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Design of Automated Production Line and Optimization of Production Scheduling for Die Casting of New Energy Vehicle Motor Shell

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Abstract. For the production of drive motors for new energy vehicles, this article focuses on the die-casting island as the production core. By adding robot modules in the handling and transfer process, the automation process around the die-casting island is improved to achieve automatic loading and unloading of the overall production process. Then, based on the production order requirements, the optimization of the entire production process of the motor order is taken as the scheduling objective. Production sorting optimization is carried out through scheduling sub batches, and a composite production cost composed of mold replacement cost, storage cost, and waiting time of the soup changing robotic arm is established as the objective function for optimizing the production scheduling of the die-casting workshop. In terms of solving the optimal solution, the simulated annealing algorithm is integrated into the particle swarm algorithm, and the improved particle swarm algorithm is used to optimize the objective function. Finally, the number of die-casting machines and orders in production are simulated to verify the effectiveness of the scheduling algorithm in this paper.

Keywords: electric motor casing, integrated die casting, particle swarm optimization algorithm, production scheduling

1 Introduction

New energy vehicles represent the primary direction for the transformation, upgrading, and green development of the global automotive industry. Additionally, they serve as a crucial path towards achieving “carbon peak and carbon neutrality” within the automotive sector. China places immense emphasis on the advancement of the new energy vehicle industry, having established the world’s most comprehensive industrial chain. The scale and technological prowess of China’s new energy vehicle industry are globally leading. The electric drive system constitutes a vital component of new energy vehicles, typically comprising a drive motor, motor controller, transmission device, among others. As the primary actuator of new energy vehicles, the drive motor is the core component that determines the vehicle’s power performance, and it also represents one of the key competitive strengths in the global automotive energy and drive system technological revolution and industrial transformation [1].

There are many participants in the drive motor industry, including traditional vehicle manufacturers both domestically and internationally, as well as large component suppliers and new cross-border technology enterprises. The participation of numerous enterprises has continuously refined the design and production process of drive motors, and improved their performance. At present, the drive motors used in new energy vehicles are classified according to their types and working principles, mainly including DC motors, switched reluctance motors, and AC motors [2].

With the explosive growth of the market share of new energy vehicles, the development momentum of China’s drive motor industry is strong, and the industry scale of drive motors is rapidly increasing. While meeting domestic demand, the export volume has also doubled.

According to statistics, influenced and driven by the rapid growth of production and sales scale of new energy vehicles, the installed capacity of drive motors for new energy passenger vehicles in China was 5.78 million units in 2022, and reached a new high of 8.33 million units in 2023, a year-on-year increase of 44.1%. Among them,

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permanent magnet synchronous motors occupy an absolute dominant position in China's passenger car drive motor market, with a market share of over 90% [3].

The motor housing is the main component structure of the driving motor, and stator components are generally installed on it. Therefore, as a key component of the new energy vehicle motor module, its excellent airtightness and strength are essential conditions for ensuring the safe and efficient operation of the motor. The main materials used to make the motor housing are cast iron and aluminum alloy, and the manufacturing process mainly adopts traditional die-casting processes such as pressure casting and low-pressure casting. Currently, there is no evidence in China that the motor housing is formed by extrusion casting [4].

Die casting has become one of the manufacturing processes for large-scale production in the automotive industry due to its ability to form complex thin-walled structures in one go, extremely short production cycles, and close to net forming characteristics. With the trend of using aluminum instead of steel to achieve vehicle lightweighting, this process is widely used in the manufacturing process of body components, three electric system motor housings, engine cylinder blocks, clutch and transmission housings, chassis parts, battery protection covers, and various brackets. In 2019, Tesla launched integrated die-casting technology, which highly integrates multiple individual parts and uses a super large tonnage die-casting machine to form them in one go. It leads the manufacturing revolution in the automotive industry in terms of part performance, production efficiency, and manufacturing costs, providing a new direction for automotive manufacturing [5].

Therefore, based on the existing die-casting production of drive motor housing, this article designs a new energy vehicle drive motor housing die-casting production line, and studies the rationality of the production line design, as well as the improvement of production efficiency and product quality throughout the entire production process. The work done is as follows:

1) Firstly, based on the actual production situation, taking the die-casting island as the center, an automated die-casting system production line is set up by adding handling robots and industrial control system networks, and the overall system design scheme of the automated production line is provided;

2) For the production of a series of new energy vehicle drive motors for a certain model, a mathematical model for the production cost of the motor was constructed, which includes the cost of mold replacement, storage, and waiting time of the soup changing robotic arm;

3) The optimization objective is to minimize production costs and shorten the waiting time after changing soup machinery. An improved particle swarm algorithm is used as the solving algorithm to design the optimal scheduling plan based on production tasks;

4) Using real orders and the number of die-casting islands as parameters, simulate using the method proposed in this paper, and verify the effectiveness of cost savings through simulation results.

2 Related Work

There is relatively little research on the integrated die-casting molding process of the drive motor housing for new energy vehicles. This article summarizes some relevant research results at home and abroad, and determines the research direction of this article through comparative analysis. In the manufacturing process of new energy vehicle motors, there are relatively more research achievements related to drive motors, as they are not limited to the use of new energy vehicles.

