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Advanced Technology in Material Flow in Bar Mill and Wire Rod Mill

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Abstract

Nippon Steel Corporation's Muroran Bar Mill and Wire Rod Mill have improved their competitiveness by improving materials flow through continuous processing and automation which have reduced costs. They have also improved the quality of the surface of their products by reforming handling and they have improved the level of product identification to respond to their customer's needs. This paper outlines a billet book tracking system, an automated bar assorting warehouse, the No. 3 automatic finishing ling for bar products and an automated warehouse for wire rods as an embodiment of recent reforms in materials flow. All of these have contributed greatly to reducing labor and improving product quality.

1. Introduction

The bar mill and wire rod mill at the Muroran Works started up their operations in 1974 and 1969, respectively. The products from the two mills are used in automobiles, industrial machines, civil engineering projects, and buildings, among other applications. Chiefly for special steel bars and wire rods, the Muroran bar mill and wire rod mill have introduced generation-leading functions and have constantly pursued higher productivity, lower cost, and new products. In the last few years, capital investment has been made to improve material flow and to achieve concomitant labor savings. This article focuses on improvements to material flow and gives an overview of the following pieces of equipment with streamlining, direct connection, direct rolling, automation, handling defect prevention, and inventory cutback as keywords:

(1) Billet tracking system for bars and wire rods
(2) Automated bar assorting warehouse system
(3) No. 3 automatic finishing line for bar products
(4) Automated wire rod warehouse

2. Billet Tracking System for Bars and Wire Rods

2.1 General description

The Muroran Works produces special steel bars and wire rods, represented by those for such safety-critical parts as automotive valve springs, bearings, gears, and suspension parts. The historical tracking of the product manufacturing processes was an issue in view of the needs for quality assurance and quality improvement. At the steel-making plant, for example, a single charge 270-ton steel is refined in an LD converter, cast into blooms on a six-strand continuous caster, and rolled into 120 billets at a billet mill. It was necessary to track these materials, control their storage yards, and manage their production results. These tasks were traditionally conducted manually for some specific steels.

In October 1994, automatic marking units capable of marking hot steel with the necessary information were introduced on the cooling bed of a billet rolling line to mark heat numbers, billet ID numbers and other information at the ends of all billets. These items of marked information are read into the rolling process computer through cameras installed above the charge beds of the billet finishing lines at the bar mill and the wire rod mill, and are checked for identification. At the billet conditioning line, the marked information is re-

*1 Muroran Works

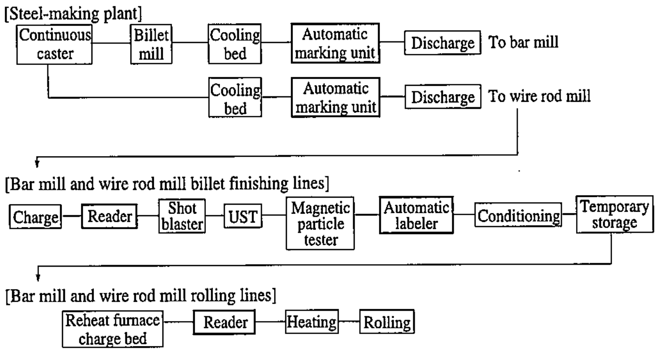

Fig. 1 Location of billet tracking system

moved by shot blasting, so that labels are affixed again to conditioned billets. The label is read again through the rolling process computer on the charge bed of the re-heating furnace and incorporated as identification control and tracking information into the product information (see **Fig. 1**). The billet tracking system is utilized as an effective tool for undertaking quality improvement activities and for investigating quality problems.

This section describes the bar and wire rod billet tracking system.

2.2 Billet tracking system technology

2.2.1 Automatic marking units

The following methods were considered for marking information at the ends of billets: 1) stenciling; 2) die stamping; 3) labeling; 4) tagging; and 5) jet marking. The jet marking method was adopted by considering the following service conditions:

(1) Wide billet temperature range of room temperature to 600°C
(2) Billet bending, torsion, or end surface irregularities
(3) Information quantity of about 20 characters required
(4) Cycle time of 19 s
(5) Readability by machine and man
(6) Labor conservation and maintenance

As the technology concerning the jet marker, the function of controlling the paint spray rate at an optimum level to suit the billet temperature, and the mechanism of automatically recognizing the billet end position by billet end image processing and of following such variations as the billet end bend, torsion, or misalignment were developed and installed.

The information marked by the automatic marking unit is described in **Table 1**.

