Research and application of flexible manufacturing cell for aluminum-magnesium casing

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ABSTRACT

In order to meet the high precision and high efficiency processing requirements of multi-variety small batch aluminum magnesium casing, the construction of flexible manufacturing cell of aluminum magnesium casing was studied. By analyzing the processing characteristics of aluminum magnesium casing and the current situation of manufacturing workshop, the overall design of flexible manufacturing cell was completed, and the model facility layout within the cell was constructed. The tabu search algorithm was used to solve the model, to further complete the study of the layout of flexible manufacturing cell of aluminum magnesium casing was. The construction of flexible manufacturing cell for aluminum magnesium casing is of great significance to solve the existing problems in the manufacturing process of aluminum magnesium casing and summarize the new processing mode of key parts of aero engine, which lays a solid foundation for the construction of intelligent workshop.

Keywords: Aluminum-magnesium casing; Flexible manufacturing cell; Tabu search algorithm

1. INTRODUCTION

Compared with the steel casing made of traditional materials, the aluminum-magnesium casing has the characteristics of small proportion, high strength, high corrosion resistance, complex structure and integrated design, and is generally used in the front deceleration, air intake, accessory transmission and other components of aero-engine[1]. The aluminum-magnesium casing has the characteristics of processing technology such as large machining allowance, difficult material processing, complex part shape, complex processing technology[2], and its processing quality is affected by many aspects such as tool performance and material, processing equipment, process parameters, and process route arrangement. Due to the various types of Al-Mg casing parts, small processing batches, long production cycle of a single product[3], and limited by casing processing technology, processing equipment and other factors, the production process of the traditional casing manufacturing workshop is relatively complex. At present, there are many problems in the traditional casing manufacturing workshop of Enterprise N, such as slow line changing speed, insufficient personnel, low utilization rate of processing equipment and high failure rate, and low fault tolerance of abnormal events. Therefore, the processing of aluminum magnesium casing parts urgently needs an efficient processing flow and information integration management processing mode to solve the above problems.

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2. OVERALL DESIGN OF FMC FOR ALUMINUM MAGNESIUM CASING

2.1 Design of flexible manufacturing cell body of aluminum-magnesium casing

The flexible manufacturing unit of aluminum magnesium casing mainly includes processing system and logistics system[4]. The machining system mainly includes a machining unit and a central tool magazine composed of a CNC lathe and a five-axis machining center. CNC lathe and machining center are mainly responsible for the processing of aluminum magnesium casing parts. The selection of machining center is the basis of flexible manufacturing of aluminum magnesium casing. The central tool magazine is one of the key technologies for efficient machining of aluminum-magnesium casing. Before and during the whole machining process of aluminum-magnesium casing parts, the central tool magazine configures the tools needed for aluminum-magnesium casing machining according to the instructions issued by the production management system. The tool transport robot transports the tool from the central tool magazine to the machining equipment in advance, reducing the tool change time and improving the machining efficiency.

The logistics system mainly includes loading and unloading station, tool transport robot, pallet warehouse, material transport robot and guide rail. The exchange of pallets between processing equipment, loading and unloading stations and pallet warehouses is completed by the material transportation robot ; the transportation of the tool between the machining equipment and the central tool magazine depends on the tool transport robot. The logistics system is equipped with a console, which can be controlled by the operator to complete the operation of pallet transfer, loading and unloading of pallet warehouse. The body design of the aluminum-magnesium casing flexible manufacturing unit is shown in Figure 1.

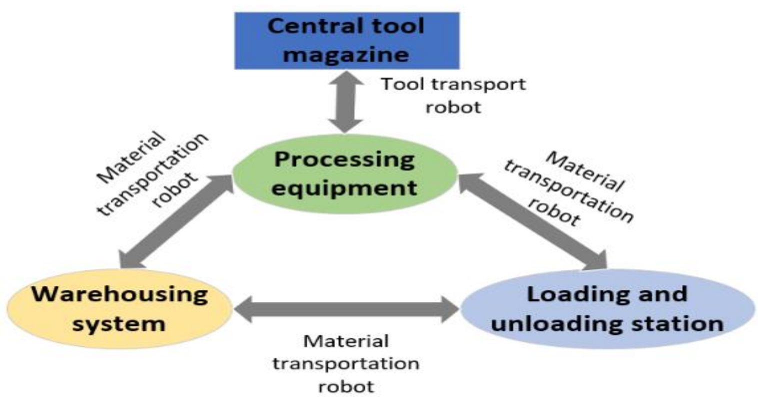

Figure 1.Overall composition of flexible manufacturing cell for aluminum-magnesium casing

