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THE STUDY AND APPLICATION OF GOLD MINE INTEGRATED AUTOMATION SYSTEM

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Abstract: By introducing the three-layer structure of Business Planning System/Manufacturing Executive System/Process Control System in stead of the Purdue model of five level, the Liaoning Paishanlou Gold Mine Integrated Automation System is designed and successfully implemented. The information flow, material flow and fund flow in the gold mine enterprise have been optimally integrated, and the processes of production and management have been optimally controlled and supervised. The intelligent control technology based on synthetic production index of grinding process provides effective control method for complicated production process. *Copyright © 2002 IFAC*

Keywords: CIPS; grinding circuit; intelligent control; manufacturing execution system

1. INTRODUCTION

Computer Integrated Manufacturing System (CIMS) technology of the process industry (is also called Computer Integrated Process System — CIPS) is taken seriously by developed countries; it is listed in the key high-technology development plan in these countries. The international famous enterprises, such as Japanese Nippem steel Co., American Exxon Co., have all realized the CIPS, and achieved remarkable benefits. IAS realizes the integration in the process of manufacturing management and control of enterprise. It relates to management pattern closely. Since management pattern of past enterprise is pyramid-style. Purdue model (CIM, 1989; Gutschke, and Mertins, 1985; Jing, 1991; Nair, 1992) is used in CIPS of process industry. It divides the structure of process industry into five layers, including process control, process optimization, production schedule, enterprise management and management decision. It separates the control from management of manufacturing process obviously, and ignores the material consumption, energy consumption in the process and the real-time control and management of equipment. The layer is many; the structure is complicated, the cost of realizing CIPS is high. It is difficult to form software platform and to extend. The control system in the process control uses the control loop performance as target at present, the production quality and technological requirements are not used as the target to carry out optimization control, so the production quality is poor, the recovery rate of products is low, and production cost is high. The international gold price becomes lower and lower, so the key problem for gold enterprise is to reduce the production cost.

This paper, combined with the actual conditions of the gold mine industry in our country, and applied the 3-layer structure (F.Blomer and H-O.Gunter, 1998; M.Nakamura and K.Masada, 2000; O.araif, 1995) — Business Planning System (BPS)/Manufacturing Execution System (MES)/Process control system (PCS) in gold enterprise, put forward the Integrated Automation System (IAS) which has been applied practically in LiaoNing Paishanlou Gold Mine successfully.

2. FEATURES IN GOLD ENTERPRISE

2.1 Production process

The production process in gold mine is composed of mining, ore dressing and smelting. Mechanized carry-scraping system is used in mining flow. Mud cyaniding — carbon starch refining technology (dissolve the gold into cyanide, then absorb it out by the activated carbon) is used in ore dressing procedure which is composed of crushing, grinding, thickening, lixiviation & absorption and refining gold. The crushing flow consists of three crushing sections and one loop; the grinding flow consists of two milling sections and two loops. The refining gold flow uses high-voltage relieving absorption and electrolysis to get high-grade gold mud, delivers it into alchemistic chamber for smelting. The main technological flow is shown in Fig.1.

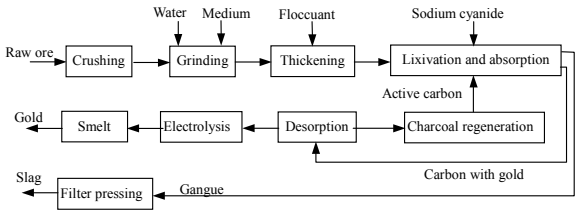

Fig.1 The technological flow of mill run

2.2 Enterprise management process

The management & administration and production process management in gold mine are divided into manager, production plan department, supply & stock office, administration department. Its management functions are shown below: The manager is the decision maker for enterprise management and its main functions is to make enterprise management & administration decision and production process management decision, such as decision of production plan (stripping & mining plan, smelting plan, material plan, production cost plan). The production plan department is the command center of the whole gold mine producing management; its functions are to execute the production plan, production scheduling, production statistics and so on. The supply & stock office is to perform supply and storage functions for raw materials, equipment and spare parts. The administration department's function is to execute the management of the funds and other economic indicators, including handling accounts, accounting cost, finance analysis & finance supervision in management and production process of gold mine.

