Automatic Melting-casting-palletizing Production System for Miniature Batch/ Mass Metal Based on Robot Technology

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Abstract. In metal recycling and smelting, especially precious metal recycling and smelting, a novel production system is put forward for the automatic and intelligent control of the melting-casting-palletizing processes based on the systems engineering principle with multi-robots. The system is optimally designed and consists of five fundamental function modules, the melting-casting robot sub-system, over-turning robot subsystem, palletizing robot subsystem, vibration-demolding table, and the ring-like rotating table. By using the modern cybernetics and intelligent control method in the whole machine control system with machine vision, location and gravity sensors and the corresponding algorithm, into to the PLC control system, achievement of energy saving and environmentally friendly small batch/mass metal recycling and ingot-making is gained with automation and intelligence.

1. Introduction

In the scrap metal smelting recycling and miniature batch/mass smelting-casting, it is usually the case: (1) heat by coal and cast by hand; (2) adopt the common smelting furnace with the primary smelting metal, especially the high-power furnace; (3) scrap metal is not recycled. In the first case, most of the waste metal melting recycling uses the original coal heating with manual casting. Labor intensity is great, production cost is high, the environment temperature is fierce, some metals under high temperature melting state have certain toxicity. There is a great hidden risk for the operators. For the smelting and casting of small batch/mass metal, if the high-power furnace is adopted, it means large energy consumption, high cost and uneconomic, and is not conducive to environmental protection, sustainable production and development.

Efforts have been made and progress has gained on induction smelting with small power matched by casting-smelting with robots. Jaesung Oh at al.[1] worked out an autonomous laser toning system based on vision recognition and robot manipulator, recognizing the accurate treatment points from the 3D point cloud data obtained with the camera. Mirjalili, Reihaneh at al. [2] presented SURENA III humanoid robot by using model predictive control scheme. The methods were general control schemes which could generate the online motions for walking. Kapoutsis, Athanasios Ch at al. [3] proposed a distributed algorithm applicable to a wide range of practical multi-robot applications. Munzer, Thibaut at al. [4] showed a novel method to learn human preferences during, and for, the execution of...
concurrent joint human robot tasks considered and realized by a team of the human operator and a robot helper. Song, Yalun et al. [5] aimed at presenting a mechatronic approach with tools clamped by robots to improve the quality and efficiency of robotic deburring with double robots. Virgili-Llop, Josep et al. [6] put forward a convex-programming-based guidance algorithm to capture a tumbling object on orbit using a spacecraft equipped with a robotic manipulator. Ashkvari, Mahyar et al.[7] Designed a 2-DOF ankle joint actuation mechanism for a humanoid robot with 3D structure. Munadi, M. et al [8] designed a motor-tendon actuator for a soft starfish-like robot with five soft motor-tendon actuators. Villagrossi, E. et al. [9] brought a flexible robot-based cast iron deburring cell for small batch production using single-point laser sensor. The proposed solutions were defined in a standard cast iron foundry scenario, where the working environment is dirty, and the production is characterized by small batches. Eslami, Mostafa et al. [10] researched on a novel three-mass inverted pendulum model for real-time trajectory generation of biped robots.

To solve the above problems, the current study puts forward and designs a novel production system, using the modern cybernetics and intelligent control. Details of the system will be depicted in the following sections.

2. Analysis of Process Requirements and Technical Characteristics

2.1. Technology Route in the Novel Process Based on Systems Engineering Principle

Automatic melting casting-palletizing production in convention for small mass metal runs with separate smelting furnace, manual casting, manual turning and manual palletizing, being low production efficiency, high cost, high labor intensity, extremely unsafe. Automatic melting- casting-palletizing machine of miniature batch/mass metal and recovery of small mass metal is suitable for processing small batch/small mass metal or recovery of small mass meta. Here, the basic processing sequence and corresponding processing methods we put forward are ore/recovery metal screening $\rightarrow$ induction shaft furnace $\rightarrow$ ring table preparation $\rightarrow$ induction smelting $\rightarrow$ casting into ingots $\rightarrow$ ring table rotating successively into the station $\rightarrow$ robot turning billet $\rightarrow$ robot stacking. The three key processes are casting ingots, robot turning billets and robot stacking.

2.2. Automation of Smelting and Casting

By using robot technology and lining furnace, integration of the intermediate frequency induction melting and the extraction of bile pouring makes it possible for the pattern of production to revolutionarily change from the pouring one ingot with one piece of ladle to a directly continuous pouring of multiple molds with the bile full of molten metal liquid. In the light of the robot technique, the method “a direct continuous pouring of multiple molds “ can be put into operation. Meanwhile, a ring-like rotating table is needed for the automatic pouring process in sequence.

\[
V_i = \int_{\lambda_1}^{\lambda_2} f_1(\lambda) d\lambda \\
V_j = \int_{\lambda_3}^{\lambda_4} f_2(\lambda) d\lambda
\]

Within the same batch, the volume of the ingot is the same, say $V_b$, then, from equation (1),we have

\[
V_i = V_j = V_b
\]

Due to the furnace structure, $f_1(\lambda)$ and $f_2(\lambda)$ are different and should be calculated according to subsection function. In addition, a sensor is set in the mold to stop pouring when the liquid level of the metal reaches the predetermined value for the ingot. At this point, the furnace pile records its position and returns to the angle of 5 ° to prepare for the next pouring, see figures 1, 2, and 3.
2.3. Robotization of Over-turning with Ingot

For the convenience of pouring, casting, and demolding, the facade of mold working cavity has been made with a certain angle. After pouring and solidifying, the liquid metal becomes into an ingot and is supposed to be timely taken out of the working cavity ——demoulding. Vibration shock demoulding technology is used to realize the rapid demolding. The mold with an ingot is turned over and laid on the vibration-demolding table and the ingot is left from the mold which is taken away from the table onto the conveyor by the robot. Figure 5 shows the process of over-turning and corresponding device for the ingot. It is pushed into a socket-like chamber on the rotor by hydraulic cylinder. Then the rotor turns 180° and the ingot is at the state of big size up and small size down, ready for stacking.

