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A process computer system installed at the finishing line of the medium-diameter seamless pipe mill of Chiba Works not only controls the entire finishing line even covering automatic warehouse and conveyor systems, but also serves for a high-level quality assurance by controlling the flow of pipes in multiple types and small lots. To this end, the process computer is equipped with a high-reliability piece tracking system and a pipe flow control system which uses several models based on evaluation coefficient, with the soundness of these models having been verified by computer simulations. The system largely contributes to improvements in quality assurance, productivity, and labor saving.

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Pipe Flow Control System in the Finishing Line for Medium-Diameter Seamless Pipe*

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A process computer system installed at the finishing line of the medium-diameter seamless pipe mill of Chita Works not only controls the entire finishing line even covering automatic warehouse and conveyor systems, but also serves for a high-level quality assurance by controlling the flow of pipes in multiple types and small lots.

To this end, the process computer is equipped with a high-reliability piece tracking system and a pipe flow control system which uses several models based on evaluation coefficient, with the soundness of these models having been verified by computer simulations.

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1 Introduction

A seamless pipe rolling control system using a process computer was completed in June 1980 after some two years of development stage following the start-up in May 1978 of the medium-diameter seamless pipe mill at Chita Works. The system attributed to the seamless pipe production of 550 000 tons up to December 1982. This was published under the title: "Development of Numerical Control Rolling Method for Seamless Steel Pipe", and awarded the Okochi Memorial Prize 1983 for Grand Production.

Taking the opportunity of the construction in 1982 of a finishing line to the existing medium-diameter seamless pipe line, it was decided to introduce a process computer system for a direct control of an overall operation of the finishing line. Aiming at improving productivity, labor saving, quality assurance and production yield, the above system has important functions such as an automatic collection and processing of data on production, quality and inspection, a furnishing of operating instructions to operators, and an automatic setting-up of various facilities and product transfer line. Moreover, several new control models have been developed for application to the pipe flow control that is increasingly demanded in the finishing line.

These efforts have made it possible for both rolling mill and finishing line to come under a total direct control system using a process computer.

The present report mainly discusses the pipe flow control system that plays the most important role in the entire system.

2 Features of Pipe Finishing Line

Owing to its excellent mechanical strength, the seamless pipe is applied to a variety of usages including oil country tubular goods, line pipes, boiler tubes, and steel tubes for machine structure purposes. Since the time of the Energy Crisis in 1973, the importance of tubings for petroleum and natural gas, and line pipes has increased. As these products require high quality with respect to mechanical properties, strength and dimensional accuracy, the finishing line must satisfy these demands adequately as the process for manufacturing final products. While functions to be assigned to the finishing line vary depending upon the type of final products and where the emphasis is to be placed, the medium-diameter seamless pipe finishing line concerned here consists of the following processes. (See **Fig. 1.**)

(1) Buffer processes between rolling and finishing processes and with finishing process (automatic warehouse for pipes)
(2) Heat treatment process for pipe
(3) Nondestructive inspection (NDI) and measuring

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** Chita Works

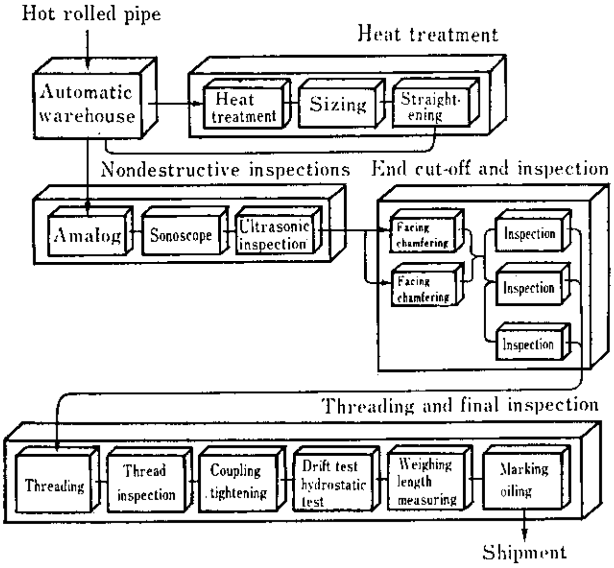


Fig. 1 Schematic flow of the medium-diameter seamless pipe finishing line

processes for quality assurance

(4) Cut-off and inspection processes

(5) Threading process (including threading, hydrostatic test, drift test, inspection and marking, and oil coating)

Not all of pipes are to pass through all of these processes: some types of pipes may by-pass some of them, making the pipe flow complicated, with the pipe finishing line characterized by the following features in contrast to other steelmaking facilities.

(1) Because of diversified applications of products, a variety of heat treatment requirements and thread specifications must be satisfied, resulting in a multi-type, small-lot production.