2.2.2 Automatic labeler

When billets are shot blasted at the billet inspection line, their marked characters are made unclear. To counter this condition, an automatic labeler is installed at the exit side of the line and is used to add the results of ultrasonic testing (UST) as well. The technique of detecting the billet end position with a laser sensor has been developed to affix labels in a stable manner against such disturbances as billet bend, distortion, stop position variation, magnetic particle suspending liquid, and UST coupling water.

Table 1 Marking information

Marking	Number of digits	Description
Heat number	6	Key for cast strand position judgement
Billet number	3	Key for cast strand position judgement
Sort symbol	3	Cast strand head or trail end
Check digit	1	Judgement of misreading
Billet status	7	Not automatically read but intended as reference information to operator

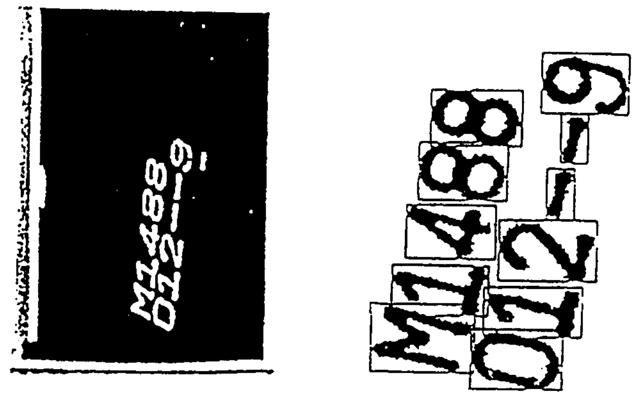

Fig. 2 Example of character segmentation by reader

2.3.3 Readers

Readers must recognize two types of characters: characters marked by the automatic marking units and characters printed on the labels. To meet these requirements, reliable character segmentation (refer to **Fig. 2**) and highly accurate character recognition logic were developed. Character segmentation had such problems as billet end surface irregularities, and billet rotation, misalignment, bend, and distortion. Character recognition had such problems as character blurring, chipping, and misrecognition. These problems were solved by: 1) all-direction illumination technology; 2) character segmentation algorithm, including distance and rotation compensation; 3) character recognition technology adapted to character blurring and chipping; and 4) feature character development.

2.2.4 Related systems

(1) Billet tracking system

An integrated control file was created by using the heat number and billet number as keys, and tracking information from each line was collected in the integrated control file. Based on this system, it was made possible to rapidly organize and supply information as required, such as for quality improvement.

(2) Identification system

At each reader installation point, the billet end information is checked with the tracking information to perform identification control with high accuracy. The billet end information contains an error check digit so that it can be properly recognized if misread. The billet steel grade is information that is not read and is printed as reference information to the operator.

2.3 Benefits of billet tracking system

The operation of the system allowed the jobs of more than 30 persons to be eliminated, strengthened the identification control function of each line, shortened the claim investigation time, and contributed to quality improvement.

3. Automated Bar Sorting Warehouse System

3.1 General description

A study was made of the direction connection between rolling and subsequent off-line finishing from the viewpoints of strengthening the quality assurance system, improving delivery service, reducing the manufacturing cost, and improving the working environment. To this end, the functions were planned of accommodating factors interfering with the direct connection, such as processing speed dif-

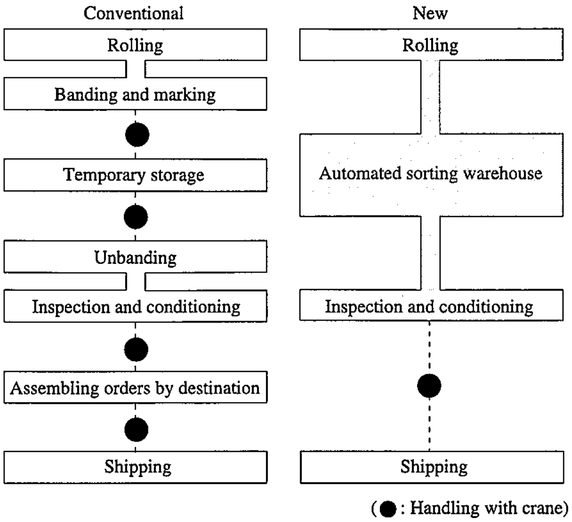

Fig. 3 Process from rolling to shipping at bar mill

Table 2 Main specifications of automated bar sorting warehouse system

Item		Main specification
Product	Size	Round bars: 19 to 120mmϕ Square bars: 42 to 90mm
	Length	3.5 to 9.0m
Number of shelves		1,800
Unit storage weight		Maximum of 4.0t and average of 3.2t
Storage capacity		5,760t
Storage and retrieval rates		Storage rate of 150t/h and retrieval rate of 110t/h
Storage and retrieval control		Application of artificial intelligence

ference, size sequence, and product temperature (see **Fig. 3**). In December, 1992, an automated bar sorting warehouse system became operable (see **Table 2**). Material flow in the bar mill was substantially improved. For example, the use of cranes at the finishing line was restricted to the final discharge of products. This section gives an equipment overview of the automated bar sorting warehouse system.

