

Dynamic Inclinometers: Enhancing Control Systems for Industrial and Construction Machinery



Dynamic Inclinometers for Modern Machinery

Dynamic inclinometers are advanced versions of the tilt-sensing devices used in industrial equipment, construction machinery and materials handling equipment. These devices provide control systems with critical feedback on the spatial orientation (tilt or inclination) of mechanical elements such as crane booms, excavator arms, booms for concrete placement trucks or mobile robotic systems. Traditional inclinometers are reliable results when stationary, but can produce erroneous results when they experience rapid motions. Dynamic inclinometers, however, contain extra motion-sensing elements that enable them to separate inertial forces (due to motion) from the gravitational forces that these instruments use to define 'which way is up'. Understanding the operation of these instruments is essential for optimizing the accuracy and reliability of control systems for fast-moving machinery.

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How Inclinometers Work

The most common type of inclinometer employs an array of accelerometers to assess the effect of gravity on tiny masses supported in an elastic suspension system. An embedded microcontroller built into the instrument compares the outputs of these accelerometers to calculate the overall orientation (tilt) of the unit.

Reliability in Static Conditions

This measurement approach has proven to be reliable for static objects. As long as the object stays still or moves slowly, the most significant force acting on the accelerometers is gravity. Vibration in the machinery can add 'noise' to the accelerometer outputs, but so long as the levels are relatively low, physical damping and simple software filters can reduce the impact of these disturbances, allowing accelerometer-based inclinometers to provide reasonably accurate tilt angle measurements.

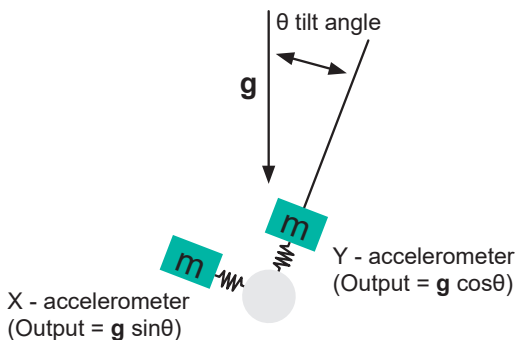


Figure 1: Accelerometer-based Inclinometer

Challenges with Dynamic Motions

When the machinery carrying the inclinometers moves, the accelerations will be picked up by the sensors, causing measurement errors. This can pose a challenge for control systems for cranes, excavators or other types of equipment that experience rapid motions – including vibrations – during normal operations.

Signal processing can help to improve the reliability of accelerometer-based inclinometers with sophisticated filtering algorithms. These algorithms are designed to isolate the true tilt signals (due to gravity) from the data

errors introduced by dynamic motions. Low-pass filters, for example, can be used to remove high-frequency noise caused by vibrations, while Kalman filters can combine previous measurements to predict and smooth the tilt angle outputs. Unfortunately, physical damping and simple data filters introduce time delays to the tilt measurements, making it difficult for the control system to follow rapid movements of the machinery it is attempting to control. The fundamental problem of measurement errors caused by the combination of gravitational and inertial forces remains.

Introducing Dynamic Inclinometers

Dynamic inclinometers are designed to address the limitations of traditional inclinometers in dynamic environments. These make use of extra sensors and sophisticated algorithms capable to distinguish between gravitational and inertial forces.

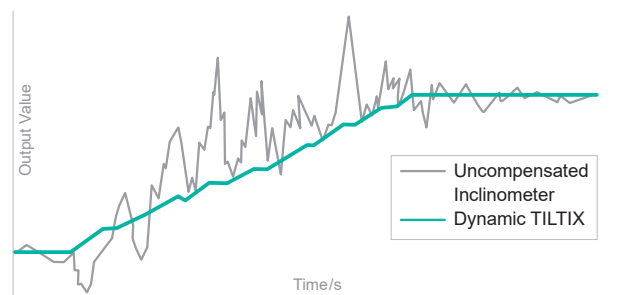


Figure 2: Effect of Acceleration Compensation for Dynamic Inclinometers

Incorporating Gyroscopes

One significant enhancement is the inclusion of tiny electromechanical gyroscopes alongside the accelerometer array. Gyroscopes measure the rate of rotation around an axis that complement the accelerometer readings. By combining the data from both types of sensors, the system can more accurately discern the actual tilt angle, even when the equipment is moving.

Signal Processing Algorithms

POSITAL's Dynamic TILTIX inclinometers are built with powerful 32-bit microcontrollers that support signal processing and communications interfaces.

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Advanced sensor integration algorithms play a crucial role in dynamic inclinometers. These process and combine data from accelerometers and gyroscopes to produce a more accurate representation of the equipment's orientation. Combining signals helps mitigate the errors introduced by dynamic movements and improves the reliability of tilt measurements.

Complex motions that combine translations and multi-axis rotations can be challenging for the sensor integration software to interpret. POSITAL engineers have tackled this problem by working with users to collect a large volume of operating data. This was used to train the analysis algorithms so that they can recognize and correctly interpret the complex combined motion situations likely to be encountered under real-world operating conditions. There are currently 62 different motion profiles stored in the signal processing software, helping the system to automatically respond to the conditions they encounter. This helps optimize tilt measurements, even when intense vibration or strong shocks are encountered.