2.2 Process flow design of flexible manufacturing cell for aluminum-magnesium casing

Based on the above design of the flexible manufacturing unit of aluminum-magnesium casing, the processing flow design of aluminum-magnesium casing unit manufacturing is completed according to the processing technology of aluminum-magnesium casing parts. The processing flow is as follows :

1) The manager sends the production information, NC program and so on to the production management system. The production management system calculates the number of tools needed in the whole process according to the production volume, the number of tools used in parts processing and the tool life.

2) According to the number of tools provided by the production management system, the operator measures the tool data on the tool regulator and automatically stores it in the tool holder chip (each tool holder has a unique ID identity).

3) The tool is loaded into the central tool magazine. The tool manipulator automatically reads the tool information through the chip and stores the tool information in the central tool magazine. The central tool magazine loads the tool into the corresponding tool magazine according to the instructions issued by the production management system. The machine tool automatically reads the tool information through the chip and stores the tool in the tool list of the machine tool.

4) In the process of using tools, the production management system needs to obtain real-time data of tool wear correction and tool life, and make information feedback on the use of tools according to the data ;

5) According to the production plan, the operator loads the parts into the fixture in the loading and unloading station, loads the fixture into the tray and finds the parts.

6) The operator scans the tray chip (each tray has a unique ID identity) and stores the tray information in the production management system.

7) The production management system transfers the pallet information to the loading and unloading manipulator and the corresponding equipment. The loading and unloading manipulator automatically recognizes the pallet chip in the pallet storehouse, the equipment automatically opens the door, and the loading and unloading manipulator sends the pallet with the corresponding fixture to the corresponding equipment. The equipment automatically closes the door and feeds the information back to the production management system.

8) The probe for parts processing is used to collect information, and the clamping of parts is automatically corrected according to the collected information.

9) The tool wear in the machining process is automatically compensated by the on-line measurement of the tool setting instrument.

10) In the process of part machining, the tool breakage or fracture is detected online by the tool setting instrument in the machine, and the alarm information to be replaced is sent out. At the same time, it is fed back to the central control system, and the sister tool is preferred for machining, and the tool to be replaced is automatically withdrawn to the tool loading and unloading station.

11) The tool life has arrived in the process of parts processing. The alarm information that needs to be replaced is fed back to the production management system. The sister tool is preferred for processing, and the tool that needs to be replaced is automatically withdrawn to the tool loading and unloading station.

12) When the production management system receives the information of the end of the parts processing, the parts are rinsed and cleaned by the cleaning equipment, and the parts are detected by the online detection equipment, and the results are fed back to the production management system.

13) When the parts are qualified, the equipment door opens automatically, and the loading and unloading manipulator loads the tray into the tray library.

14) When the parts are not qualified, the production management system automatically determines whether manual intervention is needed according to the unqualified situation:

A,the need for manual intervention, the system automatically alarms, the device automatically opens the door, the loading and unloading manipulator will load the tray into the loading and unloading station, by manually removing the fixture in other equipment for supplementary processing;

B,without manual intervention, the system automatically adjusts the tool parameters according to the measurement results.

15) The automatic manufacturing process of the casing processing unit is completed.

2.3 Determine FMC station

Before selecting equipment, it is necessary to calculate the cell production rhythm to determine the number of production equipment in the cell[5]. The calculation formula of production rate is:

$$\text{Production beat time } T_e = \frac{\text{planned effective production time } T_p}{\text{planned output N}} \tag{1}$$

According to the requirements of the production task provided by Enterprise N, the annual output of the flexible manufacturing cell of aluminum magnesium casing after being put into production should not be less than 900 pieces, and the qualification rate is 85%. The cell works six days a week, and the cell is produced in two shifts, that is, 16 hours a day. Assumed equipment efficiency: $\eta_{m_i} = 100\%$, flexible cell utilization: $\eta_u = 100\%$. Bring the data into Formula 1 to calculate the production beat time:

$$T_e = \frac{52 \times 6 \times 16 \times 60}{(900 \div 85\%)} = 282.57 \text{ min/ piece}$$

