

TECHNOLOGY TASK FORCE

Balancing Autonomy: Supporting Operator Goals & Perfomance Capabilities

As defined in NFPA's technology roadmaps, there are several machine-level technology trends that are actively shaping the future of the fluid power industry. One such area of development is exploring data analytics and intelligence to improve control, performance, autonomy, and supporting safety goals within the system.

NFPA's Fluid Power Forum engages with stakeholders across the fluid power supply chain to better understand these trends and innovations within the industry. This includes engagement with original equipment manufacturers leveraging hydraulic and pneumatic technologies. Komatsu is a leading manufacturer of construction, mining, forestry, and heavy industrial equipment that utilizes fluid power systems. In partnership with the Milwaukee School of Engineering's Fluid Power Consortium (FPIC) program, NFPA hosted a Technology Webinar on June 8, 2026, focused on **"Advancing Fluid Power With Market Ready Sensor Solutions".** Komatsu engineers participated in that webinar and spoke to the integrated sensing systems that enhance productivity, support safety, and increase autonomy within their equipment. In this study, Komatsu further explores advanced technology in their rotary blasthole drills that enhance performance and support safety goals through **operator guided system intelligence**, and provide the necessary onboard analytical tools for quick issue resolution and machine productivity.

How can drill operators benefit from onboard system intelligence?

The modern-day surface mining industry heavily relies on system intelligence to enhance operator productivity and increase Key Performance Indicators (KPIs). Blasthole drills are the first machine in the surface mining production cycle, highlighting the importance of persistent hole productivity. In-cab controls have evolved to assist operators with higher productivity metrics while monitoring system conditions support operator awareness of the machine's state. Onboard system intelligence can therefore assist operator productivity metrics while supporting operating decision-making. A leveling system is one such area where system intelligence can both allow an operator to mitigate risk and increase productivity.

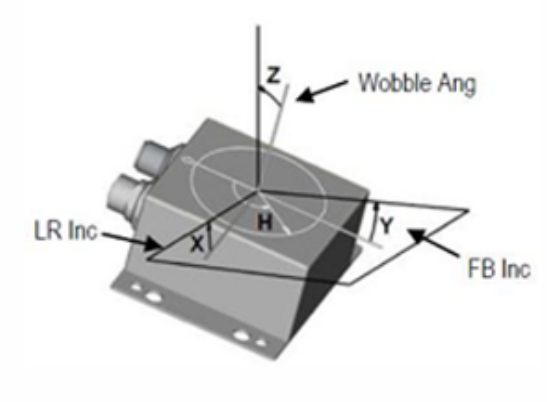
Increasing Productivity through a Proportionally Controlled Hydraulic Leveling System

To better explain how this looks in practice, it is first important to understand the system design and application. When it comes to the machine leveling system, the Komatsu ZR series rotary blasthole drills currently utilize four independent, proportionally controlled hydraulic leveling jacks. Each jack is equipped with a hydraulic load sense transducer for precision electronic load

sense control and a cylinder demand pressure transducer to accurately identify cylinder ground contact. Within each jack cylinder is a magnetostrictive position feedback sensor with mm accuracy for high accuracy position sensing of all four leveling jacks. The system uses pressure, position, and inclination inputs to estimate jack position, ground contact, and machine attitude.

Figure 1: Dual Axis Inclinometer Characteristics for Stability Analysis

(Source: Komatsu)



$$X := \sin(\alpha)\cdot(-g)$$
$$Y := \sin(\beta)\cdot(-g)$$
$$Z := \sin(\psi)\cdot(-g)$$

