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Initiatives for Automation of Hot/Cold Rolled Coil Warehouse in JFE Steel

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Abstract:

JFE Steel's West Japan Works has been working to automate the warehouse of hot/cold rolled coil products with the main purpose of saving labor in logistics. The automated system of the warehouse of hot/cold rolled coil products is not only an alternative to operator skills, but also contributes to the high efficiency of coil product handling and the improvement of shipping efficiency. This report introduces technologies introduced in warehouse automation, particularly those related to crane cycle time shortening, position recognition, and scheduler functions.

1. Introduction

Against the backdrop of a declining working-age population, JFE Steel's West Japan Works is promoting labor saving in logistics. In recent years, many of the shipping cranes used in the steel works have exceeded an operation time of 40 years and are now due for renewal. Therefore, together with the renewal of aging cranes, the hot/cold rolled coil warehouses were also automated using crane automation technologies. Here, crane automation technologies are technologies that have been developed with JFE Logistics Corporation playing a leading role since 2012. These automated hot/cold rolled coil warehouses include 2 warehouses at JFE Steel's Chiba District (East Japan Works), 8 at Fukuyama District and 1 at Kurashiki District (both West Japan Works), and 2 at the Nagoya Distribution Center, and all are in stable operation.

Hot/cold rolled coil warehouses are warehouses that are used to store hot- and cold-rolled coil products until shipment. Coil products produced by hot rolling plants, cold rolling plants, etc. are loaded onto product transport vehicles and received in product warehouses. Overhead cranes are installed in warehouses for use in receiving, shipping and relocation of products in warehouses. The methods of delivering products from warehouses differ depending on the district. However, if it is limited to the delivery operation for export products, they include transfer to a product quay by forklift, transfer directly to a product quay by overhead crane, etc. For effective utilization of warehouse space, the coil products in warehouses at West Japan Works are stacked in a maximum of 3 tiers. To assure product quality, stacking standards are strictly specified by the type of product, packaging, weight, width, outer diameter, thickness, etc.

In automated warehouses, crane operation in the receiving, shipping and relocation operations in the warehouse is performed automatically by automated cranes and an automation system. This report presents examples of techniques introduced in warehouse automation, particularly those related to crane cycle time shortening, position recognition and scheduler functions.

2. Crane Cycle Time Shortening

This chapter explains the technique introduced to shorten the time required for 1 coil transport cycle (cycle time) in order to achieve high efficiency in crane operation. As a result of various efforts, cycle time was reduced by 20 % in comparison with manual operation by an operator by introducing cycle time shortening technique at the Fukuyama District E9 automated warehouse.

2.2 Shortening of Lifting and Lowering Cycle Time

2.1.1 Quick motion lifter

Coil lifters are adopted as the hoisting accessory of

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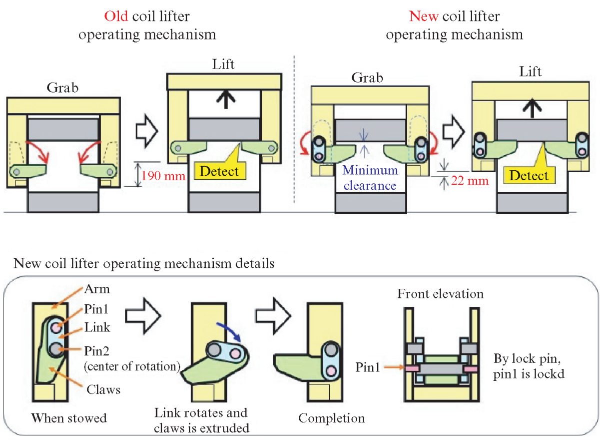

