PRODUCTION PROCESS MANAGEMENT SYSTEM FOR PRODUCTION INDICES OPTIMIZATION OF MINERAL PROCESSING

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Abstract: In this paper, the production process management system of minerals processing is established to realize the optimization of the production indices which are inventory of finished ore and capacity of equipment processing. The structure and function of the proposed system are discussed. A multiobjective optimization model is also proposed, and it aims to reduce finished ores inventory and utilize equipments capacity maximally on the basis of ensuring qualified tenor of finished ores. The way has been applied to production process of the largest hematite factory in China. The application results show that production efficiency is improved and remarkable benefits are obtained. *Copyright © 2005 IFAC*

Keywords: mineral processing; production indices (PI); Manufacturing Execution System (MES); Process Control System (PCS), Production Process Management System (PPMS)

1. INTRODUCTION

With the development of management system, CIMS structure of processing industry has been changed into ERP/MES/PCS three layers from Purdue five layers(PURDUE model[Purdue University, 1989]). As the central part of CIME (PCS/MES/PCS), MES is taken as a connecting link in CIMS, the bridge of production and management (Nakamura M, 2000, Kumagai Y,1994) and the key in development of CIMS technology (Nagalingam, et al,1999, Bruce M,1995, Sohlenius,1992, Kusiak,1994, Chai T Y，JinY H，Ren D X，et al, 2002). Up to now the most of production management systems are manpower. There are thousands of minerals processing factories in China, it has low automation level and adopts manpower in management, collecting, statistic and reporting of production data are achieved by manpower, so there lacks accuracy. This leads to delay and loss of information because there is no reasonable configuration about manpower, property substance and resources and management of production process. All the above problems lead to high production cost and great resources expenditure. At present, some math optimization algorithms are used into management system gradually(Wang D W, YU H B, 2002). On the basis of MES in minerals processing (Huang X L,et al,2004) and according to the production real status of the largest hematite, production process management system for production indices optimization is presented in this paper. Also the structure, functions and optimal methods of this system are discussed. This system has been successfully applied to the largest hematite production process in China. The application results show that production efficiency is improved and remarkable benefits are obtained by this method.

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2. DESCRIPTION OF MINERALS PROCESSING MANAGEMENT

For example, the minerals processing of hematite ore in China includes raw ore processing, roasting, milling & magnetic dressing, finished ores

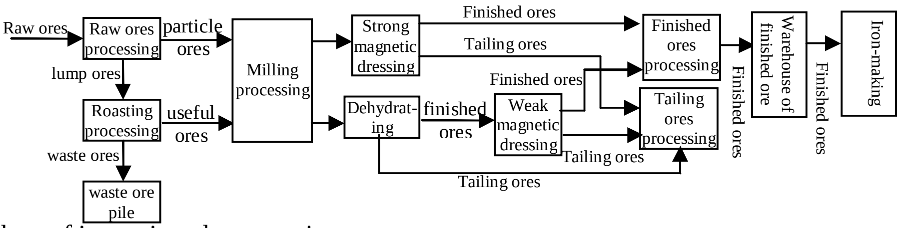

Fig.1 Flow chart of iron minerals processing

processing and tailing ore processing as shown in Fig.1.

Powder ore and lump ore are separated screen by raw ore materials through raw materials area. Powder ore is sent to strong magnetic equipment in magnetic area to be carried on strong magnetic dressing and then produced the finished ore and tailing ore. Lump ore is sent to the shaft furnace area to roast, the ore after roasting is called roasted ores, which are sent to weak magnetic equipment in magnetic area to be carried on weak magnetic dressing and then produced the finished ore and tailing ore. The strong magnetism finished ores & weak magnetism finished ores are all entered into the large well of finished ore and sent to the finished warehouse after taking off water, as the input raw material of iron-making.

Production plan indices include tenor of finished ore, recovery rate of metal, quantity of raw ore processing etc. Being the main raw materials of iron-making, finished ore plays an important role in how to distribute quantity of ore processing and tenor of finished ore for magnetic dressing to ensure reasonable sections of tenor of finished ore and also in maximizing its equipment ability, reducing finished ore inventory volume, production cost and resources expenditure.

