Model-based approach examines entire subsea BOP control system rather than address component failures with 'band-aid' solutions

Physics-based model can provide holistic understanding of BOP system, leading to improved overall reliability

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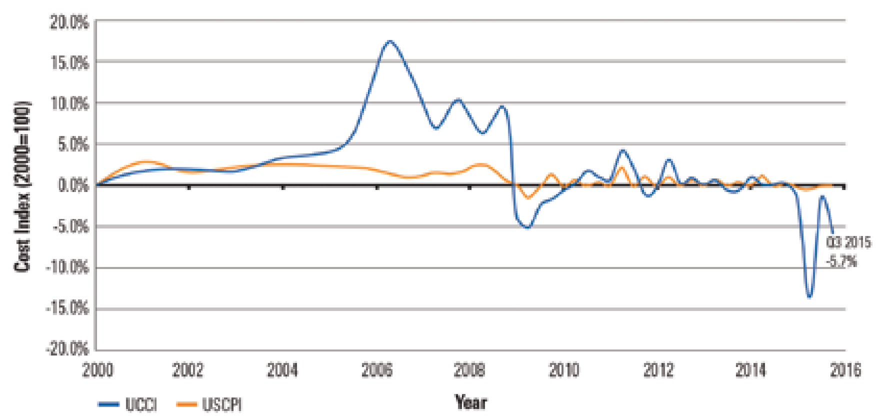

SOURCE: IHS CERA CAPITAL COST ANALYSIS SERVICE. 2016. UPSTREAM CAPITAL COST INDEX (UCCI), 2000-2015. DATA SET, IHS, CAMBRIDGE, MASSACHUSETTS

FIGURE 1: Putting temporary "band-aids" on BOP failures adversely affects not just HSE but also economics. Over the past 16 years, the annual percentage change in the upstream capital cost index reached nearly 20% at its peak. Compare that with the US Consumer Price Index, which never exceeded 3% in the same time period.

ASK SUBSEA ENGINEERS WHAT KEEPS them up at night, and failure of the BOP control system will inevitably rank high on the list. There has been a great effort to improve the reliability of these systems over the past few decades. Much of this effort has focused on analysis of the individual components. However, when those components are connected together, their dynamic interaction can result in unanticipated system-level behavior that is more than the sum of the constituent components.

As those same subsea engineers would attest, this sometimes can increase the likelihood of performance issues and system failure, which have an adverse impact not only on finances but also on HSE. Understandably, operators are insistent that the root cause of failures be identified and corrected in an efficient and cost-effective manner.

Traditionally, physical testing was the only way to validate the expected operation and dynamic stability of a drilling control system. Today, high-speed digital computing provides an alternative for modeling complex control system dynamics, reducing reliance on expensive cycles of physical testing. This constitutes a paradigm shift from traditional industry practices, charting a new course to examine and understand connected system behavior. Based on the insight that rig system behavior is more than the sum of the constituent parts, this model-based approach for solving rig control system problems is diagnosing and treating equipment problems and providing a remedy for operator frustrations.

INSTABILITY OF COMPONENTS

An example of this model-based approach was documented in a recent case study in which an operator of a deepwater vessel reported several instances of unexpected failure of a drilling control circuit, resulting in rig downtime estimated to be in excess of 30 hours per affected rig annually. The circuit failure manifested itself as instability of the hydraulic pressure control components. While functioning the actuator, the pressure regulator began violently oscillating, resulting in high pressure transients and subsequent failure and non-operability of the regulator or its associated hardware. Iterative cycles of troubleshooting, testing and measuring were conducted. Attempted corrective efforts included:

- Replacement of pressure regulator with alternatives supplied by different manufacturers;
- Incorporation of hydraulic accumulators to absorb pressure transients; and
- More robust construction and support of components.

These component changes were only marginally successful, at best improving reliability for less than one year. More importantly, a comprehensive review of historical field reports established a string of related failures recorded as far back as 10 years prior.

MODEL-BASED APPROACH

Unfortunately, stubborn field failures such as this one are all too common. The solutions discussed above illustrate what has become the canonical industry approach to resolving these problems: isolating the fault to the failing component(s), sending service technicians, conducting physical testing of a proposed solution, analyzing data and iterating until converging on a solution – often a temporary "band-aid." These cycles are costly to operators and OEMs.

Perhaps the best way to visualize this is in Figure 1, which shows the annual percentage change in upstream capital cost index (UCCI), a measure of price inflation of goods and services in the upstream sector (source: **IHS**), compared with the general US Consumer Price Index (CPI) over the past 16 years. At its peak, the annual percentage change in the UCCI reached nearly 20%. Over the same period, the metric for the US CPI did not exceed 3%. The myriad causes for this excess are left to the reader to decide, but a natural corollary is that the aforementioned build-test-troubleshoot cycles and reliability issues are contributing factors.

