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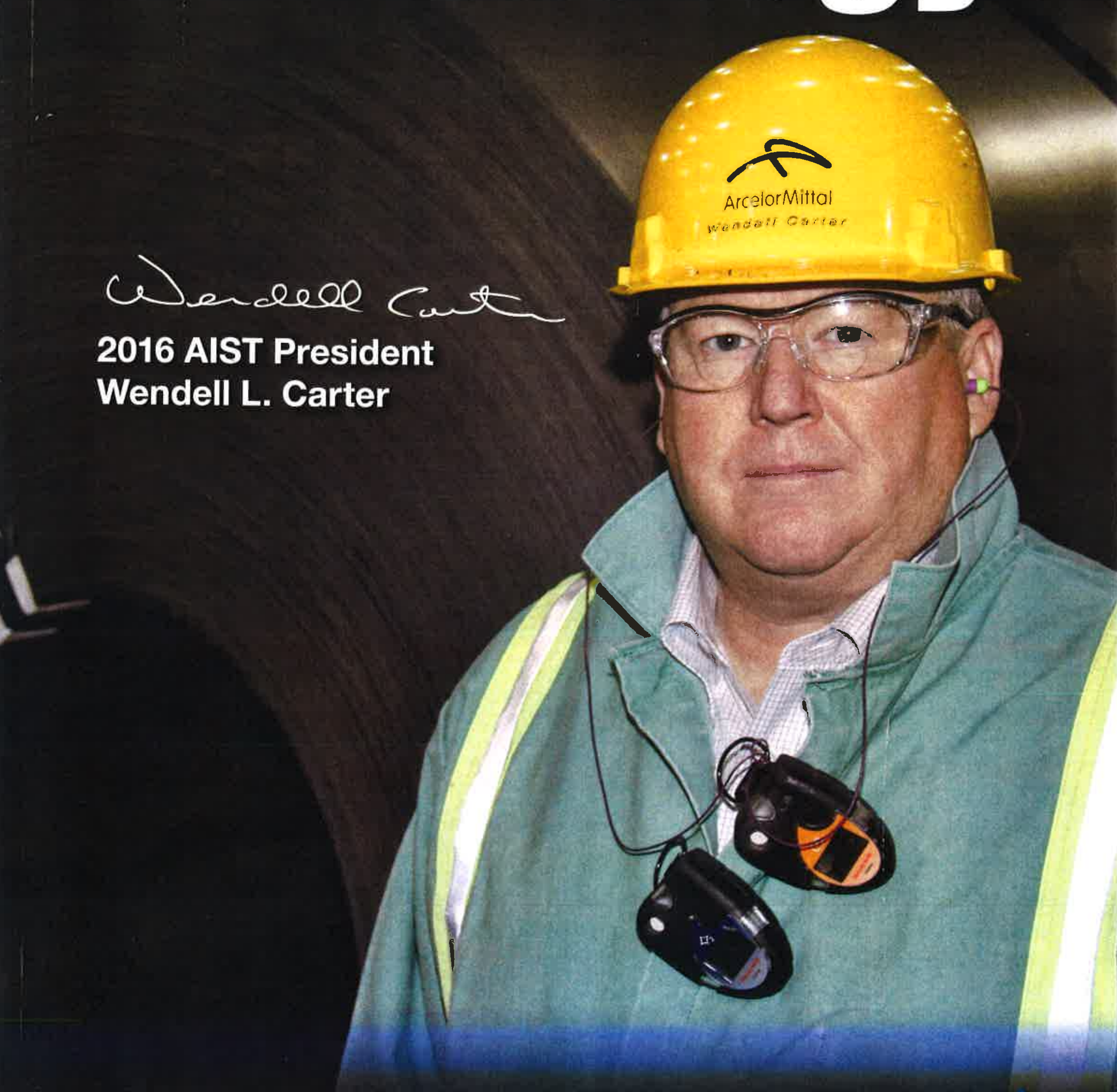

2016 AIST President Wendell L. Carter

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Motion Analysis for Determining Behavior of Automated and Manually Operated Cranes

Bridge cranes play a critical role in the manufacturing, storing and handling of steel. Whether handling scrap metal, ladles of molten steel, or coils, plates, pipe and various other finished products, electric overhead traveling (EOT) cranes and other rail-guided vehicles are subject to high stress by their very nature. Crane downtime can lead to significant, unplanned cost, and poorly controlled cranes can result in hidden costs that, until now, have been difficult to quantify.

