Welcome!

The program will begin soon.

You will not hear audio until we begin.

Webinars

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Advancing Rod Lift Design: Integrative Stress and Fatigue Models

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Introduction to the Webinar objectives

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Introduction

- Provide a comprehensive understanding of fatigue estimation and predictive models and propose ways to address the estimation of stresses.

Problem Description:

- Rod lift systems currently deal with complex stress environments that challenge the predictability of rod lift systems. Traditional stress estimation and associated fatigue models make it difficult to accurately estimate rod performance due to the dynamic nature of downhole conditions, leading to unpredictable failures and increased downtime.

Webinar Focus:

- This webinar presents an integrated framework that combines traditional design principles with additional stress analysis models, aiming to improve fatigue estimation and enhance the operational performance of rod lift systems.
- Attendees will gain insights into advanced methodologies tailored for the unique demands of the artificial lift industry.

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Content

- Introduction to Artificial Rod Lift Systems (ALS):
  - Conventional and Continuous Rods
  - Coated Rods
- Load Analysis and Fatigue Design:
  - Types of Loads in Rod Systems
  - Principles of Fatigue Design
- Stresses in Rod Systems:
  - Identification and Analysis of Stresses
  - Discussed Models
- Current Methodologies and Improvement Proposals:
  - Current Practices and Methodologies
  - Proposals to Address Challenges
- Conclusion:
  - Summary and Final Reflections

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Sucker Rod, Continuous Rod, Connections and Coatings

INTRODUCTION

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Introduction to Rod Lift Technology in PC Pump Systems

- PCP vs. RRP Load Dynamics:
  - Dominance of torsional load in PCP systems versus axial load in RRP.
  - Wellbore curvature-induced stresses, requiring design considerations.
- Standards and Design Modifications:
  - The rod in ALS typically adheres to API standards.
  - PCP systems necessitate specific design adjustments, such as enhanced connection strength, due to higher torsional or axial loads.
- Centralizing Couplings and Rod Guides:
  - Systems use centralizing couplings for rod alignment and wear reduction.
  - Rod guides are tailored for torsional resistance

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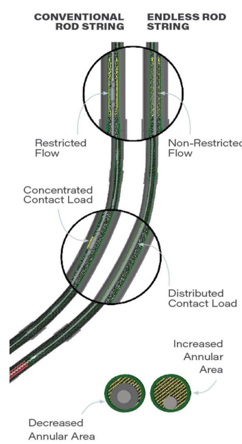
Continuous Rods and API Connections

- Continuous Rods: Design and Servicing:
  - Benefits of continuous rod design with consistent rod cross-section for managing torsional loads in PCP
  - Specialized servicing considerations, including field welding and logistics.
- API Connections and Operational Dynamics:
  - Challenges with standard API connections in PCP due to torsional forces.
  - Follow make-up guidelines to accommodate unique operational demands in PCP.



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Rod/Tubing Contact and Wear Dynamics

- Causes of Rod/Tubing Contact:
  - Gravity, rod tension, and well curvature in non-vertical wellbores.
  - Surface equipment misalignment and rotational dynamics above the pump.
- Wear Mechanisms:
  - Concentrated loads from traditional sucker rod couplings.
  - Reduction in wear through continuous rod designs and rod guiding.
- Contact Load Estimation:
  - Combination of curvature and gravity-induced components.
  - Calculated using wellbore designs or actual surveys and operational conditions.
- Factors Influencing Contact:
  - Fluid dynamics and rod/tubing interaction.
  - Dependence on wellbore profile and rod string configuration.

Worn samples of bare continuous rod (top) and J55 tubing (bottom)

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Corrosion Mechanisms

- Corrosion in Rod/Tubing Systems:
  - Corrosion as a significant factor, influenced by fluid conditions and operational environment.
- Corrosion-Wear Mechanisms:
  - Interaction between corrosive fluids and mechanical wear.
  - Aggressive erosion/corrosion wear modes in the presence of abrasive fluids.
- Predictive Analysis of Corrosion and Wear:
  - Challenges in accurately predicting combined corrosion and wear processes.
  - Role of monitoring and inspections in understanding corrosion impact and wear.

Rod body corrosion pitting

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Strategies for Wear and Corrosion Mitigation

- Wear Mitigation Techniques:
  - Coatings, centralizers, and coupling to reduce wear.
  - Use of heavy wall or specialized tubing in high-wear areas.
- Continuous Rod:
  - Benefits of continuous rods in reducing concentrated wear points.
  - Considerations for extreme abrasive conditions and lubrication.
- Corrosion management:
  - Selection of corrosion-resistant materials and coatings.
  - Implementing regular maintenance and monitoring for early detection.
- Holistic Approach to System performance:
  - Integrating wear and corrosion mitigation strategies for optimal system performance.
  - Tailored solutions based on specific operational and environmental conditions.