(2) Accordingly, the line consists of various facilities, including complex and precision machines, such as threading machines.

(3) Owing to a wide range of the finishing line, the number of pipes to be tracked amounts to as many as about 8 000 in average at any moment throughout the whole finishing line.

(4) In contrast to steel plates and sheets, most of pipe products are used directly as shipped from the plant without being processed by the user.

(5) Since strict quality control and assurance are required, each pipe must be under precise control so as to establish the traceability of quality data and production history.

(6) For this reason, it is necessary to process enormous amount of information, say, 1 500 data items per pipe.

It is nearly impossible to control manually the finishing line characterized by these features accurately and efficiently. So, we introduced a process computer as a tool, aiming at the improvement of productivity through the automation and total management of the entire finishing line.

3 Outline of Process Computer System

3.1 Purpose of Process Computer Adoption

In introducing the process computer system into the finishing line, the following basic policy was established:

(1) A full automatization covering equipment operation, material flow and data processing must be aimed at—labor saving and improvement of productivity.

(2) For the operation of equipment, plant controllers and sequencers are to be used extensively so as to implement adequate automation at a level of micro computers subordinate to the process computer—labor saving.

(3) The time interval from receiving orders to shipping is to be reduced by smoothing the material flow, shortening the span of processes (rolling, finishing, and shipping), and reducing stock of intermediate products—improvement of productivity.

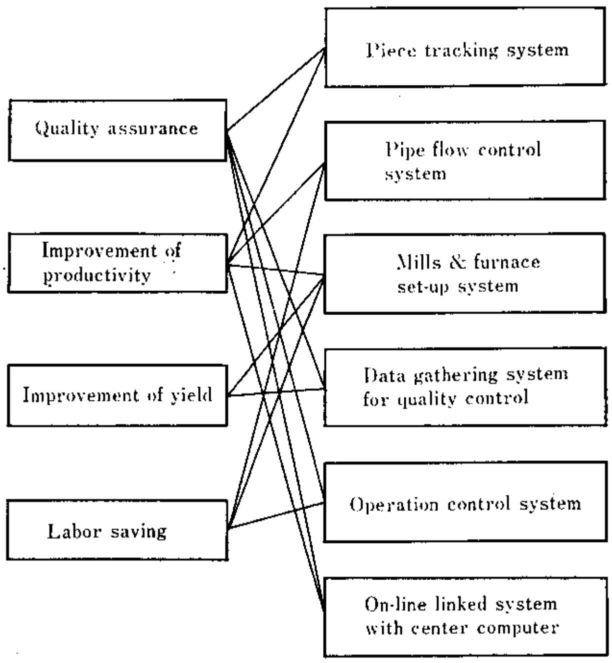


Fig. 2 Purpose of process computer installation in the seamless pipe finishing line

(4) The conditions of inspection, repair and cutting-off in the finishing process are to be grasped comprehensively. and fed back to the rolling process—improvement of yield.
(5) The conditions of production at various facilities in the finishing line are to be monitored constantly and the finish-production plan is to be optimized through the on-line link with the center computer —improvement of productivity.

The purposes such as quality assurance and productivity improvement based on these basic policy and the means of their implementation on the computer system are collectively illustrated in **Fig. 2.**

3.2 Configuration of Process Computer System

The configuration of the process computer system is shown in **Fig. 3**. Based on the features of the finishing line mentioned above, the following considerations are taken.

(1) In order to meet diversified requirements for the finishing line, the finishing line is divided into several sections to be controlled by the multi-computer configuration.
(2) In view of extensive data exchanges between individual computers, computers are interconnected by high-speed data freeway.
(3) For the purpose of exchanging signals with the subordinate plant controllers, DPI/O (Distributed Process Input/Output) devices have been adopted for the first time in the industry.

