UDC 669. 162. 1 : 181. 323

COMPUTER CONTROL OF SINTERING PLANT

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I. INTRODUCTION

While the blast furnace installation has become larger and larger in size with increase in the demand for iron and steel, the iron and steel making industry is facing too serious a problem—dificulty in procuring high quality ores.

Of the preliminary treatment methods, there is the most rationalized one called sintering method using DL (Dwight-Leoyd type) sintering plant that has widely obtained with iron and steel manufacturers in Japan. So far DL type sintering plant has been controlled by means of analog controllers, but the control results were sometimes dubious. A rapid progress made in the computer control in recent years has stimulated the iron and steel making industry and made them struggle for computer control systems to modernize their sintering plants. Almost every plant of huge size which is now planned counts on the computer control.

In Japan, some ten sets of special computer control system have been embodied in the sintering plants. Of them, eight sets were manufactured by Fuji Electric going far ahead of other manufactured in this field, and are well in business. Introduced here is an outline of the computer control system for DL type sintering plant behind which an abundance of our technical refinements and experience acquired over many years stand.

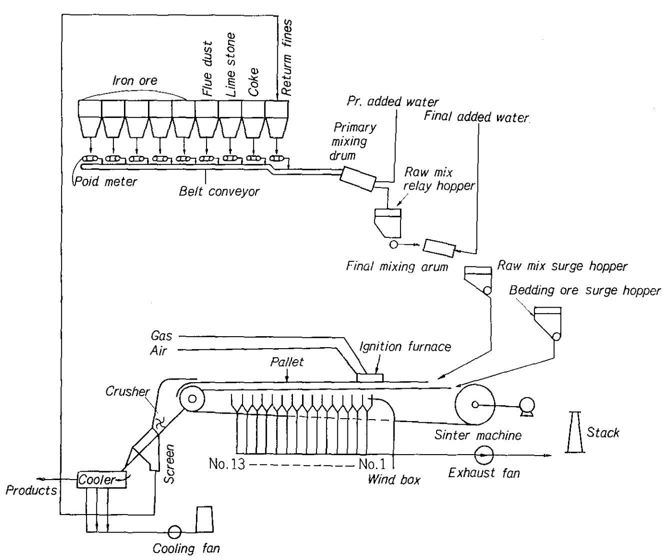


Fig. 1 Schematic diagram of sintering Plant

II. OUTLINE OF DL TYPE SINTERING PLANT

DL type sintering plant can roughly be divided into three sections; quarrying station, sintering machine and product processing line. *Fig. 1* gives an outline of the sintering plant.

The sintered ore is pulverized by a crusher, sieved by screen, cooled down through a cooler, and is sent to the blast furnace. Sieved ore is recuperated as recycled ore or bedding ore. This self-supplying of raw materials is one of the most outstanding features of the sintering.

III. CONTROL OF DL TYPE SINTERING PLANT

The sintering plant is controlled in order to raise high-quality sintered ore as much as possible. The control system comprises a number of control loops entwined with each other. The necessity and significance of typical control loops and the problems of ordinary analog control systems are discussed here, along with considerations on the introduction of computer control system.

1) Feed rate control

This is to carry out ratio control for mixing different materials furnished by respective hoppers to meet quality requirements of sintered ore for the blast furnace. *Fig. 2* shows a block diagram of this batch control system. Namely, the batch control is so accomplished as not only to meet control conditions like chemical composition of sintered ore and inventory coordination, but also to minimize unit cost of charge materials.

There have been put forth various methods including linear programming method in order to computocontrol the batching system for an optimum mixing ratio. The limestone, coke and recycled ore are regulated by feedback signal representing sintered ore quality for the purpose of compensating the calculated mixing ratio.