LS Thermoplastic coated continuous rod

Metallic coated sucker rod

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Fatigue

ROD LOADING AND DESIGN METHODOLOGY

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Load Dynamics and Fatigue in RRP and PCP

Torsional, Axial Loads, and Fatigue Considerations:

- PCP systems experience torsional loads.
- RRP is subject to axial loads from reciprocating motion.

Fluid Dynamics, Wellbore Curvature, and Rod Stretch:

- Wellbore curvature contributes to bending loads.
- Fluid composition changes in both PCP and RRP systems lead to variations in load dynamics.
- Axial load induces rod stretch, critical for proper pump alignment.
- The magnification of curvature stresses with axial load and the impact of rod guides on localized curvature.

Rod/Tubing Interactions and Movement Transitions:

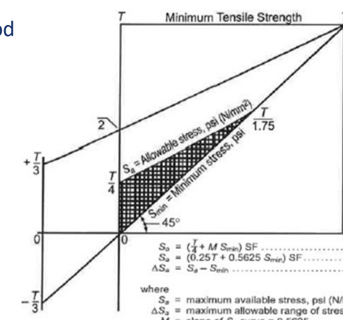
- In PCP rod/tubing interaction results in tangential and rotational loads, whereas in RRP, the interaction is compressive and sliding.
- Movement transitions above the pump (PCP: from eccentric to concentric; RRP: vertical reciprocation) bring additional potential failure risks.

API 11BR Fatigue Design for Sucker Rods

- Selection Criteria
  - Sucker rod selection is governed by a combination of stress effects, environmental conditions, and rod grade.
- Stress Impact and Fatigue Life:
  - Rod strength and endurance are linked to fatigue properties, as represented in the Goodman diagram.
  - A well-chosen, designed, and installed rod is expected to surpass 10 million load reversals, with its operational life influenced by proper handling and environmental factors.
- Corrosion Impact and Grade Suitability:
  - In corrosive environments, the durability of sucker rods hinges on effective corrosion inhibition.
  - Selection by chemical composition and strength properties, varying from several AISI grades.
- Determining Stress Limits:
  - The modified Goodman diagram methodology defines the allowable stress for sucker rods, considering both tensile strength and service conditions.
  - Adjustments to stress values are made based on a service factor that reflects the severity of environmental corrosivity.

API 11BR Fatigue Design for Sucker Rods

- Design Overview:
  - Implements Modified Goodman for fatigue-based design, validated by rod string fatigue testing.
- Operational Loads:
  - PC desing: specific considerations including torque, axial, bending loads
  - RRP design: Adheres to API fatigue criteria.
- Stress Parameters:
  - Allowable loads: 25% of tensile strength for low-strength, 36% for high-strength rods.
  - Service factors down to 0.5 for corrosion or other harsh conditions.
  - PC pump bending stresses: <5-10% of mean load, fully reversing.
  - The RRP exhibits a greater fluctuation of 10-50% in the axial load and the associated stresses.



$S_a = (\frac{T}{4} + M\ S_{min})\ SF$ 1
$S_a = (0.25T + 0.5625\ S_{min})\ SF$ 2
$\Delta S_a = S_a - S_{min}$ 3

where
S_a = maximum available stress, psi (N/mm²)
ΔS_a = maximum allowable range of stress, psi (N/mm²)
M = slope of S_a curve = 0.5625
S_{min} = minimum stress, psi (N/mm²)(calculated or measured)
SF = service factor
T = minimum tensile strength, psi (N/mm²)

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Multiaxial Stress Dynamics

ROD LOADING AND DESIGN METHODOLOGY

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Multiaxial Stress Dynamics in PCP and RRP

Multiaxial stresses encompass various simultaneous stress components acting on rod strings.

- Mean Component: The predominant mean stress is axial, primarily due to the rod's weight and the pumping action.
- Alternating Component: Arises from the reciprocating motion, moving upwards and downwards, combined with wellbore curvature and to/rod interanctions.

RRP Stress Dynamics:

- Mean Component: The mean stress component is primarily due to torque and axial load from the pump's action.
- Alternating Component: Arises from the wellbore curvature, introducing additional varying stresses as the system rotates.

