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Distribution Control System for Steel Plate Finishing Process

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Abstract:

The systematization of those finishing control tasks at the plate mill of Nippon Steel's Oita Works that were formerly performed by operators and constituted a large-scale material flow control problem is described. The working methods and knowledge of the operators were reflected in the systematization of their control tasks. A new technique that fuses a material flow simulator with an expert system was developed and applied to build a plate finishing process control support system. The new technique enabled nearly optimal solutions to be obtained at high speed and plate finishing tasks to be systematized.

1. Introduction

In recent years automation and efficiency enhancement of material flow have often come to be heard as keywords for reducing manufacturing costs. This situation may be ascribed to the following factors. One factor is that automation of processing equipment and informationalization of transfer equipment have advanced and established the foundation for material flow control. Another is that computers have developed in both hardware and software to enable the systematization of material flow planning and control that traditionally depended on human operators.

The same situation also applies to the steel industry. Steelworks are tackling the challenges of systematizing and optimizing many and varied material flow systems that convert raw materials into molten iron and steel through slabs to finished sheet, strip, and plate products.

This article describes the systematization of material flow control tasks at the plate mill of Nippon Steel's Oita Works. The systematization of these operator-dependent tasks constituted the commercialization of Nippon Steel's first large-scale material flow control system.

2. Description of Plate Finishing Process

2.1 Equipment

The layout of the plate mill at the Oita Works is shown in **Fig. 1**. The shearing line and finishing yard consist of seven plate transfer tables; two transfers connecting the tables; eleven overhead traveling cranes; and more than twenty items of on-ground and on-table plate processing equipment. Plates are temporarily stocked in stacks at a few hundred places. The tables and transfers are automatically controlled, but the cranes are operated by operators following computer-issued work instructions. The plate processing equipment may be operated automatically or manually, depending on specific processing tasks to be performed.

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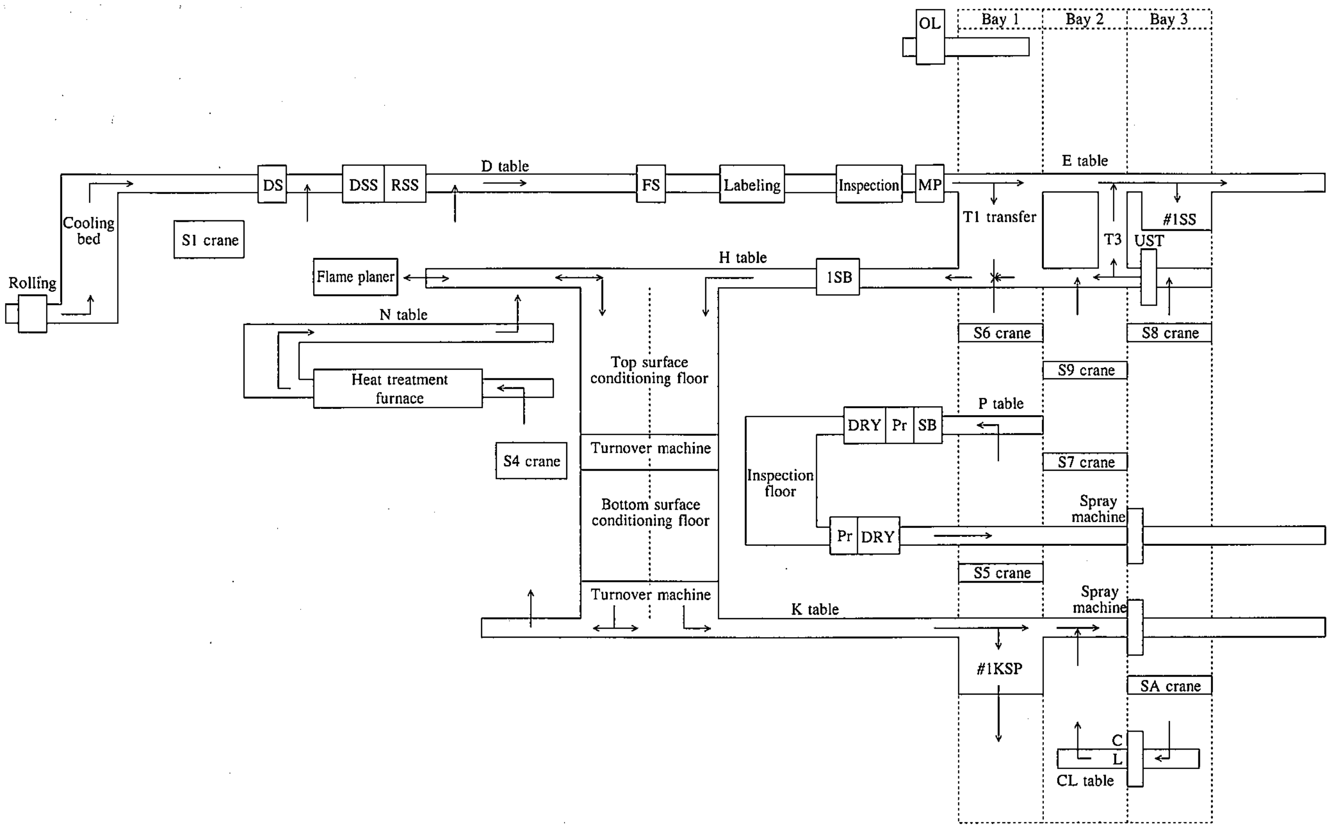