The challenges of efficiently transporting material via bridge cranes are many. The transported loads can vary by weight and can be moving in two or three dimensions simultaneously. Proper acceleration and velocity are crucial to ensuring the crane keeps up with plant demands. Load swinging and crane skewing are common to varying degrees, regardless of how the crane is being controlled. All of this makes material handling challenging and allows for optimization potential that can result in higher throughput, less crane wear, improved safety and lower energy consumption.

For manually operated cranes, the experience and skill set of the operator usually play a vital role when it comes to efficient crane operation. For semi-automated or fully automated cranes, however, the right technology can be of particular importance in ensuring highly efficient operation while keeping downtimes to an absolute minimum, and this approach is far less reliant on operator experience.

Identifying the optimization potential of a crane's motion paths can be determined by performing a motion analysis. This paper will explain how a motion analysis provides insight into how a crane behaves and performs, and identifies the disturbances that impact positioning efficiency, safety and throughput. Once these issues are identified, actions can be taken to ensure EOT cranes meet or exceed exacting standards.

Why Is a Motion Analysis Important?

The following section focuses on motion-related characteristics of crane operation that can be identified by means of a motion analysis and which can then be subsequently optimized.

Skewing of the Bridge — Bridge crane spans can vary in length, and whether manually operated, semi-automated or fully automated, all have some level of skew. Generally, the longer the span, the greater the potential for skew. The skewing of the bridge must not exceed a certain limit in order to prevent excessive mechanical wear. The bridge of an EOT crane is always subject to skewing, since it rests on two parallel supports and may travel long distances within the crane bay. If the bridge span is considerable, an individual drive may be installed on both sides of the bridge in order to provide independent skew control. Although this helps, individual motor and drive control on either side of the bridge is generally not sufficient to reduce skew to an acceptable level. Performing a motion analysis will determine the actual bridge skew across the length of the bay in which the crane travels, regardless of whether the bridge has multiple drives or is contactor-based.

To perform a motion analysis, most commonly a laser distance

Repeated positioning of a bridge crane with a high degree of accuracy and with minimal stress on crane components such as gearboxes, drives, motors, wheels and rails is both a goal and a challenge for any operator or fully automated crane. The motion analysis kit can identify positioning disturbances, drive and motor issues, component wear, and more.