3. PPMS FOR PRODUCTION INDICES OPTIMIZATION

3.1 System structure and functions

At present, production plan and production scheduling are seriously disconnected in minerals processing factories. In planning, enterprises always supervise production and in making known plan, enterprises always decompose it cursorily by its former experience. The decompose indices are always flexible space and can supervise production fuzzily. But in organizing and dictating production, enterprises are only satisfied if there are no problems in production and don’t consider whether the production is the optimal state. Every workshop only minds if its own production plan can be finished but doesn’t consider the preceding and following working procedures. Especially, the present production indices have large scale and don’t consider if these indices are optimal. How to arrange production has great randomicity. So research into the integration of production plan and production scheduling is needed.

Production scheduling and process optimization in minerals processing factories is also disconnected. Now these two fields are researched independently,

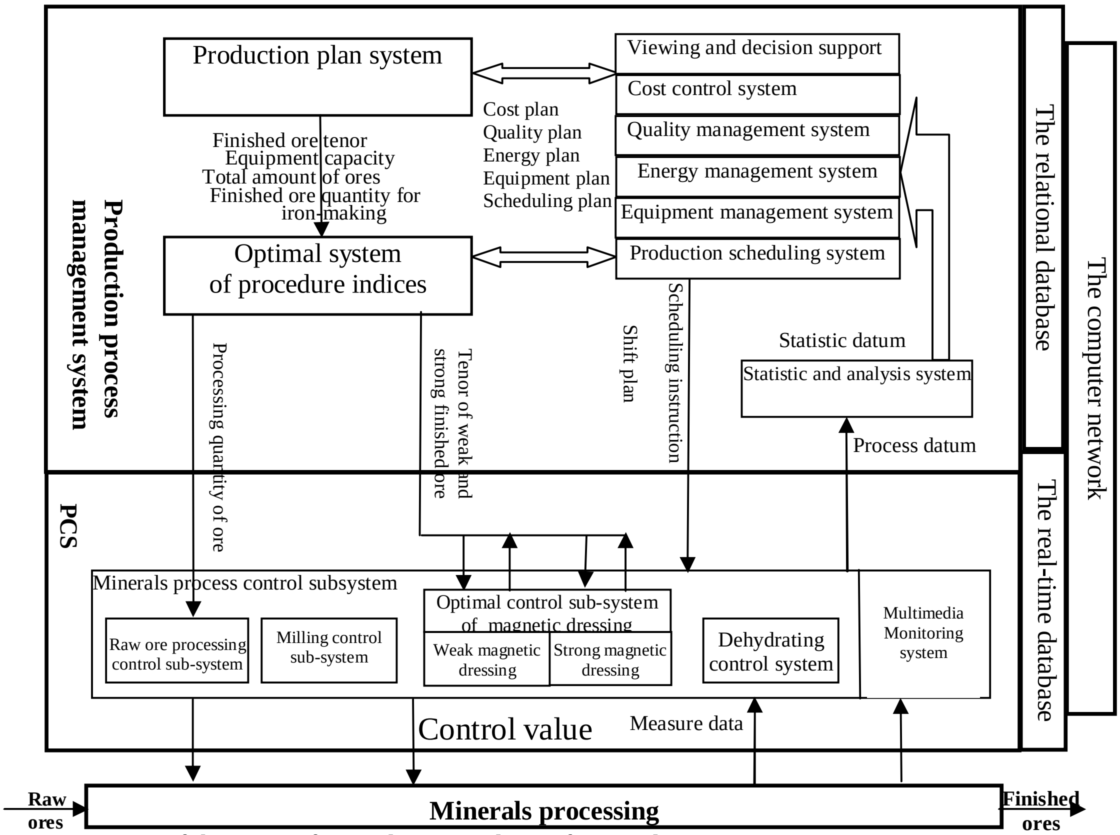

Fig.2 Structure of the PPMS for production indices of mineral process

which divides production management and PCS and leads to the “information gap” between process control and production management. It is hard to realize real integrated optimal production. So, only considering scheduling and control and realizing integration of information and function can achieve an intelligent production system with high quality and high benefits.

