Proceedings of the 35th European Safety and Reliability & the 33rd Society for Risk Analysis Europe Conference
Edited by Eirik Bjorheim Abrahamsen, Terje Aven, Frederic Bouder, Roger Flage, Marja Ylönen

doi: 10.3850/978-981-94-3281-3_ESREL-SRA-E2025-P3716-cd

Research status and development trend of risk and reliability evaluation of blowout preventer group under ultra-high temperature and high pressure

First author: Tianqi Liu
1.College of Safety and Ocean Engineering, China University of Petroleum(Beijing); 2. Key Laboratory of Oil and Gas Production Safety and Emergency Technology, Ministry of Emergency Management; 3. Key Laboratory of Oil and Gas Production Equipment Quality Inspection and Health Diagnosis, State Administration for Market Regulation, China. E-mail: 18330259973 @163.com

Corresponding author: Shengnan Wu
1.College of Safety and Ocean Engineering, China University of Petroleum(Beijing); 2. Key Laboratory of Oil and Gas Production Safety and Emergency Technology, Ministry of Emergency Management; 3. Key Laboratory of Oil and Gas Production Equipment Quality Inspection and Health Diagnosis, State Administration for Market Regulation,China. E-mail: wushengnan@ cup.edu.cn

Third author: Junhui Wei
1.College of Safety and Ocean Engineering, China University of Petroleum(Beijing); 2. Key Laboratory of Oil and Gas Production Safety and Emergency Technology, Ministry of Emergency Management; 3. Key Laboratory of Oil and Gas Production Equipment Quality Inspection and Health Diagnosis, State Administration for Market Regulation,China. E-mail: wjhui-tlm@petrochina.com.cn

Abstracts: In the field of oil and gas drilling, the blowout preventer (BOP) serves as a crucial component of well control equipment, playing a vital role in preventing blowout accidents and ensuring production safety. However, in harsh downhole environments with ultra-high temperatures and pressures, the sealing and shearing capabilities of the BOP system can easily diminish due to component failures, necessitating robust reliability management as the cornerstone of risk prevention and control. This article comprehensively analyzes the risk factors that impact the reliability of BOP systems and summarizes the current testing experiments, risk assessment techniques, and simulation technologies involved in BOP systems. Additionally, it systematically reviews the latest advancements in reliability assessment, fault prevention, and control technologies for BOP systems. Furthermore, it discusses future trends in this field. Research indicates that as drilling technology advances towards extreme conditions such as ultra-deep and ultra-high temperature and pressure wells, enhancing the systematization and intellectualization capabilities of BOP system reliability management technologies is crucial for ensuring the safety of drilling operations and promoting efficient oilfield development.

Keywords: Ultra-HTHP, Blowout preventer, Reliability, Sealing performance, Risk assessment, Failure prevention and control.

1. Introduction

In oil and gas drilling operations, various factors can lead to wellbore pressure imbalance, ultimately causing well blowouts with dire consequences such as personnel casualties, equipment damage, and reservoir destruction. To mitigate these risks, well control equipment plays a key role by quickly and precisely restoring pressure control when a blowout occurs.The blowout preventer, as the core component of well control equipment, is crucial for ensuring effective pressure management in oil and gas wells due to its reliability.

Techniques used for reliability analysis of BOP systems include failure mode and impact analysis (FMEA), fault tree analysis (FTA), reliability block Diagram (RBD), Petri net (PN), Markov modeling, Bayesian network (BN)(Kong et al., 2024a; Kong et al., 2023), Monte Carlo simulation (MCS)(Shafiee et al., 2020), etc. In recent years, a large number of scholars like to use Bayesian method to analyze blowout risk and BOP reliability(Duim et al., 2020; Kong et al., 2024b; Wang et al., 2023a). Based on SINTEF offshore blowout data and ExproSoft BOP failure data, the BN-risk human reliability analysis method was combined to identify the main factors leading to BOP failure(Yin et al., 2021); FBN model based on fuzzy set theory(Cai et al., 2022), was introduced to identify BOP failure scenarios combined with STAMP model, and the potential failure mode probability was calculated by considering the relationship among relevant personnel, components and control system(Meng et al., 2022); In addition, methods using random culture nets were developed to assess the reliability of subsea BOP systems affected by state maintenance(Elusakin and Shafiee, 2020). By fitting the three-parameter Weibull distribution to the fault data, the life distribution, reliability and failure rate functions of the key components of the BOP hydraulic system are obtained(Cao et al., 2024a; Cao et al., 2024b).