Lihua Tao from Changchun University of Technology analyzed the production layout based on the actual needs of the new energy vehicle parts die-casting automation production line. She considered the impact of the speed of the transport machine on production scheduling and the environment, and established a mathematical model for the die-casting automation production line with the optimization objectives of total idle time of equipment, equipment load balance, output of parts, and waiting time of the transport machine. She proposed an algorithm to improve production efficiency [6].

Houtao Xiao applied numerical simulation methods to simulate the flow of aluminum liquid in a certain new energy vehicle motor housing die-casting part. By comparing the flow and filling states of aluminum liquid under different pouring systems, he helped the enterprise choose the best pouring system. At the same time, he knew that during the trial mold and trial production stages, the enterprise improved the die-casting production yield from aspects such as die-casting process production line and mold use [7].

Jun Liu selected appropriate die-casting process parameters based on the structural characteristics of the casting product, and designed a pouring system. During the teaching process, CAE software was used to numerically simulate the filling and solidification processes, and then simulation experiments were designed. The simulation results verified that some positions of the casting in the initial die-casting process may have gas entrapment and cold shut defects. The optimized automated production process plan was numerically simulated and product trial production was carried out, and the gas entrapment and cold shut phenomena were greatly improved, meeting the production quality requirements [8].

Xiaodong Huang designed an automated die-casting unit for driving motor manufacturing based on intelligent equipment such as die-casting machines, various professional robots, automatic loading and unloading devices, automatic detection equipment, CNC, etc. Then, by designing a process system ERP. The comprehensive integration of intelligent units with platforms such as the Internet of Things and digital twins has achieved optimized control, intelligent scheduling, status monitoring, quality control, and cost analysis throughout the entire production process. This has improved product quality and production efficiency, reduced production costs, and provided an improvement direction for the automated production of die-casting drive motor housings from a methodological perspective [9].

Fangzhen Deng from Jiangxi believes that with the rapid development of new energy vehicles, aluminum alloy drive motor housings have become a development trend. However, the overall hardness is poor, and the bearing positions are prone to thermal deformation during motor operation. To enhance the hardness of the aluminum alloy motor housing bearing positions, steel sleeves are usually embedded in their bearing positions. To this end, the team conducted research and design on the embedded steel sleeve of a new energy vehicle aluminum alloy motor end housing, and analyzed the problems of low die-casting qualification rate caused by displacement during the die-casting filling process. They proposed an optimized design scheme for the positioning of the embedded steel sleeve in the motor end housing in the die-casting mold, which increased the qualification rate of the embedded steel sleeve motor housing product from 60% to 99.5% and reduced the cost of a single product by 39.7%. The improvement process of the overall die-casting scheme has reference significance [10].

This article mainly completes the construction of an automated production line for driving motor housings, and conducts optimization research on production scheduling for the entire manufacturing process. Therefore, the composition structure of this article is as follows: Chapter 2 introduces the research results in the design of integrated die-casting production lines and draws lessons from them as the production line design for motor housings. Chapter 3 focuses on the die-casting island, adding robot modules to the handling process, improving the automation process around the die-casting island, and completing the automatic loading and unloading function of the entire system. Chapter 4: Built an automated production system, optimized the production process based on existing production, and further optimized the overall process of electric motor manufacturing. Chapter 5 is the simulation experiment section, which verifies the effectiveness and feasibility of the proposed method through simulation experiments. Chapter 6 serves as the conclusion section, summarizing the research findings and shortcomings of this article, while discussing further research directions.

3 Design of Die Casting Automation Production Line

In the die-casting process of the drive motor housing, the core functional module of the die-casting process is the die-casting island module. The overall design direction of the entire automated production line is centered on the die-casting island. By adding robot modules in the handling and transfer links, the automation process around the die-casting island is improved, and the automatic loading and unloading function of the overall production process is achieved. Therefore, when designing and controlling the automation around the die-casting island, the core should be automated process control, following three principles:

Firstly, the control is simple. While meeting all design functions, the operation and control are not only easy to understand, but also convenient to achieve the rhythm and operating rate of the equipment, reducing the threshold for operators to use.

Secondly, it is easy to maintain, with modular program design and strong readability, making it easier for maintenance personnel to understand and quickly handle faults, reducing communication costs.

Thirdly, reduce costs, apply advanced software communication technology, use reliable and stable hardware communication systems, reduce communication hardware and complexity while improving production efficiency [11].

3.1 Overall Scheme Design of Automated Production Line

This article takes the automation of integrated die-casting production of electric motor housing for new energy vehicles as the research object. Aluminum alloy material is selected for the production of motor housing. Compared with traditional steel structural materials, aluminum alloy die-casting housing integrates multiple steel stamping parts into one aluminum alloy die-casting part. Compared with non integrated die-casting structures, the wall thickness of the integrated die-casting aluminum alloy housing structural part is smaller, and the local stiffness is significantly enhanced, achieving advantages such as lightweight, integration, and high rigidity. In addition to its basic structural connection function, the housing, as an important load-bearing component of automobiles, bears relatively large dynamic loads during driving, and also has high mechanical performance requirements for the motor housing [12]. Therefore, this article takes the die-casting automation of the drive motor housing series of a certain brand of new energy vehicles as the research object, and considers scheduling optimization for large-scale production of motor housings with different parameters. Therefore, a typical motor housing is selected as the target object, and its overall structural drawing is shown in Fig. 1.