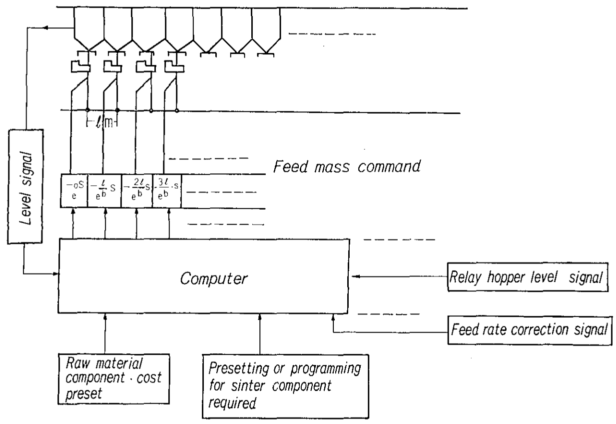


Fig. 2 **Block diagram of material control**

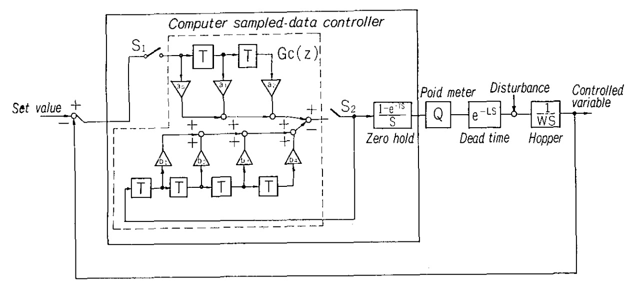


Fig. 3 **Block diagram of level control**

The quarrying ratio of each bin can be determined by the calculation of mixing ratio, whereas the total amount of quarried materials is controlled by fully taking into account the plant conditions including the level of raw mix relay hopper.

2) Feed mass control

Feed mass control means the quarrying of raw materials from ore bins in compliance with the command signal from the feed rate control. The time lag problem is incidental to the conveyor system as illustrated in *Fig. 2*; in the ordinary analog control system, it is hard to hold a specified ratio of raw materials when disturbances like the changing of settings take place. This imposes a serious problem on the entire system control.

The computer control, if incorporated in the feed mass control, can easily solve this time lag problem because the computer itself provides time lag arbitrarily, and can bring about unexpected payoff. In fact, its excellent controllability offsets more than overtaxation by investment cost.

The quarrying system is to be regulated by various control modes such as sequential or simultaneous start-up or stop. All these control modes can easily be realized if the computer is used. So is the computer indispensable for the complete ratio control of the quarrying system.

3) Hopper level control

In the sintering plant, there are many hoppers including raw mix relay hopper, raw mix surge hopper, and bedding ore surge hopper which are all required to be level controlled, as illustrated in *Fig. 1*. These hoppers are installed with a view to reducing disturbances in the line between the raw material supply and the sintering machine to a minimum, and should be controlled strictly considering their small capacity and the requirements of moisture measurement.

In the conventional analog control system, the hopper level was on/off controlled with much difficulty because it is of the system having a transportation lag. For this reason, the sampling controller has been put to practice, but it was very costly yet less effective for want of capacity. These problems are of no consequence to the computer control; the computer is able to make up a required transfer function with ease, and also performs discriminative operations if so arranged.

In addition, the computer makes it possible to realize a practical control system compatible with the capacity and functions of the hopper if its functional parts are designed ingeniously. Such being the case, the introduction of the computer to the level control is warrantable.

4) Moisture control

The amount of water to be added to raw materials has a great bearing on the gas permeability, and its control, together with pallet speed control, is one of the most important control items ruling the quality of products. *Fig. 4* shows a block diagram of moisture control system. With reference to *Fig. 4*, there are illustrated two mixers with which to add water to raw materials; the primary mixer carries out rough moisture control of raw materials, while the secondary mixer performs fine moisture control. For fine mositure control, a method using neutron hygrometer for accurate hygroscopic measurement of materials has been reported very recently. While the water content of raw materials (I_0) is widely dispersed and also is time-dependent, the transportation amount of raw materials (Q_0) is greatly affected by the level of raw mix relay hopper and the speed of sintering machine. Of course, the transportation amount (Q_1) at the outlet of the primary mixer and the transportation amount (Q_2) at the outlet of the secondary mixer are changeable. Moreover, since the system has idle times due to transportation

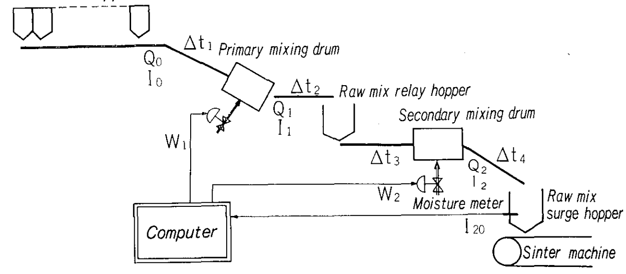


Fig. 4 **Schematic diagram of moisture control**

$\Delta t_1 \sim \Delta t_4$, the conventional analog control system was almost impossible to control this system.