Fig. 1 New and old coil lifter operating mechanism

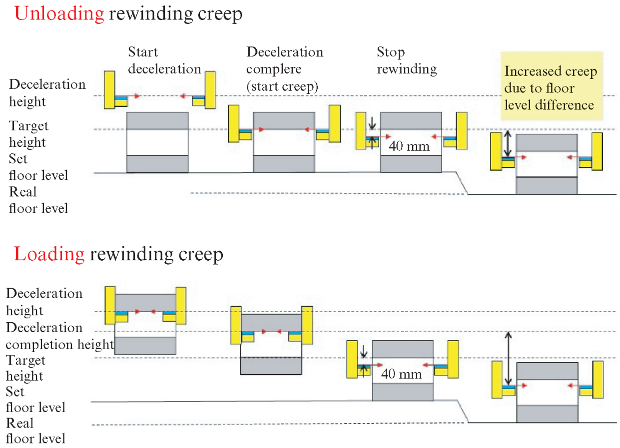

Fig. 2 The image of crane rewinding creep

the overhead cranes in hot/cold rolled coil warehouses. The claw operating mechanisms of the conventional and new type coil lifters are shown in **Figure 1**. In the conventional operating mechanism, a collapsible type claw housing is used. With this mechanism, the lifter must be lowered to a position where the inner diameter of the coil will not interfere with the motion of the claws. After lowering is completed, the claws drop into place and begin the grabbing operation. In contrast, in the new claw pushing-out mechanism (quick motion lifter), the links of the claws rotate while the lifter is lowering, and the claws are pushed out mechanically by the rotation of the links. This means that pushing-out of the claws can be completed with a small clearance between the claws and the top side of the coil inner diameter, and the grabbing operation begins at an early timing during lowering. After pushing-out of the claws, the claws are secured by a lock pin. During lowering, positioning is performed by very slow speed (creep) operation. Even if the shortened distance in lowering is small, this new mechanism has a large cycle time shortening effect. In fact, in comparison with the old claw operation mechanism, the new mechanism has shortened the cycle time for one hoisting operation by approximately 6 %.

2.1.2 Floor level learning

There are cases where the floor level in product warehouses is not uniform due to subsidence under the weight of products and wear by the travel of product transport vehicles and heavy equipment. According to the actual measured data for the automated warehouse at the Kurashiki District, the difference between the levels of the highest and lowest points was more than 100 mm. Since conventional automation systems assumed that the floor level is the same in the entire warehouse, excess crane lowering creep (operation in the very slow region) occurred during lowering of the lifters, resulting in the problem of extended cycle time. Creep during lifter lowering is shown in **Figure 2**.

In the case of unloaded lowering, the lowering speed is decelerated at a certain height (deceleration height), and deceleration is completed on reaching the target height. Then creep operation begins, and after a low spot is detected by a detector installed on the lifter, lowering continues for a constant value and the grabbing operation begins. When there is a difference between the set floor level and the actual floor level, lowering creep occurs corresponding to that distance, and the cycle time is extended. Similarly, during loaded lowering, creep also occurs from the end of deceleration until the coil reaches the floor. In order to minimize lowering creep, the proper floor level must be defined for each individual coil position. Therefore, in this automation system, a floor level learning function that retains and learns the floor level at each position was introduced, and these individual floor levels are used in calculations of the deceleration starting height of the lowering speed. This has achieved a cycle time shortening of approximately 2 % in unloaded lowering and approximately 5 % in loaded lowering.

2.2 Cycle Time Shortening in Triple Crane Operation (Lifting/Traversing/Traveling)

2.2.1 Shortest Path Search Logic

When hot- or cold-rolled coils are transported by a warehouse overhead crane, the triple operations of lifting, traversing and traveling are performed in parallel. Although transportation by the shortest path that avoids obstacles is advantageous for cycle time shortening, the shortest transport path changes depending on the situation due to the movement of vehicles and coil products, which are obstacles on transport paths. In addition, if large sway of a suspended load occurs while a coil is being conveyed, there is a danger of col-