PCP System Stress Dynamics:

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Classical methodology

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- **Application conditions**
  - Estimation of accurate field conditions
  - Technical / Heuristic knowledge
- **Field of stresses estimation**
  - Solid mechanics & constitutive models
- **Fatigue methodolog y**
  - Endurance Limit
  - Goodman Approach
- **Service Factors**
  - Historic applications
  - Holistic approach
- **Deployment in the field**
  - Determine predictability

Rod lift systems are generally reliable, however, unpredictability or premature failures necessitate further design review and solutions development.

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Multiaxial Stress in RRP Rod Strings

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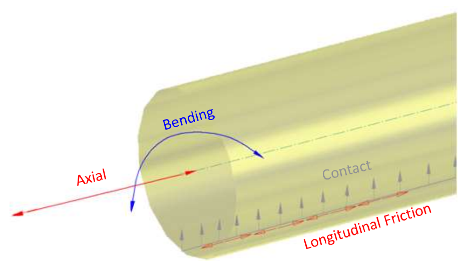
- RRP utilizes Von-Mises criteria. Primarily face axial stresses from the vertical reciprocating motion, with considerations for associated bending moments.
- Stress Contributors:
  - Vertical movement introduces varying degrees of axial stress along the rod length.
  - Bending stresses arise from deviations in wellbore trajectory and equipment misalignment.
  - Wear and Corrosion Effects



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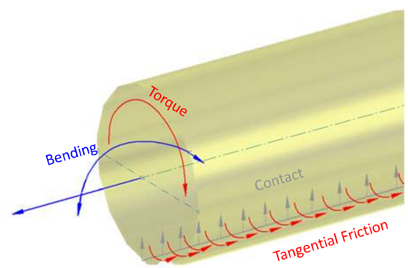
Multiaxial Stress in PCP Rod Strings

- Effective Stress Calculation: Utilizes Von-Mises criteria, primarily considering torque and axial load, with bending and both types of contact stresses factored into the model.
- Stress Contributors:
  - Torque is the predominant stress factor, yet in high lift capacity PC pumps, axial loads have a measurable effect on effective stress.
  - Bending and contact stresses, while minor, contribute to fatigue due to their cyclic nature.
  - Wear and Corrosion Effects



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Contact Stresses - Hertzian Stress

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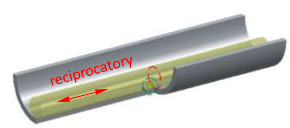
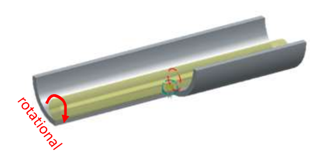
- General Overview:
  - Contact (or Hertzian) stresses arise from forces between two surfaces in contact, influencing wear and fatigue.
- RRP System Dynamics:
  - In RRP, axial sliding of the rod inside the tubing generates axial Hertzian stresses, affected by load, surface conditions, and lubrication.
- PCP System Dynamics:
  - PCP systems experience rotational contact, where rods within the tubing produce complex radial Hertzian stresses, influenced by surface roughness and lubrication.





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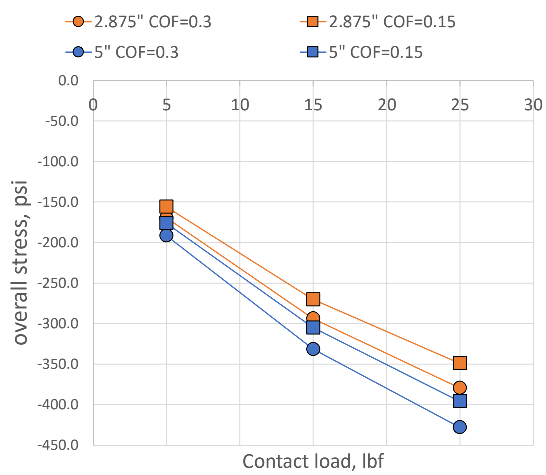
Surface Fatigue and tribology in Rod/Tubing

- Surface Fatigue Fundamentals:
  - Driven by contact stresses affected by material properties, contact geometry, load, and friction.
- Role of Tribology:
  - Analyzes surface interactions with a focus on the role of friction in fatigue life.
- Design Considerations:
  - Incorporates surface fatigue analysis, considering endurance, material hardness, and operational variables like rod diameter and friction levels.
- Crack Prevention and Endurance:
  - Emphasizes crack prevention techniques to enhance rod longevity and reliability.