3.2 Rolling, finishing, and direct shipping connection technology

3.2.1 Unmanned direct connection technology

Bars cut to length after rolling were temporarily banded and marked, were temporarily stored by crane at the yard to wait for the finishing sequence, were charged to the inspection station, and were subsequently un-banded. A system was built for storing 4-ton lifts of loose bars in an automated sorting warehouse (see **Fig. 4**). This system has provided buffer functions for the differences in processing speed between rolling and finishing, cool-down for inspection, and the wait time with regard to finishing sequences, among other conditions, and it has significantly improved productivity through un-manned operation.

3.2.2 Loose bar storing technology

Bars, which were formerly temporarily banded, are now placed in cassettes and stored loosely in an automated sorting warehouse.

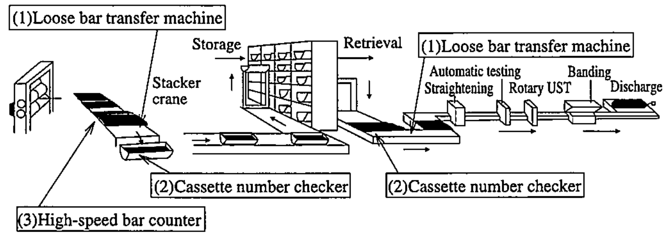

Fig. 4 Loose bar storage technology

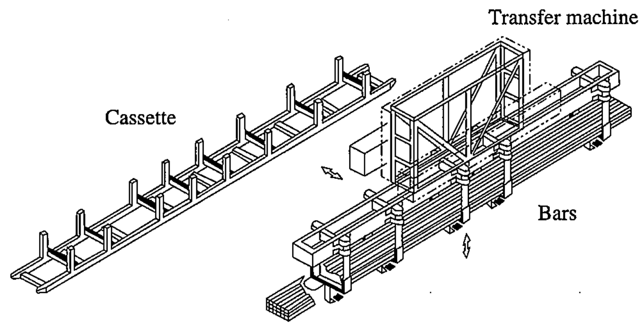

Fig. 5 Loose bar transfer machine

This practice has eliminated the un-banding work and reduced the consumption of banding materials. To achieve this technology, loose bar transfer machines (see **Fig. 5**), bar-code cassette number checkers, and a high-speed bar counter are installed. Besides the conventional high-accuracy rolling line tracking system, due consideration is given to identification control in the automated sorting warehouse.

3.2.3 High-efficiency storage and retrieval control technology

Highly efficient storage and retrieval are achieved with a compact warehouse by introduction of advanced control functions, such as highly efficient and optimum storage and retrieval control by artificial intelligence (AI). The main control functions are:

(1) Optimization of storage and retrieval crane operation
(2) Automatic selection of optimum storage rack position to suit storage rate (t/h)
(3) Automatic cassette rearrangement in anticipation of future inventory level
(4) Planning of delivery in anticipation of total material flow from order receipt to shipment

3.2.4 Hot and heavy bar storage technology

Bars have a temperature of about 300°C even after cooling bed and must be handled in lifts of 4.0 tons each in view of the efficiency of storage. Bars are 3.0 to 8.0 m long. The features of an optimum system developed to meet these conditions are described below.

1) Transfer of bars by longitudinal sliding in rack
Cassettes containing bar products are longitudinally slid for transfer. As compared with lift-up, this method can reduce the shelf space in the vertical direction. Stacker cranes for storing cassettes in the warehouse come in the vertical type in which they move vertically with respect to the longitudinal direction of bars and in the horizontal type in which they move in the longitudinal direction of bars. The former type is suited for handling long materials with high efficiency and is thus adopted to reduce the required number of stacker cranes.

2) Rack building with entry guide rollers
The problem that occurs when the cassette moves on a slider is that the motor load is increased by the wear and sliding resis-

tance of the slider. This problem is solved by replacing one entry slider with rollers. This solution allows the cassettes to be stored in a stable manner even during an earthquake.