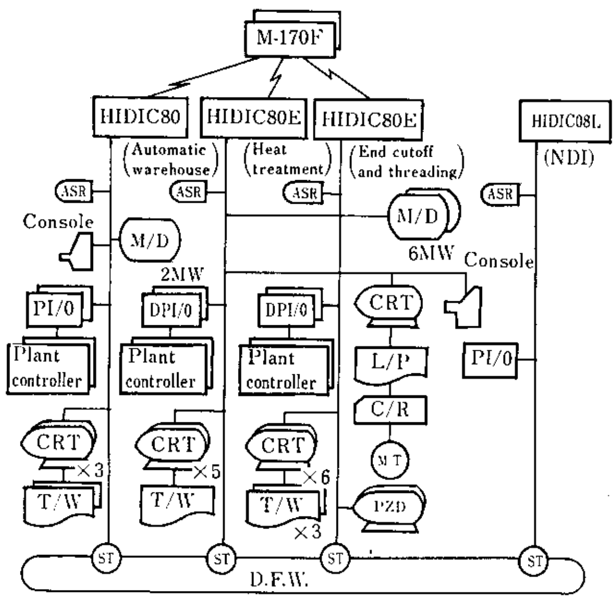


Fig. 3 Configuration of control system

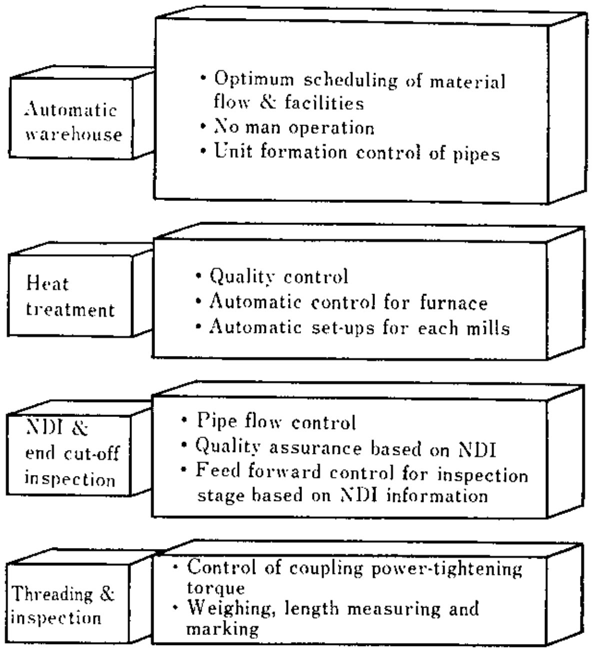


Fig. 4 Schematic functional diagram of process computer control system

(4) The process computer is connected to the center computer through the modem circuit (9 600 BPS), and independent line was installed for each computer so as to improve the responsiveness of the process computer.
(5) For a high-speed processing of the NDI quality information, an exclusive data processor was adopted.

The functional outline of the process computer system is shown in **Fig. 4.**

4 Pipe Flow Control

The finishing plant consists of various lines as shown in Fig. 1. The present section deals with the pipe flow control currently applied to the cut-off and inspection-repair processes (to be referred to simply as cut-off and inspection line, hereinafter).

4.1 Outline of Cut-off and Inspection Line

The pipe flow in the cut-off and inspection line is illustrated in **Fig. 5.** This line covers cutting-off, facing, chamfering, inspecting and repairing, following the flaw checking and measuring of pipe in the NDI line. The previous finishing line of the medium-diameter seamless pipe plant included a cut-off machine and an inspection line. In the present construction, a cut-off machine and two inspection lines were added. After a careful examination of layout plans under the

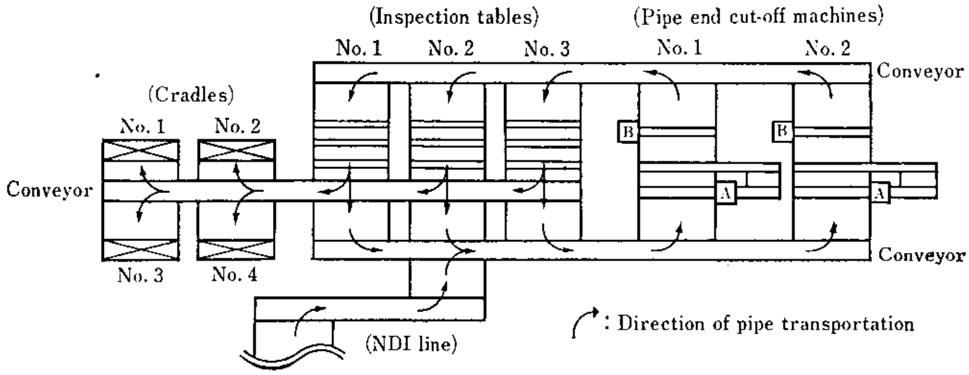


Fig. 5 Pipe end cut-off and inspection line

constraint of additional construction to the existing line, the equipment layout shown in Fig. 5 was adopted, presupposing the use of process computer, though resulting in complicated pipe flow. In the present line layout, branching and confluence of pipe flow occur at three sections: to cut-off machine, from cut-off machine to inspection line, and from inspection line to cradle. It constitutes, therefore, the key-point for improving the productivity of this line to make the pipe flow smooth in these sections. For this purpose, it is inevitable to use the process computer for piece tracking, pipe flow control and operator guidance. On the contrary, the control of a complicated pipe flow will allow parallel operation of pipes of identical specifications, and mutual backup by shifting shut-down for size change.

Moreover, it is necessary to ensure high speed processing at the NDI line so as to follow up the production capacity of the cut-off and inspection line. For this purpose, the NDI line was fully automated so as to reduce time for a size changing set-up and idle time for measurement.