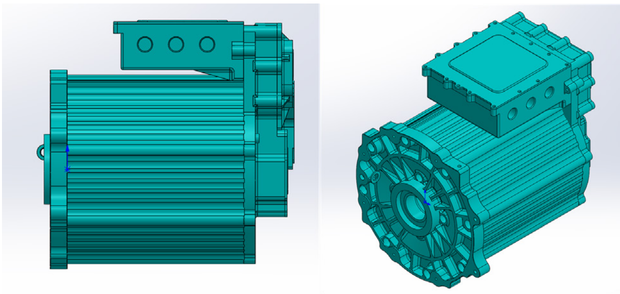

Fig. 1. Structure of die-casting motor

The working conditions of the drive motor for new energy vehicles are complex, mainly reflected in the following aspects:

1) The temperature rise load is large, and the temperature of the motor iron core can reach 170 ℃ or even higher. The working temperature difference is large, with a minimum of -40 ℃ and a maximum of 125 ℃; 2) The torque load is high, and the maximum power density of the motor is 10kW/kg, or even higher. With the improvement of vehicle power and economy, the requirements for lightweight and high-performance output of motors are further strengthened, mainly manifested in the need to reduce the weight of the motor housing, make the wall thickness thinner, increase the output torque of the motor, improve the power density of the motor, and make the temperature rise more stringent. All of these require motor optimization design to be more scientific and refined. The motor housing and stator iron core are generally interference fit, and the interference design of the motor housing and iron core is a key parameter in motor structural design. If the design is not reasonable, significant failures may occur [13].

Based on the structural characteristics of the motor housing, the production process of the entire production line is designed as follows: die-casting → robot parts taking → visual system inspection of product integrity → cooling water tank → grinding and cutting → laser engraving → product output.

The layout of the overall production line functional modules is shown in Fig. 2.

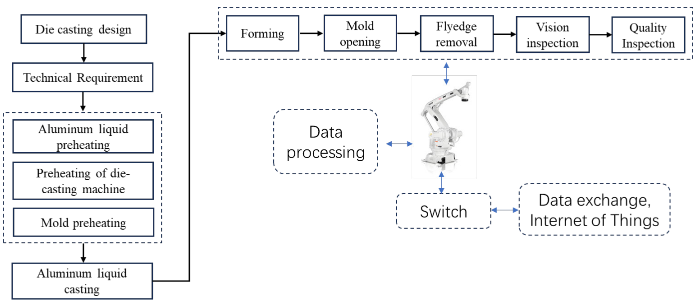

Fig. 2. Functional layout of the overall production line

The following explanations are given for some of the links in the process flow:

In the product quality inspection process, the visual system is used to detect the integrity of the product. The components are formed by the die-casting machine, and the initial production process of the shell is completed by die-casting. In the handling process, a robot is used to grab the motor shell and place it under the visual inspection system. After visual processing, the visual image is converted into an image signal, which is then transmitted to a deep learning based image processing system. The image processing system converts the pixel distribution, color, brightness, range, and size information into a digital processable signal, performs logical operations, and compares it with the target image to determine the integrity of the components [14].

The cooling water tank needs to be placed in the cooling water tank for a period of time due to the high temperature of the newly produced drive motor housing from the die-casting machine. The cooling water tank is controlled by a servo lift tower to ensure that the cooling position is consistent with the gripping position each time.

Grinding and cutting, further treatment of the surface of the drive motor housing. According to different die-casting parts, the system can automatically switch between different specifications of grinding machines to remove burrs on the surface of the die-casting housing and cut off unnecessary parts.

Laser engraving, the motor needs to print nameplates. This production line uses a laser generator to gather high-energy density laser beams and irradiate them onto the motor nameplate position, thereby engraving the nameplate on the motor housing.

In order to obtain qualified thin-walled shell parts, the shell blank needs to be subjected to trimming, X-ray inspection, visual inspection, etc. X-ray inspection can penetrate metal materials and detect defects such as internal shrinkage and porosity in components. Visual inspection is an important auxiliary detection method that can detect small casting cracks on the surface of the shell. Due to the fact that the shell is a functional assembly and requires airtightness testing, it is necessary to conduct leakage testing on the shell to ensure that the high-temperature gas flowing through the shell does not leak during operation, and to quickly establish the required pressure for work [15].

During the operation of the soup robotic arm, it is necessary to ensure the accuracy of the interval position and the smooth movement of the arm. This planar linkage mechanism can fully meet the requirements of the work. Considering that the soup feeding robot arm oscillates back and forth in a vertical plane to feed soup, the fixation of its own arm is one of the issues that needs to be considered when setting it up. The general structure of the linkage mechanism is difficult to achieve self-circulation, which is a problem of arm fixation. Given this, a two-stage rod group can be added to a typical four-bar linkage mechanism and fixed to the frame. Through the analysis of the above process, construct an overall simulation environment for automated production lines [16].

3.2 Design of Production Line Control System

In order to realize the automatic linkage in the whole working process of the die-casting machine, the sequence of the die-casting machine needs to be controlled in the whole production process is as follows: the system starts the furnace to reach the set temperature for heat preservation, and then the soup feeding manipulator carries out the soup feeding operation, and then the die-casting machine carries out the die-casting operation. The piece taking manipulator takes the pressed workpiece out of the die-casting machine, and the spray mechanism carries out spray cooling.