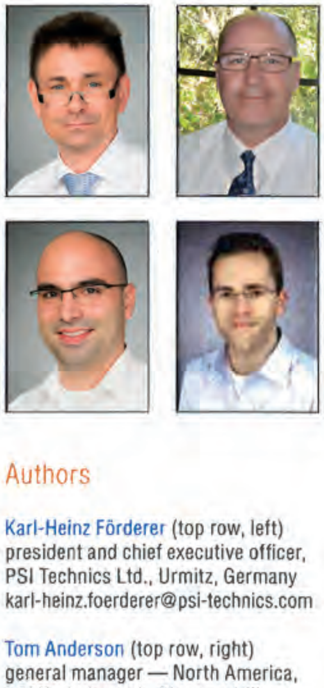

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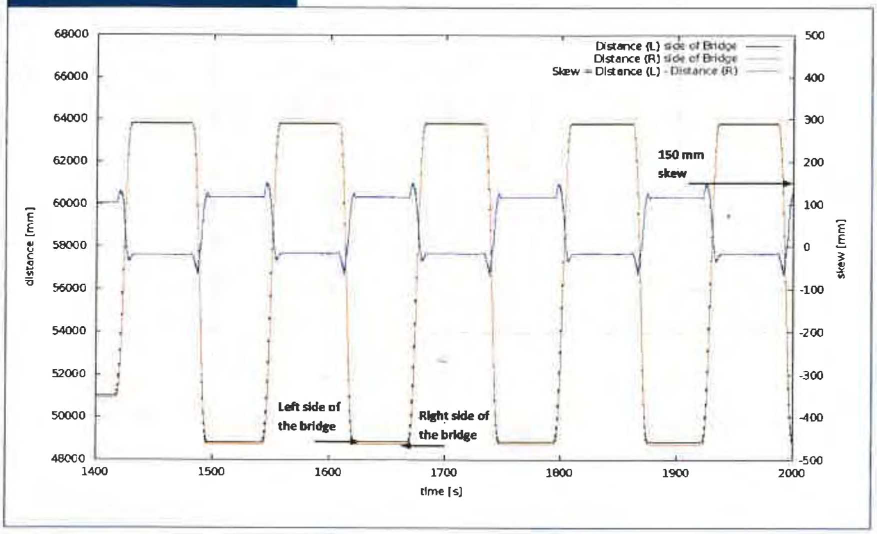
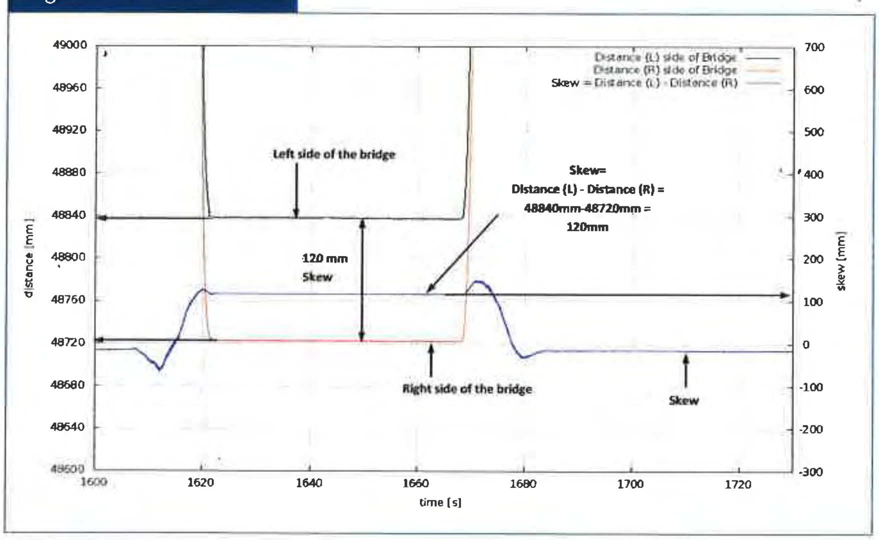
Figure 1



Skewing of a crane bridge.

Figure 2



Closer view of Fig. 1 showing crane skew.

meter and reflector are temporarily mounted on either side of the bridge and at the end of the crane bay — for example, at an end stop. Several issues must be considered when installing the laser distance meters and the reflectors, including the line of sight, ceiling height, the length of the crane bay and the rail alignment. The answers to these will determine which laser/reflector configuration is best suited for the motion analysis.

The measured distances are used to determine the skew, which is the difference in squareness of each side of the bridge at any point along the crane bay, as measured by the distance meters. Figs. 1 and 2 illustrate the skewing of a 90-foot bridge span of up to 150 mm, or approximately 6 inches, for a manually operated bridge crane. This means the bridge is 6 inches off square, which results in unnecessary wear to gearboxes, motors, crane rails, wheels and other mechanical crane components.

Positioning Repeatability — In bridge crane applications, a common goal is to position loads repeatedly at the same target positions. Examples include storing finished products or components in a warehouse, supplying parts for further treatment or processing within a production line, or ensuring a ladle of molten steel is on target so it can be safely and efficiently teemed into molds. For those applications, it is particularly desirable that the crane reaches the target without the need for repositioning, which would result in a loss of valuable time and wear on crane components.

Repositioning is defined as the need to correct the load placement when it deviates from the required target position, and is frequently seen in manual crane operation. For example, the crane may have to be moved forward or backward repeatedly to reach the final target position within the required tolerance, even though it may have been driven with a higher acceleration to reach the target faster. Higher acceleration can get the crane near its final destination slightly faster, but repositioning the crane often leads to longer overall positioning times and high acceleration induces unnecessary stress.