4.2 Study of Pipe Flow Control System

The pipe flow control is a logic to determine just into which equipment each pipe must go, and from which equipment it must come out. The typical examples of applying the similar flow control are traffic controls for railway and automobiles.

However, the railway traffic control based on a predetermined running timetable is not suited to the purpose of the pipe flow control. The road traffic control, which controls random events such as flows of pedestrians and automobiles with a system of traffic signals, can not deal with particular requirements in the plant such as preventing different lots from being mixed up and as improving operators' workability. Accordingly, it was necessary to develop an original pipe flow control model for optimizing the pipe flow control in the finishing line.

The principal factors to be taken into consideration in regard to the pipe flow control in the finishing line are given below.

(1) To minimize the idle time of main equipment.
(2) To ensure optimal load balance among plural number of facilities.
(3) To minimize the queue of pipes waiting for treatment at the buffer table.
(4) To maintain lot assembly.

Each factor was evaluated by the following methods.

Method 1: Single factor evaluation
The pipe flow is determined on the basis of evaluation of a single factor selected.

Method 2: Decision-by-majority
The pipe flow is determined by the majority of factors favorably evaluated.

Method 3: Evaluation function
The pipe flow is determined on the basis of overall evaluation for weighted factors.

Method 1 requires the operator's intervention for selecting factor to be evaluated. Method 2 has a short-coming of disregarding the weight of individual factors. So, Method 3 using the evaluation function was adopted.

The evaluation function method is to find vector $\boldsymbol{X}$ which makes the evaluation function Z maximum,

$$Z = \boldsymbol{C}^{\mathrm{T}} \cdot \boldsymbol{X} + C \qquad (1)$$

under a constraining condition

$$A\boldsymbol{X} \geq \boldsymbol{b} \qquad (2)$$

and a non-negative condition

$$\boldsymbol{X} \geq \boldsymbol{0} \qquad (3)$$

where A, $\boldsymbol{b}$ and C are constants.

Vector $\boldsymbol{X}$ represents a pipe flow route with the order of pipe flow taken into consideration. If there are n pipe flow routes physically conceivable, each route can be represented by $\boldsymbol{X}_k$ ($k = 1, \ldots, n$). Each element of $\boldsymbol{X}$ is designated as evaluation item, and each element of $\boldsymbol{C}^{\mathrm{T}}$ as evaluation coefficient.

The optimum pipe flow route $\boldsymbol{X}_m$ is defined as $\boldsymbol{X}$ which makes the evaluation function Z maximum under the constraining condition given for each of $\boldsymbol{X}_k$.

The key-point of the development is to select appropriate evaluation items and to determine the optimal evaluation coefficient. The evaluation item was selected in consideration of equipment layout, equipment capacity and operators' distribution. The evaluation coefficient was optimized through computer simulation.

4.3 Selection of Evaluation Items

When applying the pipe flow control to the cut-off and inspection line shown in Fig. 5, the following evaluation items were selected in correspondence to evaluation factors mentioned above.

(1) Evaluation items for pipe flow Control in Cut-off Machine
- ① Capacity of cut-off machine
- ② Space capacity of cut-off machine entrance table
- ③ Pipe lot change
- ④ Pipe end face shape change
- ⑤ Pipe diameter change
- ⑥ Pipe wall thickness change

(2) Evaluation items for pipe flow control in inspection line confluent to cut-off machine
- ① Pipe lot change
- ② Occupation of cut-off machine exit table
- ③ Space capacity of inspection line entrance table

(3) Evaluation items for pipe flow control in cradle confluent to inspection line
- ① Pipe lot change
- ② Occupation of inspection line exit table
- ③ Space capacity of cradle entrance table

5 Simulation Experiment

5.1 Simulation Model

In applying to the actual line the evaluation function method described in the preceding section, the computer simulation was carried out to verify the validity of this method and to determine the optimum value of evaluation coefficient.

The simulation was conducted by using the material flow in a simulated cut-off and inspection line in combination with the pipe flow control model. The material flow of the simulated cut-off and inspection line is shown in **Fig. 6**. GPSS/X[1] with complete standardized output format was adopted as the simulation language.