The computer control system is capable of calculating primary mixer addition (W_1) and secondary mixer addition (W_2) as well as of performing optimal moisture control in time with the actual material flow with idle times $\Delta t_1 \sim \Delta t_4$ taken into consideration. Also, the computer system is possible to carry out perfect moisture control even under transient conditions such as start-up and stop by punctiliously grasping plant information such as raw material tracking, start-up and stop of the raw material system.

5) Bulk density control

The gas permeability is largely affected by the granularity of raw materials, and the thickness of the materials scattered on the pallets during sintering is determined by the granularity. Since, however, the gas permeability is decreased with increase in the bulk density (which in effect is equal to the increase in layer thickness and invites reduction of production due to lengthened sintering time), whereas the decrease in the bulk density causes uneven burning because of uneven layer thickness, the bulk density must be kept at a fixed value. To maintain the bulk density at a constant value, the following two methods are available:

(1) Control of drum feeder quarrying

(2) Control of pallet speed

Method (2) is discarded because it gives disturbances to the plant control, and method (1) is usually practised. If the drum feeder quarrying control is carried out, the control loops in the preceding stages, and the level control of raw material hoppers and raw mix relay hopper are greatly influenced, which in turn results in the necessity of the raw material quarrying control. Namely, the drum feeder quarrying control cannot be executed independent of the host of other control requirements. In this case, the analog control is therefore good for nothing, and the computer control is nothing better because it is able to carry out comprehensive control on on-line information and on judgements by itself. An accepted method of measuring the bulk density is one in which electrode or the like is used to measure the thickness of the layer of the raw material tarrying on the cut-off plate.

6) Pallet speed control

The higher the pallet speed is, the larger is the production output. But if the pallet speed is too high, it could cause process materials to come at the end of the sintering machine long before they are burnt. Namely, the pallet speed should be as fast as possible unless it mars the quality of the product. This speed determination is one of the most important items of the sintering machine control.

The raw materials are ignited in the ignition furnace; the temperature of waste gas is low in the early stages since water cannot be evaporated, but it goes up as its firing plane nears the pallet surface while the materials are carried on the pallet. When the firing plane attains just the bottom of the material layer, that is, when the firing is completed at the wind box, the waste gas temperature is at peak.

The temperature is then decreased gradually by the dilution of waste gas with intake air. A point at which the waste gas temperature reaches the highest is called "Burn Through Point" (B. T. P). Usually, the control is so conducted to confine B. T. P within the last or the next preceding wind box in order to enhance the processing capacity of the sintering machine. This control scheme is applicable only to such a case where the production is the first concern, where combustion influencing factors like moisture content, gas permeability, layer thickness and coke ratio, are least liable to be changed, and where the dispersion of product quality is subordinate. Since neither such disturbances nor quality dispersion is permitted in the actual processes, the pallet speed control cannot count solely on B. T. P control which is carried out by the conventional analog controller.

The most important thing in the pallet speed control by computer is to determine an optimum pallet speed as explained below. As will be clear from *Fig. 5*, the pallet speed control system can be expressed as a function consisting of various factors including water addition, layer thickness, etc. The time required for the completion of the combustion is forecast by making use of a mathematical model to determine a required pallet speed.

On the other hand, from the recycled ore output rate and product analysis data, the mathematical model is modified for more precise control.

In actuality, however, the mathematical model which the computer must solve has an embarrassing excess of unknown factors such as time lag in the measuring system of wind box temperature, air leakage in the wind box, etc., and there has not been any established mathematical model announced for practical availability. Instead, a trial and error method using the relationship between the combustion conditions and combustion factors is the only one now available.

