SWAY TODAY, GONE TOMORROW

Crane operations today rely heavily on an operator's skill and ability to concentrate. Even the best operators can lose concentration or make mistakes while moving a load. Often the manufacturing employee given the task of operating the crane is someone hired for other areas of expertise than crane operation – machinists, process operators, etc. Plant expansions can also cause issues when new, inexperienced operators are moved into service at an accelerated rate. These factors contribute to production delays, safety issues and damaged equipment. Most manufacturers cannot afford to overlook the importance of automating their overhead crane systems to eliminate these concerns. Provo-based manufacturer IntelliServ recognized this capability and capitalized on it.

BACKGROUND

IntelliServ is a specialty manufacturer of pipe used for evaluating oil production potential. Pipes are brought into the facility where a series of machining processes are performed. Couplings and other material are manufactured and attached to the pipes so that they can be used by IntelliServ's customers. Pipe manufacturing requires several different machining operations requiring the material to be moved quite frequently by overhead cranes. Operators originally moved the pipes manually. A special grabber called the IntelliLIFT is lowered by the operator to grab and lift the pipe from the machine. As the pipes are moved, operators have the dual responsibility of concentrating on crane lift operation while carefully manipulating the load. In some cases, two operators were necessary to assist each other. Significant amounts of time were spent to assure product was carefully and properly moved from one process to the next.

IntelliServ consulted with Avtron Manufacturing regarding the potential to increase the plant's crane performance. Due to expansion of the plant, equipment location, and tolerances were discussed to determine what would be most efficient for crane performance. One major issue was the sway of the load as it was moved from each station. This made it difficult for the operators to get the pipes into the machines until the load came to rest. The load was then carefully inched into location by the crane operator until it was in final position. A second concern was the ability of the crane to move over the entire floor. A single crane was used to access machines located in different areas of the plant. Potential existed for an operator to run the load into a machine on the plant floor causing considerable damage and downtime.

Figure 1 – IntelliLift on Crane

<u>Sway Mechanics</u>

Movement of a load suspended from a crane is a natural pendulum by design. Accelerating the load will always produce some amount of sway into the system. In many applications, the load has time to settle and load sway does not effect the operation of the crane. However, in many cases load sway can have a very definite impact on production.

When a load is accelerated or decelerated by the crane, sway or swing is induced. In an ideal situation, a load can be accelerated instantaneously to the desired speed. This instantaneous change in speed will cause the load to sway and can be characterized by a sinusoidal movement. This movement is defined by three distinct variables (period, amplitude, and phase) that are graphically depicted in Figure 2.

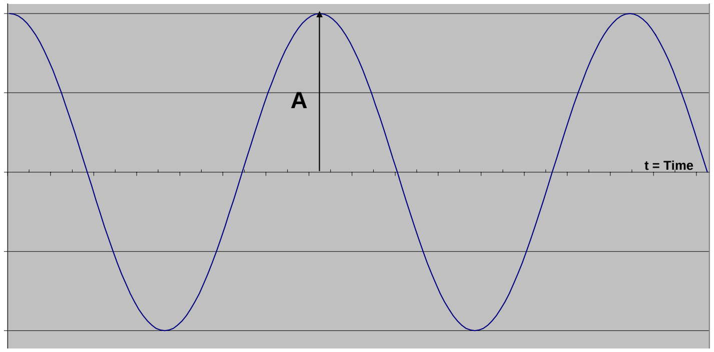

Figure 2 – Typical Sinusoidal motion of load sway

Period – Period refers to the amount of time necessary to complete one cycle of motion. Mathematically it can be shown that the sway period is directly proportional to the square root of the length of the hoist cables. An increase of four times in rope length therefore doubles the period of sway.

Amplitude – Sway amplitude is the maximum distance that the load moves from the equilibrium position during a sway cycle. It is a measurement of the amount of energy that is in the system. Amplitude is affected by the impulse of displacement on the load from center. Displacement of the load and the amplitude will have some dependency on the length of the hoist.

Phase – Phase is the measure used to describe the state of the system at any point in time. It is measured in degrees from 0 to 360 over which one complete period of oscillation will take place.

In an ideal system, an induced disturbance will cause an amplitude and period of oscillation that will not decay over time. In the real world, air resistance and friction act as natural dampers of the oscillation. It is also impossible to accelerate the load instantaneously, so ramp rates must be considered in defining and analyzing sway characteristics.