Fig. 1 Layout of shearing and finishing processes at plate mill of Oita Works, Nippon Steel

2.2 Plate flow and its characteristics

Plates rolled to a few meters in width and a few meters to a several tens of meters in length, are cooled on the cooling bed and cut to product sizes on the shearing line. If they require no further treatment, they are moved to the warehouse from where they will be shipped. Plates go to the finishing yard if their heat treatment, painting or inspection is specified beforehand, or if their size adjustment, leveling or defect removal is judged to be necessary according to the results of inspection. At the finishing yard plates are transferred by cranes and tables in a predetermined sequence between the processing equipment, processed, and finally delivered to the warehouse. The plates that must be painted flow through the following route: shearing line → T1 transfer → H table → conditioning bed → K table → crane → stack → P table → top surface painting machine → dryer → inspection bed → bottom surface painting machine → dryer → P table → warehouse. On the average about 800 plates are produced per day, and 2,000 to 2,500 plates are stored in ground stacks.

The flow of these plates is characteristic in that:

(1) The rolling process and the shearing and finishing process differ in processing capacity by product type. These differences are adjusted by the stacks that play the role of buffer stock.

(2) There are many confluence points and branch points between the tables, and two or more cranes run on the same track. Interference results between the cranes.

(3) Plates are made to order, each have different delivery dates, and must be shipped to meet their delivery dates.

(4) Since the stacks are managed on a first in, last out basis, plates must be often removed from the lower positions in the stack, degrading the efficiency of crane operation.

(5) Plates are sometimes placed on the tables from the top of the stacks, and fed to processing equipment, so that the processing equipment should not decline in their working ratio.

This flow of plates is difficult to control, partly in relation to the layout of the finishing yard.

3. Plate Finishing Control Tasks

3.1 Existing system

The material flow of the shearing line and finishing yard is so complicated that automation was instituted for this complicated material flow from the outset of construction of the plate mill. Tracking of plates and designation of plate transfer routes was automatically performed by computer[1]. What may be called traffic control concerning transfer of plates by the tables and cranes and plate processing priority in view of delivery lead time was controlled by operators or controllers. They monitored related conditions, communicated with necessary sections, and entered data into the computers as required. The distribution of these control functions is shown in **Fig. 2** and is described below.

Operation control computer: Determines plate transfer routes and issues crane operating instructions.

Process control computer: Controls the transfer of plates by the tables, tracks the plates, and controls the transfer of the plates at the table confluence and branch points.

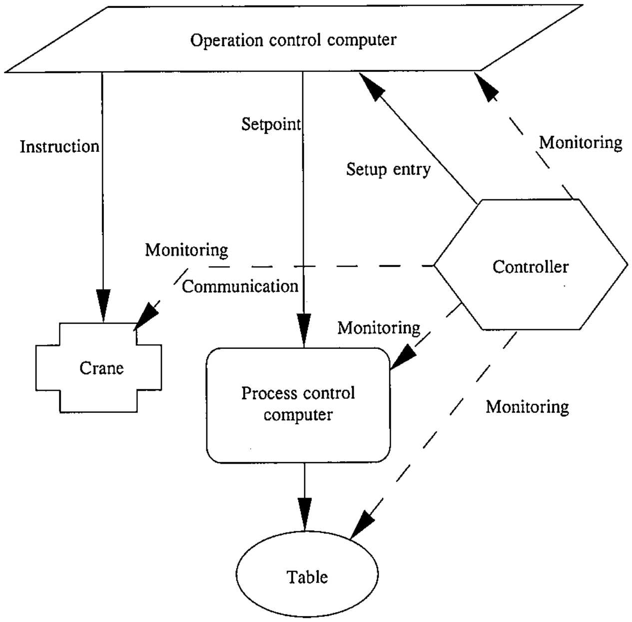

Fig. 2 Conventional control function distribution

Controller: Checks plates with critical delivery dates, determines the processing sequence of stacks, monitors the material flow, specifies the transfer direction of plates at the table confluence and branch points, and issues instructions for crane operation.

Crane operator: Moves plates by crane.

