Sway Control and Semi-Automation on an Overhead Crane

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INTRODUCTION

Crane operations today rely heavily on an operator's skill and ability. 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 such as – machinists, process operators, etc. Plant expansions can also cause issues for crane operations when new, inexperienced operators are required to service plant production capacity 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 the importance of the crane to their production 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 and the material must be moved quite frequently by overhead cranes. Initial movement of the pipes was achieved manually by machine operators. 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 by the cranes, 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 because handling lengths of pipe can be a tricky operation. 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 ability to increase their crane’s performance. Due to expansion of the plant, equipment location and tolerances were discussed to determine the best way to optimize the crane’s 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 without damaging equipment or endangering employees. After careful consideration of the Intelliserv’s requirements, Avtron Manufacturing presented a PLC-based solution that would address the crane sway issue and would also protect the plant machinery from
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damage caused by swaying loads. Avtron also presented a crane automation path that would offer the customer an increase in overall productivity.

PROJECT SCOPE

Due to high demand for its products, IntelliServ was in the process of expanding its facility and adding several new overhead cranes to its existing equipment. A typical configuration for the crane involves a single bridge with two trolleys operating independently on the bridge. IntelliServ designed and developed a special grabbing tool called IntelliLIFT for their specific crane operations. IntelliLIFT allows the crane to pick up pipe and transport it in a very controlled manner to various areas in the plant. While the two crane trolley assemblies operate independently for other plant crane operations, use of the Intellilift tool requires both trolleys to operate in a coordinated tandem fashion.

Figure 3 – Crane for handling of Steel Pipe

Crane control is provided by five Variable Frequency Drives (VFDs). The single Bridge VFD is used to run two bridge motors. Each of the two trolleys has its own individual Trolley VFD with an associated motor. Each trolley also has an individual Hoist VFD and associated motor. A programmable logic controller (PLC) provides the logic for the cranes including control of the interlocks and permissives. Cranes are operated from the floor by wireless remote control.

Implementation of the project was broken into two phases:

Phase I – Implement and commission the sway control on the main overhead crane.

Phase II – Implement and commission semi-automation to improve the crane’s performance.
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PHASE 1 - SWAY CONTROL

Sway Mechanics
Movement of a load suspended from a crane is a natural pendulum. Accelerating the load will always produce some amount of sway into the system. In many applications, the load has time to dampen 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 1.

Figure 1 – 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 2 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.
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Figure 4 – Speed Curve for Crane

The example above assumes an ideal system with instantaneous acceleration, no friction and no initial sway in the load. If sway is present in the system before movement is made, the exact same sway that was originally in the system will be maintained after the double acceleration is made. If this is the case, sensors could be added to the crane measuring the angular displacement of the load. This measurement can then be fed into the control algorithm to perform closed loop control. After analyzing project parameters, Avtron determined that closed-loop control of initial sway was not necessary for proper crane performance on the IntelliServ project.

Although simplistic in nature, calculating the proper acceleration values and times is a very complicated matter and requires advanced control methods. Avtron has developed elaborate models to model movement of the loads. These models can be used to generate precise sway control on the crane.

Sway Control System
Initial control system residing on the crane had no automation or sway capability. Avtron proposed using the existing PLC residing on the crane. A module was furnished by Avtron that resided in a spare slot of the rack. 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 fixture 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. Avtron’s sway control system 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.

PHASE II - SEMI AUTOMATION

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 dependent 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 Fundamentals
Sway control is a very powerful tool in optimizing crane performance and throughput. As was discussed at the beginning of this paper, operators can lose concentration and make mistakes. On a normal crane, when a work cycle is repeated a large number of times, cycle times are distributed in a bell curve like those shown in Figure-4.
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**Figure 6 – Operation Cycle Times**

The two bell curves represent 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. For the black bell curve, no sway control or automation is used during the crane tasks. Red represents the same crane run by the same operator with sway control enabled. 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.

Green represents the time distribution for the same crane and operator once semi-automation is put into place. 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.