Looking at the sinusoidal path of load sway, it can be seen that acceleration in speed of a particular load will induce a specific period, amplitude, and phase. It can also be shown that if the same load is accelerated the exact same amount *half of a period later*, a second sinusoid is created exactly 180° out of phase but with the same amplitude as the initial sinusoidal sway path. When these two sinusoidal disturbances are added together, they cancel each other out. This is called the “double acceleration method” of sway control.

Figure 3 shows how double acceleration works. A load is first displaced at a particular speed which will induce sway with amplitude A and a period T. At exactly 180° into the sway phase (T/2), a second acceleration of the exact same amount is introduced. With the second speed change happening exactly half way through the period, the sway is cancelled. The net result is that the load comes to rest within half of the sway period. The load will stay at rest until a change in speed is once again introduced. This same process also works when a load is decelerated.

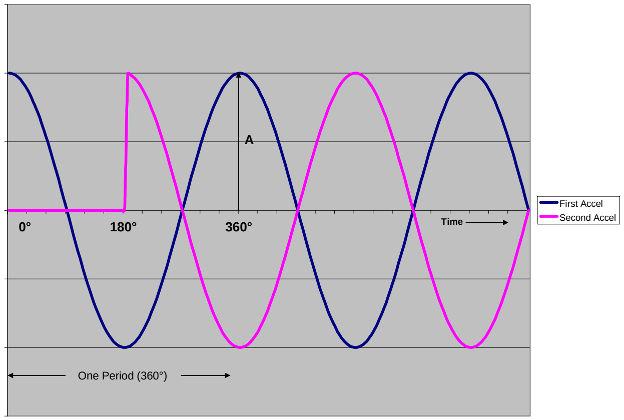

Figure 3 – Sway Cycle and Phased Sway Cycle

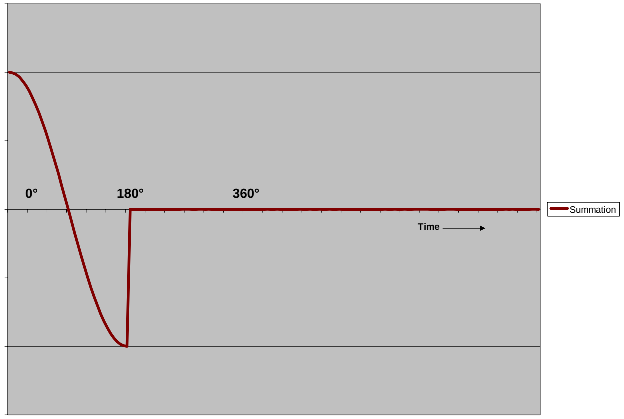

Figure 4 – Summation of both accelerations

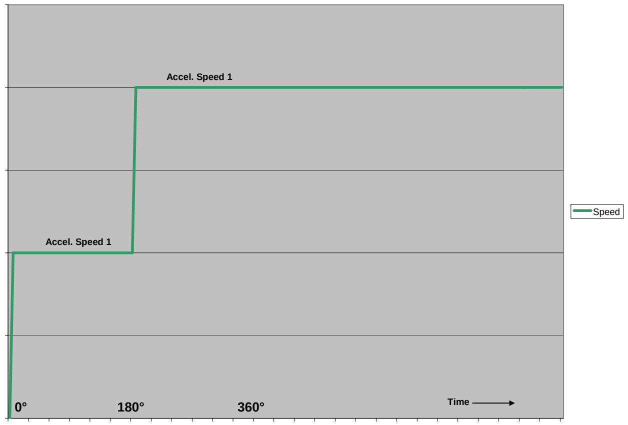

Figure 5 – Speed Curve for Crane

Although simplistic in nature, calculating the proper acceleration values and times is a very complicated matter and requires advanced control methods. Elaborate models have been developed such as Innocranes ICRAS system which models movement of the loads. These models are then used to generate precise sway control on the crane.

Sway Control System

Initial control hardware residing on the crane had no automation or sway capability. It was proposed to use the existing PLC residing on the crane. A module was furnished and installed into a spare slot in the rack. This module contained the firmware for control of the sway. Communication between the modules' control algorithms and PLC software took place on the high-speed backplane of the rack. Encoders were required on the hoist motors for height position feedback to the module and an analog reference was produced for all of the drives.