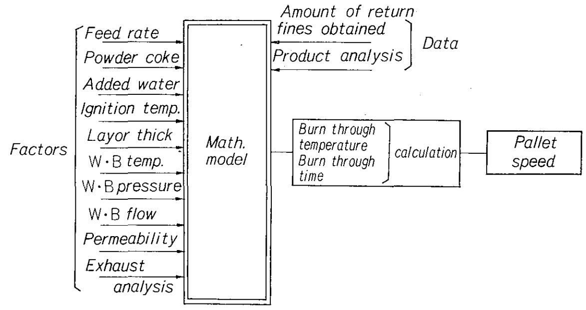
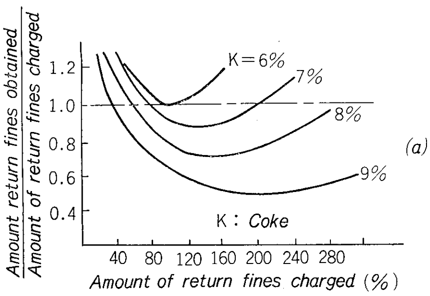


Fig. 5 **Block diagram of pallet speed control**



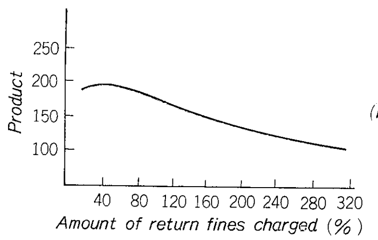


Fig. 6 Relationship of returnfines production and consumption

The iron and steel manufacturers have exerted themselves to aquire an established method of controlling pallet speed, and some manufacturers have reached considerable achievements in this field.

7) Control for quarrying recycled ore and coke

The recycled ore is used as a material of sintered ore. It must be produced in the process of sintering operation; since its output increase turns out the decrease in the output of sintered ore, it is evidently demanded that the consumption and production of recycled ore be balanced with a minimum different. Usually, the output of the recycled ore is 30% to 40% as against production output. It appears that the consumption rate of the recycled ore should be controlled to maintain the relationship, recycled ore output/recycled ore consumption = 1, with coke rate regulated to a minimum. Since, however, the output of recycled ore and coke demand vary in the actual process depending on the granularity and water content of mixed materials, the control of recycled ore and coke quarrying involves unexpectedly large difficulty, and is one of the most important themes of investigation for which each manufacturer has spared no effort.

IV. COMPUTER CONTROL

1. Introduction of Computer Control

In Chapter III, we have explained the necessity of introduction of computer control and its predicted results in comparison with the conventional analog control system. This chapter deals with the introduction of computer control system.

The main purposes of the introduction of computer to the sintering plant control are as follows:

(1) To homogenize the composition, strength, granularity and other quality levels of the product;

(2) To carry out control in such a way that the production output of products of required quality can be increased without a sacrifice of production expenses.

(3) To collect plant data (work records, logs) in order to realize full-automatic, unmanned data control for plant operation.

(4) To automate and simplify plant supervisory control including annunciation of critical conditions and emergencies to the operators.

(5) To simplify the entire plant operation by employing sequence control system in the automatic start and stop of the plant.

These are all very important, and the results will be predictable even if one or other of them is realized.

2. Introduction of Computer to the Plant Control

The control loops of the sintering plant can be classified as to the significance of computer control as follows.

(1) Loop which must be computocontrolled in order to determine optimum settings.

(2) Loop which must be computocontrolled in order to solve the problems inherent to analog control (time lag, changing of two settings or more, etc.) rather than to determine optimum settings.

The control loops are subclassified as follows.

1) Control loops coming under the category of (1) above:—(1) Pallet speed control, (2) Recycle ore and coke quarrying control, (3) Water dose rate control (The determination of settings is also important.), (4) Ignition furnace temperature control, (5) Feed rate control.

2) Control loops coming under the category of (2) above:—(1) Feed mass control, (2) Hopper level control, (3) Water dose rate control, (4) Bulk density control.

For the control loops coming under the category of (1), the determination of optimal values has the preponderance over others, and the establishment of the method and mathematical models on which to determine optimal settings is anxious for. Namely, if the setting control which has been carried out by the conventional equipment can be accomplished using the computer, it will give rise to predicted results.

