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Automatic Operation System for Yard Machines

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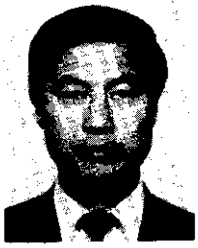
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1 Introduction

At the West Plant of Chiba Works efforts have been made since 1977 to develop automatic operation systems for stackers and reclaimers in the raw material yards in order to reduce the number of operators and improve the working environment. The development of a full automatic remote operation system of raw materials stackers has already been completed and put into operation.[1] With respect to reclaimers, however, only traveling and reclaiming have been automated and the remaining operations of landing and bench changing have so far been conducted through remote operation by using industrial TV monitors.

In May 1984, an automatic landing and bench-changing system of reclaimers was completed to establish fully automatized remote operation. This report outlines the automatic landing and bench-changing system at Chiba Works.

2 History of Automation of Stackers and Reclaimers

2.1 Automation of Stackers

The stackers in the raw materials yard at the West Plant were brought into operation simultaneously with the blowing-in of the Chiba No. 6 blast furnace in 1977. Based on experience in several previous attempts to automatize stackers and techniques developed by the company, these stackers were successfully automated at an earlier time than other yard machines.

In automatic operation of stackers, special operations such as stacking of independent smaller piles, overlay stacking on existing piles, and special multi-pile stacking, are possible in addition to usual stacking procedures. In 1979, a full automatic operation system for all stackers was completed after several improvements, including such functions as automatic travelling to specified stacking positions. The yard control efficiency of remote operation is as high as that of manual opera-

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tion on the machine side and automatic remote operation ratios are maintained at high levels. The essential functions of reduction of sintered ore size segregation and minimization of degradation are also performed satisfactorily in remote operations.

2.2 Automation of Reclaimers

The No. 12 reclaimer, which is located at a position permitting the reclaiming of various raw materials such as iron ore, coal, and flux materials for ironmaking and coking process, was selected, as the target of the automation of this reclaimer in 1978 as the start of the automatization project. Various experiments have been carried out to investigate such matters as the performance of various sensors, view areas of ITV monitors, and fluctuations of reclaiming speed. As a result, it has become possible to maintain constant reclaiming speed, including that in automatic traveling to the reclaiming positions, automatic inching, slewing, and turning motions.

Reclaiming rate is controlled by bucket wheel power, a current value, and boom slewing speed. Furthermore, turning time losses were reduced using ultrasonic sensors, and the quantitative control of reclaiming was improved by adjusting the frequency of reclaiming from the opposite side of stock piles. Owing to these improvements, a semi-automatic remote operation system of all reclaimers, excepting the function of automatic landing, was completed in April 1980.[2]

2.3 Measures to Prevent Collision of Stackers and Reclaimers

A yard machine is a balance machine as heavy as 400 t, and a collision would lead directly to its collapse. The prevention of collisions is very important in the remote operation of these machines. Therefore, the development of an anti-collision system was carried out in parallel with the automation of stackers and reclaimers.[3]

Collision of the equipment with material piles is prevented by use of two level detectors installed on each side of the machine boom, i.e., one ordinary and one emergency level detector.

To prevent the collisions between machines, the traveling and slewing positions of each machine are processed and displayed on CRT, using a microcomputer, and alarms are given for the machines for emergency stop. Furthermore, microwave sensor, anticollision devices for machines on the same rails, and laser sensor devices for two machines on adjacent rails, are provided so that both machines are stopped when they approach to a prescribed distance.

2.4 Signal Transmission by Optical Fiber

The signal transmission for stackers and reclaimers in remote operation has so far been conducted through sliprings. This method is susceptible, however, to problems such as instantaneous interruption of signals. Therefore, a slipring-less signal transmission system using optical fiber has been developed and put into practical use.

Optical fiber can transmit four types of signals: ① automatic control modem signals, ② ITV picture image signals, ③ telephone audio signals, and ④ speaker audio signals. Important control modem signals and telephone and speaker audio signals were multiplexed in develop-