Based on the above process, the control core of the entire control system adopts Siemens PLC, model S7-1200, As a controller, PLC uses travel sensors, pressure sensors, and other sensors to collect signals and transmit them to the PLC controller. After analysis and processing by the PLC controller, the signals are transmitted to the real system for implementation. The display system can be a personal client, such as a mobile phone, PC, etc. There are several control buttons set on the display end. When the controller issues an operation prompt instruction, it sends the instruction to the controller through the buttons on the display screen of the display system. The controller receives the instruction to control the execution of the component action to complete the operation, thereby enabling the die-casting workstation system to achieve automatic control function [17].

Relying on the industrial Internet big data information technology, the wireless communication system is used to upload data to the cloud platform through PLC to realize remote monitoring and control of terminals such as computers and mobile phones. At the same time, it can also realize remote control of the system, monitoring of system operation status, workload statistics, equipment fault diagnosis, health management and other functions. Therefore, the network control system framework of the entire system is shown in Fig. 3.

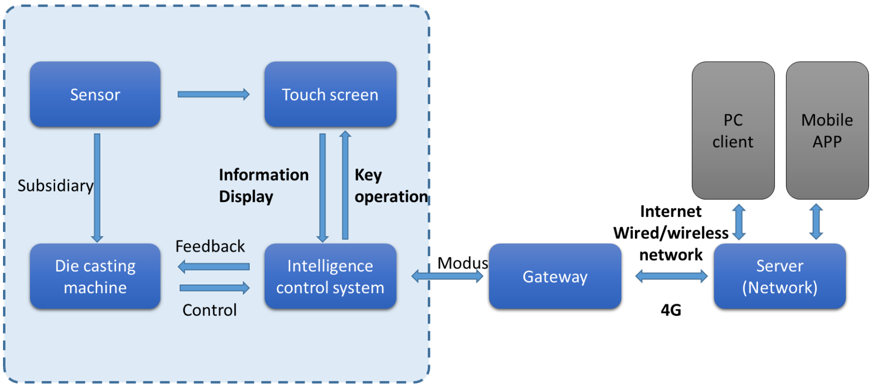

Fig. 3. Industrial internet of things architecture framework diagram

3.3 Overall Structure Design of Internet Control

The function of the overall Internet design system is designed around automatic die-casting. The overall design goal is to write control programs based on the cloud platform. Through the mobile phone APP, the PC client can easily realize real-time monitoring of parameter faults in the operation status of the die-casting machine. After the die-casting machine runs, the data collector will package the collected data through various sensors. The data detected by the system will be uploaded to the cloud platform by the router through TCP/IP network protocol. Then the operator can understand or control the operation of the die-casting machine through computers or mobile phones. The overall framework of the system is shown in Fig. 4.

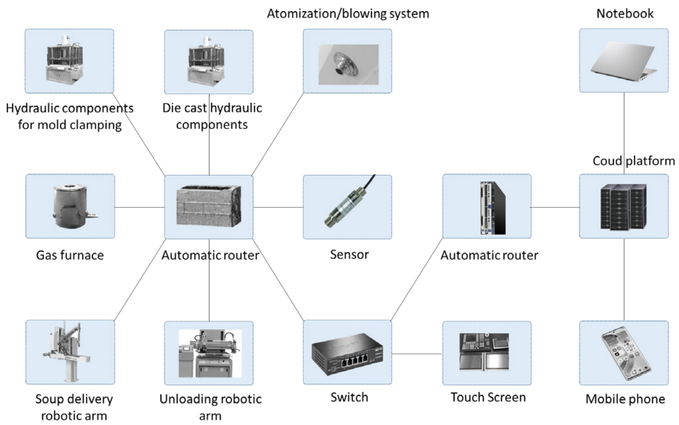

Fig. 4. Schematic diagram of the overall framework structure of the system

In this paper, the industrial Internet is used for data acquisition. The data acquisition system is installed on the die-casting machine working on the site. Through the status parameters of the on-site PLC acquisition system, the sensor network data acquisition device LF310-DTU automatic router is composed. The sensor network is composed of multiple sensors in the die-casting machine control system. The technical parameters of LF310-DTU are shown in Table 1.

The whole network first transmits the real-time data collected by the die-casting machine in the field to the data acquisition device through the PLC programmable controller and the LF310-DTU automatic router through the sensor network, then the data acquisition device packs the collected data, and then the industrial Internet gateway uploads the data packet to the cloud platform through TCMP or 4G network communication protocol.

In terms of data management, the database manages the operating parameters of the user database through the industrial Internet. With the increase in the number of die casting machine exports, in order to reduce the cost of after-sales maintenance and solve the problems encountered by customers in the process of using the die-casting machine in a timely and rapid manner, the entire network system can access the data equipment collected at the die-casting machine work site through the cloud platform. The equipment manufacturer can access the relevant web pages, enter the login interface, enter the cloud platform, and access the working conditions of the die-casting machine at the site. At the same time, the control network can modify, compile, and debug PLC programs at anytime and anywhere to achieve real-time monitoring of the working conditions at the site.