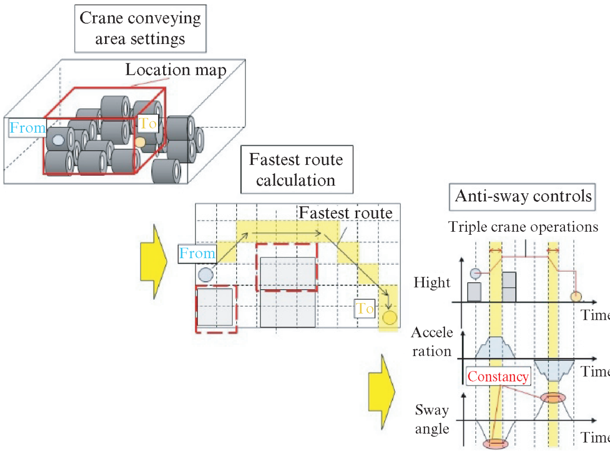

Fig. 3 Shortest path search logic in coil conveyance

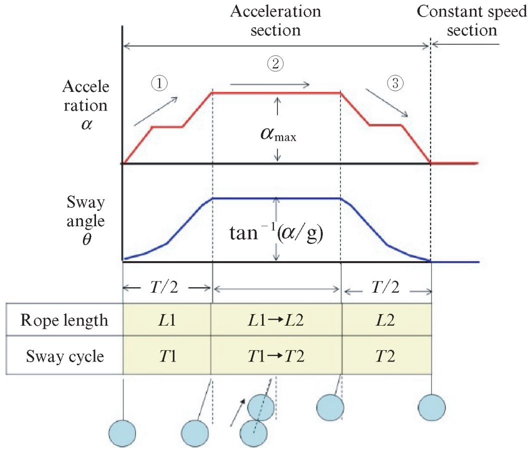

Fig. 4 Anti-sway control of crane movement

lision or dropping the coil. Therefore, a shortest path search logic was introduced to solve these problems. An outline of the search logic is shown in **Figure 3**.

First, a location map within the movement range is prepared from the coordinates (x, y, z) of coils in the warehouse for the starting and end points of conveying, and the crane conveying area is set. Next, in order to calculate the shortest path, the crane conveying area is converted to x-z plane represented by multiple grids, and evaluation values related to the moving time of the crane are set for each grid. The evaluation values are derived from the X-direction velocity V_X and the Z-direction velocity V_Z of the crane. When an obstacle such as coil product information, etc. exists in a grid, that grid is judged to be an obstacle coordinate. A shortest path search is performed based on the evaluation values and obstacle information of each grid. The triple crane operation pattern is prepared based on the shortest path derived by this method, considering anti-sway controls to prevent swaying of the suspended load. The anti-sway controls are described in the following section.

2.2.2 Anti-sway technique for triple crane operation

Various types of anti-sway controls for loads suspended from cranes have been applied in practical operation, including machine mast type sway prevention, feedback (FB) control using a sway angle sensor, sway prevention utilizing the crane speed pattern, etc.[1] In anti-sway control in triple crane operation, speed pattern anti-sway control is performed. **Figure 4** shows an outline of the anti-sway technique during triple crane operation.

The basic principle of speed pattern anti-sway control is as reported by Kuyama et al.[1] Assuming the pendulum length (rope length) is L (m) and acceleration of gravity is g (m/s^2), the sway cycle T (s) of a suspended load is given by Eq. (1).

$$T = 2\pi\sqrt{\frac{L}{g}} \qquad \cdots\cdots (1)$$

From Eq. (1), the sway cycle T depends only on the rope length L. If acceleration/deceleration is performed by an integral multiple of this sway cycle T, the sway angle will become zero. Therefore, anti-sway control is performed by the sway cycle T in the acceleration increase and decrease sections shown by ① and ③ in Fig. 4.

Assuming the acceleration of the suspended load is α (m/s^2), the sway angle θ is given by Eq. (2).

$$\theta = \tan^{-1}(\alpha / g) \qquad \cdots\cdots (2)$$

From Eq. (2), the sway angle θ depends only on the acceleration α of the suspended load. Therefore, the rope length is changed only in the constant acceleration region ② in Fig. 4, and the conveying height is adjusted to a height which makes it possible to avoid obstacles in conveying.

