Computer Control of Basic Oxygen Steelmaking Process and Problems in its Programming

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1. *Introduction*

A HOC-300 digital computer has been applied to real-time process control of Basic Oxygen Steelmaking Process (BOP) since March, 1963. In this paper, the authors introduce some programming problems in real-time computer control, and illustrate the BOP control system.

Since the BOP is a process having a transient state between two charges and responding slowly against outer disturbances, we necessarily adopted the predictive control method with initial formulas of mathematical models in the computer.

2. *Problems in the Programming*

2.1. *Time vs. space*

The prime distinction of the executive program of industrial process control from that of business data processing or scientific calculation lies in the limitation of operating time and operating memory space.

A process computer is operated repeatedly on given jobs within given time intervals. These time intervals vary from a second to a minute or an hour depending on the operational aspect or the process itself.

In memory space evaluation, on the other hand, two-pass or three-pass execution of program is not allowed in this case; as a process computer should have an ability of memory protection, addition or re-writing of instruction group by outer interruption technique or transmission from its auxiliary memory is definitely forbidden.

Accidental shortening or prolongation of sampling rate directly aggravates computer control efficiency where the mathematical model handles response speed of each part in the control system. The supervisor and the programmer of the computer control system should understand all time limitations for whole jobs to be executed including: sampling and monitoring rate of process variables, iteration rate of mathematical model calculation, treatment for plant emergency, emergency procedure in the

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computer system, time-shared print-out, and combination of status which affects sampling, monitoring and model calculation rates.

2.2. *Modification*

The next demand for a process computer program is that it should be assembled into such structures as to be easily modified in the installed field. This demand is especially recognized in case of plant newly constructed.

In changing the executive program, except for debugging its arithmetic routines, it is usually required that input and output routines are debugged within a few hours stopping the field operation, because time relations among process variables are so complicated that simulation on the punched paper tape can hardly realize these relations.

1) Adoption of table look-up method so that the least modification in program steps enables a large variation in the system operation: for instance, linearization table of non-linear inputs, self-adjusting table of mathematical model, format table of logging data, etc.

2) Construction of program structures such that every independent routine is assigned in an independent memory block under the control of the main executive routine. In case of the machine of the 1+1 address method, assignment of every routine should be particularly taken into consideration not to mesh each other.

   In HOC-300, which has a magnetic drum device of 8192 words as its inner memory and is designed with the 1+1 address method, its assembler program usually optimizes executive routines for every 128 words (i.e. for every 2 tracks of the drum memory). In this case, however, if the programmer gives an extra identification to assign into the other track (not always into the next track), optimization process transfers to the assigned track with spare addresses in the present pair-track, so that this routine can be later modified within its specified area, even with machine codes.

3) The same constant which is used in several blocks (e.g. in some of independent control equations or linearizations) must be stored separately in each blocks to be advantageous to frequent alternation of coefficients in the early operation.

4) Rigorous standarization of programming techniques is required, since an executiue routine is destined to be handled by other field engineers than the programmer after installation.

Automatic programing techniques have recently been developed in the process control field. Executive routines run before the next modification for several thousand hours, which are inefficiently framed for several hundred hours with the machine codes or the symbolic codes.

The authors developed an automatic programming system for HOC-300, named HODRAL, which can treat the language of ALGOL 60 with some restrictions. The HODRAL was, however, constructed to be put stress on the process control use, having such abilities as follows: conversion of various types of input signals into the computer oriented patterns, data compensation, treatment of various length of time intervals, bit-wise handling of information, monitoring and alarming for plant operation, treatment of various kinds of output signals such as set point adjusting signals, direct digital control signals, etc.

The HODRAL complier enables both the optimization for 1+1 address method and the memory protection for every area of the drum memory. The authors have a plan to report the details of the HODRAL later (Journal of the Information Processing in Japan, Vol. 5, No. 5 (Sept. 1964)).

2.3. *Special interruptions*

The various features of interruptions have been required for process computers since their birth. These features have made invaluable contribution particularly to their reliabilities and their strict punctualities.