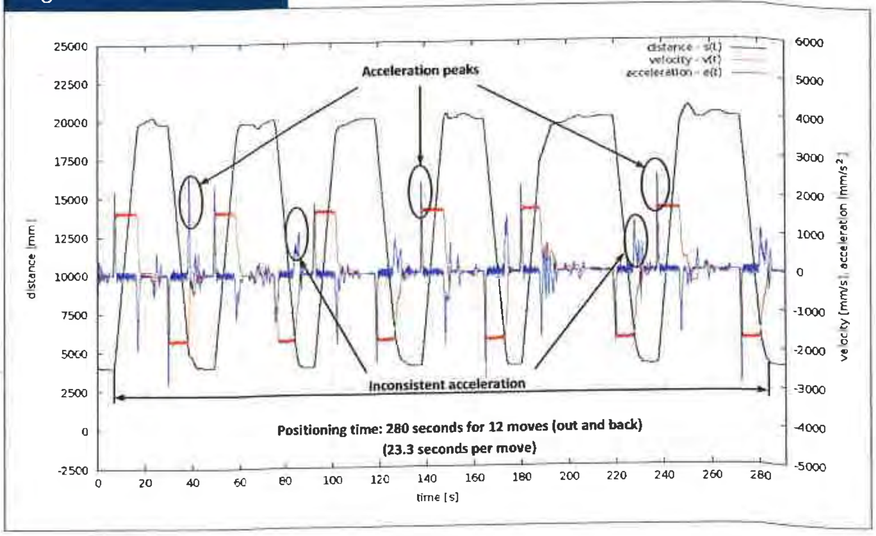
In a storage warehouse, inconsistent or inaccurate positioning can lead to problems during retrieval if the load is not properly placed. The load may have to be manually moved back into the correct position in order for the retrieval sequence to begin again.

Similarly, a bridge crane that feeds to a treatment application, such as a pickling line in a steel processing plant, mandates accurate, repeatable, and fast positioning to minimize production delays and eliminate the risk of damages to tanks and other mechanical equipment and to the load itself. Improper positioning substantially increases wear and can lead to high repair costs.

Elimination of Creeping Speeds — When the crane is manually driven by an experienced operator and high positioning accuracy is desired, manual positioning can result in significantly longer cycle times. The crane needs to be slowed down early before reaching the target to ensure the positioning accuracy can be met without causing unnecessary sway. During the deceleration phase, the crane is often driven very slowly, which is referred to as creeping speed. By using a semi-automated positioning system, creeping speed can be eliminated to minimize cycle times and maximize throughput.

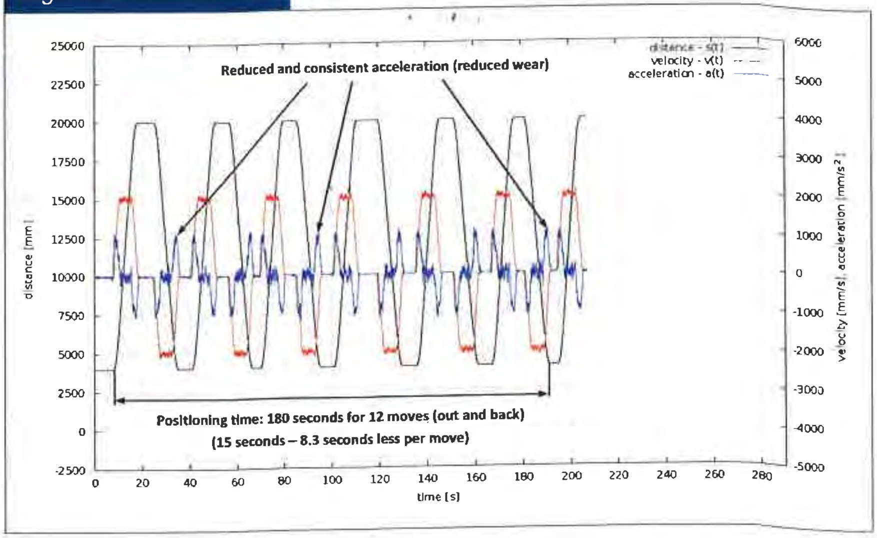
Analyzing the Traveling Movements of a Manually Operated Crane — Figs. 3–6 show six crane motion paths between two target positions that were recorded by means of a motion analysis. Figs. 3 and 5 represent the movements of manually operated cranes. Figs. 4 and 6 depict the movements of semi-automated cranes that are controlled by an automatic closed-loop positioning system and driven by an operator. A closed-loop positioning system uses feedback to control states or outputs of a crane system to eliminate motion-related issues for both automated and semi-automated operation as opposed to an open-loop system that does not use feedback to determine if the desired positioning outcome has been achieved.

Figure 3



Manually operated bridge crane: acceleration.

Figure 4



Semi-automated, closed-loop positioning, bridge crane: acceleration.