3.2 Control items and controller tasks

The controller retrieves necessary information from the computer, such as plate position and transfer route, determines the flow of plates by referring to TV monitors and the like, and enters the plate flow routes into the computer. Representative control items are the flow quantity ratio, transfer direction, and crane operation. These control images are illustrated in **Fig. 3**. The control items had to be constantly monitored, resulting in a high work load. Control methods were basically established, but were dependent on individual operators to a large extent and were not constant in control accuracy. The plate finishing process control tasks had to be systematized to solve these problems.

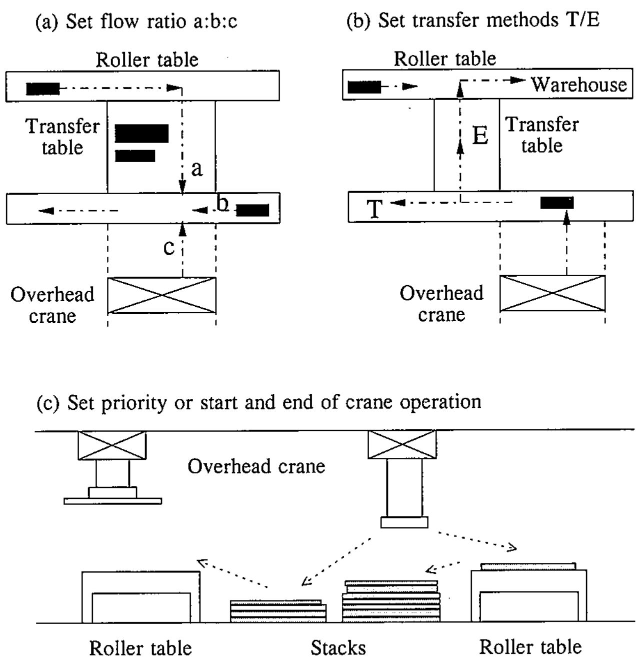

Fig. 3 Examples of control items

4. System Configuration

4.1 Operation analysis

The operator's control items that were important or whose setpoints had to be frequently changed were extracted, and 29 of such control items were selected for automatic setup.

One approach to systematization may consist of identifying all possible material flow patterns and establishing control methods for the individual material flow patterns. This is not advisable when we consider the burden of patterning the material flow that covers many product types and changes moment by moment, and the possible isolation from reality as a result of patterning. The operators who actually controlled the plate finishing process were interviewed, and their jobs were analyzed.

The basic purpose of plate finishing process control is to adjust the inflow of plates from the rolling process and the outflow of plates from the finishing process to the warehouse. It is ideal if plates exist evenly on each table and flow smoothly. To approach this ideal condition, the following actions were taken:

(1) When the inflow of plates from the rolling process is great, let the plates flow with priority so that they should not accumulate on the tables and stop the rolling process.

(2) When the inflow of plates from the rolling process is small, plates are supplied from the stack to the next processing equipment.

(3) When plates are received at a low rate into the warehouse and accumulated on the tables, do not supply plates from their stacks, even under the condition (2) above.

There are involved various constraints in addition to these simple conditions. When the inflow of plates from the rolling process is large, a plate with approaching delivery date is removed from its stack and preferentially routed through the finishing process. When the flow of plates on the table is large but entirely destined for a given item of processing equipment, another plate is unpiled and fed to another processing equipment. These constraints may be summarized as follows:

Strong constraints

- Predetermination of basic transfer route
- Limitation of buffer size by limitation of number or height of stacks
- Limitation of transfer rate or pitch by limitation of equipment or product
- Prohibiting the stopping of the rolling process due to accumulation of plates on tables
- Strict observance of delivery dates

Weak constraints

- The stacks of plates should be as few as possible to assure the desired size of buffer stock.
- Empty tables should be as few as possible to improve the working ratio of processing equipment, and as many types of plates as possible should be placed on tables.
- Interference between the cranes should be minimal.

• Accumulation of plates on the tables should be minimal.

Considering the above constraints, the operators worked as follows:

(1) Determine control methods according to prediction or anticipation of material flow over a long period (a few hours) and a short period (a few minutes).

(2) As a main criterion refer to the condition of such equipment as the tables and cranes, although the quality of products transported has some effect on material flow.

(3) Change instructions to cope with sudden changes in material flow, such as failure or abnormal quality.

(4) Change and judge material flow condition evaluation indexes and various constraints according to the production situation.

(5) Look over the entire finishing yard and comprehensively evaluate, because control at one place affects control at other places.

4.2 System configuration

From the results of the previous section, it may be said that this problem is one of planning by deciding on many setup items moment by moment while responding to the changes in the constraints. Optimization of the solution to the problem calls for the setup items to be assembled into an enormous number of combinations and for these combinations to be examined for the solution. This was very difficult to achieve by conventional techniques. The system was configured with the following characteristics to simulate the control tasks of the controller:

(1) Build a material flow simulator and run the simulator to predict the material flow.