3. Location Recognition Technique

3.1 Location Recognition Equipment

In warehouse automation, the existing manned vehicles are used as-is without equipment improvements. In the case of manned vehicles, if a vehicle stops at the prescribed position in the warehouse vehicle slot, a certain amount of error will occur in the stopping position. If error occurs in the vehicle stopping position, it will not be possible to grasp the coordinates of the coil product on the vehicle cargo bed accurately, and a collision between the lifter and the coil product may occur. To prevent this kind of trouble, a location

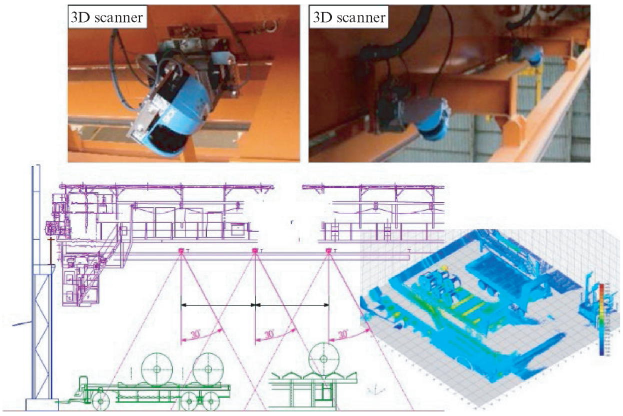

Fig. 5 Location recognition equipment

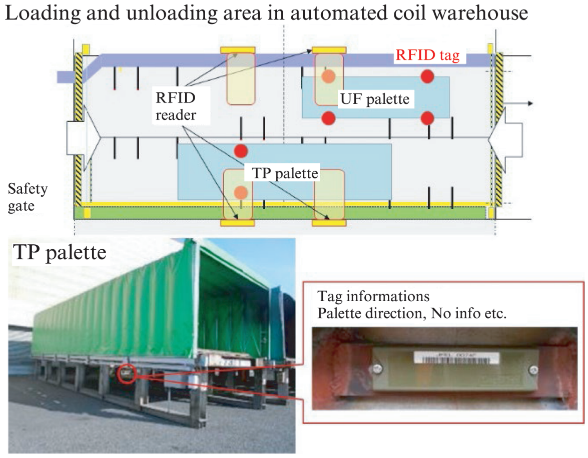

Fig. 6 Automatic recognition of palette direction

recognition device[2)] which measures and corrects the coordinates of the coil location on the vehicle cargo bed was introduced (**Figure 5**).

Multiple 3-dimensional laser scanners were installed at equal intervals on the crane main girder. This eliminated blind spots in the positions of the coil product and skid (coil cradle) on the vehicle cargo bed. Based on data including the coil product information (width, outer diameter, number of coils), vehicle information (type and dimensions), the vehicle stopping position and the coil loading position on the vehicle received from the upper level system, the vehicle and the coil product on the vehicle cargo bed are measured, and the center coordinates of the coil product on the cargo bed are calculated. The hoisting, traversing and traveling positions of the crane during measurement are moved to the set location in order to shorten the working distance to the next task, secure measurement accuracy and avoid interference of the lifter and the coil product measurement range. In addition, automatic correction of the stopping position and inclination of the crane position is achieved by installing reference reflectors in the field of view of the 3-dimensional laser scanners.

3.2 Automatic Recognition of Vehicle Direction

Because the product conveying vehicle slot of the Fukuyama District E9 automated warehouse has a layout which allows vehicles to pass through the building, as shown in **Figure 6**, two vehicle directions exist. Therefore, it is necessary to recognize the vehicle direction when the coordinates of the position of a coil product on the vehicle cargo bed are acquired. In the automated warehouses in the Fukuyama District, RFID (Radio Frequency Identification) tag technique was used as a technique for automatic recognition of the vehicle direction. Fig. 6 shows the equipment configuration of the RFID technique, together with the layout of the receiving/shipping slots of the Fukuyama District E9 automated warehouse.