It is important to note that, in this case, a true closed-loop "positioning system" is different than a closed loop within a drive system. In the latter, the closed loop just takes into account the rotations of the driveshaft, whereas in a closed-loop positioning system, other issues that can impact accurate, repeatable, and self-compensating crane movements are considered before and during each movement. These can include wheel and rail wear, varying loads, friction, and slip, as well as positioning disturbances that are common in manually operated or automated cranes using open-loop positioning systems, such as over- and undershooting, creeping, oscillations, and skew.

Significant differences between these motion paths were easily identified. The formulas are based on the travel time differences shown in Figs. 3 and 4. The positioning time of the manually operated crane exceeds the positioning time of the semi-automated crane by 100 seconds over 12 crane moves across a traveled distance of 192 m. The semi-automated system with the automatic positioning system offers time savings of 19.23% over the manually operated one, due primarily to the elimination of speed damping (purposely slowing down the crane so it can creep into position) and repositioning that needed to be performed at the target position. The idle time in the formula refers to the total time the crane remained stationary between moves.

$$\left(1-\frac{\text{Semi-automated travel time}+\text{idle time}}{\text{Manual travel time}+\text{idle time}}\right)\cdot 100\% = \text{improvement in }\%$$

$$\left(1-\frac{180\text{s}+240\text{s}}{280\text{s}+240\text{s}}\right)\cdot 100\% = 19.23\%$$

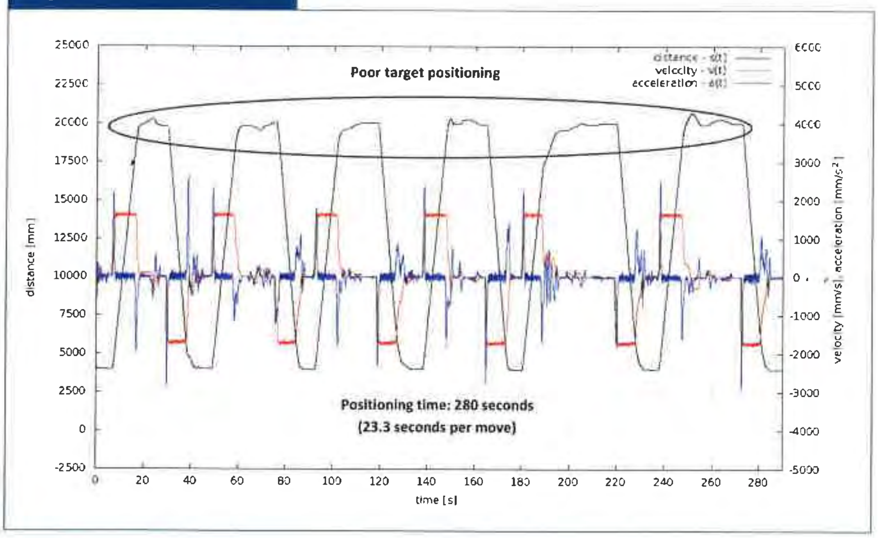
(Eq. 1)

The figures illustrate that the manually operated cranes are driven at much higher accelerations and these accelerations are not consistent for individual crane moves. In Fig. 3, the acceleration peaks are clearly visible. High accelerations place a great deal of mechanical stress on the crane system, which can be drastically reduced by providing operator training or by using a closed-loop positioning system. In Fig. 4, the crane uses this closed-loop control and the result is fast and accurate positioning at the final destination without repositioning or damping. Closed-loop positioning will more than compensate for faster acceleration in terms of cycle times and throughput.

Fig. 5 highlights the target positioning movements of the manually operated crane. The figure shows that the manually operated crane takes longer to reach the desired target position despite the higher acceleration, and positioning is not always accurate.