2.3.1. *Inner interruption (timer interruption)*

Process computer should have an accurate clock pulse generator by two reasons: to generate a real-time clock to synchronize the computer execution with the actual plant operation, and to realize or simulate the time delays of measuring and controlling devices and the time interval between two occurances.

HOC-300 has a crystal pulse generator which creates a clock pulse in every second, and packs several 6-bit counters to count the 1-sec pulses up to a minute. The timing pulse defining the minimum sampling rate is led from the specified terminals of one of these counters to the scanning jump flip-flop. Each of these counters loads the definite values by the program and these values are raised by the 1-sec pulses through a common add-1 circuit, until the overflow signal for this counter stimulates an interruption terminal. The other example is shown in the analysis of composition ratios of an objective material by an X-ray Quanto-meter. The analysis is continuously performed, in every three seconds per composition, and the motion of the slide-wire in the electric recorder takes about 500 mS. Then, the peak signal which represents the composition value is transmitted to the accumulator of the computer by the 3-sec interruption.

2.3.2. *Inner interruption (electric source failure)*

In the plant operation, temporary drops in source voltages are often inevitable.

Preservation of execution aspect at the time the source failured and shortening of the recovery time improve the reliability, the most vital bench-mark for a process computer.

The interruption in this case is illustrated as an action such that the contents of the registers and the flip-flops are sheltered to a permanent memory device before the basic clock pulse fades out from the logical circuits. Recovery of the control routine, nevertheless, is not easily completed at all even with the transfer of the sequence control counter to the previous step by the mask release function after revival of all reserved histories.

The authors have tried to make a general-purpose recovery program for each electric source failure, but did not yet succeed in this job.

It is found that some of the deliberated recovery programs are certainly useful for short failure less than a minute. In case of rather long failure there are no other means than memory dumping of the last data, execution of an extra program given from the outside which is contrived in consideration of the instance of failure and of the length of failure, mask release at the end of this program, and transfer to the initial start of the main program.

In HOC-300, all powers are supplied through a motor generator to the basic circuits and memory devices. When a 15 V drop of the 100 V AC source is detected for more than one second, the control routine is immediately interrupted and an emergency program takes over the procedure of reserving seven registers into the drum memory within 150 ms. After that, the 230 kc/s clock pulse for the basic circuits is automatically switched off.

2.3.3. *Outer interruption* (*Maximum value interruption*)

A number of gas-chromatograph analysers have been applied to the process control field in these days. An analyser of this type transmits serially the value of the composition in a stream with electric current or voltage.

Search of a peak of a composition value or integration of each composition value through the computer program forces the computer to stick exclusively on this task for several minutes of analysis.

In HOC-300, interruption for the control routine is caused from a signal which is generated at each maximum value of a composition, then the composition ratio is read in within a few second of the holding time for the maximum value. This operation occurs serially for each composition. In this way, no parallel memories are required.

The holding time of the value is dependent on the sort of composition, the column length of the analyser and the pen speed of an attached recorder, and is generally about 5 seconds with an analog recorder. The holding accuracy is out of question because the maximum value is held and transmitted to the computer on a slide wire. This single slide wire is commonly used for streams and for their compositions.

Another example of maximum value interruptions is that of the end-point temperature in the BOP.

The voltage of the immersion couple put into the melting steel varies as shown in Fig. 1. When the voltage reaches at a point (a), a maximum value interruption occurs in HOC-300. The time of reading the temperature including A–D conversion of this value and storing it into the drum memory is less than 100 mS. In practice, three end-point temperatures for three furnaces and a pig-iron temperature are processed on the same priority level. Therefore even in the worst case, where the preceding priority calls have demanded mask status, all of the above actions are finished in less than 500 mS.