Table 1. List of technical parameters for LF310-DTU

Parameter	Parameter values
Working voltage	DC24V
Work environment	-35-75°C
Networking method	4G/WIFI
Communication interface	485/ Network Interface
2G Frequency band	GSM:900/1800 MHz
WIFI standard	802.11 b/g/n 2.412GHz-2.484GHz

4 Optimization of Production Workshop Scheduling Process

In the previous chapter, an automated production system and an overall network structure were constructed for the entire die-casting process of the motor housing. In this section, based on the existing production system, the production process was optimized and the overall workshop production scheduling was optimized using a certain brand of new energy vehicle drive motor series.

The production scheduling problem in the die-casting workshop belongs to the batch scheduling of single process parallel machines, which is subject to adjustments in mold changing operations and other resource constraints. Based on its order demand characteristics, a direct batching strategy is adopted to treat the daily demand of the Precision Industry Division as sub orders. The number of sub orders is equal to the corresponding daily demand of the Precision Industry Division, and they are used as scheduling sub batches for production sorting optimization. A composite production cost consisting of mold replacement cost, storage cost, and waiting time of the soup changing robotic arm is established as the objective function for optimizing the production scheduling of the die-casting workshop, with the lowest composite production cost and shortest waiting time of the robotic arm.

4.1 Establishment of Scheduling Model

When scheduling the production of electric motor shell die-casting, the comprehensive production cost composed of mold replacement cost, storage cost, and the shortest waiting time cost of the soup changing robotic arm should be comprehensively considered, and the production scheduling plan should be formulated with the lowest comprehensive cost as the optimization objective. Therefore, the optimization model for production scheduling in the die-casting workshop is:

$$\min C_{com} = \min \sum \left(C_{mr} + C_{stor} + C_{wait} \right) \tag{1}$$

In the formula, minC_{com} represents the lowest comprehensive cost, C_{mr} represents the model replacement cost, and C_{stor} represents the storage cost, C_{wait} represents minimizing the waiting time of the soup changing robotic arm.

1) Model replacement cost

In the actual production process, mold changing time is an essential element that cannot be ignored in production scheduling. However, there are errors in the scheduling results, as shown in Fig. 5.

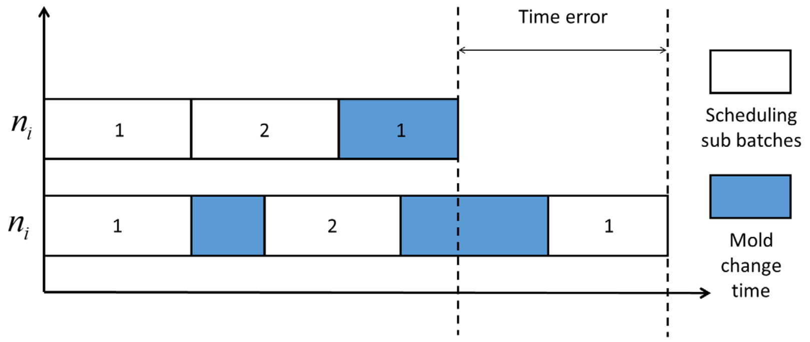

Fig. 5. Time error table for mold replacement

The cost generated during the mold changing process is mainly due to the production capacity loss caused by downtime. Therefore, calculating the mold changing cost mainly involves calculating the number of mold changes for all equipment and the corresponding mold changing time. n represents the device number, and the calculation formula is:

$$C_{mr} = \alpha \sum_{n=1}^{n} X_{ij} P_{kh} \tag{2}$$

In the formula, α represents the cost coefficient for changing the model per unit time, X_{ij} represents whether the model needs to be changed between adjacent devices ij , if it needs to be changed, the result is 1, if it does not need to be changed, the result is 0, and P_{kh} represents the time for changing the model between products k and h.

2) Storage cost

Due to the special form of order demand in the die-casting workshop, which is a phased continuous demand, that is, the demand is generated continuously for multiple days, and the daily demand quantity is not fixed. Therefore, the daily demand quantity is used as the scheduling sub batch with different delivery dates. If the completion time of the sub batch is less than the delivery date, corresponding storage time will be generated. If the completion time of the sub batch is later than the delivery date, corresponding inventory time will be generated. The start production time of sub batch B_i is S_i , the end time is E_i , and the delivery date is D_i . If the completion time is earlier than the delivery date, the time between the completion time and the delivery date is the storage time of the shell, as shown in Fig. 6.

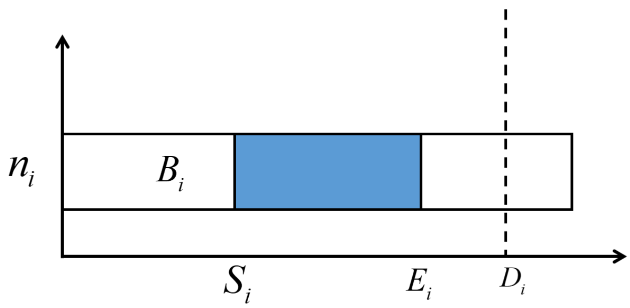

Fig. 6. Completion time, delivery date, and delay diagram

Therefore, the storage cost is expressed as:

$$C_{stor} = \sum_{t=1}^{t} \sum_{o=1}^{o} \delta p_{kc} s_{kt} \tag{3}$$

In the formula, t represents the product type, o represents the order quantity, and δ represents the unit product storage factor, which is determined by the product volume, weight, and structural complexity. The unit storage factor varies for different products. p_{kc} represents the storage time of product k's order, and s_{kt} represents the required quantity of product k's order.