On the other hand, in case the computer is introduced to the control loops under category (2), its effects may be met, should the settings be given to the ordinary analog controllers from the computer in a manner that various conditions including transportation lag etc. may be reflected in them. But almost every new sintering plant installation which has been planned very recently shows a strong tendency toword employing DDC system entirely relying upon the computer on account of immense

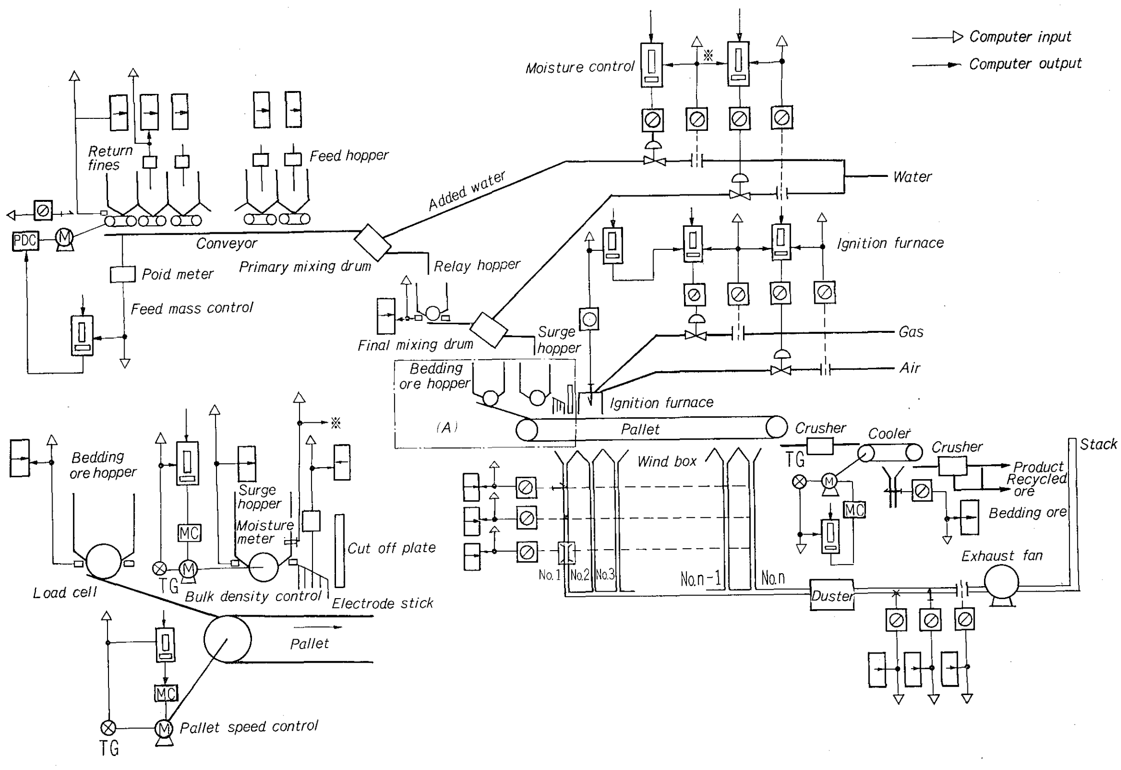


Fig. 7 Instrumentation diagram of DDC system

advantages and economy due totalized control of loops. Fuji Electric has attained a firm business achievement in the application of DDC system to the sintering plants, and they are all in service without any troubles. Now we shall enter into the details of the application of DDC system to the sintering plant.

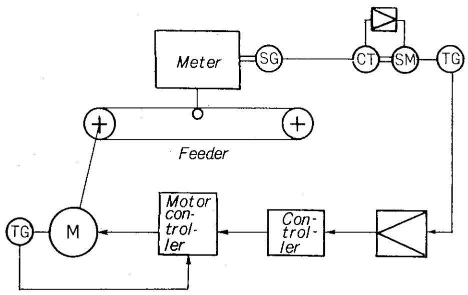
3. Introduction of DDC System

DDC system was riginated and developed primarily for chemical plants in the United States. It is reported that DDC system is economically justifiable only if the number of subject control loops is large. As regards the sintering plant, the number of control loops including those for the feed rate control is as small as 20 to 30; but the sintering plant requires comprehensive control including logging, supervisory control, determination of optimal settings, and the dynamical changing of settings, and its DDC system is a little different from ordinary ones in which the analog controllers are merely superseded by a computer with control settings being fixed.