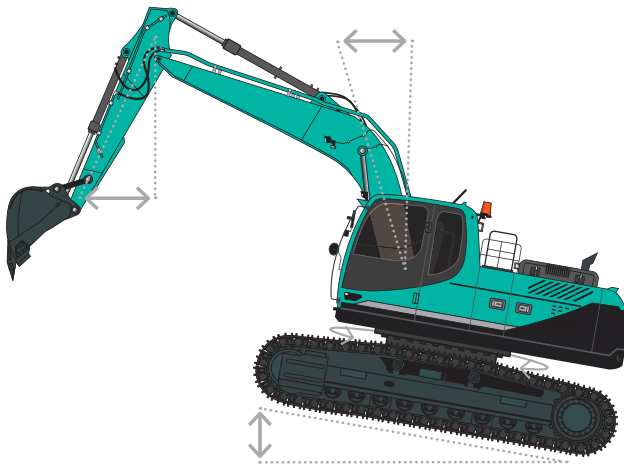


Figure 3: Controlling Tilt Angles in Construction Machinery

While POSITAL's previous generation of dynamic inclination sensors worked well in many applications, the new algorithms improve performance and safety for complex multi-axis dynamic environments. Applications that benefit from these advances include heavy construction equipment (excavators, concrete pumps,

pavers, etc.), mining equipment, industrial robots, and material handling equipment such as forklifts and cranes. The upgraded Dynamic TILTIX sensors are also suitable for safety applications, such as rollover prevention systems in off-road equipment and self-driving vehicles.

Additional Outputs Available

In addition to reliable tilt measurements, the Dynamic TILTIX inclinometers can also report accelerations and rotation rates in three axes. This capability supports additional functions that contribute to greater security. For example, the accelerations can be recorded in a targeted manner and passed on to the control system to regulate how quickly the machinery (e.g. a concrete placement boom) is moving. The controls can slow or shut off motions if defined limit values are exceeded. Another useful field of application is the monitoring of complex motion sequences on container gantry cranes or in spreaders. By monitoring acceleration forces, for example, vibrations can be analyzed to detect at an early stage whether the load exceeds the maximum permissible weight.

On huge ship- to-shore installations, Dynamic TILTIX devices ensure that prescribed inclination values are strictly adhered to and that swing amplitudes of containers are limited. If these amplitudes become too large, the control system can calm the movements by means of targeted counter- motions.

Applications of Dynamic Inclinometers

The enhanced reliability and accuracy of dynamic inclinometers make them indispensable in several applications across different industries.

Construction Machinery

In the construction industry, dynamic inclinometers are used in equipment such as cranes, excavators, and concrete pumps. Accurate tilt measurements are essential for ensuring the stability and safety of these machines during operation. Dynamic inclinometers help operators maintain precise control, prevent accidents, and optimize the performance of the machinery.

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Industrial Equipment

In industrial settings, dynamic inclinometers are utilized in automation systems, robotic arms, and materials handling equipment. These devices provide critical feedback for maintaining the proper orientation of mechanical components, enhancing the efficiency and safety of industrial processes.

Maritime and Aerospace Applications

Dynamic inclinometers are also employed in maritime and aerospace applications, where accurate orientation data is crucial. In ships and aircraft, these devices ensure proper navigation, stability, and control, even in the presence of dynamic movements and external forces.

Prospects for Dynamic Inclinometers

The future of dynamic inclinometers looks promising, with ongoing research and development aimed at further improving their accuracy and reliability. Advances in sensor technology, data processing algorithms, and integration with other systems are expected to lead to more cost effective and versatile devices. Demand is expected to grow as autonomous vehicles become more widely used, especially for off-road applications such as agricultural or construction equipment and all-terrain vehicles for rescue operations or military applications.

Miniaturization and Integration

As technology progresses, dynamic inclinometers are likely to become more compact and easily integrated into smaller devices. Miniaturization will enable their use in a



Figure 4: Dynamic Inclinometers can provide accurate feedback on the spatial orientation of robot components



Figure 5: Combined motions in Crane Operations

broader range of applications, including wearable devices, drones, and other emerging technologies.

Artificial Intelligence and Machine Learning

The incorporation of artificial intelligence (AI) and machine learning (ML) algorithms holds great potential for enhancing the performance of dynamic inclinometers. In the case of POSITAL's Dynamic IXARC inclinometers, this has already been demonstrated by the use of sample data from real-world use cases to train the signal processing algorithm to deal with complex multi-axis motions. Advanced algorithms have the potential of learning from data patterns, adapting to changing conditions, and improving the accuracy of tilt measurements over time.

Wireless Connectivity and IoT Integration

The integration of dynamic inclinometers with wireless connectivity and the Internet of Things (IoT) will enable real-time monitoring and data sharing. This connectivity will facilitate remote diagnostics, predictive maintenance, and seamless integration with other systems, further enhancing the efficiency and reliability of industrial and construction machinery. In conclusion, dynamic inclinometers are essential components in modern machinery, providing accurate and reliable tilt measurements in dynamic environments. Advances in sensor technology, data processing algorithms, and integration with other systems continue to drive their evolution, expanding their applications and enhancing their performance. As technology progresses, dynamic inclinometers will play an increasingly vital role in optimizing the safety, efficiency, and reliability of industrial equipment, construction machinery, and beyond.