KAWASAKI STEEL TECHNICAL REPORT
No.13 (September 1985)

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Highly computer-controlled vehicle (HCCV) system was brought into operation in February 1984 between the No. 1 steel making plant and the new billet mill, a wide flange beam mill, at Mizushima Works. Features and purposes of HCCV system are (1) Realization of Perfect Automatization in Material Transportation. Blooms can be automatically received and fed by combining the traverse function of the buggy with that of the receiving and feeding equipment at each station. (2) Control and Assurance of Transportation Sequence by Piecewise Tracking. Blooms are placed in a single tier so that tracking according to the rolling sequence can be ensured. (3) Thorough Pursuit of Heat Energy Saving. The buggy is equipped with a heat-insulation room provided with heat insulating doors capable of minimizing temperature drops during transportation of hot blooms.

The body can be viewed from the next page.

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Development of a Highly Computer-Controlled Vehicle (HCCV) System for Hot Cast Blooms*

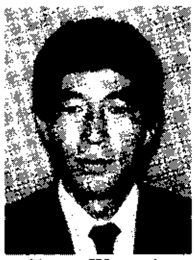


Teruyuki Nakanishi
Staff Manager, Billet Mill Technology Sec., Shape & Bar Rolling Dept., Mizushima Works

Yoshio Yoshimura
Staff Assistant Manager, Shape & Bar Technology Sec., Mizushima Works

Tsuneo Seto
Staff Deputy Manager, Development & Design Sec., Equipment Dept., Mizushima Works





Kazushi Baba
Staff Assistant Manager, Electrical & Instrumentation Technology Sec., Mizushima Works

Hiroshi Arimitsu
Electrical & Instrumentation Technology Sec., Mizushima Works

Shuzo Watanabe
Systems Planning & Data Processing Sec., Mizushima Works

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Highly computer-controlled vehicle (HCCV) system was brought into operation in February 1984 between the No. 1 steelmaking plant and the new billet mill, a wide flange beam mill, at Mizushima Works.

Features and purposes of HCCV system are

(1) Realization of Perfect Automatization in Material Transportation
Blooms can be automatically received and fed by combining the traverse function of the buggy with that of the receiving and feeding equipment at each station.

(2) Control and Assurance of Transportation Sequence by Piecewise Tracking
Blooms are placed in a single tier so that tracking according to the rolling sequence can be ensured.

(3) Thorough Pursuit of Heat Energy Saving
The buggy is equipped with a heat-insulation room provided with heat insulating doors capable of minimizing temperature drops during transportation of hot blooms.

1 Introduction

In all aspects of rationalization efforts covering iron and steel manufacture, the segment that stands out most is the continuous casting (CC) and rolling, especially the continuation of both processes, all because of the noticeable benefits obtainable such as an increase in yield, saving in energy, and reduction in labor. Stabilization of quality and operation, which is a prerequisite of the continuation of the continuous casting and rolling, has been achieved by a progress in automation and inspection techniques at continuous casting and rolling processes, and improvements in peripheral techniques such as upgrading of the levels of equipment maintenance techniques and equipment diagnostic techniques.

Against the background that Mizushima Works had long employed the ingot-making process, the continuous casting plant and the rolling mill are located at a distance from each other, and cast blooms have been transported by a railway wagon or trailer truck. Such a transport system imposed a limit to an expansion for the continuation process, and a new transport system became necessary. As part of the project of constructing a new billet shop, a system for transport of hot cast bloom, Highly Computer-Controlled Vehicle (HCCV), has been developed which can achieve quality assurance by piecewise tracking control and thoroughgoing energy and labor saving, and accomplish highly advanced continuation and synchronization of processes.

This report describes an outline of the HCCV system and its control system which started operation in February 1984.

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2 Background of Introducing HCCV System

To take the place of the conventional ingot-making and blooming processes, large-capacity bloom and slab continuous casters were put into use around 1965, with progress in CC techniques and expansion of CC applicable products. Continuation with the next process was initiated around 1975 due to expansion of continuous casting of high grade steels. Since then efforts have been made to implement a highly continuous-continuous casting ratio from the aspects of energy and production-cost saving, but such continuation efforts reached a limit due to time gap between tapping and rolling and for reasons of production control system.