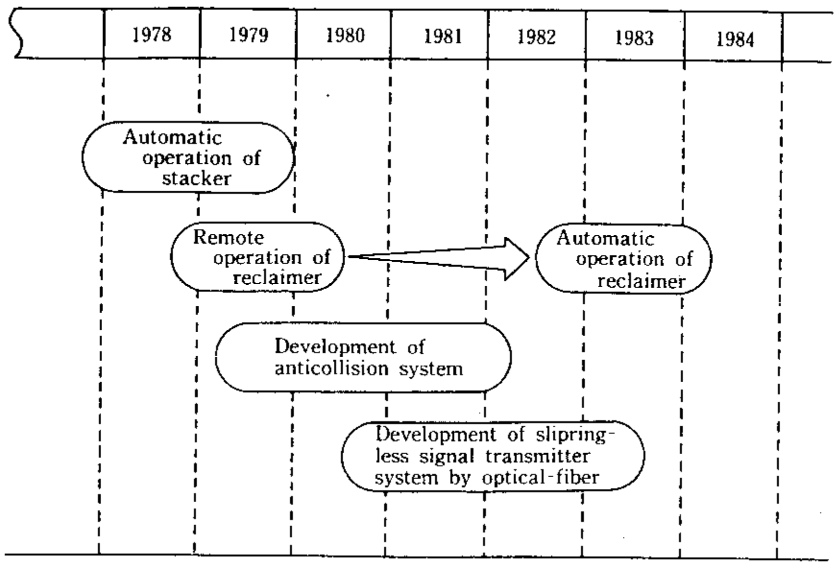

Fig. 1 History of automatic operation system

Table 1 Points and mertits of automation

Development items	Points of automation	Merits
Automatic operation of stacker	∘ Multilayer stacking operation ∘ Constant point single layer stacking operation ∘ Variable point single layer stacking operation ∘ Re-stacking to any specified position is performed automatically	∘ Labor saving ∘ Less segregation of grain sizes through multilayer stacking ∘ Yard efficiency is equall to that of the manual operation
Remote operation of reclaimer	∘ Automatic constant reclaiming operation ∘ Automatic traveling operation ∘ Remote operation of landing and bench changing by ITV	∘ Constant reclaiming ∘ Inprovement of working condition and labor saving ∘ Smooth bench level
Anti-collision system	∘ Arithmetic collision avoidance system ∘ Micro-wave collision avoidance system for two machines on the same rails ∘ Level-sensor for collision avoidance between equipment and materials heap ∘ Laser collision avoidance system between neighboring machins	∘ Accident prevention
Slipringless signal transmitter system by optical fiber	∘ Slipringless signal transmitter system by opticalfiber	∘ Integrated control and saving the control cable

ing this optical transmission system,[4] with the following results:

(1) Instantaneous interruption, noise, and other of signal disruptions were eliminated and the reliability of functions was improved.
(2) Maintainability was improved because, for example dedicated control cable has been eliminated.
(3) Maintenance jobs such as inspection and cleaning of sliprings was rendered unnecessary.

The history of automatic operation systems is shown in **Fig. 1** and the targets and effects of automation are given in **Table 1**.

2.5 Operational Status of Stackers and Reclaimers

The operation rate of stackers and reclaimers from April to September 1984 are shown in **Figs.** 2 and 3, respectively. The full automatic operation rate of stackers was more than 98%, while that of reclaimers was only 72%. Landing on the pile, bench-changing, and reclaiming from small piles remain as manual remote or machine-side operations. If automatic landing and bench changing systems for reclaimers had been successfully developed, the rate could be expected to be more than 90%.

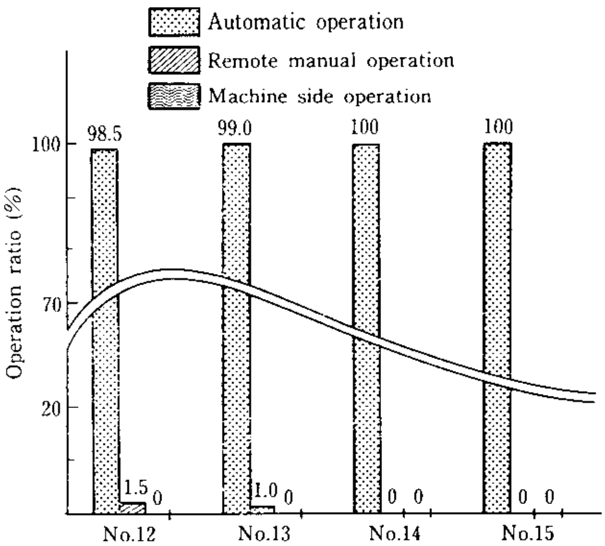

Fig. 2 Operation ratio of stackers (Apr.-Sept. 1984)

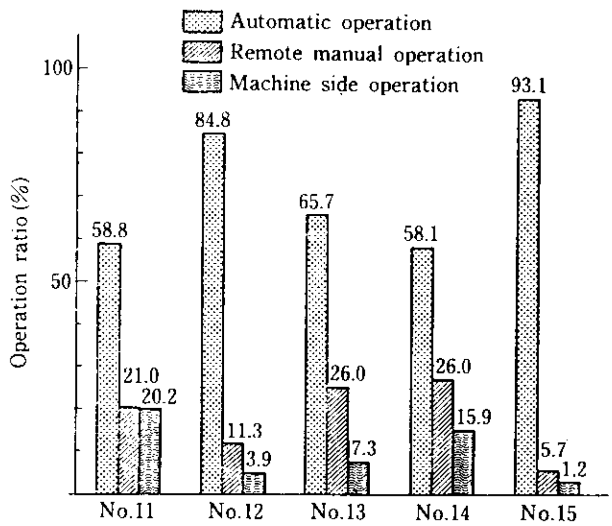

Fig. 3 Operatio ratio of reclaimers (Apr.-Sept. 1984)

3 Development of Automatic Landing and Bench-Changing System

3.1 Analysis of Present Condition and Scope of Development

As shown in **Fig. 4**, the construction of the reclaimer is such that in digging and reclaiming, the bucket wheel at the boom end is brought into direct contact with the piles of iron ore or coal. It was difficult to land the bucket wheel softly onto the pile by remote operation. Therefore, only reclaiming operations comprising repetitions of inching, slewing, and turning motions are presently carried out by automatic remote operation. The landing of the bucket wheel onto the piles and bench changing