3) Minimum waiting time for soup changing robotic arm

During transportation, in order to keep the aluminum liquid as smooth as possible in the crucible, the slower the speed of the soup changing robot arm, the better. The slower the speed of the soup changing robot arm, the shorter the total waiting time of the soup changing robot arm. The total waiting time of the soup changing robot arm is defined as optimization objective C_{wait} .

$$C_{wait} = aET_{ij} - \sum_{i=1}^{nc}\sum_{j=1}^{m} aET_{ij} \times aBT_{ij} \quad (4)$$

$$aBT_{1j} = 0, j = 1, 2, \cdots, m \quad (5)$$

$$aET_{ij} = aBT_{ij} + \frac{2DS_j}{v}, i = 2, \cdots, nc, j = 1, \cdots, m \quad (6)$$

Formula 5 represents that the moment when the soup changing robot enters the system is zero, and Formula 6 represents that the transportation process of the soup changing robot between the supply station and the machine cannot be interrupted, and the soup changing robot can only transport one crucible of aluminum liquid at a time.

4.2 Optimization and Solution of Production Scheduling

In order to improve the automation production efficiency of die-casting, reduce the idle waiting time of equipment, and achieve balanced and clean production throughout the entire process, based on the mathematical model of the lowest production cost, namely the mathematical model of the lowest practical cost of mold replacement, the mathematical model of the lowest storage cost, and the model of the shortest waiting time of the soup replacement manipulator, this paper proposes an improved particle swarm algorithm to solve the target mathematical model [18].

The central idea of the improved particle swarm optimization algorithm is to save a certain number of good individual extremum and group extremum, and establish individual extremum library and group extremum library respectively. And the simulated annealing algorithm is used to locally optimize each temporary particle, update the individual extremum library based on the optimized temporary particles, and use the optimal temporary particle as the new generation particle of the current particle [19]. The process is as follows:

1) Encoding of particles and generation of initial particle swarm. The position of each particle is encoded using one-dimensional real numbers, and the real number value is the transport speed of the transporter. Given the search range of particle positions and velocities, in order to ensure the diversity of the initial particle swarm, initial positions and velocities are randomly generated within this range.

2) Design of fitness function. The fitness function is expressed as:

$$F(V) = G \quad (7)$$

3) Particle updates. The update of particles is divided into velocity update and position update. In velocity update, the perturbation factor ϕ is used to intervene in individual and group extremum, avoiding premature convergence of the algorithm and improving its development ability. The dynamic inertia weight φ is introduced to balance the search ability of the algorithm, and the value of φ is related to the evolutionary algebra. The dynamic inertia weight φ enables the algorithm to inherit the current velocity of particles with greater inertia in the early stages of evolution, resulting in a stronger search force and achieving global search; In the later stage, the algorithm inherits the current velocity of particles with smaller inertia, so that the algorithm converges to the global best solution as soon as possible. The speed update formula is as follows:

$$v(x_i) = \varphi v(x_{i-1}) + \lambda_1 \left[p_i (1-\phi) - x_i \right] + \lambda_2 \left[p_g (1-\phi) - x_i \right] \quad \textbf{(8)}$$

Location update formula:

$$x_i = x_{i-1} + v(x_i) \quad \textbf{(9)}$$

Weight update formula:

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{G_{\max}} \times G \quad \textbf{(10)}$$

In the formula, $v(x_i)$ represents the current velocity, λ_1 and λ_2 represent learning factors, p_i represents the individual extremum of particles, p_g represents the extremum of the population, G represents the current number of iterations, and $G_{\max}$ is the current maximum number of iterations.

4) Based on the simulated annealing algorithm for optimization, in the process of updating particles, the current particle is taken as the initial solution, and the simulated annealing algorithm is used to conduct a small-scale and detailed search on the current particle.

5) The stopping criterion terminates when the algorithm reaches its maximum algebra, and outputs the optimal transport speed corresponding to the optimal particle and the optimal scheduling sequence for transporting the crucible by the transport machine at that speed.

The algorithm flowchart is shown in Fig. 7.