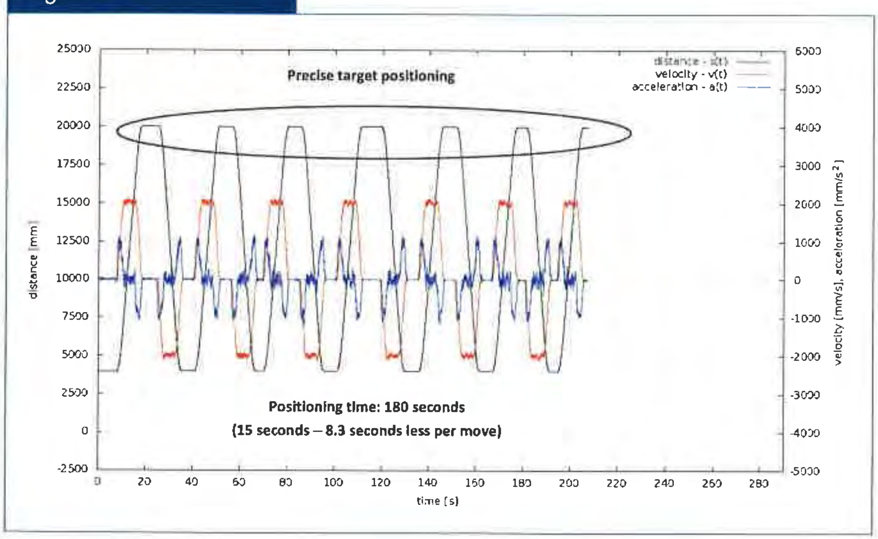
Fig. 6 highlights the capabilities of the semi-automated crane, which positions precisely and in one continuous movement without the need for repositioning, and does so due to the feedback of the closed-loop controller.

Figure 5



Manually operated bridge crane: target positioning.

Figure 6



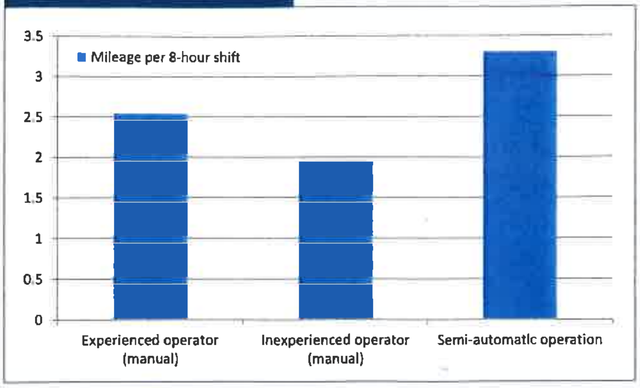
Semi-automated, closed-loop positioning, bridge crane: target positioning.

Semi-Automated Crane Systems Offer Increased Throughput Regardless of Operator Experience — Fig. 7 compares crane mileage between two manually operated cranes and a semi-automated crane. The two manual cranes show the difference operator experience makes with regard to crane mileage, and thus, higher throughput. These same two manually driven cranes are then compared against a semi-automated crane that is driven by an operator with the support of a closed-loop positioning system.

Each crane was moved over a distance of 50 m and there were 4 minutes of idle time between each movement. The increase in performance between an experienced operator and the semi-automated operation using a closed-loop positioning system amounts to about 30%. The crane operator who had the benefit of the semi-automated system simply needed to select the required target position — then, the closed-loop system positioned the crane automatically at the target, which considerably minimized the differences between crane operators' skill and experience, leading to more consistent crane operation and throughput.

Harnessing Optimization Potential for Increased Revenue — Table 1 includes an example of a potential revenue increase that can be achieved by incorporating a

Figure 7



Performance comparison between manually operated and closed-loop, semi-automated cranes.

Figure 8

Motion analysis kit.

Table 1

Revenue Increase Example for Steel Coils

	Regular throughput		Throughput increase		
	No. of coils	Revenue ($)	No. of coils	Revenue ($)	Increase (%)
Per day	30.00	675,000	2.10	47,250	7
Per month	780.00	17,550,000	54.60	1,228,500	7
Per year	9,360.00	210,600,000	655.20	14,742,000	7

Figure 9

Motion analysis kit installation diagram.

closed-loop, semi-automated positioning system on a crane that transports 30-ton steel coils. The example is based on an assumed market price of US$750 per ton and a throughput increase of 2.1 coils per day. With an estimated number of 26 production days per month, 2.1 additional coils per day would result in an increase of US$14.7 million per year. The investment costs for the crane modernization would have paid off within a very short period of time.