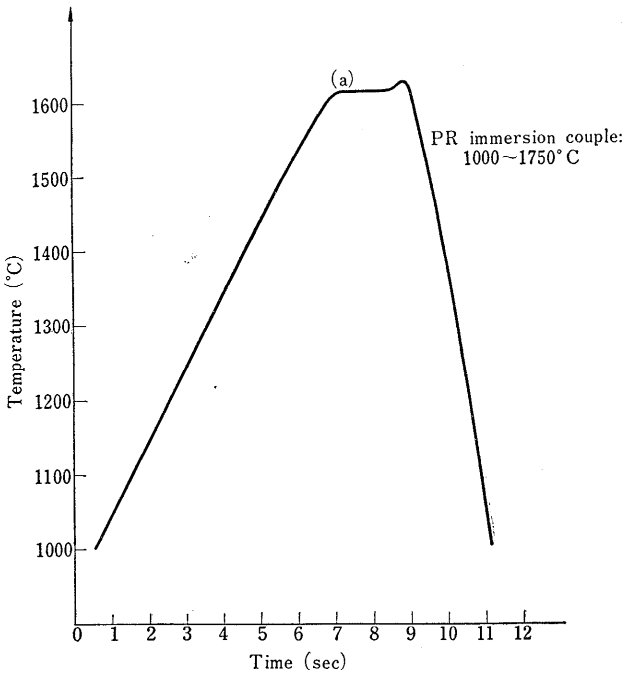

Fig. 1. End-point temperature in melting steel

2.3.4. *Inner interruption (zero code check)*

Program accessibility to every corner of logics and logical simplification in its design are two important factors of process computers. These two factors seem to be somewhat inconsistent. When an illegal code, memory parity error or overflow in the accumulator is detected, to stop the operation automatically by hardware circuits is known to be undesirable in process control fields.

HOC-300 has "no effect" code 010. Therefore, code 000 does not mean "no effect" but its hardware identifies this with "active error", and then sends an alarm to the operator's console, without stopping the computer. The content of the sequence control counter corresponding to the "instruction" of code 000 is kept and the transfer to the specified address is easily done.

Code 000 is generally due to addressing miss during in-factory arrangement. According to our experiences, the code 000 which occured in regular operations were all caused by changes in the environment which affected the whole computer functions (failure of a temperature controller in the computer room, for instance), but not by failures in the special circuits. We have, therefore, not yet have any efficient general purpose program for the illegal code processing, but stopped the computer forcibly *by the stop code.*

2.4. *Emergency program and data compensation*

In regards to the reliability or maintenance, it should be noted that the operating conditions of a process computer are definitely distinct from those of an off-line computer used in the scientific or business computation fields. No frequent preventive maintenance, and no machine stop, unless the safety of plant or economics of operations are threatened, are allowed. The process computer should monitor and compensate hundreds of the measured data all day which are its input or output. Under these rigorous conditions, a process computer should keep a higher level of reliability, 10% higher at least than that of an off-line computer.

The periodic or on-emergency execution of the stored check programs, identification of indications for each error or other result, the transfer to the specified emergency program, and data compensation are all essential functions which are brought forth from the strict requirements imposed on a process computer.

The following illustrates some of the compensating methods when an input datum is checked to be unreasonable.

(1) To replace by either the preceding sample or the mean value of the several preceding samples, or to replace by a definite value.

(2) To compare this datum with the preceding control value, then replace by a simplified function of the control value if unreasonable.

(3) To read over again the same variable, and replace by the mean value of preceding reasonable data. Or, to pass through a program filter.

(4) To replace by a desired value used in the mathematical model.

For the output check, when a control value is checked to be unreasonable, the following procedures are usually applied.

(5) To re-calculate the specified control equation, or to replace by a definite value.
(6) To re-calculate the specified control equation with some desired values instead of the sampled data.
(7) Always to suppress the control value. Or, to pass through a program filter.

The emergency programs are divided into two categories: one for emergencies of plant operating conditions, and the other for failures in the computer control system including those of the instruments.

The former has a proper feature to each plant, and the latter specifies procedures for,

(a) data losses owing to accidents in the instruments (mainly in a continuous process) or owing to troubles in operation schedules (mainlyin a batch process),
(b) the electric source failures,
(c) error detections by the check programs, and
(d) the scanner or the A–D convertor errors.

At the extreme of data losses, it is often required for the computer to open the feedback circuit before the clock pulse fades, not to interfere the action of the control valve.

2.5. *Flag input*

Several methods are devised in sampling process variables.

(1) Periodic samplings for all variables.
(2) Selective sampling for each variable.
(3) Group samplings whenever their respective flag inputs require.
More than one flag inputs are defined for a group of variables, and these flag inputs are sampled periodically or on the instant they call priorities.
(4) Priority call of key variable.