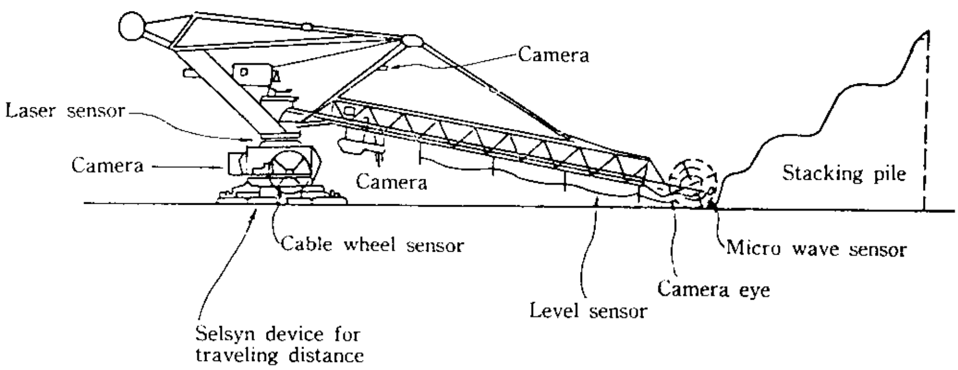

Fig. 4 General view of reclaimer

are conducted by manual remote operation, by observing the general view of the boom conveyor and the contact area between the bucket wheel and piles on ITV monitors.

The purpose of the development of the automatic landing system is to automate the landing and bench-changing operations and to establish a total automatic remote operation including automatic traveling and reclaiming operations. The No. 12 reclaimer, which is located at a position permitting the reclaiming of various raw materials, such as iron ore, coal, flux materials, and coke, was selected for research and development, system design, fabrication, remodeling work, and field tests.[5)]

3.2 Function Design and Objectives of Development

In designing the functions necessary for the full automatic remote operation of reclaimers, the following six development items were selected:

(1) Method of determining the landing point
(2) Method of determining the travel distance to the landing point
(3) Method of ensuring safe conditions around the machine during movement
(4) Method of landing
(5) Method of shortening the automatic bench-changing time
(6) Establishment of an automatic control system

The following requirement were set for design and fabrication:

(1) After the manual setting of landing position data, automatic landing must be carried out as a full automatic remote operation without operator intervention.
(2) All existing material piles permitting automatic operation must be subject to automatic landing.
(3) The time required for automatic landing must be as short as required by semi-automatic remote operation.
(4) When the automatic landing of the remaining four reclaimers is instituted in the future, the design and operation of the present system must permit easy integration with the future system.
(5) After the completion of development, this system must be capable of immediate commercial use.

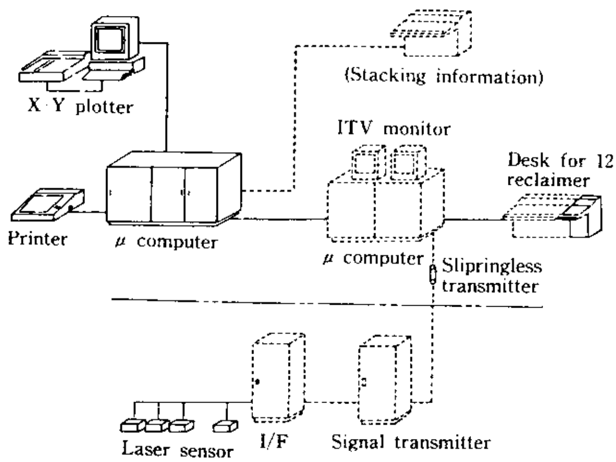

Fig. 5 Composition of auto-landing system

3.3 Outline of Auto-Landing System

The composition of the system is shown in **Fig. 5**. Existing equipment is indicated by dotted lines. The functions and specifications of principal equipment are given in **Table 2**. The arrangement of distance measuring laser sensors is shown in **Fig. 6**.

A total of ten laser sensors is installed—4 for automatic landing, 2 for automatic bench changing, and 4 for detecting obstacles. These distance measuring sensors are the most important devices in this system. Lasers were selected after comparison with ultrasonic wave, microwave, and radar devices for such features as durability, cost, accuracy, and distance measuring range.

The auto-landing system is composed of three functions: automatic landing, automatic bench-changing, and recording of stacking and reclaiming loci. The flow of operations of the auto-landing system is shown in **Fig.**

Table 2 Specifications of the automatic control device

Equipment	Specification
Laser sensor	Type : Search eye MT-100 Semi-conductor laser sensor Distance range : 0∼50 m Precision : ±1 m
Main controller	Type : Memocon sc584-302 Memory capacity : 16 kW I/O unit : input/output 4096/4096 max.
Recording apparatus	Control unit : NEC PC8801 X-Y plotter : SR-6602-6PCN Printer : FP-80
Desk for auto-landing	Position display : Digital indicator Control display : Signal lamp

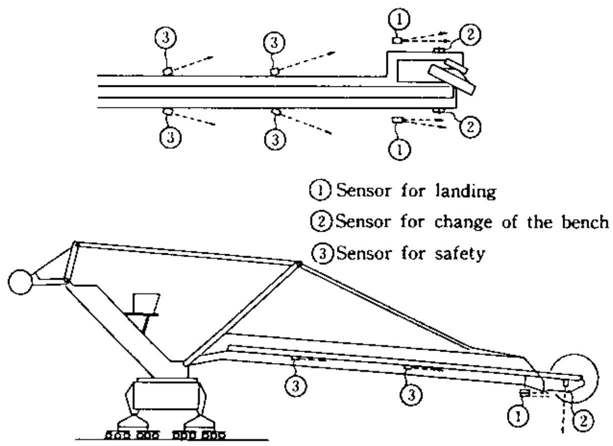

Fig. 6 Arrangement of sensors

7. Steps in the automatic landing motion of the reclaimer are shown in **Fig. 8**. Although the first landing point (traveling direction, traveling position, slewing angle, and lifting height) is set by the operator, all following operations are automatically controlled. As shown in (C) of Fig. 8, in determining the landing point, distances measured by two laser sensors are compared and the point at which $a = b$ is judged to be the edge of a pile.