Up to now the main management mode in domestic gold mine is manual operation. The collecting statistics and reporting of producing data are accomplished by hand. So the accuracy of the data is low, the information is easy to be logging and distorted when the file reported from bottom to up, thus the rational disposition in human resources, funds and material resources and the management of the production process are easy to be influenced.

3. STRUCTURE OF AIMS ON GOLD ENTERPRISE

3.1 System structure

Based on BPS/MES/PCS three-layer structure combined with characters of gold mine enterprise, the following structure of Integrated Automation System (IAS) is introduced on the basis of advanced information technology, modern management technology and advanced golden production technique, shown in Fig.2.

This system consists of Business Planning System (BPS), Manufacturing Execution System (MES), Process Control System (PCS), Enterprise Network System and Computer Supporting System. The whole resources optimization technology whose core is finance analysis is used in BPS. It includes these following sub-systems: plan management system (exploitation plan, smelting plan, material plan, production cost plan, etc) finance management (accounting management, cost accounting), human resources management, file management, fixed assets management, stock management, material supply management and comprehensive information inquire & auxiliary decision-making system and so on.

The manufacturing process optimization technology, optimization control technology and optimization management technology which regard the economic index as the target are used in MES. MES includes the following sub-systems: production scheduling, production statistics & analysis, material control & management, production cost control & management, ground surveying & collecting information management, process optimization, safety management, equipment management, quality management (including assays management) and production information handling system.

The intelligent optimization control technology whose target is comprehensive production index and the EIC (Electric Instrument Computer), which uses computer distributed control design technology, are employed in PCS. PCS include the following sub-systems: mining process control, crushing process control, grinding process control, thickening process control, lixiviation & absorption process control, high-voltage relieving absorption process control, electrolysis process control, gangue press filtration process control and so on, and multimedia production process monitoring system.

The enterprise net system includes enterprise web station sub-system, electric commerce sub-system, etc. Each sub-system realizes the overall information integration through MES and computer-supporting system which consists of computer network & database to achieve remarkable benefits.

3.2 Function description

Function of PCS EIC computer distributed control integrated design technology is adopted at kibbling &

ore dressing distributed control system in gold mine. And advanced control is combined with advanced gold production technique applied in gold mine and intelligent optimized control technology whose target is synthetically production index. For example, kibbling procedure adopts more crushing & less grinding technology. During the process of ore dressing, procedure adopts these techniques such as cyanide-carbon pulp absorbing, high efficiency thickening, non-cyanide relieving electrolysis, chemical gold mud refining, gangue press filtration etc. PCS realizes the automatic control on kibbling flow, grinding flow, thickening flow, lixiviation & absorption flow, high-voltage relieving absorption flow, gangue press filtration flow and so on. It accomplishes the logic control on electric installation's starting, stopping and chain function in kibbling flow and ore dressing flow. It also realizes the loop control of technique parameter, such as ore pulp density, liquid level, material level, interface, flow rate, pressure, temperature, PH value, etc. In this procedure it employs intelligent decoupling control technology to realize the decoupling-control on interface-height and overflow on thickening machine. It employs intelligent optimized control technology based on synthetically production index to realize optimization control on grinded particle size and load. It also employs soft-measurement and reasoning control technology to realize the control on cyanide radical ion density at the process of lixiviation and absorption. It employs self-adaptation and self-tuning PID technology to realize those above functions.