To achieve higher continuation and synchronization of processes, it was planned to introduce the HCCV system between No. 1 steelmaking plant and shape and billet rolling plant, while laying emphasis on the following points:

(1) To construct a transport system which gives the same effect as if blooms were transported between distant plants on an adiabatic roller table.

(2) To have mass transportation capacity with the loading form of respective small lots, while assuring quality by piecewise tracking control.

(3) To be able to achieve continuation and synchronization of processes between a plural number of continuous casters and a plural number of rolling mills.

(4) To realize unattended transportation and low transportation cost by automation of loading and unloading operations.

3 Functions Required of HCCV System

Automation of transporting means, the so-called "vehicle automation," has been studied mainly in the field of transportation of men, and realized as a new transportation system. Merits and demerits of completely unattended transportation means of men have been discussed[1], but in the development and introduction of HCCV, attention has been directed to complete automation and unattended operation from the viewpoint of material transit, labor saving and safety.

Features of HCCV operation, compared with transporting means of men are enumerated below.

(1) Instead of the transportation system controlled by the diagram, HCCV is operated by the demand system, that is, operated when preparation for transportation is completed at the cast bloom loading station.

(2) Transportation is made between fixed loading and unloading stations, and this combination exists in plural cases, and even the unloading station may be changed, while HCCV is still traveling.

(3) There are several loading stations for a single unloading station, and under such conditions, it is necessary to control the arrival order of vehicles.

In constructing the automatic control system of HCCV, the above-mentioned operational features and such factors that the HCCV system must possess have been taken into consideration. As a total system, HCCV must satisfy the following conditions:

(1) To be a system having 100% reliability, because it directly connects the CC plant to the rolling mill and holds the key to the continuation of processes.

(2) To be a system capable of grasping the operating conditions of both the CC plant and rolling mill on the real-time and total bases and of performing optimum vehicle allocation.

(3) To be a system that can monitor the operating condition of HCCV on a real-time basis and achieve maximum efficiency in vehicle operation.

Namely, HCCV must be a system that can optimize both the aspects of cast bloom handling and transport efficiency of vehicles.[2]

In addition, the system hardware mainly consisting of the vehicle must satisfy the following conditions:

(1) To be capable of changing automatic transportation instruction and its destination at respective stations, when troubles with the online computer (O/C), process computer (P/C), and rolling process are caused due to the characteristics of CC operation.

(2) To have transportation capacity including loading, unloading, and vehicle transportation, which is greater than the continuous-casting ability.

(3) To be equipments capable of transporting, loading, and unloading without changing the sequence of loaded blooms.

(4) To have vehicle construction which permits cast blooms to be transported under the adiabatic conditions.

4 Outline of Equipment

4.1 Layout

A railway runs connecting the CC machines Nos. 1, 2, and 3 at No. 1 steelmaking plant, the new billet mill and shape mill about 1 km away, passing midway a bloom refinery yard and vehicle maintenance yard. Cast blooms are loaded and unloaded to or from transport vehicles are provided at a total of 7 stations, including three locations on the CC side[3], three locations in the loading rolling mill and one location in the bloom refinery yard. The system transportation capacity is 2.2 million tons of cast blooms annually using six vehicles. The system is designed, so that nine vehicles at the maximum can be used to accommodate in increase in the future requirements for transportation capacity. The entire layout is shown in **Fig. 1** and its features are described below.