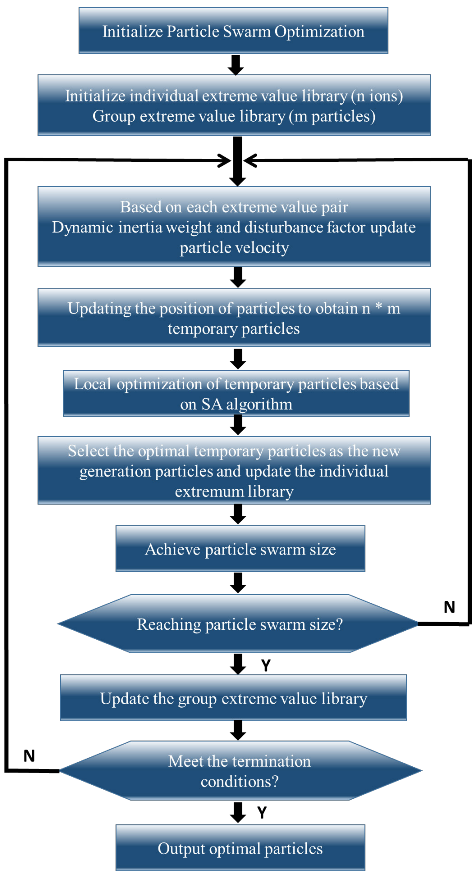

Fig. 7. Algorithm flow chart

This section focuses on optimizing the production process and overall workshop production scheduling for a certain brand of new energy vehicle drive motor series during the entire die-casting process of the motor housing. Based on its order demand characteristics, a direct batching strategy is adopted to treat the daily demand of the Precision Industry Division as sub orders, with the number of sub orders equal to the corresponding daily demand of Precision Industry. This is used as a scheduling sub batch for production sorting optimization, and a composite production cost composed of mold replacement cost and storage cost is established as the objective function for optimizing the production scheduling of the die-casting workshop. We solved the model using an improved particle swarm algorithm and completed the design of the algorithm improvement process [20].

5 Simulation Experiment and Result Analysis

After the improvement methods in Chapter 3 and Chapter 4, this section constructs a complete production line simulation system, designs the network structure, and then conducts production scheduling simulation and data analysis through real production scenarios.

5.1 Production Line Design Results

This article first constructs a more comprehensive on-site simulation layout diagram, and then completes the system function design based on the simulation system layout diagram. The improved overall production line scheme is shown in Fig. 8.

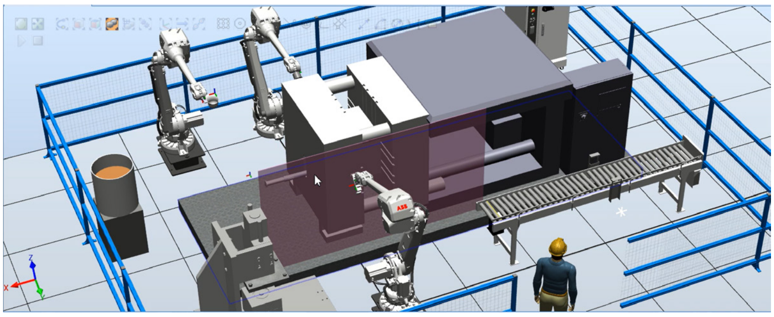

Fig. 8. Production line design structure

The production control system flowchart of the entire system is shown in Fig. 9.

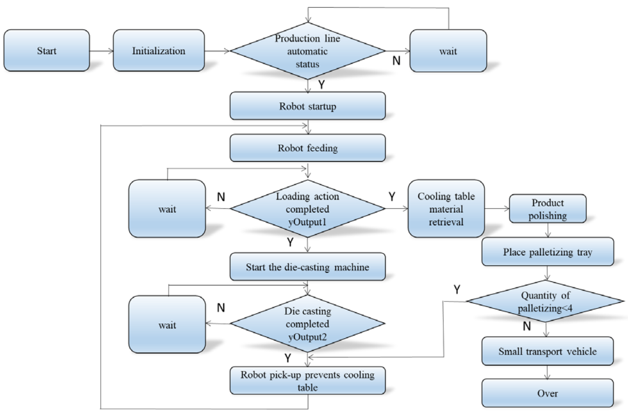

Fig. 9. System flow chart

5.2 Production Scheduling Simulation

This article completes the production scheduling of the workshop based on actual die-casting examples of motor housings with different needs. According to the content of Chapter 4, the mold change time of the die-casting model is shown in Table 2.

Table 2. Product mold change time matrix (h)

	Product 1	Product 2	Product 3	Product 4	Product 5
Product 1	3.1	2.7	2.8	3.2	2.8
Product 2	3.0	2.8	3.2	3.1	2.9
Product 3	3.2	2.9	0	2.8	3.2
Product 4	3.4	3.0	3.3	3.7	3.2
Product 5	3.1	3.6	3.6	2.9	3.5

The demand orders for the die-casting workshop are shown in Table 3, The unit of production capacity is the quantity of motor casings produced per hour.

Table 3. Order demand data

	Capacity	Product 1	Product 2	Product 3	Product 4
Product 1	85	320	0	1200	900
Product 2	123.2	0	0	0	200
Product 3	140	575	270	0	300
Product 4	97	0	310	0	0
Product 5	89.8	50	100	450	500

This article designs 3 die-casting machines with 5 orders. The improved particle swarm algorithm is used to solve and analyze the problems. The analysis results are as follows:

The total operating time of Die Casting Machine No.1 is 158.6 hours, of which the actual production time is 121.7 hours and the auxiliary mold changing time is 36.9 hours, completing a total of 3 orders; The total operating time of die-casting machine 2 is 162.8 hours, of which the actual production time is 133.6 hours and the auxiliary mold changing time is 29.2 hours. A total of 4 orders were completed; The total operating time of die-casting machine 3 is 192.6 hours, of which the actual production time is 172.3 hours and the auxiliary mold changing time is 20.3 hours, completing a total of 3 orders.

For the 5 products and 3 devices presented in the case study, the EDDLPT-FUMOD/FAM strategy was applied to plan and schedule the order requirements, resulting in an objective function value of 178.6 hours. Further analysis reveals that out of a total of 5 product orders, 4 orders were completed on schedule, while 1 order was delayed for more than 9 hours.