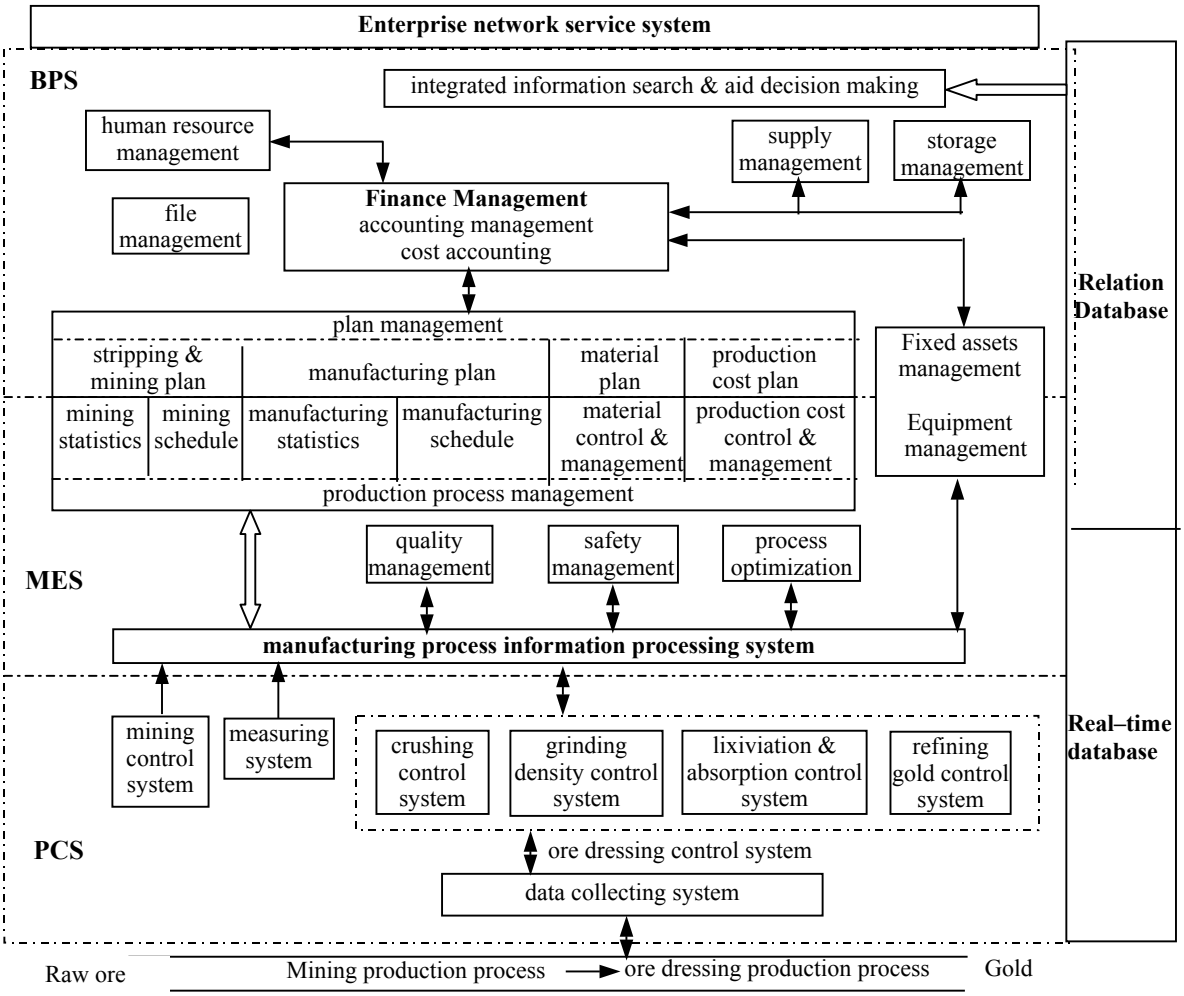

Fig.2 Architecture of gold enterprise IAS

Process monitoring & operating management expert system based on intelligent control technology includes the module of identification, the module of fault diagnosis, the module of operation guide. The module of identification identifies operating conditions on line. According to the changing conditions, the module of fault diagnosis can find out the reason of fault and abnormal operating condition. The operation guide expert system depends on changing conditions to adjust control strategies, treat the changing or abnormal operating condition in time. In a wide range of changing operating conditions it provides a safe, reliable, optimized condition for system.

