Radar-Based Collision Avoidance Between Multiple Levels of Cranes in a Meltshop

Hazards are ever-present in the steel plant environment, and a heightened awareness and emphasis on safety is a necessary priority for our industry. This monthly column, coordinated by members of the AIST Safety & Health Technology Committee, focuses on procedures and practices to promote a safe working environment for everyone.

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Overhead cranes are a critical part of the operation of a meltshop. They are necessary for moving ladles of molten steel from the furnace to the caster, and they are also needed for maintenance, such as changing out refractory, moving furnaces shells, and more. Due to their mass, however, overhead cranes have the potential to impact one another or against their end stops, which can cause significant structural damage to the crane, its rails or the building itself, a potentially massively expensive situation in both repair and productivity costs. Therefore, a reliable collision avoidance system is needed to help keep this situation from happening by slowing and stopping the cranes before they hit.

However, the environment of a meltshop is notoriously harsh on sensors due to the presence of high heat, vibrations, and airborne mill dust particles and accumulation on all surfaces of the crane. This often makes the selection of an optical collision avoidance system ill-advised, as the optical head will require frequent cleaning of accumulated dust when it is not being tripped by airborne particulates. For meltshop applications, the recommended technology for crane positioning and collision avoidance is radar, and this paper will detail an application that uses a radar-based position and collision avoidance system to help keep meltshop cranes from impacting one another.

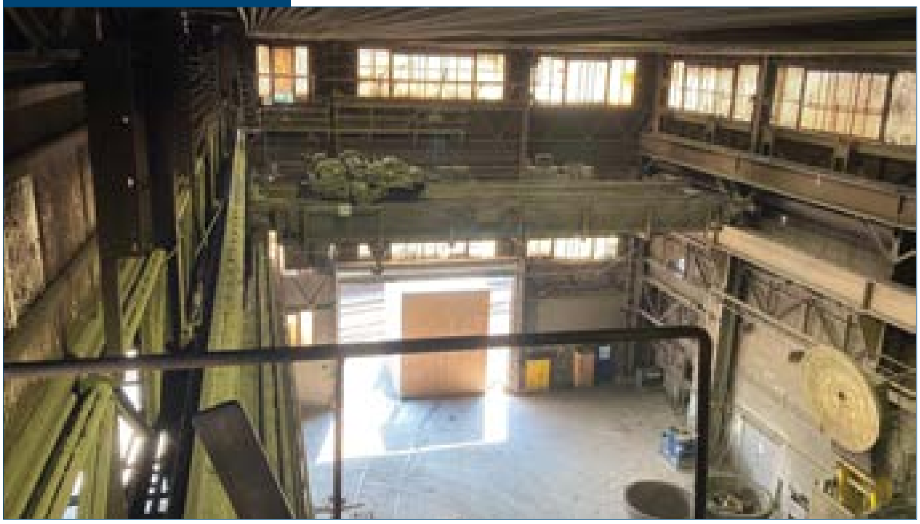
The application detailed in this paper describes a meltshop crane collision avoidance application that is significantly more complex than a typical meltshop, featuring two overhead upper-level ladle cranes and four lower-level ingot handling cranes on a 700-foot runway. There is very limited headspace between the two levels of cranes; the J-hooks on the ladle cranes can only clear the lower ingot cranes when the J-hooks are raised completely into the upper limit, and if the trolleys on the respective cranes are on the opposite sides of bridge travel (i.e., the upper trolley must be all the way north, the lower must be all the way south).

All six cranes in the meltshop are 230VDC contactors controlled, with hydraulic brakes, and operators rely heavily on reverse plugging to control the cranes. The lower ingot cranes are all cab operated and have few sightlines with which to see the ladle cranes. The upper ladle cranes, however, are operated from the ground using six operator pulpits placed around the melt aisle. These pulpits are hardwired to contactors that run up the walls and ceiling of the meltshop to the contactors on the crane.