The reliability assessment technology of BOP involves many international standards, such as API, ISO, NORSOK, etc. These standards have limitations in practical application, such as insufficient environmental adaptability, insufficient dynamic load assessment, lack of intelligent technology, lagging material technology, neglect of human factors, insufficient life cycle management and inconsistent international standards(Beal et al., 2017; Cao et al., 2024b; Cipollone et al., 2018; Enjema et al., 2018; Meng et al., 2022; Shafiee et al., 2020). By drawing on the latest research results, future standards should introduce advanced monitoring technologies, strengthen dynamic performance assessment, promote intelligent standards, update material performance requirements, incorporate human factor assessment, promote full life cycle management, and enhance the coordination of international standards. These improvements will help improve the reliability and safety of the BOP in complex operating environments.

On the basis of the risk and reliability assessment of the blowout preventer, a large number of scholars use simulation and experiment methods to further verify the factors affecting the reliability of the blowout preventer, especially the mechanical properties of key materials(Wang et al., 2022a), stress distribution(Jia et al., 2021; Zhou et al., 2024), seal failure analysis(Hu et al., 2021; Liu et al., 2023; Wan et al., 2024), and shear force evaluation(Zhang et al., 2023). The transient stress, pressure and velocity fields during BOP closure were analyzed by 3D transient simulation using CFD(Barreca and Tyagi, 2023). A BOP top seal failure analysis model was constructed by optimizing the parameters of the nitrile butadiene rubber constitutive model(Zhang et al., 2024), and the results showed that top seal corrosion(Dong et al., 2022) and wear defects had significant effects on contact seals(Wang et al., 2023b). The CrashFEM criterion was applied to the shear simulation of the subsea BOP plunger(Zhu et al., 2020), and the shear capacity and closing time of the subsea BOP were studied(Quispe et al., 2022). The above research provides important theoretical support for the design and optimization of the BOP.

In response to the risk challenges faced by the reliability of blowout preventers, some scholars have explored technologies to optimize sealing performance(Xu et al., 2024), improve operational efficiency(Khan et al., 2021; Song et al., 2020) and enhance environmental adaptability(Dui et al., 2020; Wu et al., 2021). Attempting to determine the optimal combination of structural angle and inner diameter size for rubber cores, as well as the safe operating speed of drill pipes under varying wellhead pressures(He et al., 2020); Trying to effectively reduce BOP flat time and lower drilling costs by optimizing factors such as drilling rig procedures, BOP configurations, and connection types(Khan et al., 2021). Integrating reservoir and wellbore pressure proactive modeling and monitoring technologies(Wang et al., 2022b), the process of containing subsea blowouts through "cap-and-constrain" or "cap-and-divert" methods was discussed(Khouissat and Michael, 2024).High-pressure water jet-assisted pre-cutting technology, which is currently in the pre-feasibility stage, is used to reduce the force required for BOPs to shear drill pipes(Xiao et al., 2024).