constraint

$$C_1 := g = \sqrt{s(\alpha)^2 g^2 + s(\beta)^2 g^2 + s(\psi)^2 g^2}$$

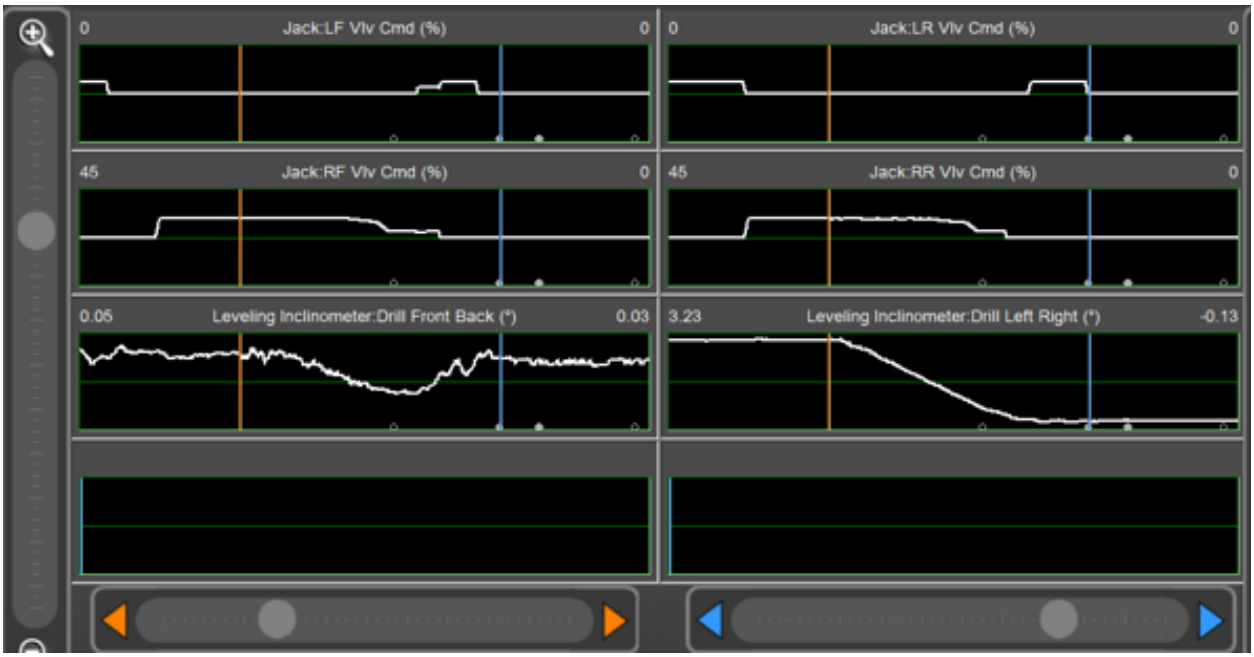


Figure 2: Lateral Stage of Leveling Sequence as viewed via on-board HMI (Source: Komatsu)

Common within blasthole drills is a machine auto leveling system with the objective of engaging all four jacks to the ground while being within less than +/-0.4 degrees leveling tolerance in both the longitudinal and lateral axes of the machine. The control system coordinates jack movement using machine attitude, jack-position, and pressure inputs to support ground contact detection and leveling within defined control parameters.

In coordination with the linear position feedback of the cylinders and tilt feedback of the 2 axis inclinometer, the leveling system initiates the ground detection sequence through a proportional jack extension. At this time, demand pressures are carefully analyzed for sudden changes in pressure which indicates a grounded state. Fine proportional control is key for the leveling phase of the routine to ensure both lateral and longitudinal axes are within the defined leveling tolerance. The entire process is performed by carefully monitoring the hydraulic load pressure at each jack to provide the proper load sense pressure at the auxiliary pump. (see Figure 3)