3.3 Benefits of automated bar sorting warehouse system

The startup of the system eliminated manual intervention, improved work reliability, raised the trackability of bar products, accomplished identification control and inventory control with high accuracy, and contributed to delivery control. Crane slinging, temporary banding, temporary marking, unbanding, and yard control were made unnecessary. Materials associated with these tasks, such as banding hoops, marking tags, and slinging wire rope can be reduced in usage which will result in a sharp reduction in manufacturing costs.

4. No. 3 Automatic Finishing Line

4.1 General

The following measures had been sequentially planned and implemented for improving the productivity of the bar finishing line: 1) installation of three shears; 2) construction of an automated assorting warehouse for direct connection between rolling line and finishing line; 3) automation and continuation of off-line finishing; and 4) direct shipment of bar products.

The No. 3 automatic finishing line is part of the project. An automatic magnaflux flaw detector with a ultraviolet laser and pipe receiver was developed. It can stably detect, especially in large-diameter bars, defects of 0.1-mm depth that have been difficult to detect with conventional automatic testers.

This chapter gives an overview of the No. 3 automatic finishing line that was started up in February 1997.

4.2 Description of No.3 automatic finishing line

4.2.1 Line Layout

The No. 3 automatic finishing line is directly connected with the automated assorting warehouse and is composed of a charge bed, straightening machine, ultrasonic tester (UST), automatic magnetic particle tester, conditioning beds, banding machine, and discharge bed. A feature of this layout is the installation of two conditioning beds for improved processing capability and the looping of the surface defect inspection and conditioning line for two-time inspection. The main specifications of the No. 3 automatic finishing line are given in **Table 3**, and its layout is shown together with that of the overall off-line finishing line in **Fig. 6**.

4.2.2 Automatic surface tester

(1) Principle of defect detection

The principle of the automatic surface tester developed in this project is illustrated in **Fig. 7**. Based on the magnetic particle testing method, an ultraviolet laser, as a substitute for a black light used for visual inspection, scans and illuminates the bar in the longitudinal direction. The light excited and emitted by the magnetic particles adhering to a defect is collected by the pipe receiver and detected by the photo-multiplier.

(2) Basic technology of automatic testing

The elementary techniques that support automatic defect detection are as follows:

1) Scanning and illuminating bar with ultraviolet laser light with high accuracy
2) Sensing excited light with pipe receiver
3) Finding defect position in circumferential direction
4) Optimizing magnetic particle pattern formation conditions

(3) Defect detection characteristics

The defect detection performance of the automatic surface tester investigated by using natural defects is shown in **Fig. 8**. The tester

Table 3 Main specifications of No.3 automatic finishing line

Machine	Item	Main specification
General	Product size	19 to 120mmϕ
	Product length	3.5 to 8.0m
	Transfer speed	80m/s
	Nominal processing capacity	8,500t/month
UST	Type	Probe rotation type Normal beam method: 5 channels, Angle beam method: 10 channels
	Accracy	Defect diameter 0.3mm × Defect length 10mm
Automatic magnetic particle tester	Type	Defect reveal: magnetic particles + ultraviolet laser light Defect detection: pipe receiver + photo-multiplier
	Accracy	Defect depth 0.1mm × Defect length 10mm
Banding machine		With stacking unit