One challenge for the system occurred each time the IntelliLIFT was installed on the crane. IntelliLIFT is suspended from the crane hooks by lifting eyes mounted on top. This lowers the center of gravity of the load relative to the hook height. Software was included to handle this additional distance whenever the IntelliLIFT was in place.

Another challenge for the system was the requirement that the crane run in a twin trolley configuration with the lifting tool attached. This requires tight coordination of the drives by the sway control module to ensure elimination of sway. Each trolley and hoist must also be capable of running independently. Implemented sway control not only controls the sway in the bridge and single trolley directions, it also controls it in the twin trolley configuration as well.

Initial conversations with the customer demonstrated a desire to be able to move a load from point A to point B with two inches of sway or less. This was the tolerance level they had designed into the milling machines to set the pipes in for processing. If sway was larger than this, operators would have to stop the load short of the machine and slowly inch it into place. After the successful implementation of Phase I, load sway was measured under the two inch requirement of the customer.

<u>Why Stop There</u>

Successful removal of the load sway allowed an increase in the ramp-rates of the drives. This resulted in faster travel times from machine to machine. However, moves were still dependant on the operator's ability to maneuver the load. Crane semi-automation was necessary to reduce the risk of an operator running a load into a machine or overshooting the intended target. Semi-automation would also enhance the cranes abilities and improve production.

Sway control is a very powerful tool in optimizing crane performance and throughput. Crane operations can be very cyclical and repetitive. On a normal crane, when a work cycle is repeated a large number of times, cycle times are distributed in a bell curve. This bell curve represents the distribution of times needed for an operator to perform a single crane task over numerous task repetitions. Typical operators will find a central point to the curve after experience is gained. Typical operator curves will be to the right side of the graph as shown in Figure 6. Adding sway control on the crane produce a bell curve as well. More consistent operation is achieved because the operator does not need to focus on eliminating sway and can focus concentration on movement of the load. This shifts the curve to the left with a faster average cycle time on the crane.

Although sway control improves performance by shifting the curve left, there is still a wide range of results and inefficiencies. By automating the crane, the bell curve turns into a rectangle shifted to the far left of the graph. The fact that most of the operator controls are automated results in very repeatable, concise and speed-efficient crane task completion with little or no effort required from the operator. This speed and repeatability of operation is represented by the very thin band at the most optimum speeds, which delineates the greatest increase in crane productivity.

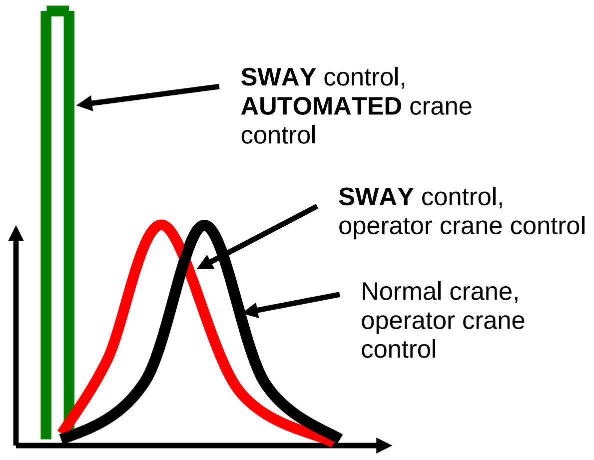

Figure 6 – Operation Cycle Times

At the heart of the Semi-automation system is the ability to provide ***Smart Speed Limits*** and ***Restricted Operating Areas***. These built-in features allow the system to offer accurate control with a minimum of set-up time and commissioning. Each offers its own benefits to the customer:

Smart Speed Limits

Typically, a crane system requires hard-wired stops at each end of the rails. A set of limit switches are installed at each end of the travel locations of the crane's rails so that if the crane is traveling at full speed and the limit switches are tripped, the crane will come to a complete stop. This prevents the crane from running into the bumpers at full speed and causing damage, and also brings the crane to a stop in such a location that the swing of the load does not run into a wall or obstacle. Additionally, a second set of limit switches is often added inside the stop limits to cause the crane to run at a slower speed. This allows for a more controlled run into the stop limits and ensures that the crane can operate up to the limits.