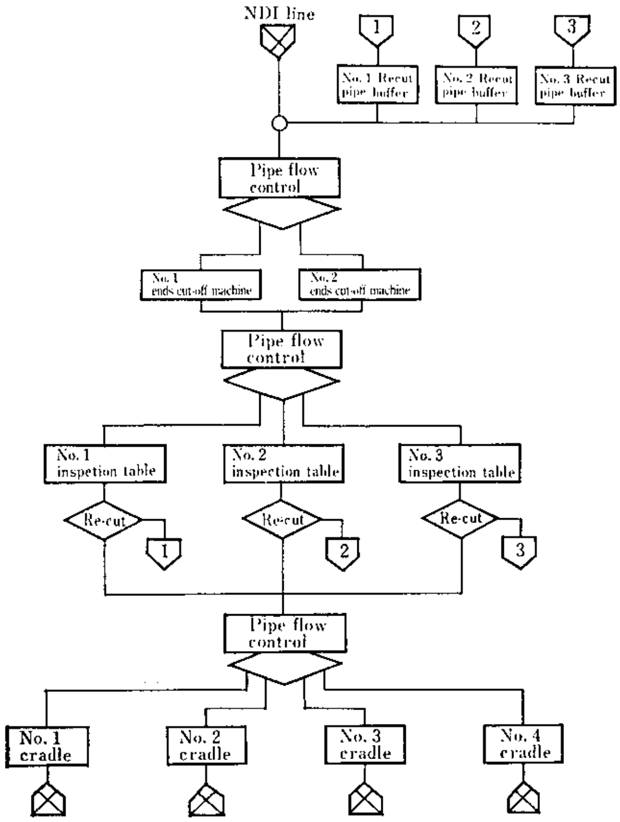


Fig. 6 Schematic flow model of end cut-off and inspection line

In modelling, GPSS/X classifies the system components into facilities and transactions. The number of facilities is fixed throughout the execution of simulation, and they correspond to equipment and buffer tables in the actual line. Facilities may include storages which can deal with plural transactions at one time, while a facility can handle only a single transaction at one time. The transaction refers to an object which moves along facilities and receives service there. In the present case, it corresponds to each pipe. Programming in GPSS/X is made by describing how the transaction is handled at various facilities.

For modelling various facilities, the following factors are required.

(1) Cut-off machine
- a. Entry table capacity
- b. Size change time for changing pipe end geometry

c. Size change time for changing pipe wall thickness
d. Size change time for changing pipe diameter
e. Cut-off machine operation rate
f. Shut-down time due to failure
g. Exit table capacity

(2) Inspection table
a. Entry table capacity
b. Pipe repair rate
c. Mean and standard deviation of pipe repair time
d. Exit table capacity

(3) Cradle
a. Entry table capacity
b. Pipe carry-out time

In modelling the transaction, the predicted finishing schedule was used, taking into consideration wall thickness, outside diameter, length and tube end geometry. A special case of cutting a pipe into two pipes was also taken into the model. The occurrence of the transaction was defined under the assumption that pipes were fed into the line at fixed time intervals.

The simulation model as described in GPSS/X is shown in **Fig. 7**.

5.2 Results of Simulation

The number of transactions (number of pipes) used in the simulation was 2 000. For the simulation experiment, FACOM M-170F was used. While the simulation was conducted for various combinations of evaluation coefficients, cases shown in **Table 1** for pipe flow controls to cut-off line and to inspection line will be presented here. Case 1 concerns making every evaluation, and weight assignment is the optimum one ultimately obtained by the simulation. For the purpose of comparison, cases 2 and 3 concern cases where no evaluation is made for lot change and table space capacity.

Figure 8(a) shows the maximum and mean number of pipes (transactions) accumulated at each table (storage) during the execution of simulation, where the abscissa represents the number corresponding to