In the flexible manufacturing cell of aluminum magnesium casing studied in this paper, due to the technological characteristics of aluminum magnesium casing, a machining center can complete multiple processes, that is, a machining center is a station, and the station design is completed, that is, the number of machining centers responsible for workpiece processing in the cell is determined. In order to ensure the continuous movement of the workpiece between the machining centers, the number of machining centers should be equal to the ratio of the total operation time to the cell production beat time. The calculation formula for the number of cell equipment is shown in Formula 2:

$$\text{Number of equipment m} = \frac{\text{total processing time of workpiece process}}{\text{production beat time } T_e} \tag{2}$$

According to the calculation of the process duration of the Al-Mg casing parts to be processed by the cell, we select the total process duration of the starter casing with the longest processing duration among the four Al-Mg casing parts to be processed, and calculate:

$$m = \frac{986.6 \text{ min}}{282.57 \text{ min}} \approx 3.49 \text{ sets}$$

Rounded up, the number of cell equipment is m=4, so a total of 4 machining centers are required in the manufacturing cell to complete the processing of aluminum magnesium casing parts. Generally, the equipment load factor K is used to evaluate the rationality of the cell equipment quantity. The equipment load factor is an evaluation index of the equipment usage. It is generally believed that if K is greater than 0.75, the cell can carry out continuous production and the quantity setting is reasonable; If K is lower than 0.75, it is considered that the equipment quantity setting is unreasonable, and intermittent production should be adopted. The calculation result of equipment load factor of this cell is:

$$\text{equipment load factor K} = \frac{3.49}{4} = 0.8725 > 0.75 \tag{3}$$

According to the calculation results, the manufacturing cell rhythm and the number of processing equipment designed in this paper are reasonable.

In the manufacturing unit of aluminum-magnesium casing, the processing equipment determined by the processing technology of aluminum-magnesium casing itself shall be removed, and the operation platform, cleaning machine and loading and unloading station shall also be included. In order to reduce the floor area, the central tool magazine and tool transport manipulator in this unit adopt truss structure and are arranged above the machine tool, so they do not occupy the station. To sum up, 7 stations are required in this unit, consisting of 4 processing equipment, 1 loading and unloading station, 1 cleaning station and 1 operation platform.

2.4 Equipment selection of FMC

1) Processing equipment. Because a large number of turning and milling processes are involved in the processing of Al-Mg casing parts, and the part surface is inclined with a certain angle[6], when selecting the processing equipment, the first equipment to be determined is the five-axis machining center. Considering the processing experience, equipment precision and equipment price of similar equipment, this paper selects THM6363 IV precision horizontal five-axis machining center, JM50m turn-milling complex machining center is used as the main processing equipment to build the casing manufacturing cell.

2) Material transportation robot and guide rail. The aluminum magnesium casing parts produced by this manufacturing cell are about 10kg, plus the tray and tooling fixture, the robot load can reach up to 100kg. According to the determined size of the machining center, the working height range of the robot and the operational space range of the workpiece transportation, the robot is required to have a maximum operating radius of at least 1000mm on the x-axis, and the robot's repeated positioning accuracy shall not be greater than ± 0.03mm. Considering the above conditions, the material transport robot finally selected in this paper is the LS500 robot. The robot is equipped with RFID reading and writing

system, which can realize the reading and writing of tray information and the tray exchange between the tray warehouse and the equipment.

3) Loading and unloading station. A dual-station loading and unloading station can load and unload two parts at the same time. Four positioning sleeves are distributed on the loading and unloading platform for the positioning of pallets. The loading and unloading station is equipped with a dial gauge clamping bracket. The bracket is of three-section type, and the three sections can be flexibly adjusted. The length of the vertical bar (over the table) is 600mm, the length of the horizontal bar is 400mm, and the length of the small vertical bar is 500mm. The loading and unloading station has good dust isolation and sealing performance, which can prevent the impact of excess on the accuracy of the loading and unloading station. The loading and unloading platform surface is driven and rotated by the motor, and the operator can control the start and stop by the pedal.

4) Pallet magazine. The tray silo adopts a steel frame double-layer structure, which can load 24 pallets. The size of a single tray silo is: long × wide × Height: 900mm × 900mm × 2000mm。 The weight of a single tray library is 150kg, and it is equipped with a waterproof mechanism, which can collect the coolant into the water pan to keep the processing area clean.

