# EXPERT OPTIMIZED CONTROL TECHNIQUE FOR ELECTROLYTIC DEPOSITION PROCESS OF HYDROMETALLURGY OF ZINC①

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**ABSTRACT** Based on expert experience model and mathematical model, optimal ratio of $H^+/Zn^{2+}$ and temperature of electrolyte were searched out according to a way of expert self-learning optimization, and optimal flowing velocity of purified solution was computed by means of analytic relations. The flowing velocity of purified solution, the liquid level of the ground trough and the status of cooling fans were controlled on line to keep the process in optimal production conditions. 0.5% more current efficiency and 1 million kWh less power consumption a year have been attained since running of the expert optimized control system. The system constitution, expert optimized techniques, real-time techniques and system implementation were introduced.

**Key words** hydrometallurgy of zinc electrolytic deposit process expert optimization self-learning real-time control

## 1 INTRODUCTION

The electrolytic deposit process of hydrometallurgy of zinc is a reaction process of purified solution of $ZnSO_4$ when direct currents flow through, $Zn^{2+}$ ions in the solution are reduced to zinc at the cathode and $OH^-$ ions will be oxidized to $O_2$ at the anode. The chemical reaction equation is shown as:

$$ZnSO_4 + H_2O = Zn\downarrow + H_2SO_4 + \frac{1}{2}O_2\uparrow \quad (1)$$

The electrolytic process of zinc is a continuous and long-line procedure. The purified solution and the electrolyzed solution are mixed in the solution-collecting trough. The mixture (electrolyte) is sent into four series of electrolyzers to be electrolyzed. The electrolyzed solution enters the ground trough, cooled by cooling fans, then reenters the solution-collecting trough to be mixed with purified solution.

There is a large power consumption in the electrolytic process, which used up to 80% of whole power consumption in the hydrometallurgical process of zinc[1]. In China, the electrolytic process is mostly operated manually. The whole production conditions depend to a large degree on the operators[2]. Therefore, it's specially urgent to establish advanced control systems, to set up optimal electrolytic conditions and to ensure lowest power consumption.

## 2 PROCESS ANALYSIS

The power consumption in the electrolytic process of zinc is in direct proportion to trough-voltage and in inverse proportion to current efficiency. To reduce power consumption means to lower trough-voltage and to raise current efficiency. Both of them are affected by many complicated factors[3]. Under some production conditions they will mainly be:

(1) Ratio of $H^+/Zn^{2+}$ in electrolyte. Proper ratio of $H^+/Zn^{2+}$ in electrolyte is the basic condition of normal electrolytic deposit process.

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If the content of $Zn^{2+}$ is too low, the density of sulphuric acid will be too high, zinc deposited at the cathode will be dissolved again, and the current efficiency will drop down; if the content of $Zn^{2+}$ is too high, the trough-voltage will increase and will also lead to increasing of power consumption.

(2) Temperature of electrolyte. The rise of temperature makes the super-voltage of $H^+$ drop, makes it more easy to separate out at the cathode, current efficiency is therefore be cut back; but too low temperature makes the resistance of electrolyte and the trough-voltage increase, then leads to increasing of power consumption.

(3) Current density. With the increasing of the current density, the super-voltage will increase as a beneficial factor to the raising of current efficiency. But too high density leads to rising of trough-voltage and increasing of power consumption.

In order to decrease the trough-voltage and increase the current efficiency as possible, the ratio of $H^+/Zn^{2+}$ in electrolyte, the temperature and the current density must be stabilized in proper values. But the relationships among these factors are too complicated to be wholly described with mathematical models. Some of them should be described with expert experience and experimental results. Usually, the current density depends on power supply conditions, which is not in the direct control of the electrolytic process. The ratio of $H^+/Zn^{2+}$ and the temperature corresponding to the highest current efficiency and the lowest trough-voltage can not be obtained with traditional analytic optimum methods. Therefore, it's necessary to combine the mathematical model based on analysis with the expert experience model based on knowledge for the electrolytic process of zinc[4, 5], to seek out the optimal ratio of $H^+/Zn^{2+}$ and temperature of electrolyte under various production conditions by means of expert optimized method, and to keep the process in optimal production conditions by means of real-time control technique.

## 3 CONSTITUTION AND FUNCTIONS OF SYSTEM

Expert optimized control system (EOCS), composed of expert optimized subsystem (EOS) and real-time control subsystem (RTCS), accomplishes the functions of optimized control of electrolytic process of zinc. The system constitution is shown in Fig. 1.