Figure 1. Pouring robot.  Figure 2. A pile with connectors.  Figure 3. Inclined pile.

2.4. Intelligent Stacking of Ingots

The stacking of ingots is done by robots. Palletizing robot is equipped with vision system and weight sensor, which can detect the appearance and weight of finished products, remove unqualified products in time, and ensure the quality of palletized packaging products. Specific processes and technical methods are described as follows:

2.4.1. Visual inspection based on machine vision technology. The characteristics of machine vision system are to improve the flexibility and automation of production. Basic inspection including appearance and weight shall be carried out before stowage of ingots. Under normal circumstances, the ingot is hot and has not been effectively cooled, the manual measurement is out of date, the machine vision technology is effective. The new ingot is determined by binocular CCD system. The basic method is to continuously shoot the ingot surface in real time through CCD lens. The sequence of shooting is sides 1,2,3,4 and the upper surface. Image acquisition card is used to temporarily store the shot signal and I/O port is used to input the image signal into the computer for processing. The machine vision testing method can greatly improve the production efficiency and automation. And machine vision is easy to realize information integration, which is the basic technology of computer integrated manufacturing. Just because of the machine vision system, a large amount of information can be obtained quickly, and it is easy to automatically process the information integrated with design information and processing control information, see figure 4. If the real feature is beyond the threshold according to formula (3). It is taken as unqualified one and should be removed away.

Figure 4. The over-turning process of ingot by a robot.

2.4.2. Weight inspection of ingots. On the workbench, the weighing is done with a electronic scale and the result is stored into the computer.
\[ |A_{\text{real}} - A_{\text{standard}}| \leq \varepsilon \]  

(3)

where \( A_{\text{real}} \) is the real feature of the inspected ingot, \( A_{\text{standard}} \) is the standard threshold.

2.4.3. Stacking by robot. The stacking of ingots is done by robots. Palletizing robot is equipped with vision system and weight sensor, which can detect the appearance and weight of finished products, remove unqualified products in time, and ensure the quality of palletized products. Specific processes and technical methods are described as follows: According to the prescribed path and algorithm, program is done in the first place. Then the palletizing robot is controlled to achieve the desired action. Here, machine vision plays an important role in the actual stacking process. From grasping the ingot, transferring, to palleting, three times visual experience and reaction are subjected to ensure barrier-free operation and avoid collision in safety and good order.

![Figure 5. Appearance inspection of the ingot by machine vision.](image)

3. Optimization of Production Line Layout and Composition of Production Process System

3.1. Economic and Technical Requirements of the Production System

(1) With systems engineering principles, optimal design is done for the overall system with the goal of production rhythm.

![Figure 6. Melting-casting-palletizing system with ring-like structure.](image)

(2) Reliability and lightweight optimization design are supposed to carry out for the five subsystems.

(3) Modern cybernetics and intelligent control methods are utilized to the control system. (4) The ring-like rotation overall layout is adopted, with the melting furnace in the center, so as to gain the maximum space-saving under the premise of meeting the function and performance of the system. (5) The ring-like multi-station table is needed, and on which the circular distribution of casting molds is realized. The casting robot is relatively fixed, while casting the molds on the working table respectively and successively, which is safe, reliable, energy saving and conducive to environmental protection. The system and function structure are shown in figure 6.
3.2. **Optimization Design of System Layout**

Optimization objective is the lightest weight or the lowest cost of the system as evaluation function.

\[
W = \sum_{i=1}^{N} \lambda_i w_i
\]

where \(\lambda_i\) is the factor of the \(i\)-th module for weight or cost; \(w_i\) is the mean value of weight or cost; \(N\) is the number of the functional modules in a layout of a casting-over-turning-stacking system.

The constraint includes the production cycle, service life, and the area the system occupies:

\[
\sum_{i=1}^{N} \beta_i t_i \leq T
\]

\(\beta_i\) is the factor for production cycle with the difference between the adjacent functional modules; \(t_i\) is the difference between the adjacent functional modules

\[
\sum_{j=1}^{N} \alpha_j A_j \leq M_{io}
\]

where \(\alpha_j\) is the money per area; \(A_j\) the area; \(l_k\) the life of the \(k\)-th functional module in formula (7).

\[
L_k \geq \min_{l \in [1, N]} l_k
\]

Decision variable: a possible production cycle, number of the function modules, and the batch:

\[X = \{x1, x2, x3\} \geq 0\]

Calculations have been done and results show that the best solution is that in figure 6 by comparison with two other feasible designs indicated in figures 7 and 8, respectively.
4. Conclusion

With the systems engineering principle to plan the overall scheme of automatic melting, casting and palletizing the ingots were realized with the minimum weight/cost as the objectives, production cycle, service life and occupation size as constraints, and the production cycle, the number of basic functional units, and batch as independent variables for solution to the problem of system optimization design. With the reliability theory and optimization method, the five sub-systems were successfully designed and unified into a whole system.

The overall layout of ring type for working table was constructed, with the melting furnace in the center, to maximize the space saving under the premise of meeting the key function, especially to save the floor space. The casting robot is relatively fixed, and the casting molds on the work table are separately and sequentially cast with high reliability and safety. The modern cybernetics and intelligent control methods were utilized to the PLC control system with visual detection systems and sensors of different kinds with corresponding algorithms for the whole system.

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