In most continuous processes, two methods (1) and (4) are adopted together. The method (2) takes such an other aspect as selective samplings only for key variables in case that the number of variables are so large that an optional selection of each variable is expensive, especially in resetting the temporary buffer storage for a digital input.

In batch processes, the method (3) is efficiently used. In case that a variable is not verified whether to be transmitted or not, to scan and fumble it is waste of time and space in the program. The method (3) is efficient in this case, besides in data compensation or in search of an emergency program.

In the application for the BOP control, HOC-300 is going along with two methods, (3) and (4).

3. *Control Routine of the BOP Operation*

3.1. *The BOP operation*

Use of the BOP (Basic Oxygen Steelmaking Process) is growing rapidly all over the world of late years, because of the following features of this process.

(1) High tonnage capacity of the process
(2) Low plant capital
(3) Low operating costs
(4) Simplicity of operation
(5) Ability to produce a quality steel at high production rates

High tonnage capacity is caused mainly from the speed of the process operation. One batch of the BOP called *a heat* or *a charge* takes less than 50 minutes, while one batch in an open hearth furnace requires nearly five hours. This important advantage of the BOP has, however, not yet fully been exploited because the control methods on this process are largely empirical.

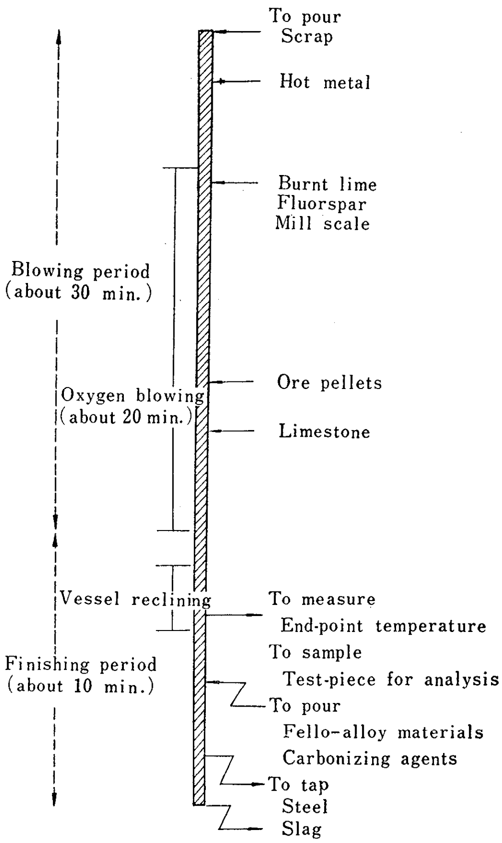

Fig. 2. One charge of the BOP

One charge of the BOP is divided into two parts, the blowing period and the finishing (or adjusting) period (Fig. 2).

During the blowing period, a vessel of melting steel of the required qualities is produced through pouring burnt lime, mill scale, iron pellets, fluorspar and other additives onto a mixture of hot metal and cold scrap blown with pure oxygen. The time when the required conditions for melting steel are attained and when oxygen blowing is to be terminated is called *end-point*.

During the finishing period, the calculated amounts of ferro-alloy materials, carbonizing agents, etc. are added to melting steel obtained at the end-point in order to produce desired ladle lumps.

In our project, main objectives of the computer control functions are concentrated in the blowing period so as to attain the desired chemical compositions and the temperature of melting steel at the end-point, and to predict an adequate amount of the adjusting materials such as ferro-alloy or carbonizing agents before the end-point. Analysis of the process and formulation of the models were made by Nippon Kokan K.K. analyst group and their IBM 7070 machine. Control of the real time process, on the other hand, is performed by the HOC-300 process computer with the models.

3.2. *Mathematical model*

The mathematical models based on the dynamics of the BOP, were worked out for extensive application to all sorts of steel including those of carbon range from 0.01% (pure iron) to 0.6% (high carbon steel) besides low alloy steel.