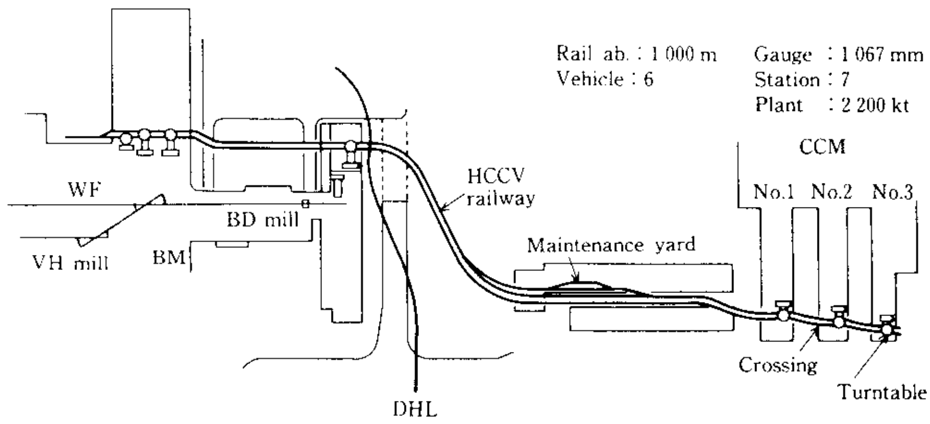

Fig. 1 Layout of HCCV system

(1) Simplification of control has been achieved by separating the independent loading and unloading railways, with the aim of ensuring the reliability and safety of transportation capacity and system.
(2) The entire lines including loading and unloading processes have been fully automated, but the maintenance yard has been excluded from the scope of automation because of the characteristics of the maintenance operation.
(3) A buggy-type truck turning system using turntables has been adopted for changing travelling directions of the vehicle to simplify the layout and achieve automation of loading and unloading operation.
(4) Crossings of the diesel truck and the ingot transport truck railway and crossings for incoming/outgoing vehicles to and from various plants and mills have been provided.
(5) Rails of 60-kg/m heat-treated steels have been used and the radius of curvature has been set at 80 m or above to prevent abrasion of rails and to relieve the load of daily maintenance of rails.

4.2 Outline of Mechanical Equipment

4.2.1 Vehicles

Cast steels that can be loaded and transported include blooms, slabs, and beam blanks, and each vehicle can load one to three pieces on the average in a single pile. Features of the vehicle are given below.

(1) The vehicle shall be of a buggy truck type with two wheel axles and four wheels to automate loading and unloading operations, and allow the buggy trucks to travel in the advancing and traversing directions, while the vehicle frame is being maintained in a constant posture, by swiveling the front and back buggy trucks by 90°, respectively.
(2) At the front and rear of the vehicle, a simplified operation room each is provided, so that the vehicle

Table 1 Main specifications for vehicle

Type	Motor car of bogie type
Loading capacity	Max. load : 30 t Max. temp. : 900°C Range of length : 3.4~12.6 m
Traveling speed	High : 250 m/min Middle : 60 m/min Low : 10 m/min
Tractive force	Starting : 3 000 kgf Rating : 1 800 kgf
Performance	Acceleration & deceleration : 0.28 m/s^2 Stoppage accuracy for fixedpoint : ±75 mm (at car weight 60 t)
Dimensions	2 500 mm W x 2 900 mm H x 15 800 mm L Wheel base : 1 440 mm Wheel diameter : 600 mm Buggy interval : 8 000 mm
Motors	DC 27.5 kW x 2
Control system	G.T.O. chopper control system

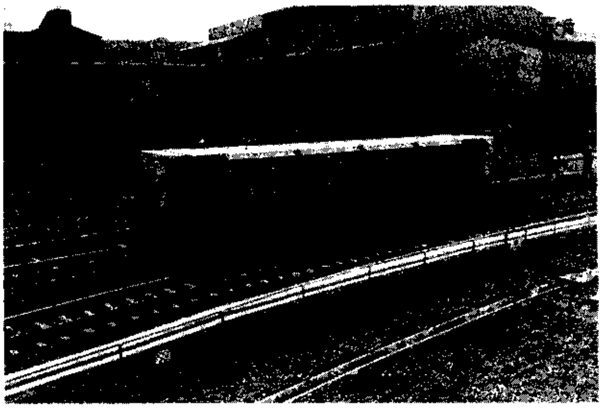

Photo 1 General view of vehicle

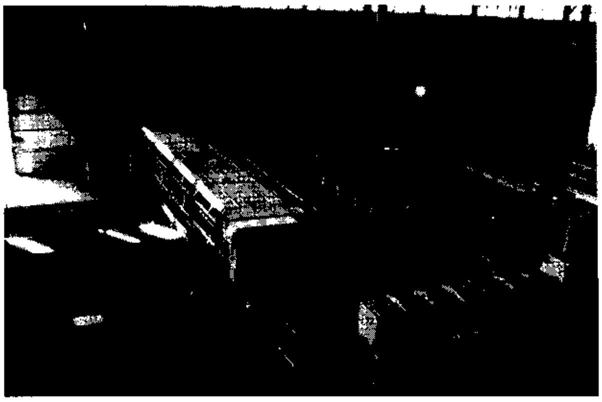

Photo 2 Vehicle and unloading machine

can be moved manually during maintenance.