Creating a collision avoidance solution for this would typically be untenable. The ladle cranes used to run a laser system for collision avoidance between one another, but it never functioned reliably due to the environment so it was deactivated; trying to design a system that could help stop collisions between the ladle cranes and the ingot cranes would be both very complicated and of questionable efficacy.

Instead, the solution that was implemented uses radar-based positioning. Radar-based positioning sensors function similarly to lasers, using high-frequency signals and time-of-flight to calculate distance, but since they are radio transmissions rather than visible light, they are largely unaffected by the harsh environment of a meltshop. Much like radio remote controls, radar measurement devices have no

Figure 1



View from an upper level ladle crane to one of the lower-level ingot cranes.

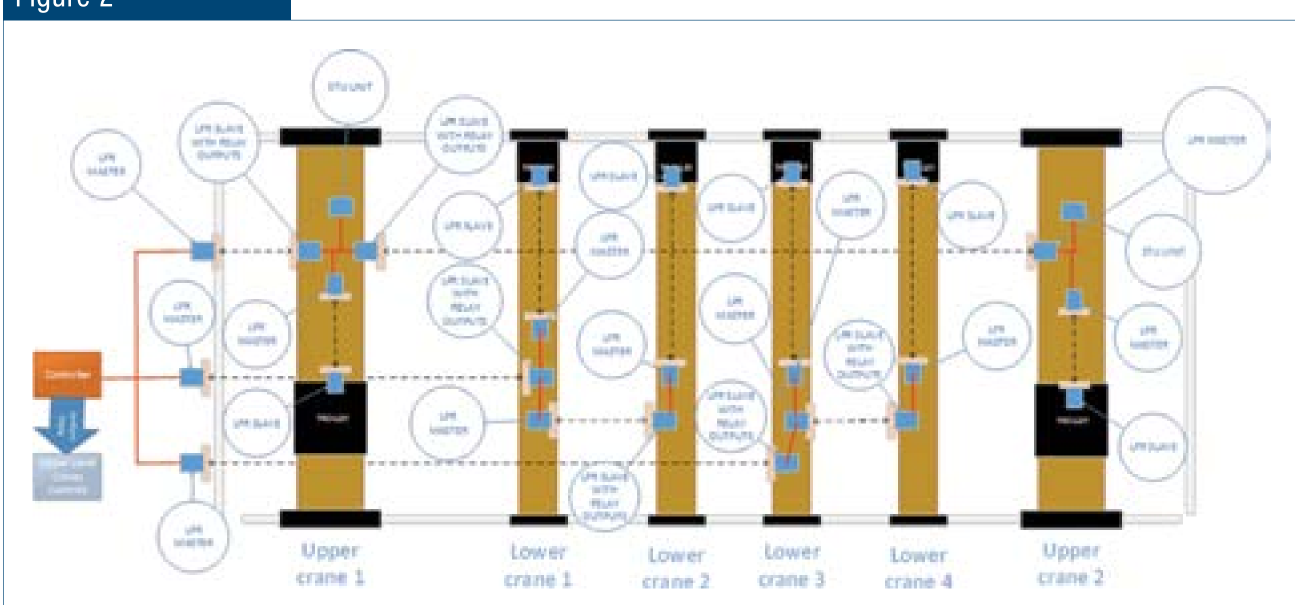
moving parts or optics to maintain or clean, airborne dust does not diffract the signal, and since they project their signals over a cone instead of a single focused beam, skew and vibrations do not affect the measurement quality or performance of the sensor.

The main trick that allowed this multi-level system to work, however, is that the radar devices also featured a built-in data transmission channel. Operating in the same 24 GHz bandwidth as the measurement channel, this data channel can be used to transmit data such as the position of multiple crane bridges and trolleys, along with digital and analog signals such as load cells and limit switches, from the cranes to the ground. This effectively combines positioning and data transmission into a single sensor. This significantly reduces the complexity of the system since it eliminates the necessity of having a Wi-Fi system.