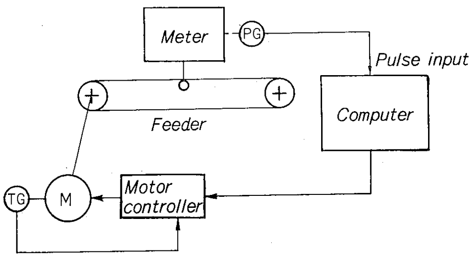
In fact, the instrumentation of DDC systems newly installed by us cost less than that of ordinary systems, and also was sharply compacted as a whole. Considering these and other various factors, the advantage of the DDC system for the sintering plant will be even more amplified.

The only problem which must be taken into account in embodying DDC system into the sintering plant control system is back-up protection. Although it is desirable to provide ordinary controllers for all control loops for purposes of bace-up protection, but the increased installation cost might possibly offset the merits of DDC system. For this reason, such back-up protection should be limited to those loops which are not only vital parts of the plant, but also require constant regulation because of large and frequent excursion of control variables. Such loops are gas flow loop and air flow loop of the ignition furnace. As explained in the foregoing, these loops are considered to be controlled satisfactorily without full computerization, but by partial modification of the ordinary system to the extent that the settings of the ignition furnace can be controlled variably by means of computer. If, therefore, these loops were isolated from DDC system, the cost of back-up protection system would largely be curtailed since manual back-up will suffice for other control loops. *Fig 6* shows an instrumentation diagram of DDC system for the sintering plant.

For details of equipment and practices of DDC system, refer to relevant items. One of the advantages of DDC system lies in that PID control of diversified modes can be accomplished instead of ordinary analog control. Namely, pertinent control outputs can be generated punctually, by making the computer examine in a real time various process conditions and input signals, whether the process is in a transient state such as start-up or shutdown, whether large disturbances are existent, and whether input signals are abnormal. Another advantage is simplification of the plant system configuration.



(a)



(b)

Fig. 8 Control system of poidmeter

The following will exemplify these advantages with respect to the feed rate control having the most largest number of control loops among others.

In the ordinary analog transmitter type poidmeter as shown in *Fig. 8(a)*, the control is carried out using synchronous generator, receiver, servomotor, tachometer generator and amplifier in combination with analog controller. In lhe computer control system, pulse signal system can easily be handled, largely simplifying the control system as in *Fig. 8(b)*.

The simplification of the control system has a great bearing upon maintenance, and above all the total economy of the control system. Since the revolving speed alone is processed by computer with a number of stages of complicated conversion of mechanical displacement to and from electrical signal cut away, the accuracy of the control system is almost dependent of the accuracy of the poidmeter itself, making it possible to realize high precision control compared to the analog control system. This is a decided advantage with the sintering plant in which a number of poidmeters are used as the hub of its control system. As will be clear from the above explanation, the introduction of DDC system into the sintering plant control brings about an immeasurable advantage, and should be closely examined.

The board attended by an operator is an operator console which is designed to allow the operator to easily communicate with his computer with respect to the setting of control commands and constants, changing of control modes and indication, etc. in DDC system control. In some cases, those controllers and loop stations which require comparatively much manual operation may be incorporated in this system.

4. Application of Computer to the Data Management

The data logging is carried out through computer for the purpose of managing operation records. Usually, followings are involved:

1) Logging
2) Daily report
3) Managing operation print
4) Supervisory and sequential control

The data logging is so conducted to record the details of plant conditions and time by printing, especially when a change like start-up, stop or changing of control setting is noticed, in order to make the plant operation reflect them. An acute shortage of manpower is a serious problem every iron and steel manufacturer is facing in recent years. Procurement of skilled workers is far beyond their hope. It is therefore today's practice to automatically carry out emergency scrambling and operation guide for standardized processing operation with various patterns of plant conditions and countermeasures related thereupon memorized in the computer. Although the sequential start-up and stop of the sintering plant is very sophisticated, it can be performed in a clever way if the computer is employed.

V. CONCLUSION

The computer control of the sintering plant shows all signs of prospective future, but it leaves many problems to solve. The production of sintered ore meeting the quality and quantity required by the blast furnace and complete on-line quality control are main themes for future studies. Our continued efforts will be dedicated to the development of more improved softwares and mathematical models by making the most of our past experience.