(3) The vehicle is provided with a heat insulation room to prevent the lowering of cast bloom temperature during transportation.

(4) The vehicle is equipped with rise-and-fall type adiabatic doors at its both flanks to allow the cast blooms to be stored and transported in the heat insulation room.

Main specifications of the vehicle are shown in **Table 1**, and the vehicle and unloading condition are shown in **Photos 1** and **2**, respectively.

4.2.2 Turntable

Turntables are installed at respective loading and unloading stations, and two turntables form one set. The front and rear buggy trucks of the vehicle which have stopped at each fixed point on the turntables are simultaneously swiveled by 90° to change the traveling direction of the vehicle. The main specifications of the turntable is shown in **Table 2**. The operation explanatory diagram of vehicle transportation and loading and unloading operations of cast blooms by combining a vehicle and turntables is shown in **Fig. 2**. Vehicle ⓐ loaded with cast blooms ⓒ (①, ②, and ③) travels on to the turntable ⓑ and the buggy trucks at the front and rear of the vehicle are caused to stop at the swiveling centers of two tables. By operation (1), turntable ⓑ is swiveled, thereby changing the direction of only the buggies by 90° without changing the posture of the frame of the vehicle. The heat insulating door on the unloading side is opened, and the vehicle is driven, and the vehicle travels in the transverse direction upto the fork of the transporter ⓓ as shown by operation (2). By operation (3), transporter ⓓ rises and unloads cast blooms ⓒ at a stroke in the sequence of the loaded order, i.e., ①, ② and ③. by the signals of the loading sensors, each installed on the vehicle and transporter, the vehicle travels in the transverse direction as shown in operation (4), stops at the swiveling center of turntable ⓑ, and closes the heat insulation door. Operation (5) swivels the turntable, and the vehicle travels to the loading station. On the other hand, transporter ⓓ performs operations (4') and (5') to automatically transport cast blooms to the next process. On the loading side, the reverse of the above-mentioned operations are also performed, so that the transportation sequence of cast blooms will not be changed from loading at the continuous-casting plant to unloading at the rolling mill. In this way, the piecewise "distinguished quality assurance" is securely maintained by automating a series of operations as mentioned above and by controlling the transportation schedule and actual loading and unloading of each vehicle.

4.3 Outline of Electrical Facilities

In electrical facilities, enhancement of the system operation rate is treated as the most important theme, and energy saving and safety are also taken into consid-

Table 2 Main specifications for turn-table

Type	Turn-table of 90° reversible type
Loading capacity	Max. load : 50 t
Performance	Torque of rotations : 3 000 kgf·m Rotational speed : 2.05 rpm
Dimensions	Diameter : 2 260 mm Railgauge : 1 067 mm Size of out ward : 3 150 mm W × 1 050 mm H × 4 000 mm L
Motors	AC 11 kW × 2/set