The control system is structured as follows: each crane has a pair of sensors for measuring bridge position, and a pair for measuring trolley position. Each pair consists of a "local" sensor and a "remote" sensor. For bridge position, the "remote" sensor features on-board relays, whereas the reverse is true for trolley position — the "local" sensor has the relays, and the "remote" is simply a powered receiver. All sensors not on the trolleys are connected to each other via Ethernet. In the case of the lower cranes, the middle two cranes are positioned using the outer cranes as a reference; the "local" bridge sensor in this case is on the outer ingot crane, rather than the wall.

In addition, an input/output device was installed on the upper ladle cranes that receives the state of the upper limit switch and transmits it to the ground via the trolley remote sensor. Since the J-hooks can only clear the lower-level cranes when raised to the upper

Figure 2

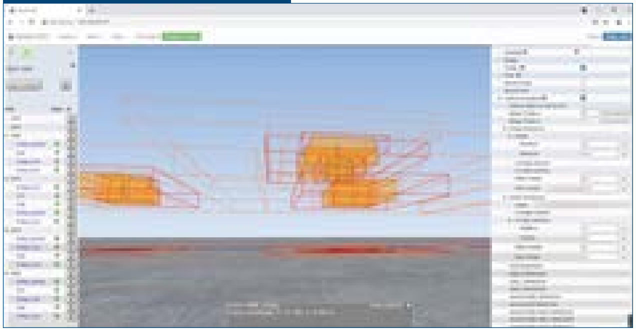


Layout of the collision avoidance system.

Figure 3

Radar sensor and the remote input/output device for the limit switch state, as mounted on a ladle crane.

Figure 4



Screenshot of the control software, showing a ladle crane interacting with an ingot crane.

hoist travel, the system will not allow the ladle cranes to travel over the lower cranes if the limit switch is not engaged.

The crane contactors are controlled using the sensors' on-board relays, which open when a collision event is activated. This is accomplished using interpose relays, which cut power to the crane motors for that contactor, causing the crane to slow down. When the stop event is active, power is cut to the motors in that direction, which still allows the operator to travel in the opposite direction. Due to the generation on the DC bus caused by hoisting, each sensor power supply is protected by an uninterruptible power supply to filter out excess voltage. Since the ladle crane contactors are controlled from the ground, a small programmable logic controller (PLC) was installed to control them there instead of on the crane.

The signals from all these sensors are sent via hardwire Ethernet to a central controller, which is in a control house in the middle of the meltshop. This controller, provided by the sensor's manufacturer, takes the measurements given by every sensor in the installation and determines when to open relays. It then controls the relays on the sensors via the on-board data channel, effectively using the relays are a remote input/output.

During commissioning, the most critical part of the system is making sure that all wiring is correct, that all the sensors are communicating correctly, and that the crane positions are properly calibrated.

Relay states can be forced on the control software to check that the interpose relays are wired correctly. The sensors use M12 connectors for power, Ethernet, and relays, so these also required checking to ensure there were no loose wires or miswirings. This extended to the limit switch, which is used in its normally open state to indicate hoist height.

Calibration was accomplished by marking out a spot in the bay that is reachable by every crane, and then having each crane position its hook directly above it. Once complete, the system is tested by having the cranes approach one another. Ladle cranes are brought close to the ingot cranes with the hook down, then again with the hook up, and when the trolleys are on opposite travels to see if they clear. This process requires much tuning on the software, as the stopping distances are as much defined by operator "feel" as it is by calculated inertia. However, since the software is on-site, the customer can adjust these margins as needed.

Over time, the system has been modified to deal with the operation, such as adding a bypass button for tandem lifts with the ingot cranes, along with a positioning system that uses the feedback from the radar sensors to show ladle crane operators where they are. However, since installation in mid-2021 the sensors have worked reliably in the environment with almost no cleaning, with one failure on a trolley remote sensor due radiant heat that was later resolved by adding a heat shield.

Conclusions

Going with a radar-based collision avoidance and positioning system, this paper is meant to demonstrate that no matter how complex the setup or difficult the environment, there exists a viable solution for implementing a collision avoidance system for overhead cranes. ✦