3.4 Functions of Auto-Landing System

3.4.1 Method of determining landing point

Reclaiming from a stacked pile in the raw materials yard, it is first necessary to determine the starting point of reclaiming, i.e., the landing point of the bucket wheel at the reclaimer boom end on the pile.

Since the principal objective of the development of the auto-landing system was to attain full automatic operation of a single reclaimer at the earliest date, the setting of the starting point was kept as manual operation.

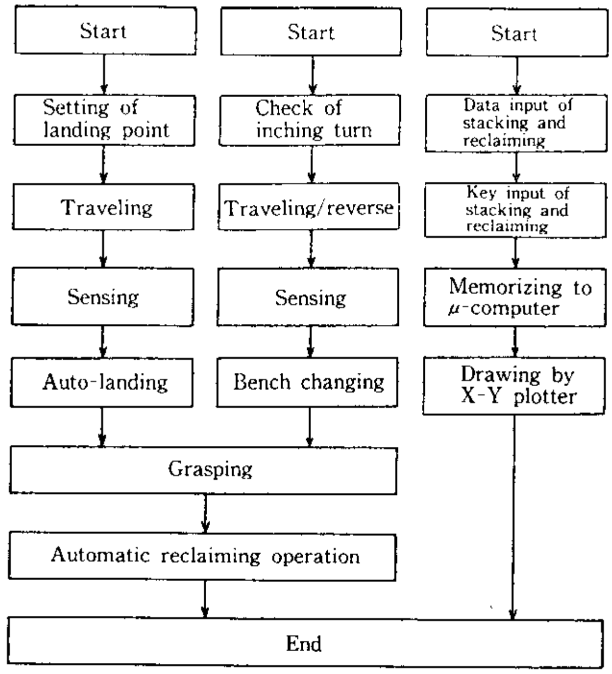

Fig. 7 Auto-landing flow of reclaimers

The operator sets the reclaiming starting point based on an overall consideration of the yard map, operation plans of materials yard, and newly added data on shapes of piles obtained from a stacking and reclaiming locus recorder using X-Y plotting (**Fig. 9**).

As for the function of the stacking and reclaiming locus recorder, as shown in Fig. 9, whenever the electrostatic sensor at the boom end senses a position change during the stacking operation, the boom end position data, i.e., traveling position, slewing angle, and lifting height, are entered and recorded on a floppy disk. When reclaiming is performed by a reclaimer, the position data of the reclaimer itself (traveling position, slewing angle and bench height) are also recorded on a floppy disk.

The operator reads out these data on a CRT display at any time using the keyboard of this system; he adds information on stacking and reclaiming such as the type of raw materials, the date of operation, amounts handled, and the name of operator. If data are available on already stacked piles, he combines them with data obtained from the present work to perform automatic data correction, and the updated data are recorded on the floppy disk. These data are drawn by the X-Y plotter in the form of contour lines differently colored for each bench height so that positions of pile edges can be easily determined.