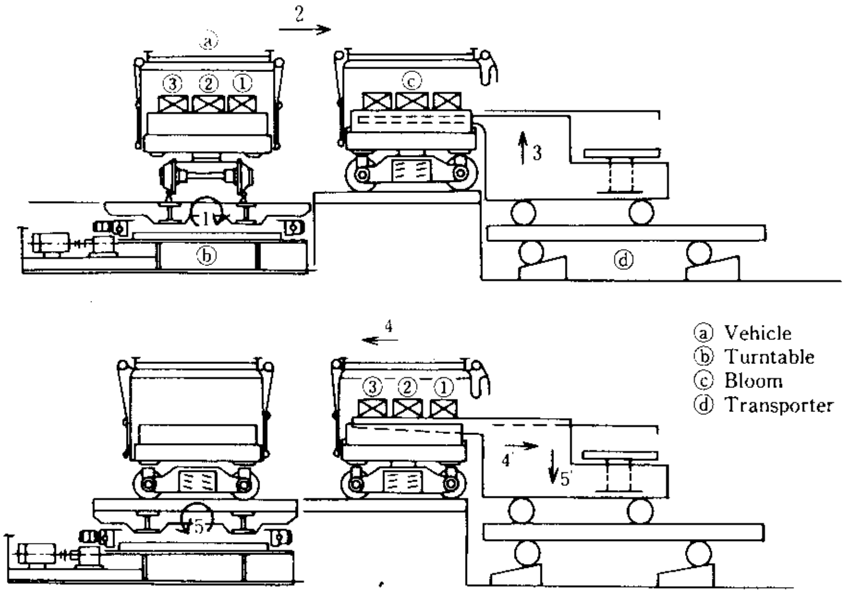

Fig. 2 Motion of vehicle and transporter

Table 3 Main specifications for electric equipment

Drive and control system	Electric driving method: Series D.C. motor (hanging type) 27.5 kW × 2/car, DC 180 V 315 rpm Control method: Chopper control by G.T.O. (with regenerative braking)
Power supply system	Dual mode 1 AC 460 V, 3 φ, 3 W contact bar 2 Lead acid strage battery DC 192 V, 516 A·h
Control device fixed side	For control: DDC controller; 32 kW (duplex type) For operation: Programable display + Micro computer Signal transmitter: Multiplex transmitter (with back up) Inductive radio (loop antenna)

eration. Specifications of main electric equipment are shown in **Table 3**.

4.4 Automatic Control System

4.4.1 Transportation information control system

As mentioned in Sec. 3, the HCCV control system must be able to achieve optimization of both cast bloom handling and transport efficiency of vehicles. For this reason, system configuration consisting of 3 hierarchies of O/C[4], P/C[5] and DDC for HCCV and their respective shares of functions have been determined as shown in **Fig. 3**. This concept is aimed at optimizing cast bloom handling by O/C and transport efficiency of vehicles by DDC, and at obtaining the balance between the two by using P/C. Therefore, O/C and P/C constitute the transportation information control system, and DDC is caused to concentrate on transport efficiency of vehicles, without being given the function of processing transported cast bloom information.

The P/C which is situated in the midway of the system has the function of controlling both the vehicle and transportation information, and **Photos 3** and **4** show examples of vehicle transportation control and vehicle loading information control, respectively. Photo 3 shows the operation desk indicating the control condition of each vehicle. Photo 3 indicates that Vehicle No. 6, for instance, is travelling in loaded condition from No. 1 CC to billet mill (BM), and Photo 4 indicates information concerning cast blooms loaded on Vehicle No. 6.

4.4.2 DDC system

System configuration diagram is shown in **Fig. 4**. The DDC which is the main control unit of this system is installed at the control room of the reheating