(2) Define a performance function[2] to evaluate the material flow condition of the entire plate finishing yard, and search for an optimal solution according to the performance function.

(3) Switch control at short intervals to cope with disturbances or sudden material flow changes. At the same time; incorporate important changes as triggers, and reset control values.

(4) Build control rules into an expert system to arrange and utilize the knowledge of the controllers and to facilitate their response to the production situation.

The control block diagram to the setup of the control items is shown in **Fig. 4**. Material flow conditions, such as the positions, sizes and transfer routes of plates in the shearing line and finishing yard, are entered as initial values from the high-level computer. Items of information absent in the high-level computer, such as long-term processing equipment operating plans and failures, are entered by the controller. The initial values of the control items are set according to these entries. Next, simulation is run with the initial values to predict how the material flow will change. According to the results of prediction, the controller identifies obstacle points (such as long-time collection of plates on a table) and causal relations with setpoints, changes the setpoints, and runs another simulation using the new setpoints. There are as many as 29 items to be set, and the setup results affect each other. One change alone cannot correctly evaluate this effect and cannot produce setpoints with high accuracy. Nearly optimal setpoints are obtained by repeating the above series of operations for a specified number of times and evaluating the results of each prediction according to the performance function.

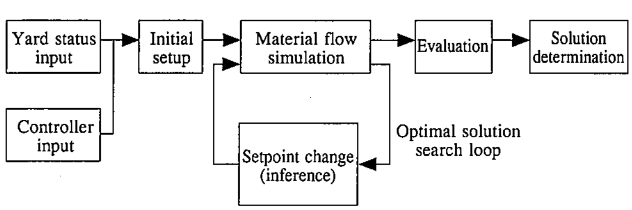

Fig. 4 Control block diagram

The performance function, J, is as follows:

J = {∑(Coefficient × Accumulation ratio of transfer tables) + ∑(Coefficient × Occupancy ratio of transfer tables related to accumulation) + ∑(Coefficient/Occupancy ratio of transfer tables unrelated to accumulation)}/Total number of items for evaluation

4.3 Implementation

The hardware configuration of the plate processing process control support system is shown in **Fig. 5**. The system runs on the workstation (NSSUN SP10 Model 131 with a 64-MB memory) and communicates with the high-level operation control computer to acquire necessary information and to output setpoints for use in the operation of the plate finishing process. Duplication improves the reliability and test efficiency of the system.

The high-speed inference engine[3] developed by Nippon Steel's Systems Research & Development Center is adopted in the expert system portion of the system. There are 320 inference objects and 930 rules. The system fires the rules at a high speed of about 10 ms per rule. Since the tables and cranes are easy to handle as objects, the material flow simulator is built using C_{++}, an object-oriented language.

The control switching intervals are set short so that simulation should not deviate from reality, long so that the controllers can make effective judgments with respect to changing yard conditions, and short so that the yard conditions should not change excessively. As a result of tuning, it was decided to update the data from the operation control computer at 15-minute intervals, to divide the 15 minutes into three parts, and to switch control at 5-minute intervals.

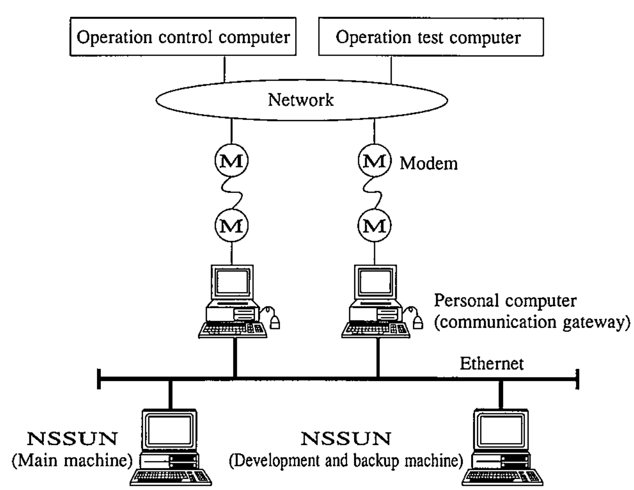

Fig. 5 Hardware configuration

5. Conclusions

The plate finishing process control support system was put into commercial operation in June 1994. After several functional additions and control rule reviews since then, it now operates 24 hours per day, reducing the work load of the controllers and accomplishing labor savings in the plate finishing process.

Plate finishing control targeting systematization is a kind of material flow control job and has greatly depended on operators to date. There are still many other material flow control tasks at the Oita Works. We intend to apply to these material flow control tasks the methods we have established through the automation of the plate finishing control tasks.

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