According to the paper[Huang X L, et al,2004] proposed the CIMS structure of ERP/MES/PCS and combing the actual characteristic of this minerals processing, the production process management system for production index is proposed based on 2-layer of production management/process control as shown in Fig.2. Different from the standard framework, a new function block, namely the production indices optimal system, has been included, which performs the transformation of the production indices into a group of optimal setpoints. Production process management system of minerals processing has the following subsystems: production indices optimal system, production plan, production scheduling, quality management, production cost control, energy management, equipment management, viewing and decision support, and statistic and analysis system.

Production index optimization system is mainly according to production indices that plan system gives out, such as quantity of raw ore processing, quantity of ball mill per hour, the inventory range of finished ore, the tenor range of finished ore etc, to realize the optimization target. Under the rational range of tenor of finished ore, the multiobjectives of maximum of equipment’s capacity and inventory volume’s deviation balancing are realized at the same time, and then the quantity of ores processing that raw ores processing procedure needs and the tenors of weak & strong magnetic finished ore that magnetic dressing procedure needs can be obtained. Transport these optimization indices to optimization control subsystem correspondingly. Change the situation of index setting only by experience.

Production plan system makes production plan, quality plan, cost plan, energy plan, equipment plan and material plan for minerals process. Then the production scheduling performs real-time scheduling according to the production plan. Otherwise, the plan indexes values are given to the production index optimize system, and then carried on index optimization. And the indices optimized are given to the process control subsystems corresponding to practice produce and realize the goal of plan.

Production scheduling management: The task of production scheduling is mainly to organize production of whole factory according to production plan and operation state of equipment; the information monitoring mainly realizes information once more to main equipments state and all working procedures technology, including output information, quality examination information, technology & economy indexes information and cost monitoring information. Scheduler may master rapidly important status of production field so as to guarantee the production operation in safety; scheduling management sends out operation scheduling to each working procedure, records scheduling connecting instructions and provides gist for the manager and scheduler know about scheduling status.

Cost control system Cost control system obtains the material consumption data and output data from the production scheduling system, the energy consumption data from the energy system, the material tenor datum from the quality system, the production planning data from the statistics & analysis system, the quota material data from equipment management system to handle the cost data (material, human, fee) of the factory, carries out the cost information integration, calculates the cost composing thing of the factory in order to make the cost accountant find out the cost trends of production process at daily times, carries out difference analysis and examination, makes the material flow of the whole line in the cost control and reduce the cost.

Equipment management system: Including equipment file management, equipment running management, equipment examination & repair management, spare parts management, fixed assets management, comprehensive statistics management and system management

Quality management system and energy management system: It is mainly statistics and analysis to the quality information and energy consume information, and to evaluate the product quality state and energy consume state, find out the reason of the unusual state produced.

Statistic and analysis system acquires the process data through the control system, and offers to the subsystems of production scheduling, quality management, production cost control, energy management, equipment management and material management, and collects and analyses the data of production conditions, to guarantee the completion of the plans. The operation of equipment and the maintenance of equipment are managed to guarantee the safe operation of the equipment. Through collecting laboratory data of ore materials, ore pulp, and material feed, the real-time management and control of product quality are carried out.

Viewing and decision support system offers the information to help the operator adjust the plan according to the data about quality, cost, energy, equipment and material, etc

The computer support system consists of the relational database, real-time database and computer network system. Integration of production process management system, production indices optimal system and process control system with the help of the computer network and database ensures the optimal control of production indices.

3.2 Optimization method of production indices

The meaning of the production index optimization is to determine the processing quantity of different raw ores that ore processing PCS sub-system needed and the tenors of weak & strong magnetic finished ores that magnetic dressing PCS sub-system need. according to the production index assigned by planning system, such as finished ores' target tenor within $[P_l, P_h]$ range, the quantity of iron finished ore needed every day in iron-making M_t , Primitive inventory volume of finished ores $I(0)$, the restriction range of inventory volume of finished ore $[S_L, S_h]$, the quantity of weak & strong ball mills processing per hour E_1, E_2 , the limitation of the total amount of i^{th} kind of ore Gi etc.. Obtaining the multiobjectives which make sure that maximum of equipment capacity and approximates to the low boundary of inventory of finished ore, so the objective model of production index optimization is established.

Defining decision variables as follows: x_i (t): is denoted input quantity of i^{th} ore of period t, I(t) is the inventory of finished ore of at period t. $f_1(\mathbf{x})$ is denoted balance deviation of inventory volume of finished ore, $f_2(\mathbf{x})$ is denoted the capacity of equipment production.