An RFID tag is attached to a leg of the product conveying carrier called a pallet. In addition to the vehicle direction, information such as the vehicle No., etc. is also included in the tag. The RFID tag is read by the antenna of the RFID detector, which is installed at the warehouse vehicle slot, and information on the vehicle direction is acquired using the information read from the RFID tag. In combination with this, automatic tracking of the coil products is also possible by acquiring product information from the upper level system using the vehicle No. This eliminates the need for the driver to get out of the vehicle. In addition, the risk of coil product identification errors has also been reduced because tracking of coil products no longer requires human intervention.

As an alternative to the RFID tag technique for automatic recognition of the vehicle direction, the location recognition technique explained in section 3.1 is used at the Kurashiki District. The shape of the vehicle cargo bed is recognized by the 3D laser scanning system, and the direction of the vehicle is recognized. In the case of pallets which have a canopy to prevent wetting by rain, the canopy shape is recognized, and pallets without a canopy are distinguished by a reference sphere installed on the pallet. However, since it is not possible to track coil product information other than the vehicle direction in this case, some other means of recognizing the vehicle information is necessary. Therefore, the vehicle information is given in a barcode attached to the leg or other part of the pallet, and it is possible to track the coil product information by reading the barcode with a hand scanner.

3.3 Vehicle Automatic Loading Function

In the case of dedicated vehicles used within the steel works, automatic unloading and loading are performed by acquiring the coordinates of coil products on the vehicle cargo bed by combined use of the information of the upper level system and data measured by the location recognition system. However, automatic loading and unloading were difficult with general-purpose trailers, which can also transport products to destinations outside the steel works, due to customer instructions about the loading position and the direction of the coil products on the cargo bed (e.g., transverse loading or longitudinal loading). As an additional problem, because vehicle information (type and dimensions of vehicle) for various general-purpose trailers is not available on the system, it was not possible to designate the coordinates of coil products on the vehicle cargo bed with sufficient accuracy. Therefore, automatic loading of general-purpose trailers was achieved by installing positioning reference points near coil product loading/unloading positions to enable recognition of coil product loading positions. Accurate measurement is possible, even when the dimensions of the vehicle are unknown, by automatic recognition of these reference points from the data measured by the 3D laser scanner system and analysis of the vehicle shape near those points. Loading that will not cause cargo collapse during transportation has also been achieved in automation operation by combining this with a loading operation logic (patent pending) which was developed at the same time. The methods described above have made it possible to perform automatic receiving and shipping with almost all of the product transport vehicles handled by automated warehouses, including general-purpose semi-trailers.

4. Scheduler Functions

4.1 Overview of Scheduler Functions

In receiving and shipping in conventional warehouses, an operator in the control room made judgments based on ship loading plans and warehouse plans. In addition, coil relocation was performed by the crane operator immediately before shipping work. In warehouse automation, a scheduler function was constructed and gives work instructions for the crane based on ship loading plans, warehouse plans and vehicle arrival information input by personnel in the upper level system[3]. The scheduler function is shown in **Figure 7**. In the scheduler function, work instruction information is constructed by the crane instruction scheduler and the coil relocation scheduler function. The role of the crane instruction scheduler is to decide the work (receiving/shipping instructions for target coil products) to be executed by the automatic crane based on the set priority order. Priority order settings can be switched optionally from the system terminal. Relocation is performed when there are no instructions that can be carried out. The following section describes coil relocation scheduler in particular.