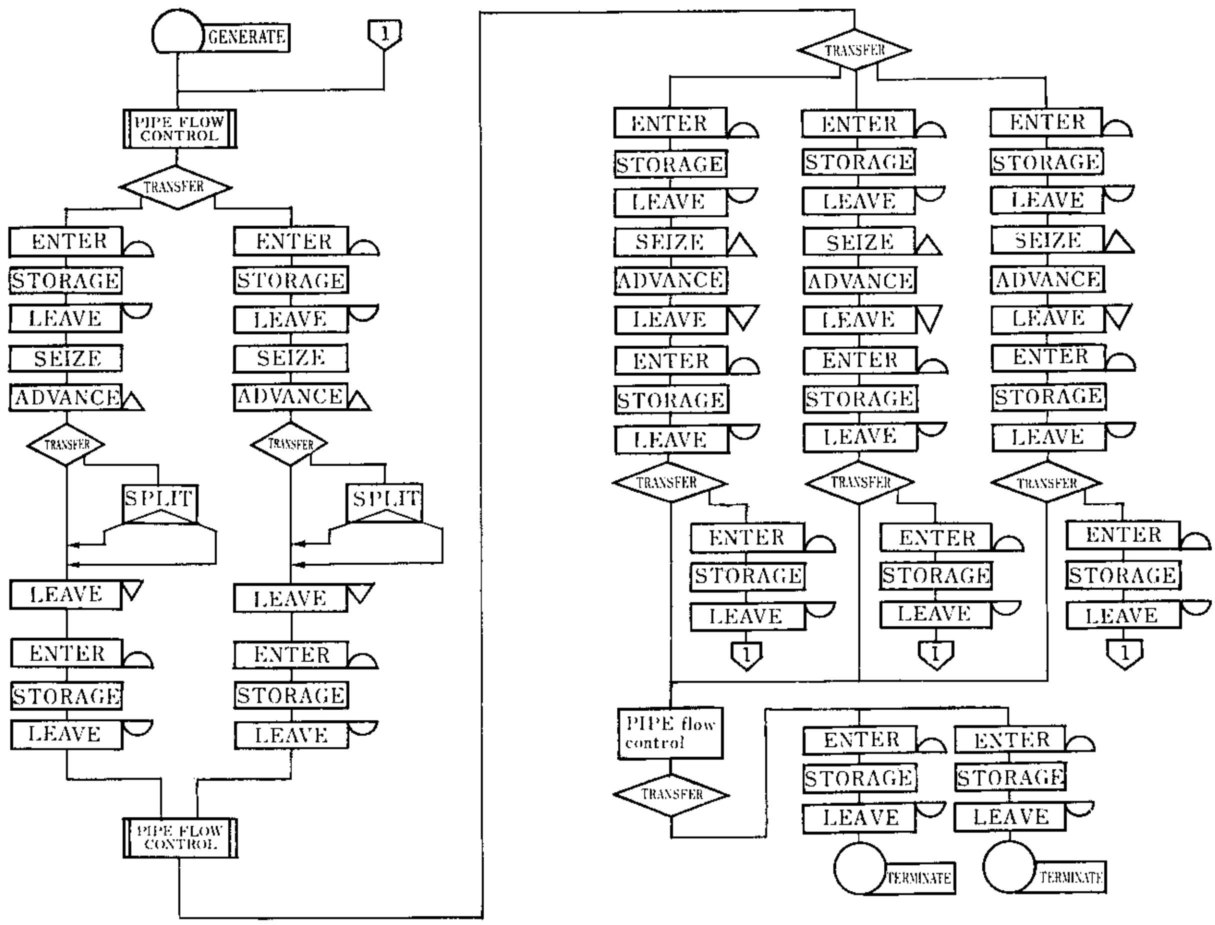


Fig. 7 Simulation model according to GPSS/X

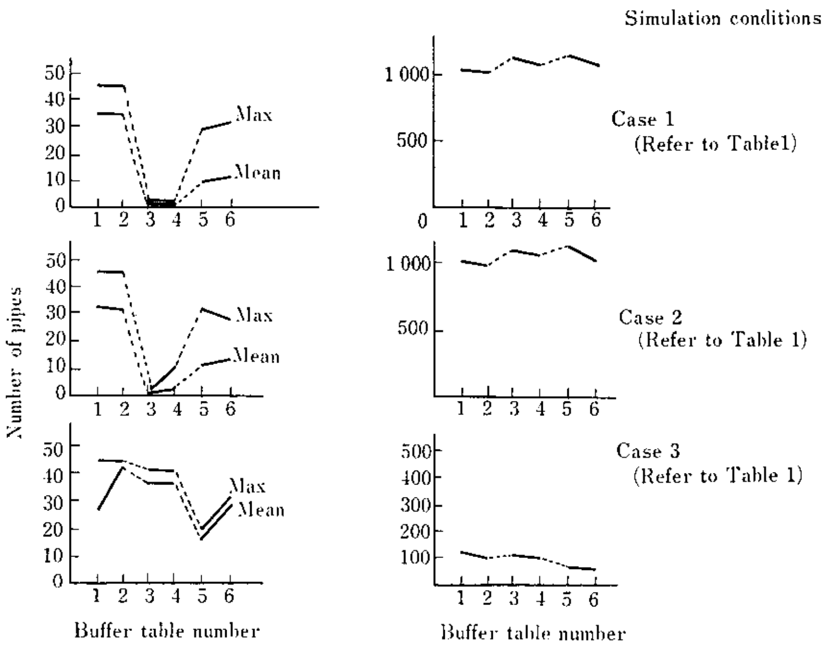
Table 1 Simulation conditions of pipe flow control

Evaluation factors	Weight (%)		
	Case 1	Case 2	Case 3
(for end cut-off line)			
Capacity of ends cut-off machine	5	5	5
Unfilled area's volume of ends cut-off machine's entrance buffer table	30	30	0
Change of pipe lot	40	0	40
Change of pipe diameter	10	10	10
Change of pipe thickness	5	5	5
Change of pipe end shape	10	10	10
(for inspection line)			
Change of pipe lot	60	0	40
Filled area's volume of ends cut-off machine's delivering buffer table	20	20	0
Unfilled area's volume of inspection stage's entrance buffer table	20	20	0

tables, and the ordinate the number of accumulated pipes. **Figure 8**(b) shows the cumulative number of pipes which have passed through each table in the course of excuting the simulation.

