

Emerging Safety Technologies

Digitally compensated tilt sensors boost crane safety systems' performance.

BY MICHAEL R. PUCCIO

From construction sites to seaports to countless industrial locations, mobile cranes have been instrumental in building our world. It's hard to envision how we got this far without them, but unfortunately, it's not difficult to imagine the number of fatal crane accidents that happened along the way. The most common of these involved cranes tipping over under load, precipitated by a change in the center of gravity. Subsequent investigations into the root cause, i.e., operator or human error, training deficiencies, improper use of equipment, and/or negligence, have yielded various conclusions. Regardless of the cause, there is one common denominator in most of these accidents: If the operator had been warned of the impending risk, the majority of accidents could have been avoided.

More than 50 years ago, an alarming rate of crane accidents were occurring. These accidents not only put the workers' safety at risk but also resulted in damaged equipment and lost production. It was evident contractors needed a protective safety system for their cranes.

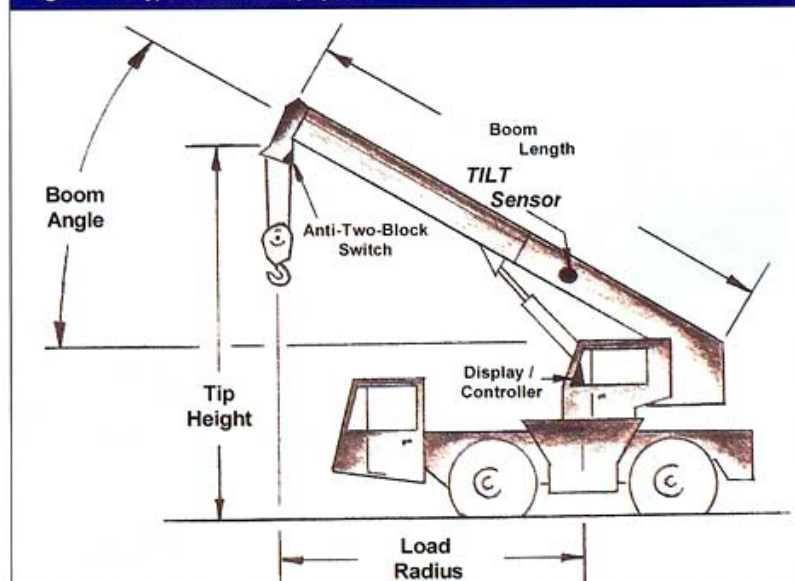
Gradually, these systems began to emerge in the marketplace. The first crane safety systems were relatively crude mechanical devices. As technology progressed, they evolved into electromechanical systems and ultimately into today's fully electronic, microprocessor-based systems. Known as operational aids, indicating devices, or load moment indicators, these sophisticated systems are capable of monitoring numerous crane variables, such as boom angle, load, telescoping

length, two-block conditions, and wind speed, via various sensors (see Figure 1).

How do they work? During operation, signals from the individual sensors are fed into a central controller where geometric calculations are made, updated, compared to the crane manufacturers load charts, and displayed continuously. When the crane reaches a preset percentage of its safe working load, visual and/or audible alarms alert the operator. Some systems also have the ability to interface directly with the crane operating system and lockout particular control functions to prevent unsafe conditions.

The overall system quality and effectiveness are directly related to the accuracy of sensors measuring the crane variables. Looking specifically at the crane's boom angle, changes in fractions of a degree can equate to a

Figure 1: a typical crane safety system.



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dramatic difference in the actual working load, depending on the configuration. For example, if the sensor measuring the boom angle has a stated accuracy of $\pm 2^\circ$, the system must consider this error to prevent erroneous indications of a safe working condition. However, this scenario artificially exaggerates the measured working load, or specific measured variable, within the system to compensate for the inaccuracy of the sensor. Although this is an effective approach to prevent an unsafe condition, it limits the operator from using the crane to its full capacity, thereby reducing jobsite productivity.