Currently, BOP fault prevention and control technologies primarily include real-time monitoring and diagnostics, predictive maintenance, redundancy design, intelligent control, materials and coating technologies, and human factor mitigation(Cai et al., 2013; Lukin et al., 2023; Mutlu et al., 2018; Wang et al., 2023c; Wassar et al., 2019). Real-time monitoring technology utilizes sensors and the Internet of Things (IoT) to enable continuous surveillance of BOP operating conditions, significantly improving the timeliness of fault detection. Predictive maintenance technology, based on historical data and machine learning algorithms, optimizes maintenance schedules and reduces the risk of unexpected failures. Redundancy design enhances overall reliability by incorporating backup systems. Intelligent control technology leverages artificial intelligence to achieve rapid response and precise operations. Advanced materials and coating technologies significantly improve the durability of critical components in extreme environments. Human factor mitigation technology reduces human errors through training and operational protocols. However, these technologies still face limitations in practical applications, such as the high installation and maintenance costs of real-time monitoring systems, the reliability of intelligent control technologies in extreme environments yet to be fully validated, and the lack of standardized specifications for the application of new materials. Therefore, future research needs to further optimize existing technologies, reduce costs, and enhance adaptability, while promoting the updating and refinement of relevant standards to comprehensively improve the fault prevention and control capabilities of BOPs in complex operating environments.

However, there is a lack of a comprehensive framework for BOP reliability management. This paper delves into various risk factors that impact the reliability of blowout preventer systems, and summarizes the performance testing and reliability assessment techniques currently applied to these systems. Additionally, it comprehensively reviews the latest research findings on fault diagnosis, prevention, and control for BOP systems, and discusses the future development trends in this field.

2. Basic principles and reliability evaluation of BOP

2.1. *Basic principle*

BOPs maintain pressure balance within the well by adjusting the flow rate and pressure of drilling fluid, thereby preventing blowout accidents. In practical field applications, the appropriate type and combination of BOPs should be selected based on specific operational requirements. A common ultra-high-pressure BOP stack is shown in Fig. 1.

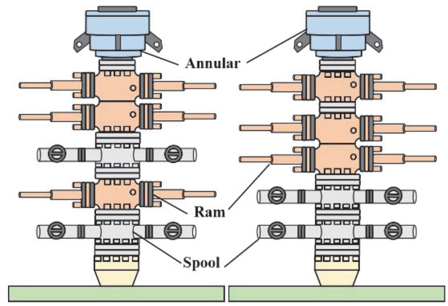

Fig. 1. Combination method and structure diagram of BOP

2.2. *Reliability analysis technique*

In the field of oil and gas drilling and production, the commonly used equipment reliability analysis techniques include failure mode and impact analysis, reliability block diagram analysis, stress-strength interference analysis, fault tree analysis and Monte Carlo simulation.

However, the evaluation of the reliability of a BOP system also requires special attention to the problem of common cause failure, that is, the simultaneous failure of multiple components due to the same underlying cause. In view of this, in recent years, more and more scholars tend to use bayesian networks to analyze the reliability of BOP (Cai et al., 2013; Liu et al., 2015; Liu et al., 2022). In particular, the dynamic bayesian model is widely used for the characteristics of the fatigue degree of each component in the BOP changing with time. As shown in Fig. 2, the model is divided into three layers of risk event layer, component layer and system layer, and each node has two states of normal ("YES") and failure ("NO").

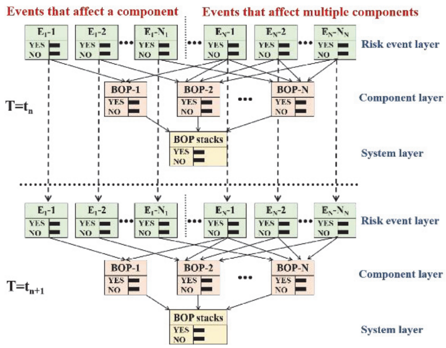

Fig. 2. Bayesian model of BOP system dynamics

Currently, the reliability analysis technology for BOP systems confronts core challenges such as inadequate technology integration, limited intelligence levels, and significant difficulties in collecting field data.

3. Cause analysis of BOP failure

The risk factors that lead to the failure of BOPs are highly complex and diverse, and these risks mainly stem from fatigue degradation of materials, improper operations, and extreme operating conditions where pressure or temperature exceeds the designed tolerance range (Ma et al., 2017; Tang et al., 2013), as shown in Fig. 3. In order to deeply explore the key parameters that affect the sealing and shear capacity of the BOP, so as to optimize its structural design and improve its overall reliability, many scholars have carried out a large number of test experiments and simulation studies.