Figure 9 shows the balance among tables of pipes assigned to various equipment. The abscissa represent the lot size (the number of pipes in lot) and the ordinate the ratio of assigned pipes for each lot, n/N, where n denotes the greater of the number of pipes assigned to each table, and N total number of pipes in the lot concerned.

For case 1, the number of pipes flowing through each line is divided nearly into two equal lots. In smaller lot containing less than 30 pipes, they maintain a neat group appearance. In case 2, pipes are assigned rather evenly to each facility, which is not favorable for operation since even a small lot is further divided. The subdivision of a lot makes it difficult to keep pipes in a neat lot in the downstream processes. In case 3, the simulation was suspended mid-way owing to time-over. This is because pipes were kept on feeding



(a) Number of pipes on the each buffer tables
(b) Number of pipes throughout each buffer tables

Buffer table number
1. Entrance buffer of No. 1 ends cut-off machine
2. Entrance buffer of No. 2 ends cut-off machine
3. Exit buffer of No. 1 ends cut-off machine
4. Exit buffer of No. 2 ends cut-off machine
5. Entrance buffer of No. 1 inspection table
6. Entrance buffer of No. 2 inspection table

Fig. 8 Results of the computer simulation (transit pipes through each buffer tables)

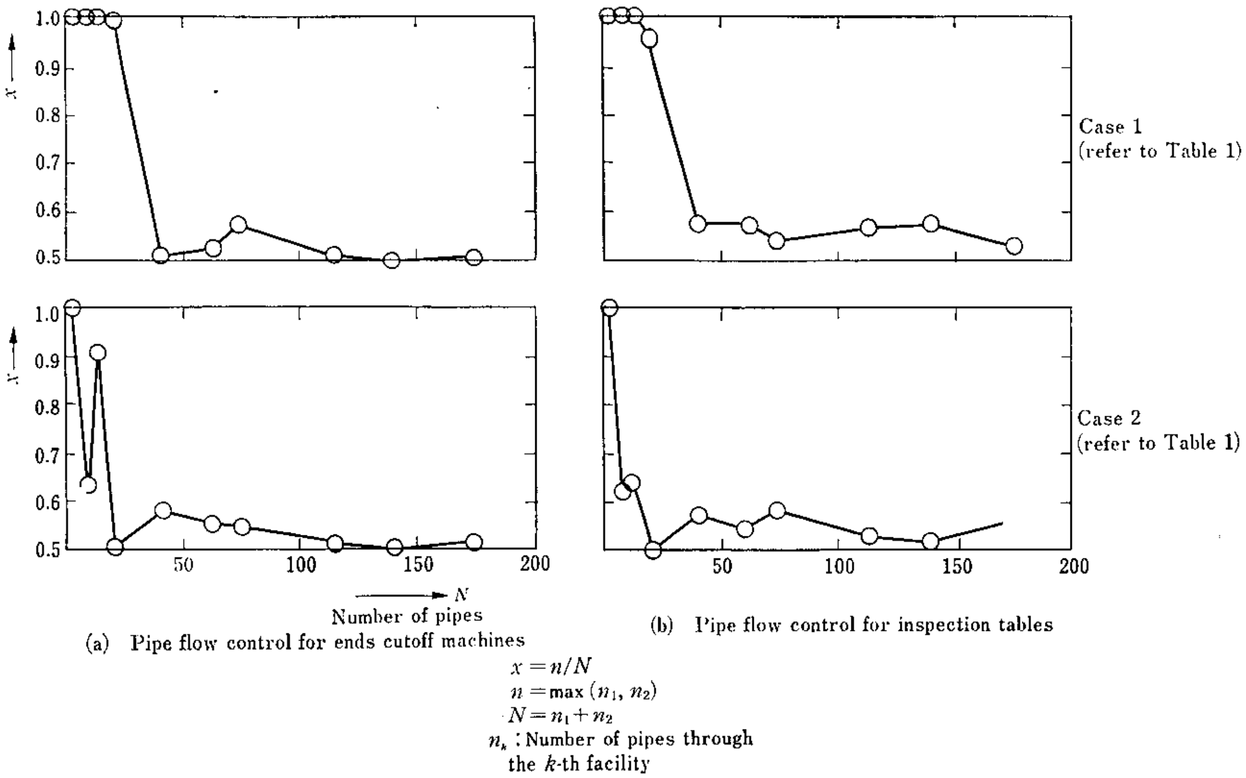


Fig. 9 Results of the computer simulation (a balance of pipe lots devided by "pipe flow control")

into the buffer table which had been filled up, making the line congested frequently. This indicates that the evaluation of table space capacity is indispensable in the pipe flow control.