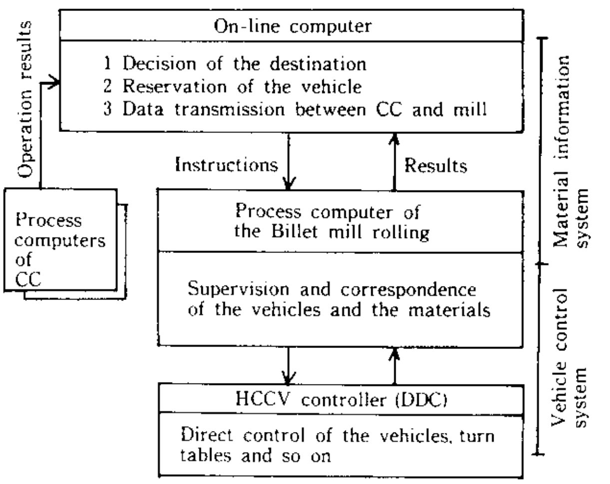

Fig. 3 Configuration of HCCV system

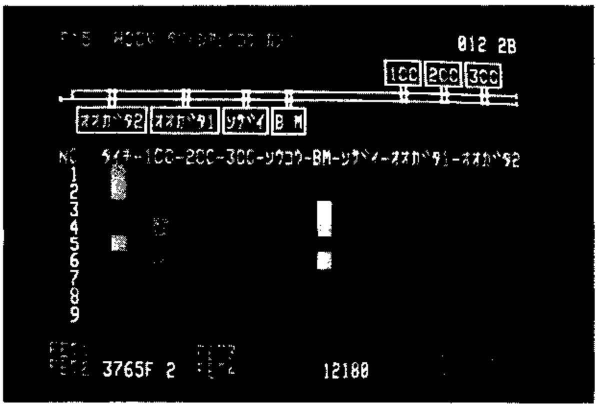

Photo 3 A CRT display example of HCCV traffic

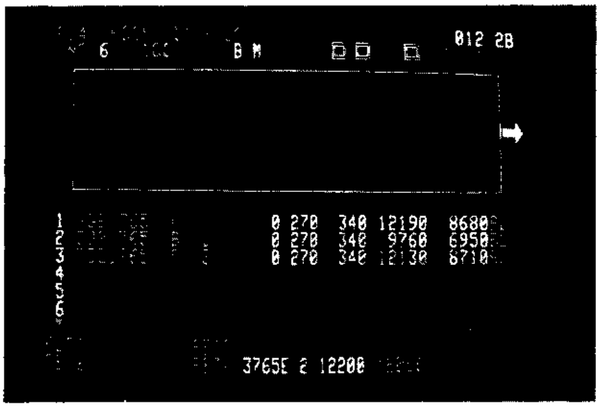

Photo 4 A CRT display example of bloom information HCCV

furnace of the new billet mill. It is directly linked with a loop-antenna type inductive radio device for signal delivery with the vehicle as well as turntables and unloading stations at the new billet mill. It is connected to the turntables and various stations of the CC plant and shape mill by means of the remote I/O system. The outline of the system configuration is given below.

(1) The data transmission line is provided with three sets of programmable-display microcomputers for operation and plant monitoring. Of the three sets, the two for operation, that is, the schedule unit (CRT-S) and guidance unit (CRT-G) are accommodated in the operation desk of the reheating furnace control room and used as CRT operation units for performing automatic start-up of the system and manual interrupt. The outline of the operation desk is shown in **Photo 5**.
(2) The troubleshooting device (CRT-M) is provided with floppy disks. It can troubleshoot while continuing automatic transportation of cast blooms, and has a function of performing software simulation under the off-line condition.
(3) Since the automatic transport equipment directly connects a plural number of the CC plants (Nos. 1 to 3) to the rolling mill, new billet mill and shape mill, its system breakdown inflicts serious damage. For this reason, the automatic transport equipment is given a system configuration to permit free partial input and release of the system and to resume automatic transportation of cast slabs while the specific portion of the system is left open.