At the heart of Avtron’s semi-automation solution 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 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 the wall. 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(a) represents a conventional floor plan for the crane’s operation. Full capacity space is represented in green, unused space in yellow, and the areas where the mechanical limits are in place are shown in red. It can be seen that the stop and slow-down limits used in a conventional crane system generate a large area of unusable floor space.
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Figure 7a – Traditional limit configuration results in loss of usable floor space

Figure 7(b) – Smart Limits increases usable floor space

Figure 7(b) shows that by adding Smart Limits, the unused yellow space can be converted into usable floor space. This is achieved by allowing crane software rather than the crane operator to monitor position and to determine what the operational speeds should be. Operators no longer have to worry about manually slowing down or hitting a stop limit and endangering the load. Incorporated with sway control, the load swinging into the wall or other stationary objects is also eliminated. Usable floor space can increase by as much as 10% or more.

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. Avtron’s sway control system incorporates a Restricted Areas feature which allows for an unlimited number of restricted areas to be defined.

Figure 8 – Conventional Restricted Areas

When a piece of machinery or a stationary object is located on the operating floor, there are several ways to handle its protection. One conventional method is to put hardwired stop limits around the area to prevent the crane from moving in that area. The operator must maneuver the load around the object, which increases the amount of time getting the load to the desired location. Some systems also incorporate software limits to create a “slowdown” area around the object which slows the speed that the operator may move around or over the object. This also adds time and effort to moving the load to the desired location.
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Figure 9 – Avtron Restricted Areas

Avtron’s control system allows the crane system to build 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 command is issued, and the load comes 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 in the path. If the load is clear then no slow downs are required. 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 necessary.

Control System for Semi-Automation

Semi-automation requires additional feedback to that needed for sway control. In addition to hook height, the automation system needs feedback indicating the position of the crane in both the bridge and trolley directions. To incorporate this on Intelliserv’s crane system, laser sensors were installed for the bridge and trolley positions as seen in Figure 8. Both trolleys incorporate their own individual sensor so that they can be operated on their own when not using the IntelliLift fixture. The bridge and trolley laser sensors provide the control system with the load’s position relative to the crane.

Figure 10 – Typical laser and target mounting

Position lasers on the bridge and trolleys were calibrated so that each hoist assembly’s (X, Y) coordinate position was known. Feedback from each hoist was also provided, generating the Z coordinate of the crane. Together, the load’s position in 3-dimensional space is known at all times. Inherent to the sway control package, a required stop distance is generated at all times for each crane direction. This value
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can be compared to the actual position to stop the crane should a limit be approaching. Stopping distance is calculated based on present speed and is optimally calculated to ensure the best performance.

Restricted areas as discussed above were determined and programmed into the system. These areas protect equipment located on the floor. As Avtron’s sway control system is a dynamic package, the system functions in the complete (X, Y, Z) plane of movement. If a restricted area is being approached from a diagonal, the system will stop the crane’s motion in that particular dimension for protection.

CONCLUSION

Direct cooperation between IntelliServ and Avtron Manufacturing produced an automated crane control system that met or exceeded every aspect of the project’s goal. Phase I implemented sway control so that the load would not swing while being moved from station to station. With the anti-sway system in place, ramp-rates of the drives were increased, decreasing the time needed to move from place to place. This allowed the operators to get material to their machines quicker and in a safer manner.

Phase II provided the Semi-automation that worked in conjunction with the sway control to improve overall performance. Smart Limits were put in place to help widen the customer’s usable floor space. Restricted areas were developed to protect machinery and operators and to allow for fast, safe, efficient movement of the material throughout the plant. Operators were also able to completely concentrate on the task at hand so that fatigue did not play a role in crane efficiency. Optimum movement speed and pathway efficiency helped speed-up the processing of material.

The successful implementation of both phases of the anti-sway control and semi-automation system resulted in production throughput increases in excess of 20% for IntelliServ on the main crane. With this success, IntelliServ is in the process of installing six additional sway packages on all cranes used in the process. When complete, sway control and semi-automation control will be functional from the initial unloading of material delivered to the plant to the loading of completed pipes for IntelliServ’s end customer.