The majority of tilt sensors, or inclinometers, commonly used to measure boom angle either perform well in terms of linearity but have relatively large temperature coefficient errors, or they perform well in both linearity and temperature but have poor repeatability and/or hysteresis, or vice versa. When deriving the accuracy specification for a particular tilt sensor, the manufacturer must add all the effects described above together to obtain a true representation of performance. Some system manufacturers have gone through the painstaking measure of characterizing each sensor for linearity and temperature to reduce their aggregate system error. This is both time-consuming and costly. Finally, some tilt sensors perform well in all respects, but they are cost-prohibitive.

Solution for today's world

At Spectron Systems Technology, recognizing which system improvements were needed was the first step the company took in designing a cost-effective, high-performance inclinometer. While its standard electronic inclinometer was meeting the bulk of mechanical and environmental requirements, issues relating to the electrical interface and accuracy needed to be addressed. While nearly all analog input/output device manufacturers were producing or developing systems for the next generation, accurate digital input data from peripheral sensors could have used some improvement.

Changing the electrical interface was a relatively easy issue to resolve. The input circuit could be designed to accept unipolar, bipolar, and/or unregulated DC voltages. Off-the-shelf digital drivers were inserted into the present circuit to provide the desired output.

The more significant challenge was improving the accuracy from more than $\pm 2.5^\circ$ nominal to $\pm 0.5^\circ$ maximum with all effects considered.

Testing revealed the repeatability of the sensing element itself was extremely good, not only in ambient conditions but

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also through temperature excursions. This was germane to making finite error corrections possible. However, the data also indicated corrections would have to be made to the actual linearity curve, as well as the temperature coefficients of null (zero) and scale, to achieve the accuracy target.

Early on, as various error correction methodologies were being explored, it

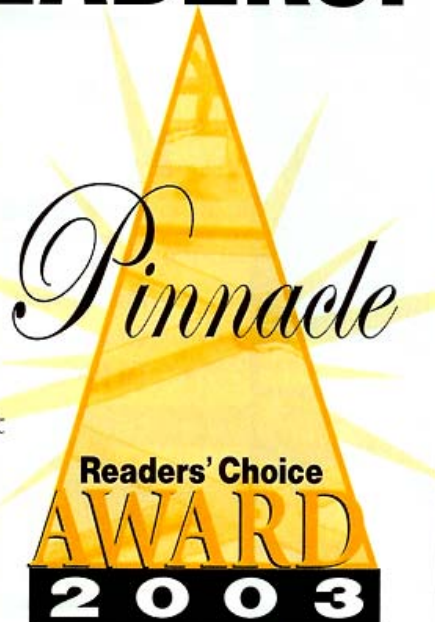
was determined that a digital compensation routine would have to be used for numerous reasons. Foremost, the base linearity of the sensing element could not be improved further without adding significant cost. In addition, the random nature of the temperature coefficients, in terms of polarity and magnitude, ruled out traditional compensation techniques and blanket corrections. This



Spectron Systems Technology's Spectrotilt™ electronic inclinometer.

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did, however, present opportunities to correct errors via software, thereby enabling sensing elements, which otherwise would have been unusable. In addition, all calibration and compensation routines could be accomplished in a fully automated test system, therefore significantly reducing labor content.

Spectron Systems Technology's newly modified electronic inclinometer provides an accuracy of $\pm 0.5^\circ$ over a $\pm 60^\circ$ angular sensing range. By employing linearity correction, on-board temperature sensing and compensation, and custom algorithms, intrinsic errors have been eliminated.

As new opportunities arise, the flexibility afforded by the digital circuit design allows many of the performance parameters to be modified via software. The angular range, scale factor, resolution, and number of readings internally averaged, can be custom tailored to satisfy most applications. In addition, the digital output signal is ideal for long cable runs, eliminating concerns over signal loss and noise. The viscosity of the fluid inside the sensing element also can be altered to decrease susceptibility in high vibration environments.

In the lifting industry, applications for a digital electronic inclinometer are endless. For example, tilt sensors on telescopic handlers and aerial work platforms can be used to measure machine variables for safety systems. In other industries, such as mining, crawler drills can use tilt sensors to closely monitor and control the drill mast angle. Future advancements can only broaden the range and flexibility of digital tilt sensors, and therefore, will increase the safety performance levels of lifting equipment. ■