Motion Analysis Using an Analysis Kit or Service

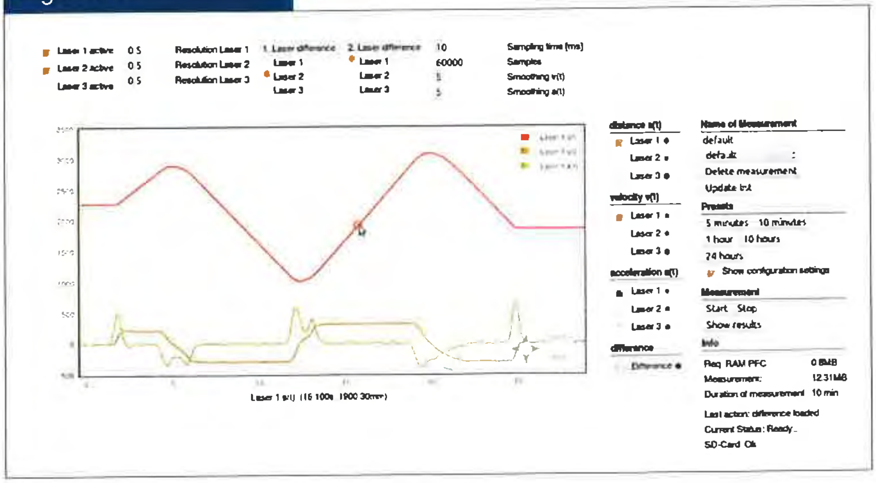
A commercial motion analysis kit or service should offer a simple and convenient way of analyzing motion of cranes and other rail-guided vehicles. It should consist of a motion analysis controller, laser distance meters, reflectors, cabling and a wireless local area network (WLAN) access point in an easy-to-carry case. The laser distance meters should have a magnetic mount so they can be quickly installed and removed from the crane after the motion analysis is complete to minimize impacts to production. During setup, the controller is connected to the laser distance meters and is responsible for recording the crane's motion path in real time. The kit is operated via the controller's Web interface — the installation of additional software should not be required. The recorded data (distance, velocity, acceleration and skew) should then be shown via a Web interface as interactive diagrams that are easy to understand.

Installation of the Motion Analysis Components — Fig. 9 shows a motion analysis kit installation diagram for a bridge crane. The case includes the controller that is linked to the magnetically mounted distance meters and placed on the crane bridge.

Fig. 10 contains an example of a motion analysis Web interface. Users can control the motion analysis Web interface from the factory floor using a laptop computer or other smart device that includes a Web browser.

Positioning sequences can be measured for cranes that are manually controlled by different crane operators on different shifts. Comparing the results can lead to identifying training needs for less-experienced crane operators. Similarly, a motion analysis can be conducted periodically for a particular crane to see what may have changed so that mechanical fixes and

Figure 10



Motion analysis Web interface.

controlled systems. A motion analysis is minimally disruptive and can be conducted on any crane to identify optimization potential. The analysis can then be repeated over time to show improvement in crane behavior and operator proficiency. Depending on the analysis requirements, a motion analysis kit should be available for rent or purchase.

The introduction of a closed-loop positioning system can prove very useful and provide additional benefits in terms of reduced wear and maintenance, increased availability, and throughput. Modernizing a manually operated crane to a semi-automated system by adding a control panel that includes pushbuttons for individual target positions is a proven method for improving crane operation. With a semi-automated installation, the operator just needs to select the required target position and the positioning system automatically controls the crane's travel path. Velocity and acceleration of the crane system are optimally adjusted and the crane is positioned in one continuous movement without the need for repositioning. This considerably decreases mechanical wear and cycle times and reduces the strain on the crane operator. Such a control system is generally also expandable to easily include the load weight of transported goods or a collision avoidance system, if desired.

A motion analysis kit is an easy-to-use tool that allows facility operators to quickly and easily detect motion-related weak spots in their crane installation. Experience has shown that practically any crane installation has optimization potential that is worth identifying. Every facility employing EOT cranes and other rail-guided vehicles should aim to reveal and harness unused crane potential to improve operational efficiency and safety while reducing wear and tear. ✦

maintenance activities can be planned. A motion analysis Web interface should also have a zoom capability that enables users to quickly identify disturbances or motion-related issues.

Analysis of the Recorded Data — The recorded data should be displayed on the interactive Web interface and saved to an SD card. After the motion analysis is complete, the user should be able to create a detailed report to identify optimization potential. By saving recorded data, crane and operator behavior can be contrasted over time, as data from previous motion studies can be re-analyzed and compared with more recent ones.

Conclusion

Until now, it has been difficult to really understand how an EOT crane behaves, regardless of how the crane is controlled. But with the advent of motion analysis capabilities, this has changed. Data that is recorded during a detailed motion analysis can reveal extensive optimization potential for bridge cranes and other rail-guided vehicles, especially for manually

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