The basic form of the control equation is as follows:

$$y_{e,0}=y_{m,1}+\Delta y_{e,0-1}$$
$$=y_{m,1}+f(u_1v_0-v_1),$$

where

$$u=u\left\{\sum_1^n (y_{m,n}-y_{e,n})\right\},$$
$$v_0=v\{x_0^1, x_0^2, \cdots, x_0^n\},$$
$$v_1=v\{x_1^1, x_1^2, \cdots, x_1^n\},$$
$$y_e=\text{target value of control objective } y,$$
$$y_m=\text{measured value of } y.$$

$x^1, x^2, \cdots, x^n$ denote variables functioning on the objective y, suffix 0 means current charge, i means the previous i-th charge tracing back to the past from the current charge.

v is a function derived theoretically from the chemical equilibrium, relation of heat balance, of material balance, and of Vecher-Hamilton, and is refined subsequently by statistical analysis on actual data.

This basic formula denotes that the target value of an objective of the current charge ($y_{e,0}$) should be calculated and controlled by combination of the measured value of the previous charge ($y_{m,1}$), moving average of hitting deviations of several past charges (function u) and adjusting term (v_0-v_1) that appeases influences of such unknown factors as inner status of vessels, conversions of CO to CO_2, temperature loss through fume and slag compositions.

The mathematical model handles eleven control equations corresponding eleven objectives. Some of them are shown in Fig. 3 and Fig. 4.

3.3. *Control routine*

The first control program was coded with machine language of HOC-300 because the HODRAL compiler had not yet been completely debugged. Its master flow is shown in Fig. 5.

144 variables are scanned and are put into the computer. They are identified to what charge they belong, and then stored in the memory addresses assigned by their input channel codes.

Each control equation is related to a specified flag input. When the related flag input is read and recognized to be significant, then the equation is computed as if all of the variables subjected to that equation have been renewed or stored. In this stage, another compensation of a datum is performed from that in scanning stage. One instance is collation of the composition value transmitted from the X-ray Quanto-meter with the target value. This procedure cancels influences of analysis errors

Objectives / Variables	End-point carbon	End-point phosphorus	End-point temperature	Total weight of steel
1. Controllable variab				
Hot metal amt.	○	○	○	◎
Cold scrap amt.	○	○	○	○
Scrap amt.			○	◎
Burnt lime amt.	○	◎	○	○
Mill scale amt.	○	○	○	○
Orc pellets amt.	○		◎	○
Fluorspar amt.	○	○	○	○
Lance height	○	○	○	○
Oxygen pressure	○	○	○	○
Oxygen flow rate	◎	○	○	○
2. Uncontrollable variables				
Hat metal carbon %	○			○
Hot metal silicon %		○	○	○
Hot metal manganese %				○
Hot metal phosphorus %		○		○
Hot metal temperature			○	
Inside conditions	○	○		

(Variables with double circles are controlled.)

Fig. 3. Objectives and variables in blowing period

Variables \ Objectives		Ladle carbon	Ladle manganese	Ladle phosphorus	Ladle silicon
1. Controllable variables					
Fe-Mn	amt.	○	◎		
Si-Mn	amt.	○	○		○
Ca-Si	amt.				○
Fe-Si	amt.				◎
Al	amt.	○	○	○	
Cold scrap	amt.	○	○		
Carbonizing agents	amt.	◎			
Fe-P	amt.			◎	
2. Uncontrollable variables					
End-point carbon	%	○	○		
End-point manganese	%	○	○		
End-point phosphorus	%			○	
End-point temperature					
Total steel wt.		○	○	○	○
Molten slag conditions		○	○		

(Variables with double circles are controlled.)

Fig. 4. Objectives and variables in finishing period

on succeeding computations which are derived from the basic form of the control equation.

Inter-linkage with the small linearizing computer attached to the X-ray Quanto-meter is formed by some timing buffers, not by the function of priority interruption. Receiving a "ready" signal from the linearizing computer when it finishes outputting one composition value, HOC-300 opens the input gates of accumulator.

Hot metal temperature, end-point temperature and numerical indication for the operational guide in the operating sites are read or displayed by priority interruptions called from their respective operating sites. Measurements of temperatures are ranked on the same level of priority, while displays on the lower level than measurements of temperatures.