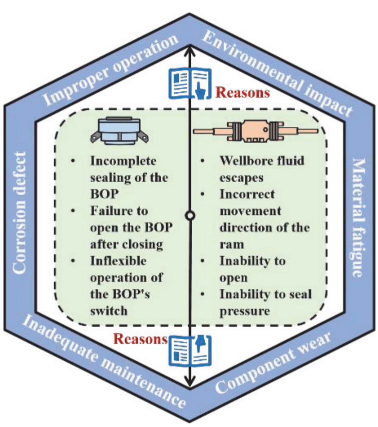

Fig. 3. Common failures and causes of BOP

3.1. *Test experiment of BOP*

The test experiment of the BOP is the cornerstone to ensure its quality and safety, which forms a comprehensive quality control system from raw material selection to finished product delivery. This system includes not only the overall performance test of the BOP to verify its sealing, shearing and bearing capacity under extreme conditions, but also specific tests for key components such as the core, which are designed to further evaluate the temperature, wear and corrosion resistance of the core, so as to ensure that the BOP can continue to perform a stable role in the complex downhole environment (Liu et al., 2023; Wang and Li, 2023; Xu et al., 2024; Zhao et al., 2012). The primary categories of BOP tests, along with their respective objectives, are outlined in Table 1. These tests collectively serve to systematically appraise the performance indices of the BOP, thereby furnishing a robust scientific foundation for enhancing its design optimization and reliability improvement endeavors.

Table 1. Types and purposes of BOP tests

Test class	Test purpose
Pressure test	Sealing integrity under extreme downhole pressure conditions.
Switch test	Smoothness of opening and closing, and ability to complete action within specified time.
Material property test	Strength, high-temperature resistance, corrosion resistance, et al.
Dimensional compliance test	Internal diameter, flange face, seal groove, et al.
Fatigue test	Performance of ram and core after repeated switching.
Hydraulic closing ram test	Seal effect after closing ram .

However, BOP testing has faced limitations such as difficulty replicating extreme well conditions, high cost, narrow test scope, and human-induced uncertainties.

3.2. *Simulation of BOP*

Prior researchers have undertaken comprehensive and meticulous simulation studies pertaining to the structural optimization of blowout preventers, as exemplified in Fig. 4.

On the one hand, for annular BOPs, they employed the Yeoh constitutive model and various mechanical test data to simulate the large deformation behavior of nitrile rubber. This allowed for a detailed investigation of the stress and deformation patterns of the full-size rubber core during operation, aiming to enhance the service life and sealing performance of the rubber core (Dong et al., 2023; Li et al., 2019).

On the other hand, for ram BOPs, finite element models of the ram and drill pipe were constructed (Xu et al., 2024; Zhang et al., 2017). Through variable-parameter simulations, the stress distributions under different pit defect conditions were calculated, and the fatigue crack propagation characteristics of the housing and their impact on service life were thoroughly discussed. The relationship between the structural parameters of the ram and drill pipe and the maximum shear force was determined, providing a scientific basis for optimizing the design of tool structural parameters.

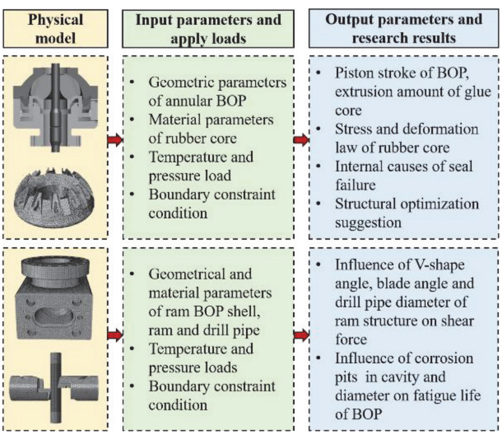

Fig. 4. Simulation model and results of BOP

BOP testing experiments and simulation modeling complement each other, jointly providing multidimensional data support for BOP reliability assessment, thereby comprehensively revealing its performance and potential risks under actual operating conditions.