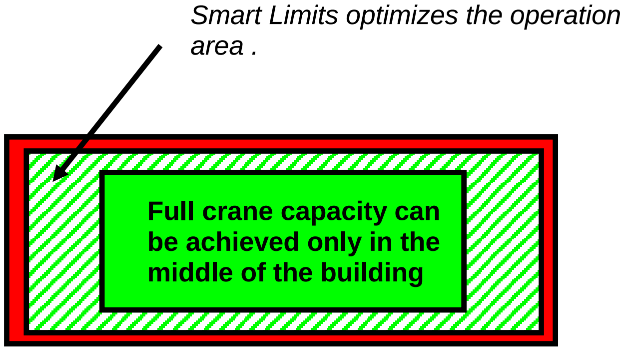

Figure 7 – Smart Limits

By adding smart limits, cranes can incorporate an unlimited number of stop point locations. Built-in features allow for easy installation that can optimize floor space and crane operation. Crane position and speed are monitored throughout movement. Values are compared to the desired location to determine how far away from the target position the load is. Once the system determines that the load is at the optimum point to decelerate, it controls the cranes speed to stop at the target position without inducing sway regardless of the operators command. This places the load at the targeted position in the shortest amount of time with no load swing.

Smart limits allow users to increase available floor space by providing controlled stopping points on the perimeter of operation. With load swing control and smart limits, the operator can not run full speed into the stop limits causing potential damage.

Restricted Operating Areas

Another area of concern when operating overhead cranes is the potential for the operator to accidentally run a load into another load or into machinery on the floor. Cab-operated cranes can be most susceptible to this due to visibility limitations of the crane operator. Restricted Area capabilities are included with the system to provide unlimited protection areas on the operating floor.

Restricted Areas provide a three dimensional "box of protection" around the object. Incorporated with the sway control, the system *automatically* detects the restricted area and determines the correct slowdown speed to use while optimizing the crane's speed. Stopping distances are also measured so that, when the load is coming to a point where it will hit the object, a stop is issued resulting in the load coming to rest a safe distance from the area. Load height is also monitored so that the system knows if the load will clear the object or not resulting in movement to continue. This allows the operator once again to focus only on the task at hand, resulting in the load being moved to the desired location in the shortest amount of time.

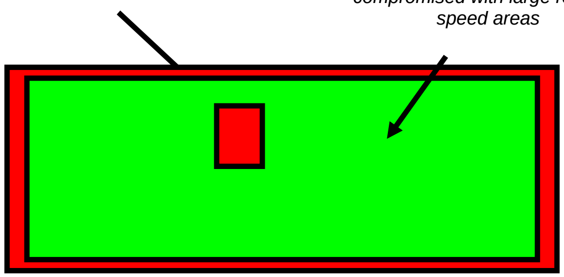

Figure 7 – Restricted Areas

Automation to the Rescue

Inteliserv realized that automation of the overhead cranes could significantly improve the plants performance. Floor space was very crowded with machinery and operators. Safe movement of loads at an optimal pace would greatly improve the plant's overall performance. Laser measurement devices were installed to locate the cranes bridge and trolley position at all times. Hoist height was already known from the position sensors installed for the sway control. Software was added that utilized Smart Limits and Restricted areas.

Smart Limits were installed that located the pick-up and drop-off points for loads. Operators can move the crane into position in a timely manor. Smart limits are also used to allow operation of the crane near building walls and objects.

Restricted areas offer Intelliserv safety of equipment and personnel. With machinery locations throughout the floor, three dimensional restricted areas are set-up. These zones allow the cranes to move around the machines but not through them. This not only protects the equipment but the people operating them as well. Should a load be moved at a machine, the system will stop the crane before a problem occurs. This allows the operator to re-position the load to the proper location or move to another area.

Time is Money

Sway control and automation can have significant impacts on production throughput and safety. By installing both of these systems, IntelliServ has realized a production increase of 20% or more. In addition, working areas are safer and machine operators can concentrate on running the machines that produce IntelliServ's products.

Sway control and automation offer a variety of advantages to the user including:

- Optimal control improves efficiency and equipment life.
- Reduced peak loads decrease wear on mechanical parts.
- Reduced load collisions reduce damage to loads, cranes and lifting tools.
- Reduced mechanical stress reduces mechanical component breakdowns.

IntelliServ's installation of the first system was so successful, that systems are currently being installed on six additional cranes throughout the plant.