EOCS has functions as follows:

(1) Seeking the optimal ratio of $H^+/Zn^{2+}$ and the optimal temperature of electrolyte by means of expert control technique;

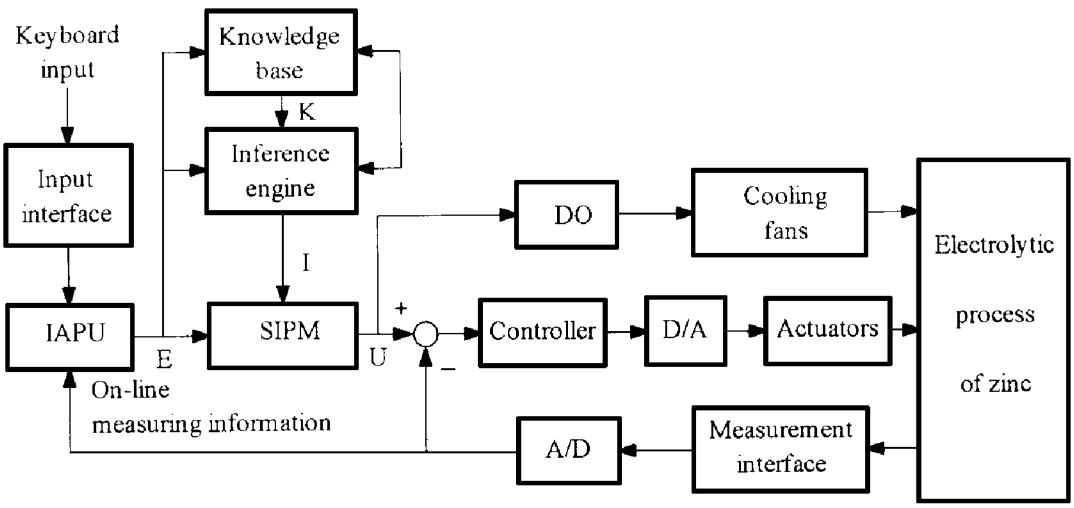


**Fig. 1 The constitution of EOCS**

IAPU —Information acquiring and processing unit;
SIPM —Synthetic information processing mechanism; DO —Digital output

(2) Real-time controlling the flowing velocity of purified solution, and keeping it at the given value corresponding to the optimal ratio of $H^+/Zn^{2+}$;

(3) Real-time controlling on-or-off of cooling fans in cooling tower, and keeping the temperature of electrolyte at the optimal value;

(4) Real-time controlling the liquid level of the ground trough, ensuring a stable flowing velocity of electrolyzed solution to the solution-collecting trough, and keeping from leak, overflow and cut-off;

(5) Real-time monitoring the main parameters in the production process, providing real-time information for operators and optimization processing;

(6) Fault alarming and synthetic information processing, detecting and diagnosing faults, sending out alarms, providing operating guides, storing relevant data for later inquiring, and tendering historical curve and process parameter curve.

## 4 EXPERT OPTIMIZED SUBSYSTEM

EOS takes the current efficiency and the trough-voltage in the electrolytic process as its optimal performance index to seek the optimal ratio of $H^+/Zn^{2+}$ and temperature of electrolyte. The performance index is expressed as

$$P_I = \alpha_1 \eta^2 + \alpha_2 E_T^2 \quad (2)$$

where $P_I$ is the optimal performance index, $\eta$ is the current efficiency, $E_T$ is the trough-voltage, $\alpha_1$ and $\alpha_2$ are weighted coefficients. They are calculated by linear regression among data which have been acquired from the process for many years.

EOS contains four parts. They are information acquiring and processing unit (IAPU), knowledge base(KB), inference engine(IE) and synthetic information processing mechanism (SIPM). Its model can be described as[6, 7]

$$U = f(E, K, I) \quad (3)$$

where $E = \{e_1, e_2, \cdots e_m\}$ is the output set of IAPU, also the input of EOS; $K = \{k_1, k_2, \cdots, k_n\}$ is the set of items of knowledge; $I = \{i_1, i_2, \cdots, i_p\}$ is the output set of IE; $U = \{u_1, u_2, \cdots, u_q\}$ is the output set of EOS. $f$ is an intelligent operator, its basic form can be stated as

IF $E$ AND $K$ THEN ⟨IF $I$ THEN $U$⟩

*i.e.* inferring according to input information $E$ and knowledge $K$, then outputting the corresponding control action according to the inference result.