3.4.2 Method of determining travel distance to landing point

The starting point of reclaiming is set by the opera-

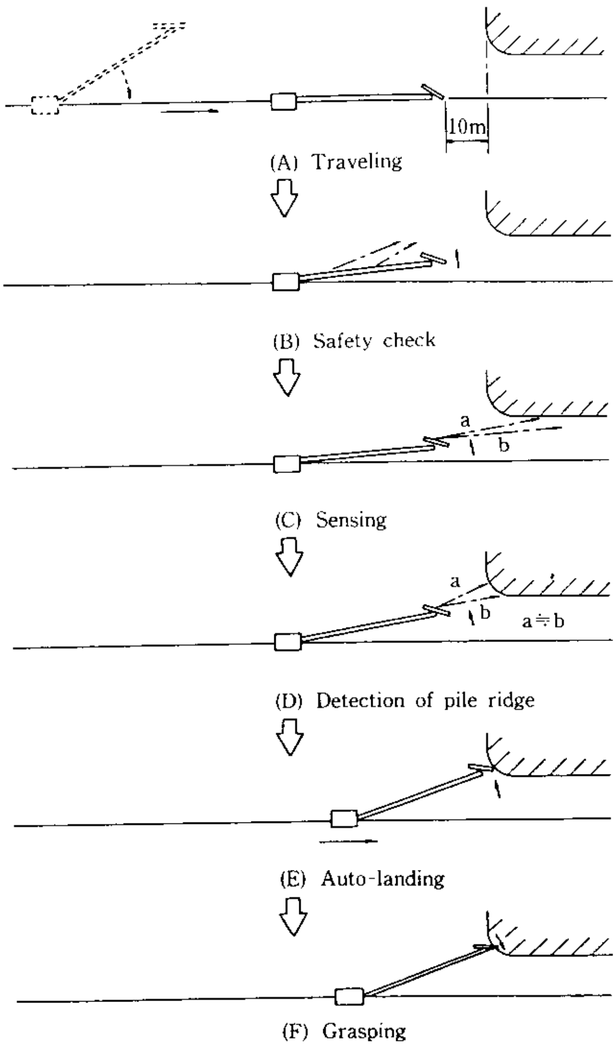

Fig. 8 Auto-landing procedure

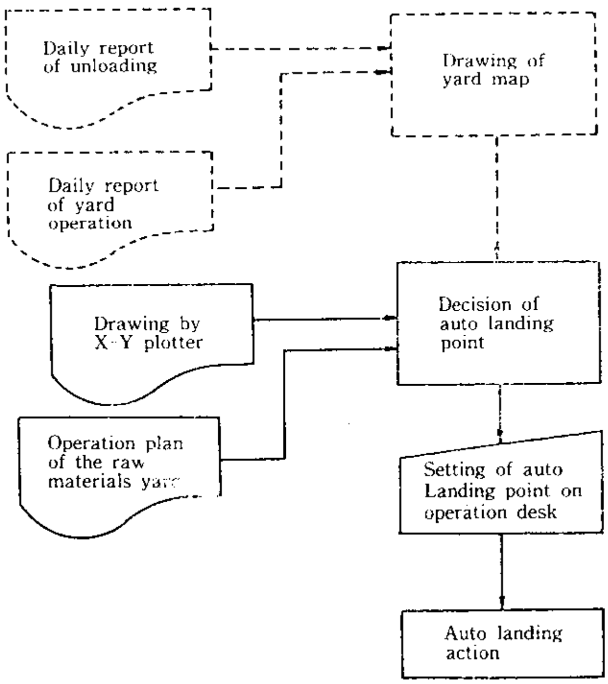

Fig. 9 Decision flow of auto-landing point

tor in the form of a three-dimensional coordinate, consisting of traveling, slewing, and lifting. However, this setting value is not necessarily accurate. It is necessary, therefore, to correct the set position by determing the actual shape of the pile by sensors. For more efficient landing onto the pile slewing operation should start from the track side edge of the pile.

In determining the pile edge, it is necessary to measure a certain distance without directly touching the pile edge. Moreover, the sensor must possess high directivity. For this reason, the laser sensor was selected and its performance was verified in field tests.

Next, two laser sensors were installed to the boom end–one parallel to the boom and the other facing outward. The distance between the boom front and the pile was measured during the time slewing toward the yard. Several field tests were conducted to study whether the pile edge nearer to the machine could be located.

As a result, it was found that detection errors are $+4$ m to -3 m in the traveling direction and $+7°$ to $-1.7°$ in the slewing direction if the angles between the two beams are kept within 10 to 15°, and it was judged that this sensor system was practicable.

To detect the heap edge by laser sensors, laser beams must be projected so as to strike the cutting face of the bench on which the bucket wheel is to land. Therefore, it is necessary to adjust the laser sensor position in coordination with the lifting height of the reclaimer boom in order to keep the laser sensors at a constant height from the bottom face of the bucket wheel. It is also necessary to keep the sensors in a horizontal position. In view of these requirements, a height control device of laser sensors was developed, as shown in **Fig. 10**.

3.4.3 Method of ensuring safe conditions around machine during movement

In the existing equipment, an electrostatic-capacity type switch is used to prevent the boom from contacting with obstacles, and a wire serving as an electrode and a weight are attached to the boom. In this method, an early detection of obstacles in the horizontal plane is difficult, although obstacles in the vertical plane present no problem. This method, however, was sufficient because the operator was able to monitor the surroundings constantly using ITV monitors.

In the automatic landing operation aimed at, on the other hand, the machine itself must detect the existence of obstacles around the boom to minimize the necessity of the constant monitoring by the operators, and it

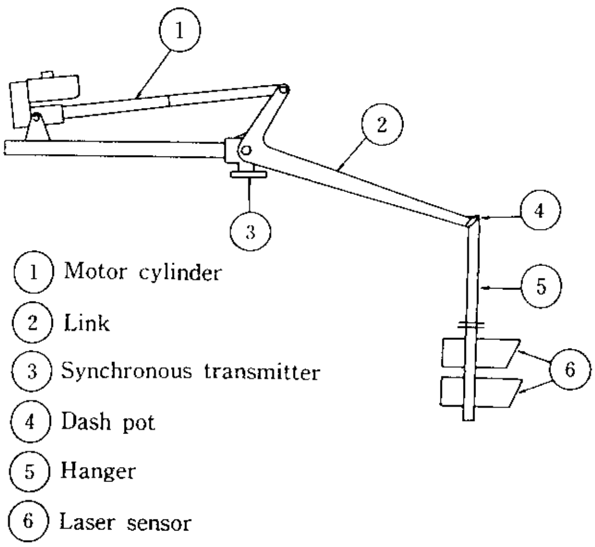

Fig. 10 Height control device of laser sensor

should move only after safety is confirmed. In case obstacles exist, they should be detected as early as possible, and a judgment made as to whether or not automatic landing is possible.

The laser sensors for obstacles are of the same type as those for auto-landing, as they must be capable of monitoring at distances of 40 to 50 meters to ensure safety. Laser sensors are installed at four points on the reclaimer boom, some parallel to the boom and facing outward so that the distance to obstacles around the boom can be constantly measured in order to ensure safety. When an obstacle exists in the safety range, the distance masured by the laser sensors will be below a set limit. In such cases, a danger can be predicted and an interlock signal for a emergency stop of slewing will be given to the circuit.