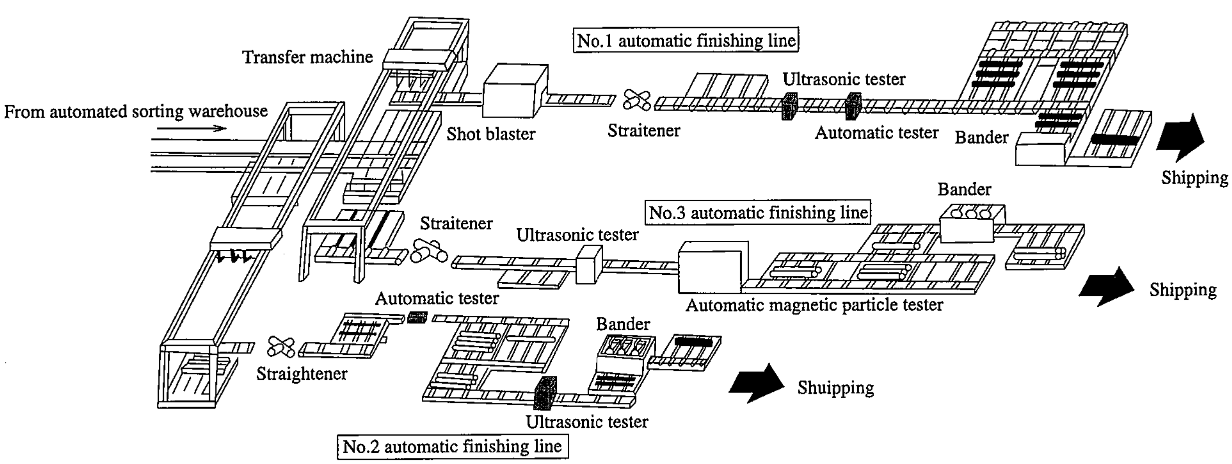

Fig. 6 Layout of No. 3 automatic finishing line

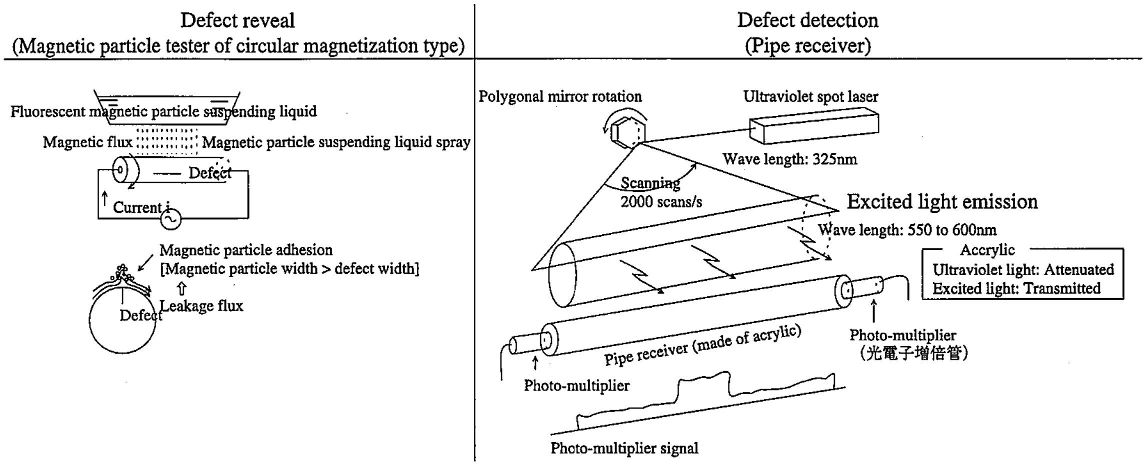

Fig. 7 Principle of automatic surface tester

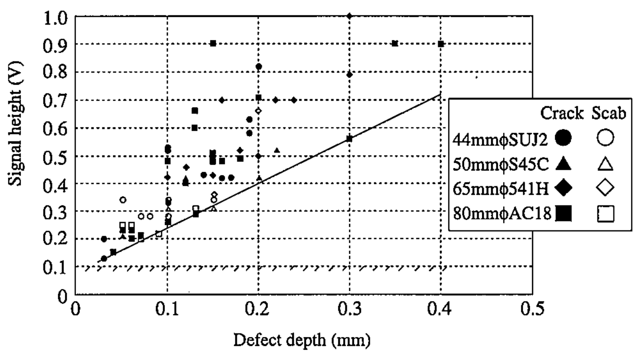

Fig. 8 Defect detection performance

has a high enough capability to detect 0.1 mm deep defects. It also solved the problem of defect detection noise observed with an automatic magnetic particle tester of the leakage flux rotation type for bearing steels.

4.3 Benefits of No. 3 automatic finishing line

The completion of the No. 3 automatic finishing line made it possible to process all bar products but square bars on a continuous line and to achieve labor savings by significant improvement in material flow as compared with the conventional non-continuous line. The improved off-line processing capacity also reduced the work-in-process inventory awaiting finishing.

5. Automated Wire Rod Warehouse

5.1 General description

Formerly, rolled wire rod products were finished and banded on a power-and-free conveyor, temporarily stored with a crane or ram lift at a product yard, and discharged from the product yard as requested by the shipping department. In April 1995, an automated warehouse was constructed and directly connected with the power-and-free conveyor line by automated guided vehicle (AGVs). This has reduced the amount of handling, reduced labor, improved surface quality, and enhanced the identification control of wire rod coils on an individual basis (see **Table 4**). This section gives an overview of the automated warehouse and guided vehicles.