The algorithm iteration during the solving process is shown in Fig. 10, From Fig. 10, it can be seen that the pentagram represents the optimal solution, the data on the left side of the parentheses is the algebra of the target optimal, and the data on the right side is the target value. As the number of generations increases, when the algorithm reaches the 40th generation, the total goal converges to the minimum value of 602300 yuan, and the shortest waiting time for the soup changing manipulator is 1.6 seconds.

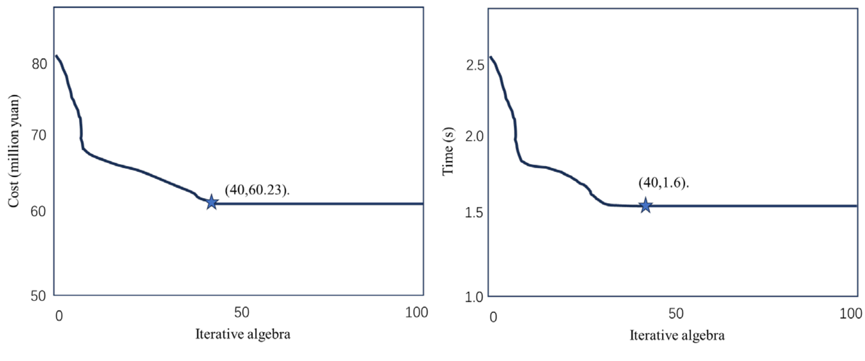

Fig. 10. Schematic diagram of algorithm iteration effect results

After the above process, the design of the simulation experiment and the implementation of the results have been completed, verifying the effectiveness of the method proposed in this paper.

6 Conclusion

This article comprehensively analyzes and solves the design of an automated production line for the die-casting process of the drive motor housing of new energy vehicles, and proposes an optimization plan for the production scheduling of die-casting automated production lines in enterprises. The summary of the entire work is as follows:

1) In response to the actual needs of a die-casting automation production line for a certain drive motor housing die-casting enterprise, this paper considers the non-negligible role of transport aircraft in the die-casting production scheduling process and the important impact of die-casting machine speed on the aluminum liquid scheduling results. A comprehensive optimization mathematical model based on multi-objective scheduling problem for die-casting automation production line is established.

2) This paper proposes an improved particle swarm optimization algorithm based on the standard particle swarm optimization algorithm. The improved method includes the introduction of the essence particle library to store the individual extreme value library and the population extreme value library of particles, so that the individual extreme value and population extreme value of particles in the update process can be updated using the better particles in the essence particle library, preventing the limitations of single particle guidance, and improving the search performance of the particle swarm optimization algorithm; And in the process of evolution, disturbance factors and inertia weights that vary with algebra were added when guiding particle updates through individual and population extremes.

Additionally, this paper exhibits several shortcomings during the research process, which will guide future research directions:

Despite optimizing and improving die-casting molds through experiments and numerical simulations, numerous conclusions still require further verification and practical application due to time and resource constraints. Although this paper has conducted detailed simulations of the casting process, die-casting process parameters, and the establishment of automated production lines for shell castings, practical testing in actual production has not yet confirmed the true operational status of the automated production line established in this paper due to inadequate conditions. The primary shortcomings of this paper are outlined below:

1) The front-end of each die-casting machine studied in this article does not have a specific number of buffer zones. When the mechanical arm loads aluminum liquid and reaches a certain die-casting machine, there may be a situation where the equipment is still in the processing state. At this time, the mechanical arm can only wait for the equipment to be completed before unloading the current aluminum liquid, resulting in the mechanical arm waiting. When the order task is large and the processing time is tight, each die-casting machine may need to operate without any idle time to meet the order requirements for processing and production. At this time, timely delivery of materials is particularly important. The addition of buffer zones can reduce the idle time of the robotic arm, and the priority of timely delivery of materials is higher. However, the setting of buffer zone size is also worth studying. If the buffer zone is too small, materials will wait, the robotic arm will stagnate, and if the buffer zone is too large, it will cause space waste and increase management costs. Therefore, optimizing the number of buffer zones and the size of each buffer zone is extremely important.

2) The scheduling problem of the die-casting automation production line studied in this article belongs to the coordination scheduling problem between production and transportation. However, the current research in this article only considers the aluminum liquid transportation and die-casting process from a single robotic arm to various die-casting machines. When production is in short supply and the order quantity is large, the robotic arm is limited by transportation speed and cannot meet the production capacity requirements of various die-casting machines. At this time, it is necessary to consider the coordination of multiple robotic arms and multiple transport machines for aluminum liquid transportation simultaneously. The speed optimization of multiple robotic arms and the rational scheduling and allocation of aluminum liquid are extremely complex optimization problems, but such problems are widely present in actual production processes, especially in die-casting manufacturing enterprises with high demand for products.

3) This article only considers the two processes of aluminum liquid transportation and processing in the early stage, and defaults to unobstructed transportation for the subsequent transportation process of producing die-casting parts, without careful consideration and integration into the mathematical model. If accurate analysis and

consideration cannot be made, the automated die-casting production line may experience processing stagnation due to insufficient capacity in the die-casting buffer area caused by delayed follow-up of subsequent transportation, resulting in the inability of workpieces to leave the workstation of this process normally.

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