The model of balance deviation of inventory of finished ore $f_1(\mathbf{x})$:

$$f_1(\mathbf{x}) = \underset{t=1\sim T}{} \{1-(S_h - I(\mathrm{t}))/(S_h - S_l)\}$$

Where:

$$I(\mathrm{t}) = I(0) + \sum_{t=1}^{t} \sum_{i=1}^{N} x_i(\mathrm{t}) \sum_{l=1}^{M} (m_{il}/s_{il}) - \sum_{t=1}^{t} M_t ,$$

$t = 1, \mathbf{L}, T$

S_h, S_L $I(0)$ $I(t)$ denote the inventory volume of higher boundary, lower boundary, initial and instant separately. *t:* plan period, *i:* is denoted all kinds of ore（*i*＝*1*，、、、，*N*），*l:*is denoted lump ore and powder *(l=1,2)*，m_{il}： Proportion of lump ore & power ore， s_{il} : concentration ratio， M_i : the quantity of finished ore that the iron-making factory needs in every period *i*.

The model of processing capacity of lump ore and powder ore $f_{2a}(\mathbf{x})$， $f_{2b}(\mathbf{x})$is as follows:

$$f_{2a}(\mathbf{x}) = \underset{t=1\sim T}{} \left\{ \sum_{i=1}^{N} x_i(\mathrm{t}) \times m_{i1} / E_1 \right\}$$

$$f_{2b}(\mathbf{x}) = \underset{t=1\sim T}{} \left\{ \sum_{i=1}^{N} x_i(\mathrm{t}) \times m_{i2} / E_2 \right\}$$

$$f_2(\mathbf{x}) = f_{2a}(\mathbf{x}) + f_{2b}(\mathbf{x})$$

Where: E_l $(l = 1,2)$：Production capacity of weak & strong ball mills.

The tenor's model of finished ore of weak, strong and comprehen sive is as following:

$$P_1(\mathrm{t}) = \sum_{i=1}^{N} (m_{i1} \times r_{i1} \times h_{i1}) x_i(\mathrm{t}) \Big/ \sum_{i=1}^{N} (m_{i1}/s_{i1}) x_i(\mathrm{t})$$

$$P_2(\mathrm{t}) = \sum_{i=1}^{N} (m_{i2} \times r_{i2} \times h_{i2}) x_i(\mathrm{t}) \Big/ \sum_{i=1}^{N} (m_{i2}/s_{i2}) x_i(\mathrm{t})$$

$$P(\mathrm{t}) = \sum_{i=1}^{N} \sum_{l=1}^{M} (m_{il} \times r_{il} \times h_{il}) x_i(t) \Big/ \sum_{i=1}^{N} \sum_{l=1}^{M} (m_{il}/s_{il}) x_i(t)$$

Where: r_{il} iron content rate， h_{il} : recovery rate of metal.

Optimization multiobjective model:

$$\min f_1(\mathbf{x}) = \max_{t=1\sim T} \{1-(S_h - I(\mathrm{t}))/(S_h - S_l)\} \quad (1)$$

$$\max f_2(\mathbf{x}) = \min_{t=1\sim T} \left\{ \sum_{i=1}^{N} x_i(\mathrm{t}) \times m_{il} / E_l \right\} \quad (2)$$

s.t.

$$\sum_{t=1}^{T} x_i(\mathrm{t}) \le G_i, i = 1, \mathbf{L}, N, \text{ where } G_i : \textit{total amount of raw ore} \quad (3)$$

$$\sum_{i=1}^{N} x_i(\mathrm{t}) \times m_{il} \le E_l, l = 1,2, \mathbf{L}, M, t = 1, \mathbf{L}, \quad (4)$$

; E_l : *capacity of equipment processing*

$$S_l \le I(\mathrm{t}) \le S_h, t = 1, \mathbf{L}, T , \quad (5)$$

$$P_l \le P(\mathrm{t}) \le P_h , t = 1, \mathbf{L}, T ; \quad (6)$$

$$x_i(\mathrm{t}) \ge 0 , \quad i = 1, \mathbf{L}, N , \quad t = 1, \mathbf{L}, T ; I(0) = S_0 , \quad I(\mathrm{t}) \ge S_l \quad (7)$$