4. Study on prevention and control strategy of BOP failure

4.1. *Failure detection technique*

Nondestructive testing technology and pressure monitoring technology are important means of failure detection of BOP (Chauveau, 2018; Wang et al., 2022b; Zolfaghari et al., 2018).

In the non-destructive testing technology, ultrasonic testing can effectively detect the internal cracks, pores and other defects of the blowout preventer by virtue of its high sensitivity and strong penetration characteristics in the material; Magnetic particle detection is applicable to ferromagnetic materials, judging defects by magnetic field and magnetic particle distribution; Penetration detection is simple and effective by applying special penetrant to observe surface cracks.

Pressure monitoring technology utilizes pressure sensors to monitor real-time changes in downhole air pressure, converting these signals into electrical signals for recording and analysis. This allows for the timely detection of abnormal pressure changes, thereby assessing the failure risk of BOPs. The comprehensive application of these technologies aims to ensure the safe and reliable operation of BOPs, providing robust support for oil drilling operations.

4.2. *Failure prevention measures*

In view of the common failure modes of the blowout preventer, in addition to optimizing the structural design, the prevention and control measures of the oilfield site are shown in Table 2.

Table 2. Prevention and control measures of BOP failure

Type of BOP	Failure of BOP	Field measure
Annular BOP	Incomplete sealing of the BOP	Replace the rubber core in time.
	Failure to open the BOP after closing	Clean the cement paste remaining under the glue core.
	Inflexible operation of the BOP's	Purge with compressed air.

	switch	
	Wellbore fluid escapes	Close the ram immediately and activate the emergency plan.
Ram BOP	Incorrect movement direction of the ram	Check the connection line and manual release mechanism.
	Inability to open	Check seals and connections and try manual operation.
	Inability to seal pressure	Adjust seal size to ensure adequate pressure.

To address the limitations of human response speed and information transmission efficiency, the industry is actively developing intelligent BOP control systems with remote monitoring and automatic adjustment capabilities to enhance fault prevention and control efficiency.

5. Future trends and challenges

5.1 *Intelligent BOP technology*

The integration of advanced technologies such as artificial intelligence, signal processing, computer science, and pattern recognition has gradually transformed BOP fault detection, with methods like vibration, temperature, pressure, and acoustic monitoring, visual inspection, and oil analysis becoming increasingly prevalent. However, challenges persist in practical applications, particularly in achieving high accuracy, stability, and timeliness due to insufficient interdisciplinary collaboration and the harsh downhole conditions of high temperature and high pressure, which hinder comprehensive data collection. To address these limitations, future advancements should focus on developing high-precision sensors, optimizing signal processing algorithms, and promoting real-time monitoring and intelligent warning systems. By deepening technology integration, advancing intelligent upgrades, and overcoming field data collection challenges, these efforts will significantly enhance the accuracy and timeliness of fault diagnosis, providing robust support for the safe and efficient operation of oil and gas drilling activities.

5.2 *BOP life-cycle management*

Due to the increasing complexity of drilling environments and the growing demand for operational safety, the future trend of BOP reliability management is characterized by its systematic, flexible, and forward-looking advantages, encompassing a full lifecycle management approach that integrates risk identification, assessment, mitigation, and continuous monitoring. In response to this trend, we have proposed a preliminary framework to address these challenges effectively, as shown in Fig. 5.