3.4.4 Method of landing

The operation for landing the bucket wheel onto the reclaiming point is composed of four steps: setting of the coordinates of the reclaiming starting point, travelling to the point, sensing, and landing. The flow of this landing operation is shown in Fig. 8.

(1) Setting of Coordinates of Starting Point of Reclaiming

Starting point of reclaiming, traveling direction, slewing angle, bench number, yard number, and reclaiming direction are set based on the operator's judgment. The lifting height corresponds to the bench number, and is derived from settings in the microcomputer. The operator forms a comprehensive judgment based on yard maps, operation plans for raw materials and shape drawings of stock piles prepared by the stacking and reclaiming locus recorder.

(2) Traveling of Machines

First, the boom is lifted to its upper limit for the sake of safety, then slewed toward a specified direction until it reaches the limit for travelling. After slewing stops, the boom is lowered to a horizontal position. The machine next travels at high speed until the boom end reaches a point 10 m before the setting position, where it stops temporarily before proceeding with the next steps.

(3) Sensing

When the boom end is within the track, the boom is first slewed until it leaves the area of the track, then lifted until its height corresponds to the height of the specified bench. At this point, boom height is adjusted by inching to within the tolerances of 0 to +200 mm against the setting so that the bucket wheel does not bite the lower bench. The height of the laser sensors is also controlled in accordance with the height of boom conveyor belt, and laser beams are directed to the surface of the bench specified for reclaiming. Although there are two pairs of laser sensors on each side of the boom end, the two in the slewing direction of the boom are used for sensing and the other pair are raised to their upper limit to avoid collision with obstacles.

When the lifting position corresponds to the specified bench, an interlock with the belt conveyors activates and the feeder, boom belt conveyor and bucket wheel are begin operation in turn. The edge of the pile on the track side is then located by measuring the distance to the specified pile while the boom is slewed toward the yard.

The laser sensor installed parallel to the boom is denoted by A, the distance measured by this sensor, a, the other sensor, facing outward, B, and the distance it measures, b. The sensing operation continues until the relation $a \leqq b$ is obtained. The point at which the beam from the laser sensor A strikes the pile and $a \leqq b$ is located as the pile edge. The projected starting point for reclaiming (boom end position and boom slewing angle) is then calculated.

If $a \leqq b$ prior to the start of sensing, then the laser beams may strike near the middle of the pile instead of striking the pile edge, which means the pile edge cannot be located by the above-mentioned method. In this case, the machine is travels at low speed toward the setting until the relation $a > b$ is reached, and sensing is then performed by slewing them boom.

(4) Landing

When the starting point of reclaiming has been determined by the sensing operation, the boom is slewed until the slewing angle meets the calculated angle, and the machine travels toward the boom end position to start reclaiming. At this time, the initial traveling speed is low and inching starts when the machine has approached within 5 meters of the position. Even if the position is in the low-speed-zone, the traveling speed will change to an "inching mode" if the measured distance is below a specific value.

The load current of the motor for driving the bucket wheel is measured constantly during traveling. When this load current value is higher than the average load during idle running by a certain value, the bucket wheel is considered to have grasped the surface of the pile. In this case, travelling stops immediately.

When the bucket wheel has grasped the pile, the boom is slewed from the yard side to the track side. Thus, the grasping position is adjusted. The slewing speed at this time is controlled by monitoring the current value of the motor for driving the bucket wheel in order to prevent wheel locking. After grasping the material, the sensing function is transfered from the yard side laser sensors to the track side sensors. Laser beams are projected on the cutting face of the bench and the pile edge is located using measured values.

Slewing is stopped when the pile edge has been detected, and automatic reclaiming operation is then started.

3.4.5 Method of shortening automatic bench-changing time

The No. 12 reclaimer had an automatic bench-changing function. This, however, required much time because priority had to be given to safety for reasons of sensor reliability. The following method was contrived to shorten this time (refer to **Fig. 11**).

The number of inching movements at each turning position is counted in ordinary reclaiming operation, with bench changing carried out when the cumulative number corresponds to a set value. At that time, bench-changing must be at the track side edge instead of opposite side, in order to increase the operation efficiency. The number of inching motions is added only when the boom reaches the pile edge on the track side.

When the present lifting position of the boom is not at the lowest bench, the reclaimer travels backward at low speed while the distance to the bench surface is measured by the laser sensor and down-facing ultrasonic sensor on to the boom end. The difference between the initial distance and the present measured distance becomes larger than the height to the next bench, the reclaimer continues to travel a distance equivalent to that between the boom end and sensor position.

When travel stops, the boom is lowered to the height of the next bench. This lowering operation is conducted