For a neat handling of pipes in a smaller lot, a larger evaluation coefficient must be considered to meet changes of pipe lot. In this case, however, it should be noted that the evaluation of the table space capacity decreases relatively, causing jamming.

In this way, the execution of the simulation permitted to confirm the validity of the pipe flow control system described in this paper. Moreover, it was also ascertained that the layout of cut-off and inspection line was appropriate for applying the pipe flow control system.

6 On-line Application and Its Results

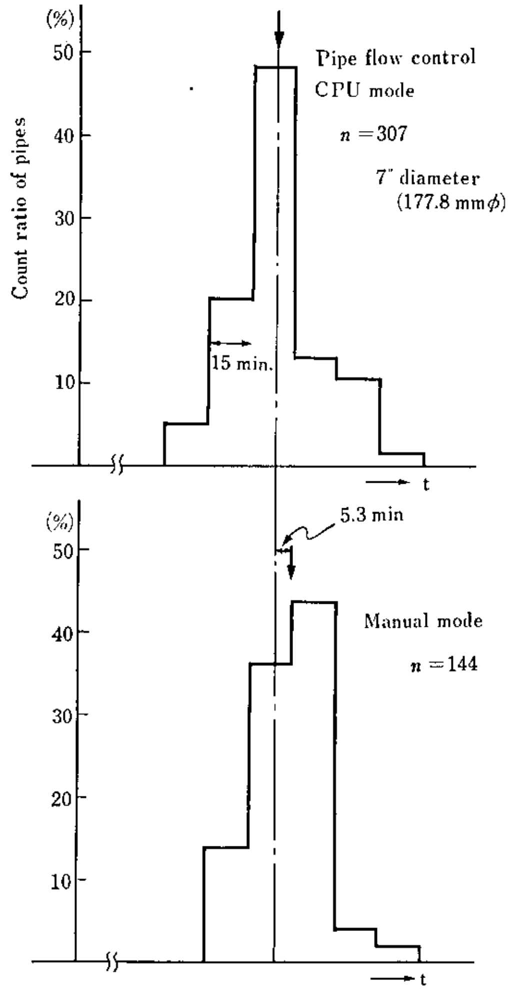
Through the simulation described above, it was found feasible to apply the pipe flow control system to the on-line operation, and the pipe flow control with the process computer was carried out in an approximate synchronization with the production of the finishing line.

In the fine tuning of evaluation coefficients in the trial operation for adjustment, results obtained in the simulation were fully utilized, and it was attempted to optimize various factors for the practical operation. This allowed about 30% cut of the period of trial operation and adjustment.

At present, the pipe flow control is effectively utilized, and the percentage of its on-line application has been maintained 100%.

Figure 10 shows an example of pipe flow control with the process computer and an example of manual operation by operators. The adoption of the pipe flow control system made it possible to reduce the pipe transfer cycle time on the cut-off and inspection line by about 8%. (In these examples, pipes of 177.8 mm diameter were handled, with the inspection-repair rate nearly equal for two cases.)

Besides the present pipe flow control, another pipe flow control to optimize the facilities in the automatic warehouse system has been developed to pursue thorough labor saving. The total labor saving effects are shown in **Table 2**.



Lead time in end cut-off and inspection line

Fig. 10 Improvement of lead time by pipe flow control

Table 2 Operator's labor saving in the finishing line

Line	Labor saving
Automatic warehouse	42 persons
Heat treatment	12 persons
End cut-off and inspection	24 persons
Threading	8 persons
(Total)	86 persons

7 Conclusions

With regard to the pipe flow control system in the medium diameter seamless pipe finishing line, the process computer system, the pipe flow control model, the results of its simulation, and the effects in the practical operation have been introduced.

At the time of planning, there was no example in the whole world of a computer control of an extensive pipe finishing plant, with a great number of problems remained to be solved. Under these circumstances, an original control model was newly developed, aiming at the basic tracking technology and the efficient pipe flow, and the finishing line was successfully automatized.

Thus, in combination with an already developed full automation of rolling mill, an extensive automation system from rolling to finishing with a process computer has been completed in the medium diameter seamless pipe plant. Consequently, a number of achievements have been made, including the enhancement of quality control system, labor saving and improvement of productivity.

Subsequently, several additional control systems are under development, along with data collection on the side of center computer for technical analysis and a process planning system, with further successes in expectation. Moreover, technologies developed for and accumulated along with the present system are applicable to other processes, and expected to expand gradually.

The authors are deeply grateful to Hitachi, Ltd., Yasukawa Electric Mfg. Co., Ltd. and others for their cooperation in the development of the present system.

Reference

1) Instruction Manual for FACOM GPSS/X, Fujitsu Ltd.