Function of BPS Based on the characters of production administrator & management flow and its arrangement structure, BPS in gold mine enterprise uses the overall resources optimization technology whose core is economical analysis

decision. The standard production cost is determined by profit index of enterprise. At the circumstance of standard production cost, the production plan is worked out according to sale contract and market anticipation. The production plan includes stripping & mining plan, grinding & smelting plan, material requirement plan and production cost plan. The overall resources optimized distribution is used in human, money, material for continuous balance production and less store of material & spare as possible as it can. Finance management not only executes accounting management and cost accounting, but also integrates management in material supply, product sale, material spare parts, and human resources through financial analysis decision to ensure the production cost lower than standard cost. The above functions are realized by net, database and applicant software.

Function of MES MES adopts 3 ”O” (Optimized operation, Optimized control, and Optimized management technique), which regards financial index as its goal. MES is a key point at 3-layer structure.

According to the production plan of BPS, MES carries out the real-time adjustment at the processes of mining, ore dressing and smelting, and also carries out data statistics & analysis of production condition to fulfill the production plan. Additionally, according to the production dynamic cost plan of BPS, MES measures online the consumption of material and energy in order to obtain a cost anticipation. Compared with target cost, it not only executes cost veto, but also gives an operation guide to decrease production cost. According to the material plan of BPS, MES controls and manages the material by the balance material at the processes of mining, ore dressing and smelting. According to the equipment real-time monitoring, MES manages the equipment maintenance and provides anticipation of equipment repair plan for safe operation. According to the timely assay on ore, ore pulp and additive, MES manages and controls product quality real-time and searches best operation condition at the process of production. At the circumstance of changing producing condition and operating condition, it guarantees to search optimized operation condition for optimized operation in producing process.

Ground surveying & collecting information management system founds 3-dimension ore bed model through ground surveying & collecting data, optimizes the mining and stripping ratio, realizes the simulation mining, design block holing project and transportation dispatching project. All these are used to guide mining production in order to improve efficiency in mining and decrease the cost of mining. MES carries out real-time management on production plan, production schedule, material balance, production cost, equipment and quality by the hand of integration of production process control in gold mine and management information.

3.3 Function of integration

Integration technology in BPS/MES/PCS 3-layer structure of modern CIPS is guided by enterprise target and built on the base of knowledge chain. The BPS and PCS are integrated through MES for realizing information integration on administration decision, production process management and process control.

The production plan in BPS is integrated with production process data collecting system in PCS through production schedule, production statistics & analysis and production information management system in MES. Information treatment feedback and decision are made to response the changing market by production command center. The mining production plan is integrated with ground surveying & collecting real-time system in PCS through ground surveying & collecting information management system in MES. Thus optimized decisions of mining and stripping ratio are accomplished. In a word, it improves the ability to make production plan and also the efficiency in production plan.

Financial plan and production cost plan in BPS are integrated with production process data collecting system in PCS through production cost dynamic control system and production process information management system in MES. Its main task is to decompose target cost and carry out real-time control & management. According to production process dynamic cost, it also gives out the operation guide to decrease production cost, thus realizes dynamic control of production cost.

Fixed assets management and spare parts management in BPS are integrated with equipment-monitoring system through equipment management in MES. It realizes the whole management with the static management, value management, dynamic management, equipment overhaul and spare parts management of equipment to centralized management. Thus it realizes the optimized operation, optimized control and optimized management in production equipment system. And so it improves equipment-operating ratio.

Material requirement plan in BPS is integrated with material in-out-store data collecting system in PCS through material balance, control & management of production process in MES. It decreases the material consumption and increases gold reclaim rate.

4. APPLICATIONS AND EFFECT OF IAS IN PAISHANLOU GOLD MINE

4.1 Summary of system

Liao Ning Paishanlou gold mine is a giant open cast, which includes mining, ore dressing and smelting. Its ore reserves is 17,000,000 tons, gold is 43 tons. It belongs to low-grade ore mine with the average grade of 2.7g/per ton. Cyaniding-char absorbing gold, electrolytic procedure, and gangue press filtration were used in ore dressing procedure. The production technological flow includes kibbling, grinding, thickening, lixiviation & absorption, electrolytic, smelting, acid treatment char regeneration and press filtration.