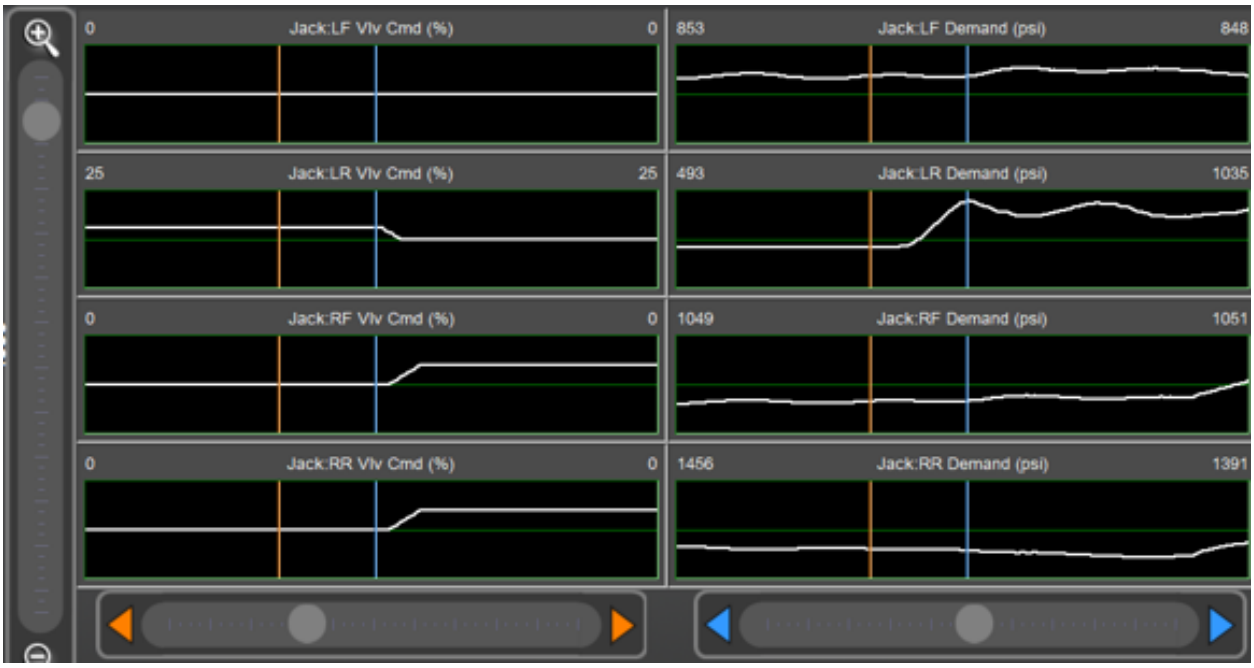


Figure 3: Demand Pressure Spike on Left Rear Jack Signaling Ground Contact (Source: Komatsu)

The embedded system controls actively monitor the system for pressure conditions that might indicate a change in jack loading during the drilling sequence. If a change in pressure conditions is detected, the system gently reapplies extension to the jack to reground and balance the system load without shifting load off the already grounded jacks.

The proportional hydraulic load sense control and cylinder position feedback provides the necessary control to **speed up the automated sequence.** In internal evaluations of specified configurations and conditions, the control approach has demonstrated reductions in automated leveling cycles **by as much as 20%** over a similar model without this system. The accuracy and fine control of the proportional hydraulics are intended to help the machine reach a level state while reducing unnecessary overshoot. When a drill overshoots its leveling target, it may affect jack loading or crawler contact, potentially leading to a machine skyjacking situation depending on ground conditions, machine configuration, and operator actions. “Skyjacking” is an industry term in which the machine is lifted off the ground and no longer in contact with the propel crawlers which may result in a heavily loaded hydraulic system, higher mechanical load on the frame, and overall decreased stability.

How does safety factor into this?

Automated sequences driving toward higher productivity can be designed so that they are *not at the expense of safety*, but rather be complimentary. A leveling system which values speed, precision, and accurate ground detection may help reduce the likelihood of machine skyjacking scenarios under appropriate operating conditions. Faster leveling generally improves KPIs which provides more incentives for operators to use the automated system rather than attempting to level the machine manually. This can support more consistent machine positioning during drilling, and may help reduce unnecessary structural loading and hazards when the system is used as intended.

But an auto leveling system is not a replacement for manual control in every scenario. The embedded control system, as intelligent and capable as it may be, does not assume it knows the intentions of the operator or the best course of action for every situation. There may be times when manual overrides may be appropriate for certain operating conditions when used in accordance with the operator's manual and site procedures. However, there are ways to establish boundaries on manual operations to allow the overall action maintaining operation within defined control limits. One such method is the "Grounded Stability Tolerance" – this feature allows the drill to operate and level on slopes up to the machine's "Critical Stability Tolerance" (the allowable deviation before loss in functionality) subject to limitations and procedures in the applicable machine documentation, but binds jack motions for leveling at a much tighter tolerance called the Grounded Stability Tolerance. The system achieves this by monitoring the grounded status of the four leveling jacks in the same way it does for auto leveling. Before the jacks are grounded, the system prohibits corresponding extension or retraction of the cylinders beyond the wider Critical Stability Tolerance. After the jacks are grounded, the system prohibits corresponding movement of the cylinders beyond the tighter Grounded Stability Tolerance. Without this dynamic exception, the system would not be able to return to the ground it initially leveled on as it would violate the tighter leveling window. Monitoring the jack demand pressures tells the system when the tighter window is no longer applicable as the control logic applies different limits depending on the detected jack-grounding state and machine attitude. This is especially useful in skyjacking situations.