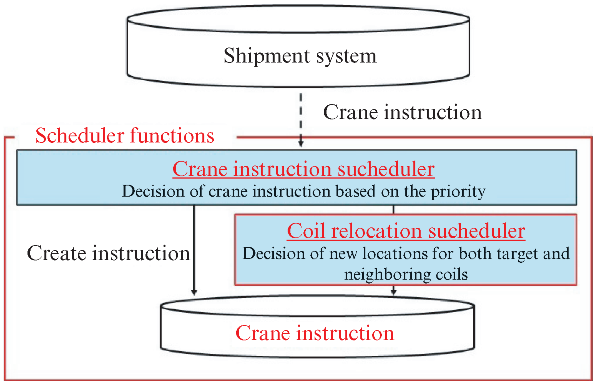

Fig. 7 Coil relocation scheduler

4.2 Coil Relocation Scheduler Function

The role of the coil relocation scheduler function is to decide the target coil products for relocation and their new locations. One of the functions of the relocation scheduler is rearrangement of coils for more efficient use of storage space. The aim of this function is to increase the number of coil cradles available for receiving in the storage area. Coil products which can be stacked on the 2nd tier or 3rd tier in the storage space are extracted and relocated. As the timing of execution, relocation is performed when there is no other work with a high priority order, and when the number of coil cradles available for receiving in the warehouse is small. Coil products which are not in the same shipment lot are not stacked on top of coils with earlier shipping dates. This rearrangement operation optimizes the arrangement of coil products each time, and thus maximizes the storage capacity of the warehouse.

Another function of the relocation scheduler is the advance relocation function (relocation preparing for shipment), which is used to gather coil products in the same shipment lot in the warehouse. (In the case of shipments by ship, "same shipment lot" means products to be stowed in the same ship's hatch.) Coil products in the same shipment lot are gathered in a designated area in the storage space, and coil products from different shipment lots should not be stacked on top of them. This is because stacking products from a different, unrelated shipment lot on the target coils will cause unnecessary work, called "take-off work", to remove those products and move them to a different storage area. If a large amount of take-off work is necessary for export products to be shipped by ship, shipping efficiency will be reduced, and in particular, this will also lead to an increase in ship loading time. **Figure 8** shows the features of this advance coil relocation function in preparation for shipment. This function

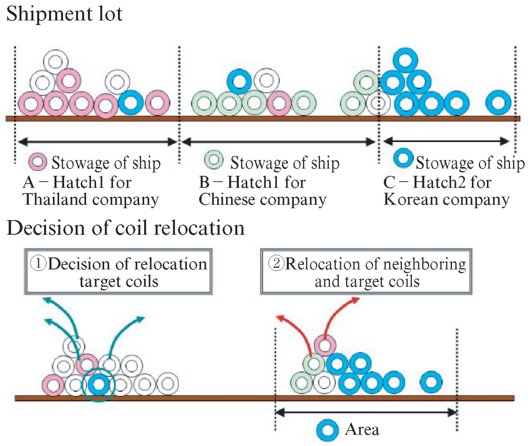

Fig. 8 Feature of coil relocation preparing for shipment

automatically sets the areas in the warehouse in a shipment lot unit. In the example in Fig. 8, areas for coil products for companies in Thailand, China and Korea are created automatically in shipment lot units. After the areas are created, the products for each of these destinations are gathered. Taking the coils for the Korean company as an example, coils for Korea which had been arranged in other areas are extracted and relocated to the area of products for the Korean company. Furthermore, if there were other products for the Thai company in the area for Korea, those coil products are also relocated to another area. In this way, improved efficiency and unmanned work were achieved in warehouse receiving and shipping work by automatically optimizing the lots of the products for the shipments concerned which are stored in the warehouse.

5. Conclusion

This paper has described initiatives for automation of hot/cold rolled coil warehouses at JFE Steel's West Japan Works. Initiatives for product warehouse automation in the JFE Group began with an automated crane at the S-8 warehouse in the Chiba District of East Japan Works, and were then developed horizontally to the Fukuyama District and Kurashiki District of West Japan Works. Technical improvements were also carried out on each occasion. As an effect of introduction, in the Fukuyama District, more than 90 % of non-pickled hot-rolled coil for export are already received and shipped from automated warehouses. Similarly, in the Kurashiki District, in addition to a large improvement in crane operating time, the ratio of receiving and shipping from the automated warehouse has also been achieved as originally expected. Although automation of hot/cold rolled coil warehouses in the Fukuyama District, Kurashiki District and distribution centers is planned for the future as well, we also intend to improve the level of automation technology in line with the operational situation in each district, including measures to improve safety in automated warehouses, control of multiple cranes in the same warehouse, etc.

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