Method of solving

According to the linear weighting method [Steuer R E.(1996)], the objective function (1) and (2) are unified as following:

$$\min f(\mathbf{x}) = l_1 \max_{t=1\sim T} \{1-(S_h - I(t))/(S_h - S_l)\} + l_2 \max_{t=1\sim T} \left\{ 1 - \sum_{i=1}^{N} x_i(\mathrm{t}) \times m_{il} / CE_l \right\} \quad (8)$$

Where: $l_1 + l_2 = 1, l_1 > 0, l_2 > 0$.

Because multiobjective function of model includes non-linearity item, it is linearized, and then using the popular linear programming software in common, the quantity of ore processing $x_1(t) \ldots . x_N(t)$, tenor of weak /strong/comprehensive finished ore $P_1(\mathrm{t})$, $P_2(\mathrm{t})$, $P(\mathrm{t})$,: inventory of finished ore $I(\mathrm{t})$ and capacity of equipment processing $f_2(\mathbf{x})$ are obtained.

4. INDUSTRY APPLICATION

4.1 Introduction of production management system of a minerals processing factory

The largest factory for hematite in China has 22 roasters in roasting, eight series of 15 mills in the milling and 29 strong & weak magnetic dressing machines in dressing etc., and then has the two major technical systems of lump ore strong magnetic dressing and powder ore weak magnetic dressing.
It has an annual processing capability for five hundred million tons of iron ores, and the tenor of the hematite is thirty-three percent. The average tenor of ore can be up to about 52% after the magnetic dressing. The control of the main working procedures, such as, raw ores sieving, dry dressing and transportation of raw materials, roasting, milling, magnetic dressing, dehydrating and condensing are all handled by human operators, and the management of plan, scheduling, quality, cost and equipment operation are all complete by manual work which results in redundant personnel, low efficiency, high cost and high expenditure

Considering the actual situation of this minerals processing factory, the production process management system is built adopting the proposed method. The system is shown in Fig.3. The ControlLogix system of Rockwell is used in the control system and personal computers and Hewlett Packard LH3000 servers in the production indices optimal system and production process management system. The information integration of production process management system, production indices optimal system and process control system is achieved with ControlNet, DeviceNet, Ethernet, real-time database and relational database.

4.2 Optimal control system of production indices

A hematite factory requires in the plan period *t*[1,7] days, making ore dressing of four ores, the total quantity of seven days'raw ore is G_i, the quantity of finished ore that iron-making needs every day is about 6000 tons usually. Every day's inventory volume is required to be in the range of *[Sl ,Sh*](i.e.7000-1000 tons). The tenor of finished ore is in the range of [p_l, p_h] (i.e. 52.20-54.20). The processing quantities of weak & strong magnetic mill per hour are 75 and 65 tons per hour separately. This equipment ability chooses ball mill mainly, because ball mill is bottleneck of ore dressing's whole equipments. The time of operating of equipment in practical production, mainly relies on the operation time of ball mill. other boarder conduction m_{il} , r_{il} , h_{il} , s_{il} is shown as table.1.

Utilize the above-mentioned model and algorithm to solve the optimization value of quantity of ore process and the tenor of finished ore. According to the production experience accumulated actually, l_1, l_2 fetches different value respectively, proving by the model, when the l_1, l_2 are 0.4, 0.6, the result of C point value is the optimum. It meets the objective that the minimization of balance deviation of inventory volume and the maximization of equipment's production capacity. It reasonably distributes every kind of ore's processing quantity of every day and strong/weak finished ores grade index.