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Stress Analysis in PCP Rod

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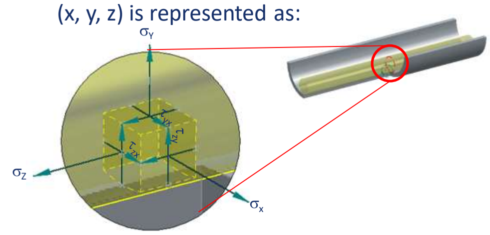
- **Torsional Loads:** Primarily affect shear stresses (τxy, τxz) in planes perpendicular to the rotation axis.
- **Bending Loads**: Influence both normal (σxx, σyy) and shear stresses (τxy, τyx) creating stress gradients across the rod's diameter.
- **Axial Loads**: Impact normal stress σzz typically uniform along the rod's length under constant axial load.
- **Contact Loads:** Generate significant normal stress (σxx, σyy) and shear stresses (τxz, τzx) is influenced by friction.
  - Lead to complex, non-uniform stress distribution around the rod's circumference.
- **Residual stresses:** Arise from operational and manufacturing influences, contributing to overall stress dynamics in the rod system.

$$\sigma_{a,m} = \sqrt{\frac{(\sigma_x - \sigma_y)^2 + \left(\sigma_y - \sigma_z\right)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)}{2}}$$

Triaxial (adds contact)

- A rod rotates inside a stationary tube involves considering torsional, bending, axial, and contact loads.
- The stress tensor in Cartesian coordinates (x, y, z) is represented as:



$$\begin{bmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{zz} \end{bmatrix}$$

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Stress Analysis in PCP Rod – summary

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Stress Tensor Component	Associated/Related Loads	Multiaxial Stress State (Including Contact Stresses)	Classical Methodology (Excluding Contact Stresses)
σ_{xx}	Bending, Normal Contact, Axial Load (if deviated)	Influenced by lateral loads, contact pressure, and bending	Influenced mainly by bending and any axial misalignment
σ_{yy}	Bending, Normal Contact, Axial Load (if deviated)	Influenced by lateral loads, contact pressure, and bending	Influenced mainly by bending and any axial misalignment
σ_{zz}	Axial Load	Dominated by axial loads, including weight and operational forces	Dominated by axial loads, including weight and operational forces
$\tau_{xy} = \tau_{yx}$	Torsion, Bending	Shear stresses from torsion combined with bending and potential lateral contact forces	Shear stresses primarily from torsion and bending effects
$\tau_{xz} = \tau_{zx}$	Torsion, Sliding Contact	Influenced by friction in sliding contact, along with torsional stresses	Influenced mainly by torsional stresses
$\tau_{yz} = \tau_{zy}$	Torsion, Sliding Contact	Influenced by friction in sliding contact, along with torsional stresses	Influenced mainly by torsional stresses

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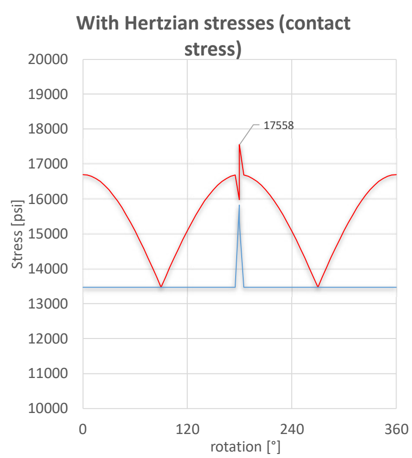
PCP Case: Stress Models

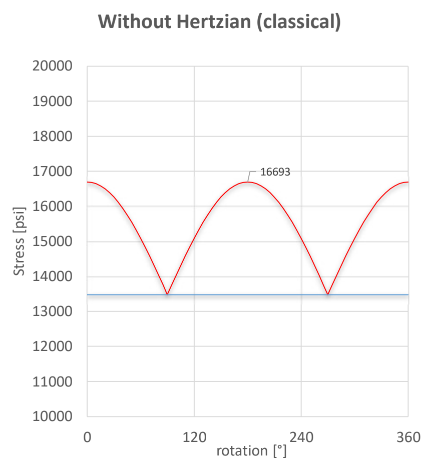
- Exploring stress distribution at a material point on a PCP rod, subject to varying load conditions.
- Model 1 - With Hertzian Stresses:
  - Integrates contact stresses from rod-tubing interaction.
  - Analyzes stress distribution across a 360° rotational cycle, considering both wellbore curvature and Hertzian stresses.
- Model 2 - Without Hertzian Stresses:
  - Focuses on torsional, axial, and curvature-induced stresses, omitting contact stresses.
  - Analyzes stress distribution across a 360° rotational cycle, considering wellbore curvature alone

PCP Case: Stress Models

Stress Distribution Analysis over a 360° Rotation:

Incorporating Wellbore Curvature and Hertzian Stresses in Continuum Models based on Contact Stress Theory.