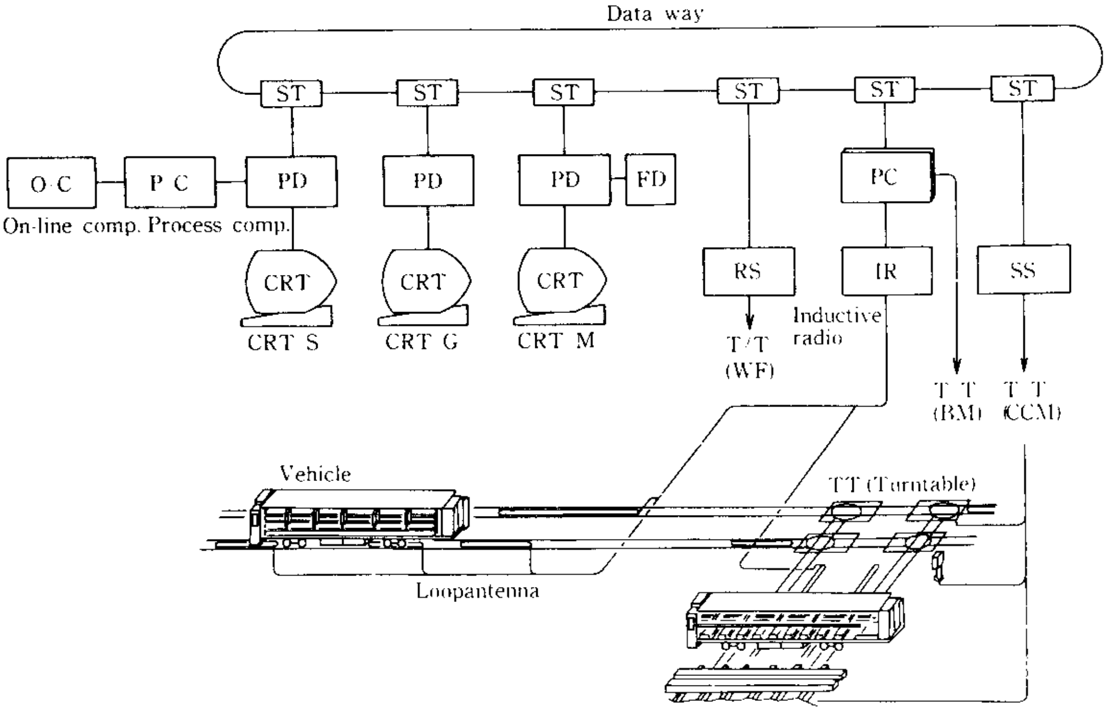

Fig. 4 System configuration of DDC

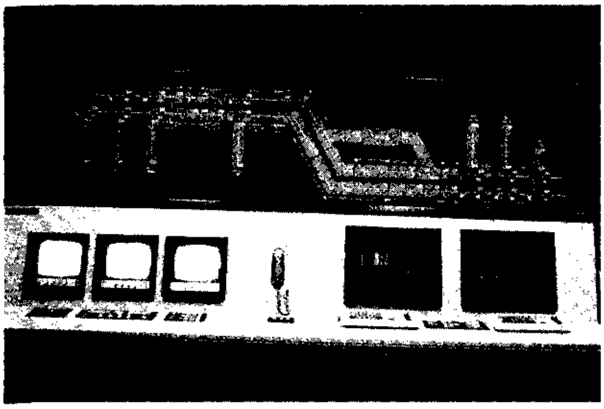

Photo 5 Operation desk

(4) The DDC has a duplex constitution to permit instantaneous change-over. It acts as interfaces with the operation and running control of the vehicle, setting-up of the transportation route by contrölling the turntables, etc., and with loading and unloading facilities, all without intervening with automatic billet transfer.

(5) Signal exchanges with upper-rank process computer are all performed by CRT-S, so that even when the process computer is out of order, automatic transportation can be performed by setting "From–To" to CRT-S.

4.4.3 DDC functions

An outline of functions of DDC which forms the nucleus of the HCCV system is shown in **Fig. 5**. The functions are broadly classified by system control, operation control, running control, inductive radio (IR) control, turntable and point control, and crossing monitoring. Main substances of the control are given below.

(1) System control acts as the main control portion, and performs confirmation of vehicle operation specified-conditions and that of the operational states of equipment, vehicles, travelling routes, thereby checking if the operation of the system is proper or not.

(2) Operation system determines transportation routes and assigns schedules to vehicles, using the schedules from CRT-S and system registration information from CRT-G.

(3) Running control is one of the most important functions and effects vehicle running control centering around block control which is the basis of the running control.

(4) In vehicle existence recognition for performing block control, induction radio loops are used, and in the present system, 44 loops in total are installed on the entire lines.
Through these loops, DDC judges the speed and stoppage of vehicles from the length, interval and location of the loop, and guides vehicles to the prescribed destinations while paying attention to collision prevention.

(5) Vehicle stoppage control includes the system emergency stop and system temporary hold as well as simultaneous speed reduction and stoppage control of all vehicles.
Control is also effected on instructions for turntable turning and point change-over before and after guiding vehicles to the respective stations.

(6) Signal delivery between the vehicle and the controller is performed through the transmission and reception channels of IR which is connected to the above-mentioned loops. IR control gives instructions for the channel combination according to the vehicle running control.

(7) Turntable and point control perform the control and monitoring such as the processing during use, swiveling and change-over of turntables and points, according to the request from the running control side.

(8) Crossing monitor control does not perform crossing open/close control, but constantly monitors the closed signal during system operation, and when the closed signal is turned off, it instructs emergency stop. During the system temporary hold, it monitors the normal/abnormal condition of the crossing and crossing facilities, outputs the crossing opening permission and displays guidance for crossing open/close operation on CRT-G.

(9) As a means for recognizing tracking information by hardware, a car indicator and load detector are provided, and vehicle No. and empty/loaded vehicle information are sent to the upper-rank process computer by way of DDC.