IAPU collects all information of production process from on-line measure units and input interface, characterizes all these acquired information including flowing velocity, liquid level, varied series of current, ratio of $H^+/Zn^{2+}$ in electrolyte, trough-voltage and current efficiency. The characterized information can be received by KB, IE and SIPM.

KB, the basis of EOS[8], is composed of database and control rule set (CRS). Where database includes the range of technological parameters, experience value required by operators, contrast list of parameters' relationships. Each group of these parameters under varied production conditions is stored in the list, by which we can find out the proper ratio of $H^+/Zn^{2+}$ and temperature value that makes the trough-voltage relatively low and current efficiency relatively high under a production condition. CRS induces and summarizes the control pattern and experience which can be obtained from human experts and technical references in the field. They are described by production rules. Typical rules are as follows:

Rule 1: IF $C_S > r_S + K_1$
THEN $F_I = n_1 \cdot F_o$;

Rule 2: IF $C_Z > r_Z + K_2$
THEN $F_D = n_2 \cdot F_o$;

Rule 3: IF $T_e > r_T + K_3$
THEN turn on $m_1$ cooling fans additionally;

Rule 4: IF $T_e < r_T - K_4$
THEN turn off $m_2$ cooling fans additionally.

In above rules, $C_S$ is the acid content of electrolyte(g/L), $r_S$ is the normal value of acid content (g/L), $F_o$ is the original flowing velocity of purified solution(L/h), $F_I$ and $F_D$ are the flowing velocities which should be increased or decreased (L/h), $C_Z$ is the content of $Zn^{2+}$ of electrolyte (g/L), $r_Z$ is the normal content of $Zn^{2+}$ (g/L), $K_1$ and $K_2$ are positive deviations from $r_S$ and $r_Z$ respectively (g/L), $T_e$ is the temperature of electrolyte (℃), $r_T$ is the normal temperature (℃), $K_3$ or $K_4$ is positive or negative deviation from $r_T$ (℃). Parameters $n_1$, $n_2$, $m_1$, $m_2$ come from experience data. Experience data and contrast lists of parameters' relationships can be on-line changed, according to such a principle "if the performance indexes corresponding to the present parameters' relationships is better than the original one in the list, then replace the original one with the present relationships of parameters, otherwise lets KB remain unchanged." Therefore, KB has self-learning and self-adapting functions.

Inference engine (IE) compares the characterized information came from IAPU with what stored in KB, infers the possible work states of each parameter, then abstracts different control rules from KB by means of forward chaining inference method, acquires the possibly permissible optimal range value of the ratio of $H^+/Zn^{2+}$ in electrolyte, the value of the flowing velocity of purified solution, the number of the cooling fans to be turned on or off.

The electrolyte is a mixture of purified solution with more $Zn^{2+}$ ions and electrolyzed solution with more sulphuric acid. When keeping the liquid level of the ground trough stable, the flowing velocity of electrolyzed solution is also stable. Thus, if more purified solution flows to the solution-collecting trough, the content of $Zn^{2+}$ will increase, *vice versa*. The numerical relationships between the ratio of $H^+/Zn^{2+}$ in electrolyte and the flowing velocity of purified solution can be described as[1]

$$Q = \frac{(r \cdot p_2 - q_2) \cdot F}{q_1 - r \cdot p_1} \tag{4}$$

$$\eta = \frac{(p_1 - p_2) \cdot Q}{I \cdot g \cdot N} \tag{5}$$

where $Q$ is the flowing velocity of purified solution flows into the electrolyzer (L/h), $F$ is the flowing velocity of electrolyzed solution flows into the electrolyzer (L/h), $p_1$ and $q_1$ are the content of $Zn^{2+}$ and the content of acid in purified solution respectively, $p_2$ and $q_2$ are the content of $Zn^{2+}$ and the content of acid in electrolyzed solution respectively, $r$ is the ratio of $H^+/Zn^{2+}$ in electrolyte, $\eta$ is the current efficiency, $I$ is the electric current through the electrolyte, $N$ is the number of series electrolytes, $g$ is the electrochemical equivalent of zinc.