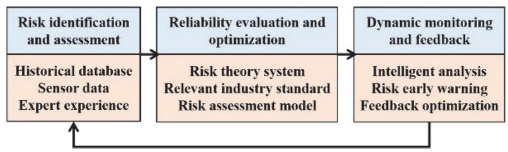

Fig. 5. BOP system reliability management framework

The BOP reliability management framework is a comprehensive and systematic approach designed to ensure the safe and efficient operation of BOP systems. It begins with the Risk Identification and Assessment module, which utilizes historical data analysis and expert evaluations to identify and classify key risk sources into technical, operational, and environmental risks. Building on this foundation, the Reliability Assessment and Optimization module employs dynamic Bayesian models to quantify risks, evaluate their probability and potential impact, assess the overall reliability of the BOP system, and propose targeted optimization measures. Finally, the Dynamic Monitoring and Feedback module integrates real-time data monitoring and intelligent analytics to continuously track the operational status of the BOP system and refine risk management strategies based on actionable feedback. Together, these interconnected modules form a robust and adaptive framework that addresses the full lifecycle of BOP reliability management.

6. Conclusions

This study reviews the testing experiments and simulation technologies of the BOP system, summarizing the latest advancements in reliability assessment and fault prevention, providing support for maintaining system performance and ensuring operational safety.

In the face of the trend of drilling technology to extreme conditions, the future BOP system needs to improve systematic and intelligent management capabilities, and use the Internet of Things to achieve real-time monitoring and early warning.

Acknowledgement

The research is supported by National Natural Science Foundation of China (No.52474019) and Science Foundation of China University of Petroleum, Beijing (No. 2462024QNXZ004) . The authors will be grateful for the reviewers' and editor's helpful comments.

References

Barreca, D. and M. Tyagi, "Transient Analysis of Fluid Flow through a Closing Blowout Preventer Using Coupled Domain Computational Fluid Dynamics," in Spe Drilling & Completion (2023).

Beal, V.E., M. Araujo, J. Oliveira, R.T. Claro, S.Q. Figliuolo, F. Silva, and Asme, "CHALLENGES ON DESIGN, MANUFACTURING AND SUPPLY CHAIN DEVELOPMENT OF A BLOWOUT PREVENTER FOR ONSHORE OIL & GAS WELLS IN BRAZIL," in ASME International Mechanical Engineering Congress and Exposition (Tampa, FL: 2017).

Cai, B., Y. Liu, Z. Liu, S. Yu, Y. Zhang, Q. Fan, and Y. Zhuang, "Security and Reliability Research of Remote Access for Subsea Blowout Preventer System," in International Conference on Materials Science and Mechanical Engineering (ICMSME 2013), Applied Mechanics and Materials (Kuala Lumpur, MALAYSIA: 2013).

Cai, B., L. Zhao, Y. Liu, Y. Zhang, W. Li, X. Shao, Y. Zhao, Z. Liu, R. Ji, and Y. Liu, "Quantitative risk assessment methodology of installation process for deepwater oil and gas equipment," in Journal of Cleaner Production (2022).

Cao, Y., Y. Zhang, C. An, and Asme, "USING 3-P WEIBULL DISTRIBUTION EVALUATE RELIABILITY OF DDV AND SPM VALVE HYDRAULIC SYSTEM OF BOP," in ASME 43rd International Conference on Ocean, Offshore and Arctic Engineering (OMAE) (Singapore, SINGAPORE: 2024).

Cao, Y., Y. Zhang, S. Wu, and C. An, "Reliability analysis of DDV and SPM in BOP-based Weibull model and expand fault dataset using deep learning," in Ocean Engineering (2024).

Cipollone, R., F. Fatigati, and D. Di Battista, "Model-Based Design of Energy Accumulators for Control of Subsea Wells," in Journal of Pressure Vessel Technology-Transactions of the Asme (2018).

Dong, L., Y. Tang, and L. Wang, "Influence of oil pipe corrosion defects on the sealing performance of annular BOP," in Structural Engineering and Mechanics (2022).

Dui, H., C. Zhang, and X. Zheng, "Component joint importance measures for maintenances in submarine blowout preventer system," in Journal of Loss Prevention in the Process Industries (2020).