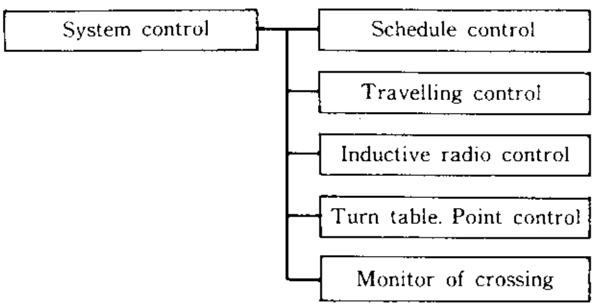

Fig. 5 Function of DDC-Controller

5 Safety of Transport Operation

In order to maintain high ratios of its operation, the HCCV-DDC system has the backup functions for achieving perfect block control and enhancing the reliability of signal transmission, and performs control so that a fail-safe operation can be maintained at all times. However, since it is an unattended transportation system between distant plants, its interaction with other facilities, things, and men is sometimes unavoidable. Ensuring safety between HCCV and its surroundings is an important problem, and the following measures have been taken:

(1) Assuring Safety between HCCV Equipment and Other Things or Men
   (a) To prevent a third party (man or thing) from trespassing on the railway area, safety fences have been installed along the entire lines to isolate HCCV.
   (b) Grade separation by the overbridge has allowed workers to safely cross the railway.
   (c) No manual operation on the vehicle is allowed, and entrance/exit of vehicles to and from the maintenance yard has been automated.
   (d) Between the block control loops, emergency loops are installed to monitor the entire lines, and emergency shutdown has been made possible from any control room.

(2) Safety of Vehicle for Transport of Hot Cast Blooms and Diesel Truck
   (a) Crossings have been made at four locations for operating vehicles and at one location for the diesel truck. All these crossings are made into the remote-controlled open/closed type.
   (b) When the crossing is opened to allow other vehicles to pass, the system is put to automatic temporary hold, and HCCV is made to stop.
   (c) Stopping position of HCCV is set on any optional automatic control loop, and after closing the crossing, it has been arranged that quick automatic start of the vehicle can be made.

(3) Safety in Relation to Operating-yard Crane
   (a) The vehicle is of the battery-operated in-yard travelling type, so that no electrical accident will occur due to the trolley line.
   (b) The interface with the overhead travelling crane in the yard has been established by automating the vehicle and loading/unloading facilities.

6 State of Operation

The system was started simultaneously with the commissioning of the new billet mill in February 1984. On the basis of the actual record after the start of operation, transportation to the shape mill was started in May 1984. The start-up trouble after the commencement of operation was ended and the transition of the transportation record is shown in **Fig. 6**. Through the running control by cast-bloom-loaded vehicles and the automation of loading and unloading operations, tracking control of cast blooms has become possible, thereby establishing a piecewise quality assurance system. The travelling cost by the HCCV system has dropped to 1/15 to 1/20 compared with that by the conventional trailer truck operation, and the temperature drop of cast blooms by the HCCV system is only 20 to 30°C. Also through the adoption of unattended operation of transport vehicles, automation of loading and unloading operation and the systematization of a centralized operation monitoring, the transport system of 1 man/shift has been inplemented and the intended objective has been achieved.

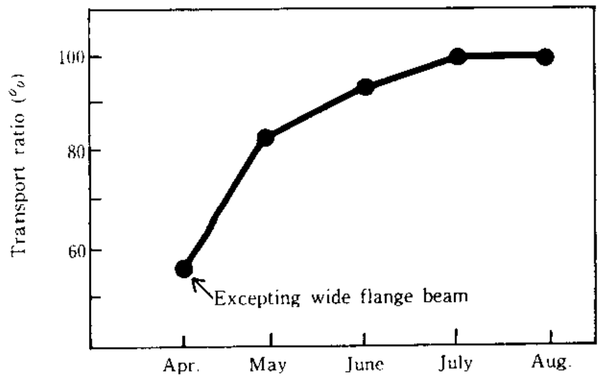

Fig. 6 Monthly change of transport ratio

7 Concluding Remarks

The HCCV system was developed and introduced as a means of achieving highly continuous process and synchronization between the CC plant and the rolling mill. The system, following its installation at Mizushima Works, appeared somewhat like a kind of field tests, but the originally intended target was achieved.

In the future, efforts will be made to enhance the system reliability, shorten the transport time cycle and improve transporting efficiency by making more efficient vehicle allocation with less waiting time. Although the system has been developed with the aim of achieving continuation between the CC and rolling processes, it is considered that the system will be sufficiently applied to other material flow systems.

Finally the authors would like to express their deep appreciation to staff concerned at Toshiba Corporation for their valuable and kind assistance rendered in the course of the system development.

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