Based on the EIC & computer distributed control system integrated design technology, control system in the processes of mining, ore dressing and smelting have been designed. The multimedia control system has been used in manufacturing process. The automatic control system in crushing workshop is GE Company's PLC. The automatic control system in ore-dressing plant is the SCAN 3000/S9000 computer control system of American Honeywell Co. The computer network is Ethernet, its structure is network topology, and it includes management network and real-time control network. The database system consists of real-time database and relational database. The SQL server was used as the main database management system to build Client/Server application mode.

4.2 Grinding System

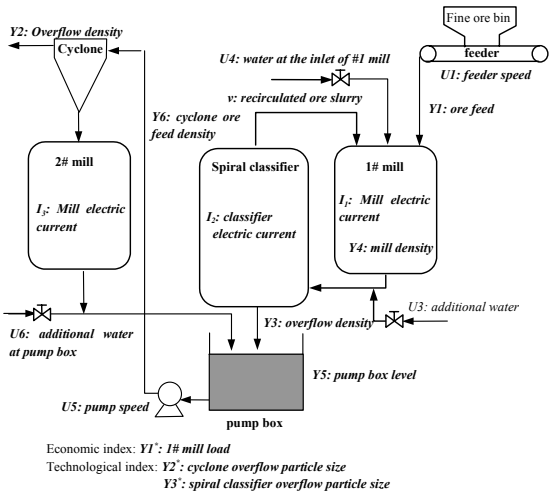

Fig.3 Grinding process flowchart

Shown in Fig.3 grinding classify process is the most important workshop section in influencing gold rate of recovery in ore dressing plant and its consuming energy is most. The optimization control target in grinding flow is to keep the steady particle size index of grinding production, improve efficiency of grinding flow, that means working at the optimum load. The particle size and mill load can not be measured continuously on line, can not be described by input/output of the control system, and can be interfered from interior (equipment wear) to exterior (the ore nature changing, the ore feed changing). So the grinding flow has some features of uncertainty, such as long-lagged, strong coupling, serious-non-linear and so on. The controlled output can not be measured continuously on line, it is difficult to describe with mathematical model (KARR, and YEAGER, 1995; KARR, and WECK, 1996; Niemi, *et al*., 1992), and it is difficult to realize optimization control. On the basis of the paper (Chai, 1998), the intelligent optimization control technology whose target is the integrated production index is used. Shown in Fig.4 & Fig.5.