5.2 Technology for direct connection between rolling and shipping

5.2.1 Technology for direct connection between rolling line and automated warehouse

The wire rod coil positions at the product yard were all computer controlled as the x-, y- and z-coordinate values, and coil identification and other tasks involved were rationalized. There was still room for rationalization. The coils were stacked in two or three tiers. When they were re-stacked to discharge lower ones, they had the problem of surface defects.

AGVs, shown in **Photo 1** and **Table 5**, were introduced to carry the coils from the power-and-free conveyor to the automated warehouse. Stations for exchanging the coils with the cranes for packaging and annealing, for example, were installed at the respective spans of the product yard. This allowed the size of yard control personnel to be sharply cut and prevented the occurrence of surface defects by eliminating product stacking and reducing the amount of handling.

5.2.2 Storage method in automated warehouse

The wire rod coils may be stored in the automated warehouse by: 1) installing cantilevers in the rack and threading the cantilever through a coil; 2) installing coil cradles in the rack and placing a coil on the cradle; 3) or depositing a coil on a pallet and storing the pallet into the rack. The third pallet method was adopted after comparing the storage efficiency, stored coil stability, maintainability, and investment required, among other factors. The pallets are fitted with turnover prevention stanchions as shown in **Photo 2** for the stable storage of coils with low banding pressure.

5.3 Benefits of automated wire rod warehouse

The completely unmanned operation of the automated wire rod warehouse has proved effective in accomplishing the saving of labor and in preventing handling defects. The automated warehouse has

Table 4 Main specifications of automated wire rod warehouse

Item	Main specification
Number of shelves	2,160
Unit storage capacity	2.5t
Storage capacity	4,300t
Storage and retrieval rate	110t/h
Storage and retrieval control rate	80t/h

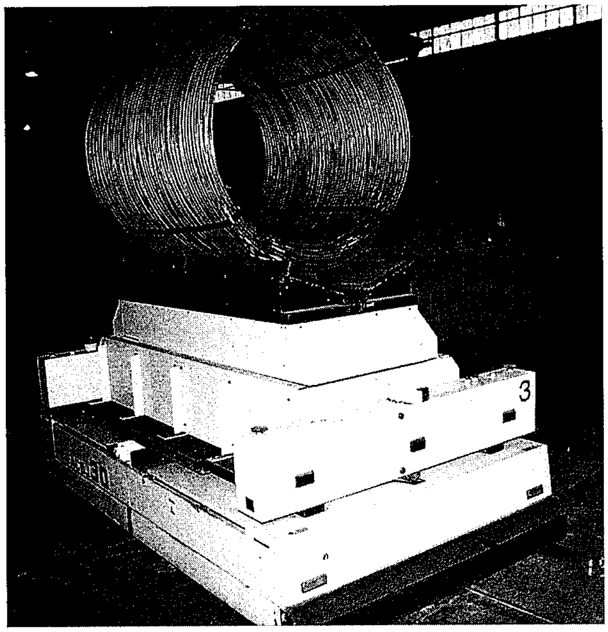

Photo 1 General view of AGV

Table 5 Main specifications of AGV system

Item	Specification
Transfer weight	Maximum of 3t × 1 coil
AGV speed	3.6km/h
Number of AGVs	6
Transfer capacity	110t/h
Drive method	Battery: 48V(charging period: 8h), onboard motor
Safty devices	Non-contact optical sensor, contact bumper sensor, etc.

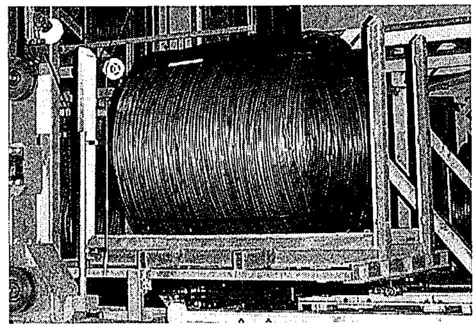

Photo 2 Wire rod coil stored in cassette

minimized the occurrence of dew condensation and rusting, and has enabled stable product delivery.

6. Conclusions

The Muroran Works provides automation and continuation from steel-making to shipment, has a complete tracking system for blooms, billets and products, and performs strict quality control. Some of these facilities have been introduced here. They are indispensable for the manufacture of special steel bars and wire rods, and embody our experiences of working with many customers. We will strive further to make new and conventional special steel bars and wire rods of higher quality at lower cost in a shorter delivery lead time.