Vertical wellbore and 15°/100 ft.

Axial load of 10,000 lbf.

Torque: 500 lb-ft.

side Load: 20 lb/ft.

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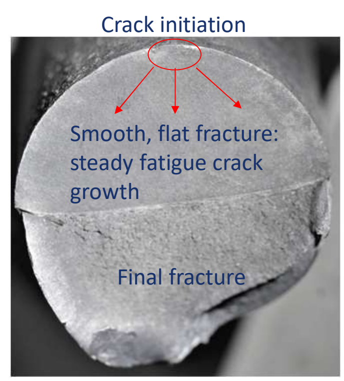
Fatigue Failures in Rod Strings

- Fatigue failures typically occur at loads lower than expected, signaling potential fatigue issues.
- Most non-connection rod failures start with surface cracks leading to full body fractures due to fatigue.
- Cyclic growth of surface-initiated cracks can lead to overload failures when the rod's remaining cross-section is compromised.
- RRP applications face greater alternating loads but fewer cycles, impacting fatigue life and analysis on the Goodman diagram.
- Increased load magnitudes in RRPs may cause unique failure modes, challenging the accuracy of existing predictive models.



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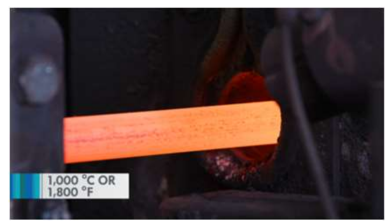
Fatigue Failures in Rod Strings

- Additional factors on fatigue:
  - Minor surface irregularities, often overlooked in specifications during hot-rolling or forging, can significantly impact fatigue performance.
  - Residual stresses from these manufacturing processes are critical in shaping fatigue life, affecting stress distribution and resistance.
  - Corrosion amplifies manufacturing defects, creating stress concentrators that may initiate cracks.
- Advancing Testing and Modeling:
  - The interplay between manufacturing defects, residual stresses, and corrosion demands advanced testing and more sophisticated modeling.
  - To enhance fatigue life predictions and rod design, testing must delve into the complexities of varied loads, particularly contact and residual stresses.



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Tribology and mutiaixal fatigue

ADVANCED TESTING AND STUDIES

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Fatigue Predictability and Industry Standards

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- Industry Standards and Predictive Challenges:
  - Absence of specific PC standards; RRP standards insufficient for PC applications.
  - Current models fall short in predicting real-world fatigue outcomes.
- Call to Action for Enhanced Testing:
  - Need for industry-specific tests and enhanced theoretical models for accurate fatigue life prediction.
  - Companies should invest in refining fatigue models by integrating advanced theoretical understandings that more accurately forecast fatigue life.

Current Capabilities

- Torsional Load up to
- 600 ft·lbs with alternating component up to 50%
- Axial Load up to 15K lbs
- Fully Reverse Bending up to 700 deg/30m
- Speeds up to 500 RPM
- Rod sizes ¾” to 1 3/16”

Capabilities To Be Added

- Contact Load
- Environmental Corrosion Chamber

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Fatigue Predictability and Industry Standards

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- Tribological Studies Enhanced by Tribometry:
  - Tribometers enable a deeper understanding of wear mechanisms, wear rates, and friction forces in contact elements, crucial for product optimization.

Testing configuration with coated continuous rod and tubing

Current Capabilities

- up to 75 lbs/ft for continuous rods and 200 lbs/coupling for sucker rods.
- speeds from 50 to 500 RPM.
- oil/water/solids mixtures and temperatures up to 90°C.
- Continuous measurement of rod/tubing contact torque
- Enables direct comparative testing for enhanced analysis

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Takeaways and Conclusions

Complex Load Dynamics:

- Complexity of static and dynamic loads in PCP and RRP systems, emphasizing the critical role of stress analysis for optimal design and operation.

Challenges in Predictive Modeling:

- Limitations of current predictive models in accurately representing real-life multiaxial load conditions.

Impact of Contact Stresses:

- Underscored the importance of understanding Hertzian stresses in rod performance.

Advancing Rod String Design:

- Industrial tests replicating real-world conditions and innovative design strategies tailored to the specific challenges of various downhole environments, improve predictive fatigue models.

Collaboration for Future Progress:

- This discussion reinforces the value of collaborative efforts in evolving downhole technologies for enhanced efficiency.

QUESTIONS & DISCUSSION

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