However, perhaps there is a way to beat the status quo. The method that proved effective in this case study was using dynamic computational models to estimate system behavior. In contrast to the traditional approach, such a model can provide a baseline estimate of system performance a priori, and then digitally iterate ad infinitum until finding an optimal solution (Figure 2).

At its core, a model is simply a way of relating the input of a system to its corresponding output. In turn, that system can be decomposed into constituent subsystems and components. While a drilling control system is a complicated hydro-mechanical system, often a relatively simple low order physics-based model can still quantify the system behavior with an acceptable degree of integrity. Using elementary principles of fluid mechanics and dynamics, just such a model of the failing hydraulic control circuit was developed in a discrete simulation software package.

FINDING A SOLUTION

Through the model-based process, the root cause of the high-pressure transients causing the field performance issues was identified. A modality was discovered for air to ingress into the circuit as a result of how the components were connected together, which altered the fundamental fluid properties and drove an oscillatory hydraulic response. The model predicted that a simple check valve would eliminate the issue by preventing air ingress into the circuit. The salient point is the failure arose not as the result of intrinsic deficiencies in the regulator or other components but because of the emergent behavior of these simple components when connected together once installed on the rig.

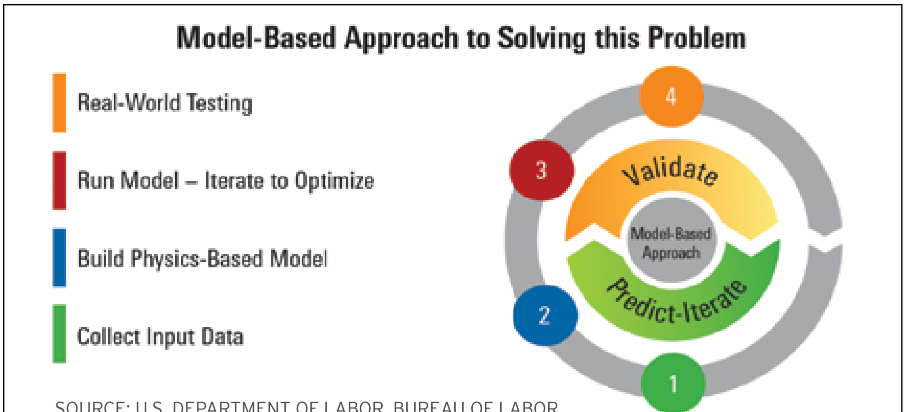

FIGURE 2: The model-based approach to resolving field performance issues relates the input of a system to its corresponding output.

SOLVING REAL WORLD PROBLEMS

The prescription for success was to apply a system solution to a system problem rather than a component solution to a system problem. Ultimately, the focus on components' symptoms had belied the truth – a larger system disorder was at work. This disorder arose as the result of the connection of seemingly simple components. But the key takeaway is not that model-based design works but why it works. British mathematician **George Cox** is credited with the aphorism, "All models are wrong; some are useful." By definition, models are an approximation of reality. To develop a model, abstraction is required to capture the salient features of the underlying system, while suppressing the supposed extraneous, higher-order effects.

In fact, the model developed in this case study initially predicted results contrary to what was observed in the real world system. This discrepancy is an often-cited critique of modeling and simulation. However, the apparent lack of resolution should not be a cause to eschew the model-based process. A physics-based model is conducive to an intuitive, holistic understanding of the system in terms of engineering first principles. It allows us to see the bigger picture of how an assemblage of components moves in complex ways over time and captures the emergent behavior of the integrated system.

In this case study, this glimpse of the bigger picture allowed a testable hypothesis to be posed: Could increasing fluid capacitance due to entrapped air contribute to the pressure transients responsible for the component failures? The value of the model was less about answering this question and more about arriving at this question in the first place. Rather than providing answers, it forces us to perform the more difficult task of asking the right question.

SAFER, MORE RELIABLE SYSTEM

Experience is a hard teacher – we get the test first, then the lesson. Nonproductive time on a drilling rig is an expensive lesson to learn. Fortunately, advanced digital tools and a paradigm shift in engineering processes are allowing our industry to take a "sneak peek" at the test questions in advance. Model-based design and analysis of drilling control systems offers a complementary approach to understanding system behavior on the front end. The case study discussed here presents only the tip of the proverbial iceberg; more recent applications have played a pivotal role in resolving a multimillion dollar performance issue on a subsea BOP control circuit.

The bottom line: By combining first principles of mathematics and physics with real world data, we can go beyond static engineering drawings and begin to capture a holistic, dynamic representation of the modern drilling control system. This will result in a safer, more sustainable and more reliable drilling ecosystem for us all. DC

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