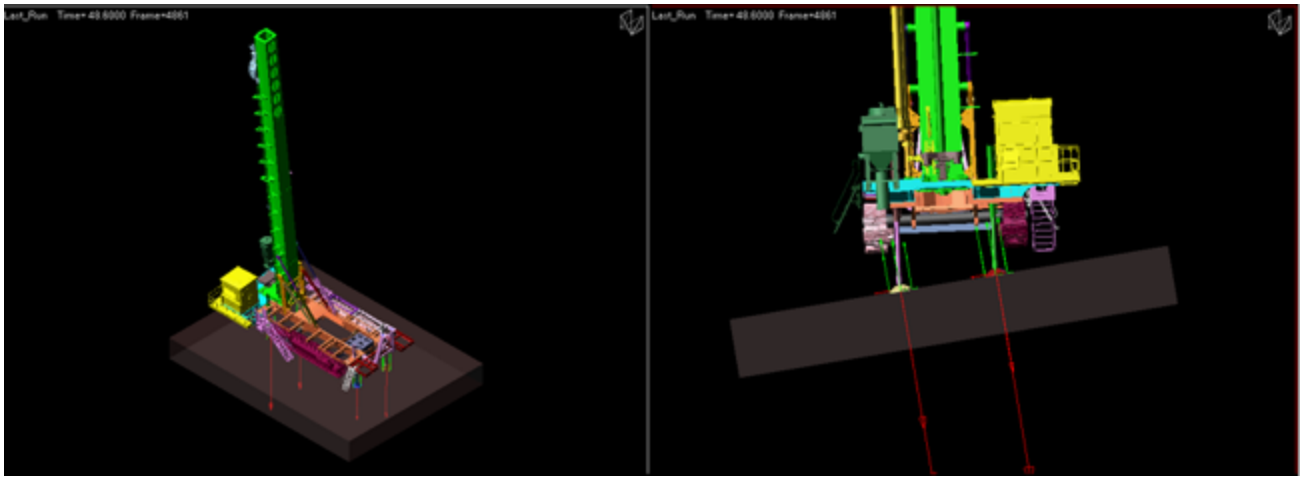


Figure 4: Stability Model in Skyjacking Scenarios (Source: Komatsu)

Key Takeaways:

- **Smarter sensing improves operator confidence and hydraulic control:** Integrated pressure, position, and inclination data give the control system a more accurate understanding of the machine state, supporting operator use of automated leveling while the hydraulic system maintains better load balance, ground contact detection, and cylinder positioning when used in accordance with manuals and procedures.
- **Data-driven automation improves productivity and hydraulic performance:** Proportional hydraulic control and sensor feedback speed up the automated leveling sequence by reducing overshoot, unnecessary jack movement, and pressure spokes, helping the system reach target position faster while improving pump demand management and overall machine efficiency.
- **Autonomous behavior cares for operators, equipment, and hydraulic components:** Continuous analytics allow the system to detect jack ground contact, leakage, and stability risks promptly, then automatically reapply extension or rebalance loads in a manner designed to reduce skyjacking, limit excessive hydraulic loading, and manage stress on cylinders, pumps, and the machine frame.
- **Intelligent boundaries keep operators in control while optimizing hydraulic response:** Features such as Grounded Stability Tolerance preserve necessary manual override capability while analytics-based controls guide jack movement within defined control limits, supporting smoother proportional response, and more stable load sharing allowing operators to use autonomy in changing ground conditions.

Want to know more? *Watch the NFPA / FPIC Technology Webinar on "Advancing Fluid Power With Market Ready Sensor Solutions" for more information about Komatsu's technology solutions.*

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