Diagnostic programs stored in the computer memory are executed for every scanning period or at an emergency call. Besides such indicating lamps as A–D converter check, scanner check, or overflow check for accumulator, twenty lamps are mounted on the operator desk. They are used for block-wise or historical indications of calculation or operation errors. They are also useful in recognizing break points in the control routine or interruptions.

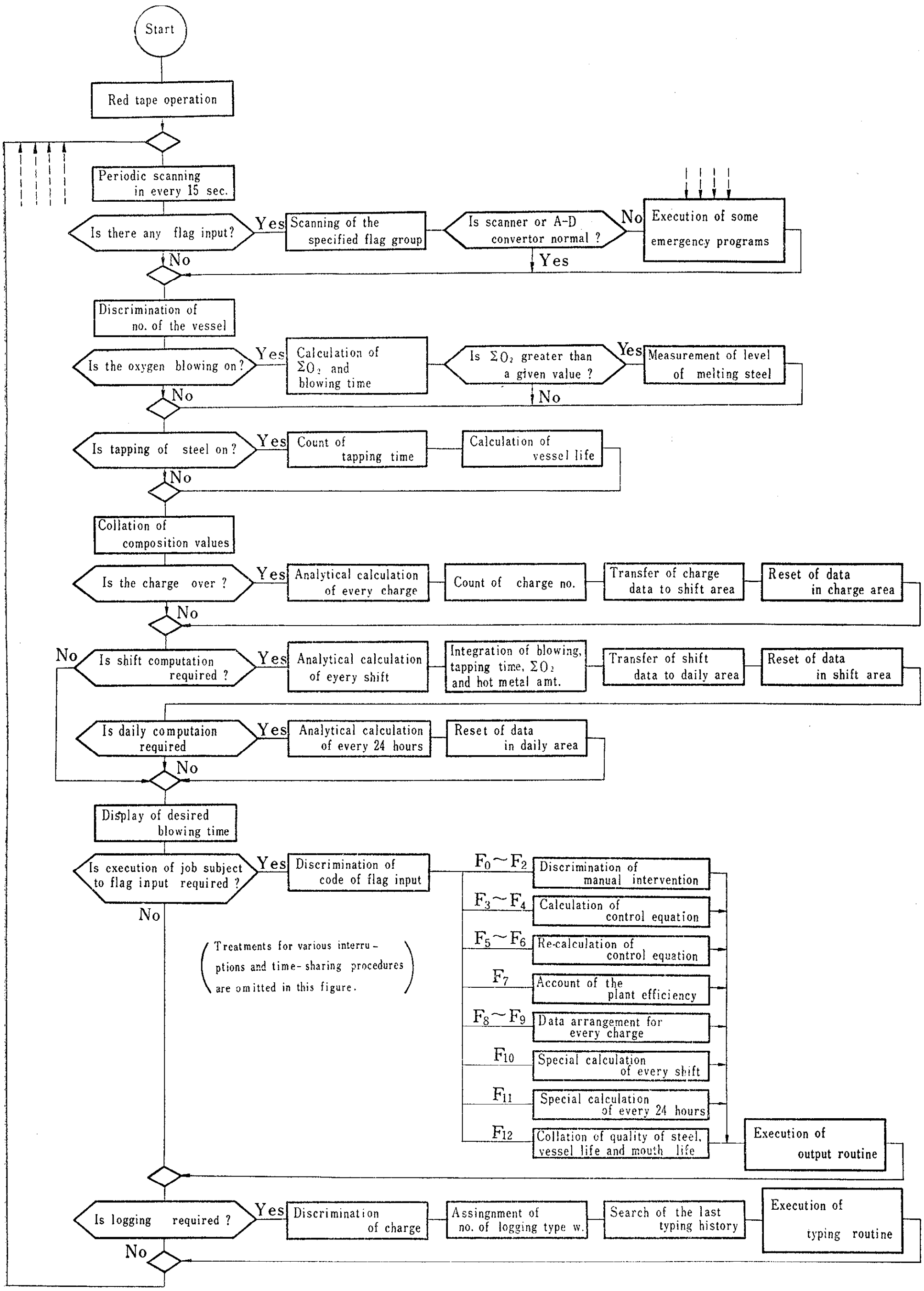

Fig. 5. Master flow chart of control routine

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