The synthetic information processing mechanism (SIPM) searches out the optimal given value of the flowing velocity of purified solution by utilizing the conclusion from IE and formulas (4) and (5). It also finds out which fans should be turned on or off according to the number of the fans to be turned on or off and the current actual state of the fans, then sends the code number of these chosen fans and the given value of the flowing velocity of purified solution to RTCS for real-time control.

## 5 REAL-TIME CONTROL SUBSYSTEM

Real-time control subsystem (RTCS) is used to ensure the production process running at or near the optimal ratio of $H^+/Zn^{2+}$ and the optimal temperature. It includes the real-time control of the flowing velocity of purified solution, the liquid level of the ground trough and the state of cooling fans. The flowing velocity of purified solution is controlled by means of regulating the rotational speed of purified solution pumps. It should follow the given value, and should also overcome the disturbance in its closed-loop. Its controller adopts PI control algorithm with dead-space. The given flowing velocity of purified solution comes from EOS or keyboard decided by soft-switch. The liquid-level of the ground trough is controlled by means of changing the rotational speed of electrolyzed solution pumps. It mainly overcomes the disturbance signals added to the liquid-level. Considering that there is a big lag from the change of rotational speed of electrolyzed solution pumps to the change of liquid level. WAS control algorithm is used in its controller. The state of cooling fans is controlled directly by means of outputting digital signals to open or close the relays of cooling fans. The block diagram of RTCS can be illustrated as Fig. 2.

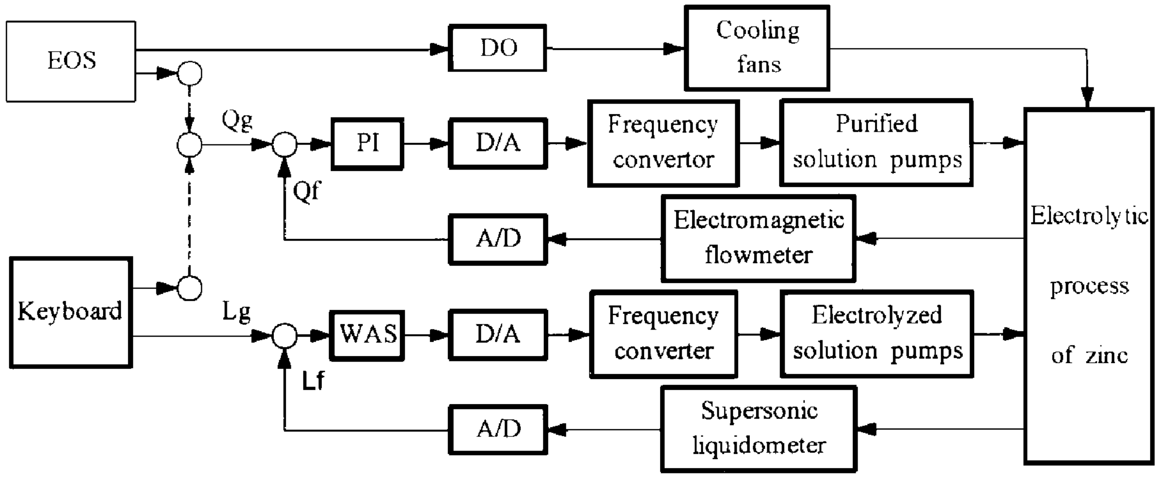


**Fig. 2 The block diagram of RTCS**

## 6 SYSTEM REALIZATION

EOCS is implemented by an industrial control computer. The computer is equipped with A/D modules, D/A modules, thermal resistance temperature detection modules (RTD), digital input (DI) modules, digital output (DO) modules and their interface boards. The applied software of optimized control and administration are programmed in Borland C++ language and assembly language, based on modularity and structural programming methods. It is general adaptable and easy to be modified.

## 7 CONCLUSIONS

Since EOCS was put into running in the nonferrous metal smeltery in 1995, it has revealed its advantages that operators can get the production data of the whole electrolytic process in time, directly and completely, the ratio of $H^+/Zn^{2+}$ is controlled in the range of 3∶1～3.5∶1 firmly, the current efficiency increases from 88% to 88.5% at same trough-voltage. It means 10 kWh power consumption reduction per ton of zinc production, 1 million kWh power consumption reduction a year if 100 thousand ton of zinc is produced. EOCS is a successful example of expert control techniques used in automation area. It indicates that the using of expert techniques in the real-time control of complicated production process will improve the performances of process automation, and will bring about striking economic benefits and social benefits.

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