each slide.
- Slide 1: Title, authors, logos
- Slides: Technical content. Company logos are not permitted.
- Final Slide: References, acknowledgements, required DOE disclaimers (if applicable)

Technical Paper PPT Requirements

- Make sure font colors and backgrounds have sufficient contrast.
- Confirm that all graphics and text is clearly legible on a 13” laptop screen.
- Slides are due **Monday, September 13, 2021**