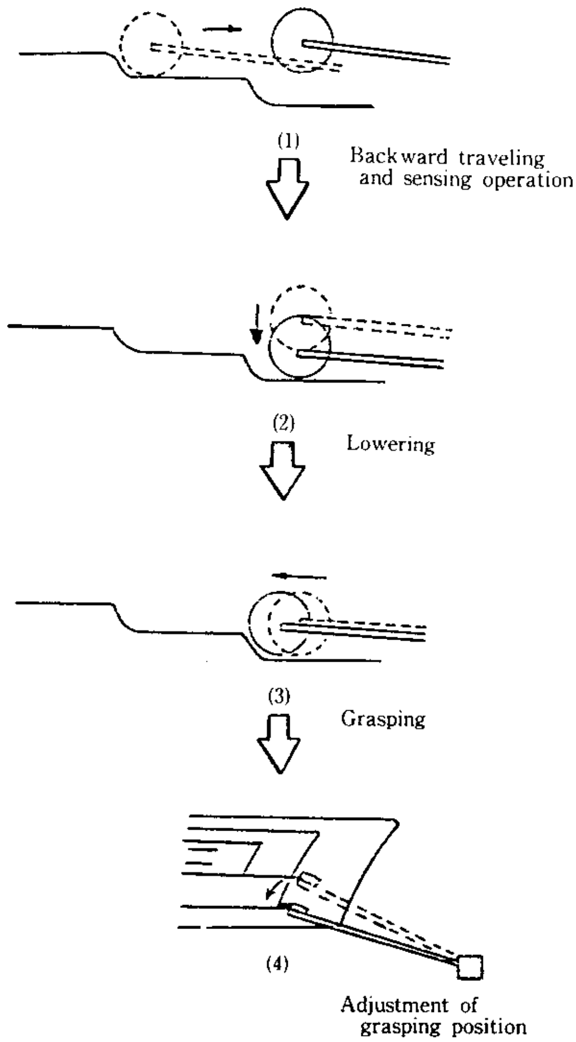

Fig. 11 Automatic changing procedure of bench

by inching to maintain a tolerance of 0 to +20 mm. When the lower bench is grasped during lifting, the lifting height is increased by 200 mm before the start of the next action, but only when that position is within the range of +200 to +500 mm of the setting.

When the lifting height has been determined, the reclaimer travels by inching to grasp the pile. As with the landing action, this grasping operation is controlled using the load current of the motor to drive the bucket wheel.

At the lowest bench, the boom is first raised to the highest bench and then sensing, movement to the landing point, and grasping are carried out in order, i.e., in the sequence of automatic landing.

3.4.6 Automatic control system

The configuration of the auto-landing system is shown in Fig. 5. The basic concept of this system is described in the following.

(1) The existing automatic yard machine operation system using a microcomputer is utilized as far as possible. The full automatic operation of the reclaimers is achieved by adding the auto-landing system to the existing system.
(2) A new control device is installed so that the new auto-landing system can be separated completely from the existing automatic operation system. This control device is installed in the central control room so that it can also be used in the future automation of the remaining reclaimers. The signal interface with the existing equipment is simplified as far as possible.
(3) The auto-landing control system must permit easy program changes during field tests and have both computation and communication functions, with programmable controller of the ladder type using relay symbols as its programming language.
(4) The signal transmission between the central control room and the machine is incorporated in the existing multiplex transmission system to decrease the amount of construction work.
(5) A personal computer capable of easy communication with the auto-landing control system is newly installed as a control device for the X-Y plotter, which draws pile shape charts.
(6) The reliability and maintainability of sensors are improved.

The functions of the present automatic reclaiming system are maintained as they currently exist when connecting the auto-landing system to the present system. The automatic operation program is by-passed by waiting instructions given by the auto-landing control device when the operator selects an automatic landing or automatic bench-changing mode using the landing console. During this period, individual instructions (for traveling, slewing, lifting, etc.) from the auto-landing system are transmitted to the machine.

When landing or bench-changing is completed, waiting instructions are automatically canceled, the ordinary automatic operation program is started, and individual instructions from the auto-landing control system can no longer be received. However, programs for activities such as maintenance, monitoring, positioning, and indication continue normally.

Therefore, even when the auto-landing system is out of operation, the existing operation system is not affected. Furthermore, it will be possible to use this auto-landing system for the remaining reclaimers when their landing function is automatized in the future.

4 Field Test Results

Field tests have been conducted since March 1984 to verify the performance of the auto-landing system.

4.1 Motion Tests

Automatic landing and automatic bench-changing were carried out on two yards and in each reclaiming direction, and it was confirmed that the sequence motions are normal. Furthermore, the signal connections and the division of control between the new and existing systems were checked, and performance tests of safety devices were carried out. No problems were found in any of the tests.

4.2 Automatic Landing Motion

4.2.1 Motion tolerances

The greatest problem in automatic landing is the accuracy of location of pile edges in the yard. For the traveling motion component, errors can be allowed to some degree, because the distance to the pile is constantly measured and corrected during the traveling motion for grasping by means of the laser sensors. Empirically, there is no practical problem if tolerances of ± 8 m are held.

For the slewing motion component, corrections are made after grapsing. In this case, errors on the minus side cannot be allowed, because in such a case, the pile edge would not be reached, and grasping could not take place. Tolerance of up to $-1°$ are acceptable, even when machine inertia is considered. When errors are on the plus side, that is to say when the bucket wheel has landed at a slewing position away from the pile edge on the yard side, it is necessary to adjust the position after grasping by bringing the bucket wheel to the pile edge on the track side. Therefore, the higher the plus value, the larger time loss will be. Obtained tolerances are about $+5°$.

4.2.2 Accuracy of landing point detection

An investigation was made of the degree of assured accuracy of landing point detection with this system. A comparison was made between the landing point, or target, initially set by the operator and the landing point as judged by sensing.

The differences in the traveling motion component are compared in **Fig. 12**. The difference is from -3 to $+7$ m, although this depends on bench height. Thus, there is no practical problem.

As shown in **Fig. 13**, errors in the slewing motion component range from -1 to $+5°$. There is no problem in this case.