Duim, F.A.C., P.A.A. Garcia, P.L.C. Saldanha, C.M.C. Jacinto, and G.B.A. Lima, "Experts' opinion-based Bayesian Inference for the Coverage Factor in BOP Reliability," in Ieee Latin America Transactions (2020).

Elusakin, T. and M. Shafiee, "Reliability analysis of subsea blowout preventers with condition-based maintenance using stochastic Petri nets," in Journal of Loss Prevention in the Process Industries (2020).

Enjema, E.M., M. Shafiee, and A. Kolios, "An integrated bayesian network and cost-benefit analysis model for blowout preventer configuration selection in deepwater offshore fields," in 28th Annual International European Safety and Reliability Conference (ESREL) (Trondheim, NORWAY: 2018).

He, Y., Y. Fan, P. Wu, C. Xia, J. Huang, J. Wu, L. Qian, and X. Liu, "Fatigue life optimization towards rubber core sealing surface of under-balanced drilling rotating blowout preventer," in Engineering Failure Analysis (2020).

Hu, G., M. Wang, G. Wang, T. Zhu, and L. Wei, "Sealing performance and failure mechanism analysis of packing unit used in rotary blowout preventer for under-balanced drilling," in Engineering Failure Analysis (2021).

Jia, J., Y.N. Su, Y. Shen, G.X. Hu, L.T. Zhang, L. Wang, and L.M. Sheng, "Influence of the Blowout Preventer Shut-Off Process on Wellbore Pressure," in Chemistry and Technology of Fuels and Oils (2021).

Khan, J.A., S. Irawan, A.S. Thurai, and B. Cai, "Quantitative analysis of blowout preventer flat time for well control operation: Value added data aimed at performance enhancement," in Engineering Failure Analysis (2021).

Khouissat, A. and A. Michael, "Blowout Contingency Decision- Making Leveraging Reservoir/Wellbore Pressure Modeling: Cap-and-Restrain or Cap- and-Divert?," in Spe Journal (2024).

Kong, X., B. Cai, J.A. Khan, L. Gao, J. Yang, B. Wang, Y. Yu, and Y. Liu, "Concurrent fault diagnosis method for electric-hydraulic system: Subsea blowout preventer system as a case study," in Ocean Engineering (2024).

Kong, X., B. Cai, Y. Liu, H. Zhu, C. Yang, C. Gao, Y. Liu, Z. Liu, and R. Ji, "Fault Diagnosis

Methodology of Redundant Closed-Loop Feedback Control Systems: Subsea Blowout Preventer System as a Case Study," in Ieee Transactions on Systems Man Cybernetics-Systems (2023).

Kong, X., B. Cai, Z. Zou, Q. Wu, C. Wang, J. Yang, B. Wang, and Y. Liu, "Three-model-driven fault diagnosis method for complex hydraulic control system: Subsea blowout preventer system as a case study," in Expert Systems with Applications (2024).

Liu, Y., L. Qian, C. Xia, J. Zou, Z. Lian, and X. Yi, "Failure analysis and structural optimization of rubber core and support rib of full-size spherical blowout preventer," in Engineering Failure Analysis (2023).

Lukin, N., M. Bruenig, and L. Driemeier, "Metamodeling of structural failure: Case study of API S-135 steel tube cut in BOP," in Geoenergy Science and Engineering (2023).

Meng, X., G. Chen, J. Zhu, and T. Li, "Application of integrated STAMP-BN in safety analysis of subsea blowout preventer," in Ocean Engineering (2022).

Mutlu, M., T. Wassar, M.A. Franchek, A.E. Omrani, and J.A. Gutierrez, "Real-Time Condition and Performance Monitoring of a Subsea Blowout Preventer Pipe Ram," in Spe Drilling & Completion (2018).

Quispe, J.L.P., L. Zhu, S.F. Estefen, and M.I.L. de Souza, "Ram Performance and Hydraulic Modeling of Subsea Blowout Preventer Control System," in Spe Drilling & Completion (2022).