Table1:Quantity of every ores and border conduction

Border conduction	Ore1 $x_i(t)$	Ore2 $x_i(t)$	Ore3 $x_i(t)$	Ore4 $x_i(t)$
m_{i1}	64%	0%	0%	60%
m_{i2}	36%	100%	100%	40%
r_{i1}	34%	0%	0%	48.5%
r_{i2}	31%	28%	48%	47.25%
h_{i1}	79.55	66.13	78.3	84.8
h_{i2}	66.13	66.13	78.3	84.8
G_i	75420	5640	2000	3488

Table2: result of model calculation

l_1	l_2	$f_1(X)$	$f_2(X)$	point
0.1	0.9	0.9440	0.1667	A
0.3	0.7	0.9181	0.1710	B
0.4	0.6	0.8376	0.1794	C
0.5	0.5	0.8261	0.1885	D
0.7	0.3	0.6	0.3674	E
0.8	0.2	0	0.8418	F

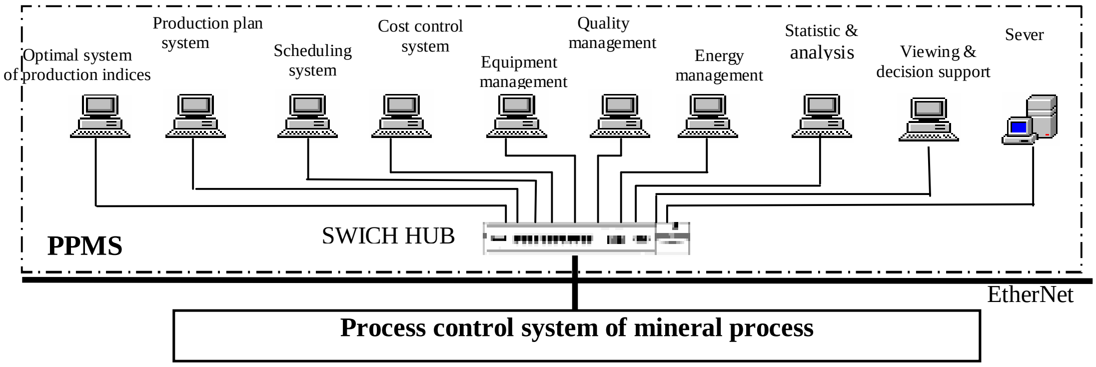

Fig.3 the PPMS for production indices of mineral process

Table3: The input quantity of ores for ore processing $x_i(t)$ and finished ore tenor for magnetic dressing

T	Ore processing working procedure				Magnetic dressing Working procedure		result		
	Ore1 $x_i(t)$	Ore2 $x_i(t)$	Ore3 $x_i(t)$	Ore4 $x_i(t)$	Weak finished ore $P_1(\text{t})$	Strong finished ore $P_2(\text{t})$	Comprehensive finished ore $P(\text{t})$	Inventory volume $I(\text{t})$	Equipment capacity 1- $f_2(\mathbf{x})$
1	9231	1350.4	446.6	0	57.79	46.20	52.4	8000	82%
2	10365	1011.3	0	944.4	58.8	46.6	52.8	7077	82%
3	10365	1011.3	0	944.4	57.88	46.6	52.8	6154	82%
4	11250	283.6	786.7	0	56.79	46.09	53.4	5231	82%
5	10625	1028.6	0	666.8	58.80	46.45	53.1	5000	82%
6	10365	1011.3	0	944.4	57.8	46.80	53.1	5000	82%
7	11250	303.6	766.7	0	58.67	46.40	52.7	5000	82%

Table 3 provides the result calculated by above-mentioned optimal models: such as per day processing quantity of ore, tenors of weak magnetic finished ore & strong magnetic finished ore, capacity of ball mills and inventory volume. The values of all kinds of processing quantity are sent to ore processing working procedure; the values of weak & strong magnetic finished ore are sent to operation process control sub-system of magnetic dressing. The long term operation results indicted that adopting the method has achieved for the minerals processing with 2.01 percent improvement in metal assay of finished ores, 0.57 percent improvement in the tenor of finished ores, 50 percent reduction in operating personnel, 20 percent reduction in consumption, 2.98 percent improvement in the equipment operation rate. Realized the objective of finished ore tenor, quality of ore process, metal recovery rate, improved the capability of equipment operation, decreased production cost.

5. CONCLUSIONS

A multi-objective programming method is presented, which is to realize minimum in inventory balance deviation of inventory and maximum equipment ability at the same time. Adopting this method, the production management system for production indices optimization has been presented. This system has been successfully applied to the largest hematite production process in China and run for 16 months. Production cost is reduced, operation efficiency is improved, production management is optimized, management efficiency is improved, speed of information delivery and disposal is increased and manpower is reduced. This optimal method is proven to be effective and can be applied to other minerals process industries.

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