4.2.3 Operation time

Although the existing system had on automatic bench-changing function, this operation required much time and was not practical in this respect. Therefore, a new bench-changing function was developed for the

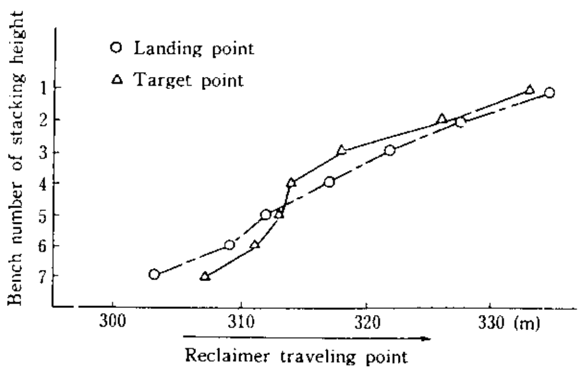

Fig. 12 Result of field tests (1)

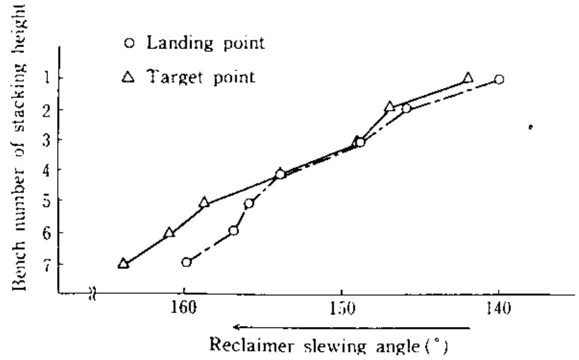

Fig. 13 Result of field tests (2)

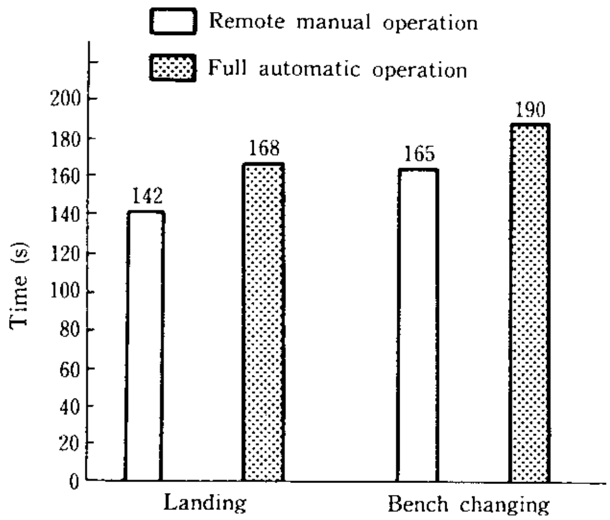

Fig. 14 Comparison of reclaiming time

present auto-landing system.

To evaluate the automatic bench-changing function of the auto-landing system, the time required for operation was measured under the following conditions, and the fully automatized operation was compared with manual remote operation.

Landing starting position: traveling 345 m, slewing 154°, lifting 7 m

Bench length: approximately 4 m

Results are shown in **Fig. 14**. The time to grasping at the landing point in full automatic operation is about 130% the time required in manual remote operation, and the time to the first turning position in automatic reclaiming operation of the existing system is about 120%. These values are near target values, which, as set, were approximately equal to those of manual operation. Further improvements in the future will be possible, because operation is now carried out below full potential speed, in consideration of safety; futher time reductions are still to be realized.

4.2.4 Grasping

Grasping on automatic landing and automatic bench-changing are verified by checking the load current of the bucket wheel drivemotor. Grasping can be sensed from a current value difference between grasping and idle operation of the bucket wheel, which exists to prevent the wheel locking caused by excessive grasping and the grasping of irregularities in the upper part of a bench.

A bucket wheel power chart and a bucket wheel current chart, when grasping, are given in **Fig. 15**.

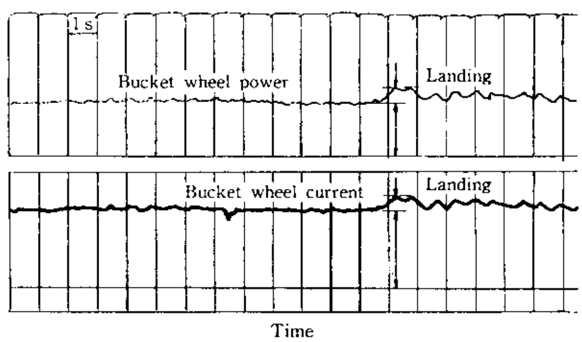

Fig. 15 Reclaimer chart

5 Conclusions

At the raw materials yard of the West Plant of Chiba Works, automatic operation of yard machines has been progressing since 1977. However, only the landing and bench-changing of reclaimers have remained as remote operations using ITV monitors, while the other motion have already been completely automatized. In this connection, an automatic landing and bench-changing system was developed and put into commercial operation.

This system comprises a microcomputer and multiple distance-measuring laser sensors. An anti-collision system is incorporated to ensure safety in every conceivable aspect.

Higher operating efficiency, improvement in the working environment, realization of an integrated yard control system, better quality control of raw materials, higher yard control efficiency, and other improvements can be expected from this fully automatized operation of yard machines. Further improvements will be made in the future to increase the efficiency of the auto-landing system and improve its advantage in practical use.

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