Shafiee, M., T. Elusakin, and E. Enjema, "Subsea blowout preventer (BOP): Design, reliability, testing, deployment, and operation and maintenance challenges," in Journal of Loss Prevention in the Process Industries (2020).

Song, F., K. Li, C.S. Rivas, K. Bieneman, T. Yap, and Asme, "MULTIDISCIPLINARY OPTIMIZATION-ENABLED DESIGN AUTOMATION AND OPTIMIZATION FOR BLOWOUT PREVENTER PIPE RAMS," in ASME International Mechanical Engineering Congress and Exposition (IMECE) (Electr Network: 2020).

Wan, Z., Z. Lian, T. Xie, J. Shi, Z. Zhao, and N. An, "Analysis of sealing performance of the rotary blowout preventer rubber ring in ultra deep wells," in Journal of Rubber Research (2024).

Wang, C., B. Cai, X. Shao, L. Zhao, Z. Sui, K. Liu, J.A. Khan, and L. Gao, "Dynamic risk assessment methodology of operation process for deepwater oil and gas equipment," in Reliability Engineering & System Safety (2023).

Wang, J., D. Ma, Y. Xia, Z. Lian, Y. Mou, and Z. Wan, "Failure mechanism analysis of ram BOP in HTHP gas well and mitigation measures," in Engineering Failure Analysis (2022).

Wang, S., L. Zhang, J. Yu, and J. Fan, "Influence of Top Seal Damage on Contact Seal in Ram Blowout Preventer," in Materials (2023).

Wang, S., L. Zhang, P. Yu, Q. Xu, J. Fan, and J. Yu, "Buried Defect Detection Method for a Blowout Preventer Seal Ring Groove Based on an Ultrasonic Phased Array," in Materials (2022).

Wang, Y., Y. Pei, Y. Sun, Z. Yu, L. Ding, Y. Wu, J. Guo, and K. Du, "Gas gushing damping mechanism and its engineering application of bottom hole combined drilling tool," in Journal of China Coal Society (2023).

Wassar, T., M. Mutlu, M.A. Franchek, and O. Hattab, "Model-Based Health Monitoring of Annular Blowout Preventers," in Spe Drilling & Completion (2019).

Wu, J., Y. He, K. Wu, M. Dai, and C. Xia, "The performance optimization of the stripper rubber for the rotating blowout preventer based on experiments and simulation," in Journal of Petroleum Science and Engineering (2021).

Xiao, S., M. Xiang, J. Guo, J. Cui, Q. Tang, and J. Jiang, "Study on the Shearing Force of Ram and Fracture Characteristics of Drillpipe Under Precutting," in Spe Journal (2024).

Xu, Y., F. Li, Q. Li, Y. Wang, J. Nie, and L. Yang, "Numerical simulation method and structural optimization for shearing capacity of ram blowout preventers," in Geoenergy Science and Engineering (2024).

Yin, B., B. Li, G. Liu, Z. Wang, and B. Sun, "Quantitative risk analysis of offshore well blowout using bayesian network," in Safety Science (2021).

Zhang, F.-L., J.-T. Ni, L.-B. Zhang, Y.-S. Chen, and J.-J. Wang, "BOP shear force evaluation under complex scenarios," in Petroleum Science (2023).

Zhang, J., Q. Li, C. Zhang, P. An, Y. Yan, M. Liu, T. Chen, L. Zhao, and D. Wang, "High-temperature sealing performance and structure optimization of rubber core for conical blowout preventer," in Geoenergy Science and Engineering (2024).

Zhou, Z., B. He, Y. Xu, H. Liu, and Z. Zeng, "Dynamic calculation of stress influence law of rubber core sealing surface of the rotating blowout preventer with defects," in Journal of Strain Analysis for Engineering Design (2024).

Zhu, L., S.F. Estefen, and M.I. Lourenco, "Fracture criteria applied to numerical simulation of blowout preventer ram shearing," in Engineering Failure Analysis (2020).