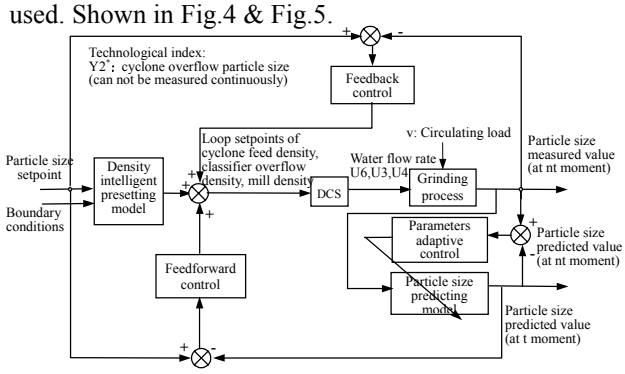

Fig. 4 Configuration of overflow particle size optimal control method

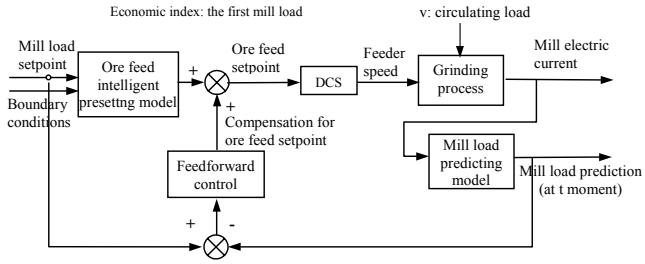

Fig.5 Configuration of mill load optimal control method

In Fig.4 & Fig.5, the pre-setting model gives the setpoint values of the density and ore feed in DCS loops based on the boundary conditions and technological index. The predictive model is to forecast the overflow particle size and mill load, which cannot be measured directly and continuously. According to errors between the predictive values of particle size & mill load and technological index, the setpoint values are modified in real-time dynamically by the feedforward control model, feedback control model and adaptive model. Thus multistage losed-loop control and rolling optimization are accomplished. At the same time errors between the real out put value and the predictive values are used in self-adaptive adjustment on predictive model. So it has the self-adaptive & self-learning function. Since intellective PID technology is used in every loop control, self-adaptive & self-adjusting of controlling parameter are realized. From Fig.6 when ore composition and operation condition are changing, ore feed to grinder is regulated automatically in order to ensure the grinder at the state of best load and the error of cyclone overflow density is about ±3%.

4.3 Application effect

PCS solves the control problems with density,

particle size and PH value in ore dressing production process and makes it possible to avoid

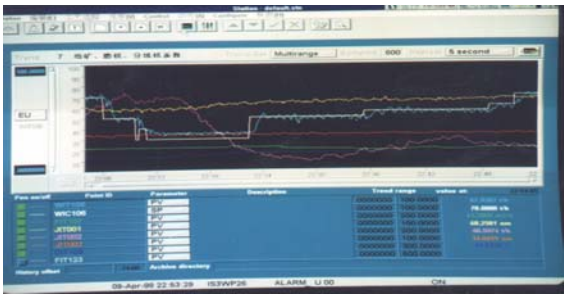

Fig.6 the control curve of grinding process

mill blockage, thickener gold overflow and scraper pressed. Grinding control system increases the percentage of final ore size (-200) at 79.8% and it also increases gold recovery ratio by over 1.0%. Since the optimized control of grinder load is applied, the daily production capacity increases from 1200 tons to 2000 tons.

Ground surveying & collection system in developed MES determines the optimized mining and stripping ratio, it decreases the stripping ratio from 10:1 to 6.5:1 now and ore resource utilization ratio can reach 95% or more. Equipment management system in MES carries out synthetically management on operation, fault, life, overhaul and spare parts of key equipment. Equipment operating ratio can also reach 95% or more; it is in the lead at domestic enterprises.

Ore dressing cost in gold cost decreases from 73.03 Yuan/ton to 37 Yuan/ton. Mining cost decreases from 57 Yuan/ton to 43 Yuan/ton. At the circumstance of lower gold price, the enterprise also can make profits to a certain extent. In recent years the enterprise has digested much loss which was brought by lower gold price (In 1996 96.46 Yuan/gram till now 70.84 Yuan/gram. The lost profit is about 41,250,000 Yuan/year). It improves working environment, decreases the intensity of labor. The average labor productivity is about 750,000 Yuan/year, about 17 times than the average level of domestic enterprise. At last it also controls environment pollution. The cost of the whole system is about 7,000,000 Yuan (RMB) [843,000 US $]. The hardware system is about 5,500,000 Yuan (RMB) [663,000 US $]. The cost of software development is about 1,500,000 Yuan (RMB) [180,000 US $]. The level of synthetically automation in this gold mine is in the lead at home and advanced abroad. Panshanlou gold mine has become the model for gold enterprises and opens up a path for the construction of low-grade ore mine.

5. CONCLUSION

Modern CIPS in gold mine consists of BPS, MES and PCS. MES is in the middle of this 3-layer structure. This system simplifies structure of CIPS and integrates enterprise management & administration and production process control and management on mining, ore dressing and smelting. This system, which uses grinding process intellectual control based on synthetic production index, provides effective method for complicated production process whose target is synthetic production index. The 3-layer modern CIPS based on BPS/MES/PCS is also in common use in complicated process (M.Nakamura and K.Masada, 2000).

ACKNOWLEDGEMENTS

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