5) Zero positioning tray. According to the aluminum magnesium casing parts and their clamps to be clamped, determine the size of the zero positioning tray as Φ 630mm, the tray accuracy is 0.01mm. The tray positioning mode is high-precision four-cone pin over-positioning, and equipped with an air blowing device for cleaning the cone pin positioning surface, which makes the positioning accuracy more accurate. In order to further improve the rigidity of the worktable, the tray uses the four-cone pin built-in cylinder locking mode, so that the locking point and the positioning point coincide.

6) Central tool magazine and tool loading and unloading station. The main body of the central tool storage adopts a truss structure, which is located on the upper part of the machine tool and can improve the transportation efficiency. There are 120 tools in the tool storage, and the specification of tool handle is HSK63A. The tool transport manipulator adopts a truss structure, which can transport one tool at a time. The tool transport manipulator is equipped with RFID reading and writing equipment to read and write tool RFID information.

7) Washer. The equipment includes washing host, 360-degree automatic spray cleaning system, liquid storage tank and circulating filtration system. It can remove impurities and machining residues on the surface of parts and meet the requirements of cleaning and drying of aero-engine casing.

8) Protective system. The cell is equipped with a fence to avoid accidental intrusion and accidents when the single material transport robot is carrying out transportation activities. A protective door is installed on the fence for solving problems in the production line and maintaining the production line. When the equipment breaks down or requires maintenance, personnel can enter the cell through the protective door.

After determining the number of processing equipment and stations in the cell, this section completes the selection of main equipment in the cell, including processing system, logistics system and auxiliary system. The determination of the model and quantity of equipment in the cell lays the foundation for the layout of facilities in the cell in the next step.

3. LAYOUT DESIGN OF FMC FOR ALUMINUM MAGNESIUM CASING

3.1 Establishment of mathematical model

1) Objective function

The research object of this paper is the flexible manufacturing cell of aluminum-magnesium casing, and the workpiece transportation path in the cell is a straight line. Therefore, this paper chooses the minimum material handling cost as the optimization objective, and E represents the logistics cost, and the objective function expression is:

$$\min E = \min \sum_{i=1}^{m} \sum_{j=1}^{m} e_{ij} Q_{ij} (| x_i - x_j |) \tag{4}$$

2) Constraints

The model built in this paper mainly considers hard constraints, including the following two aspects[7]:

Equipment coincident constraints. The equipment placed in a straight line should meet the minimum safety distance requirements to ensure that there is no interference between the equipment and avoid affecting the normal operation of the cell.

$$\frac{1}{2}(l_i + l_j) + d_{ij} \leq |x_i - x_j| \tag{5}$$

$$y_i = y_j \tag{6}$$

Shop size constraints. The casing production workshop contains more than one aluminum magnesium casing manufacturing cell, so it is necessary to complete the equipment layout within the given range, so that the overall size of the cell does not exceed the given space.

$$\frac{1}{2}(l_i + l_j) + |x_i - x_j| \leq L \tag{7}$$

$$W_i \leq H \tag{8}$$

Minimum safety distance. The equipment in the cell must ensure the minimum distance, namely $d_{ij}>0$。

3.2 TS algorithm design for linear layout of cell

1) Coding and initial solution. In this paper, when solving the single-line linear layout model, the decimal sequence coding is used. The constructed cell includes 2 turn-milling compound machining centers, 2 horizontal five-axis machining centers, 1 dual-station loading and unloading station, 1 washer and 1 quality inspection station, a total of 7 stations, and the coding form is 1-2-3-4-5-6-7. The initial solution is determined by heuristic method.

2) Neighborhood structure and candidate solutions. When constructing neighborhood, neighborhood U is divided into two parts[8]: left neighborhood L and right neighborhood R: left neighborhood L is used to place excellent solutions and complete centralized search; The right neighborhood R is used to place random solutions for diversity search to avoid falling into local optimum. $U=L\cup R$。

3) Fitness function

Since the objective function used in this paper is the maximum logistics cost, the optimization objective is to minimize the logistics cost. The fitness function constructed is shown in Formula 9:

$$\text{fitness} = \frac{1}{\text{Alpha} \times s_t + E} \tag{9}$$

4) Taboo object, Taboo table, Taboo length. The taboo object selected in this paper is to exchange the positions of two devices and put them in the taboo table. According to the scale of the problem studied in this paper, the tabu length T=7 is determined.

5) Flout the Code and terminate the Code. The contempt criterion used in this paper is the criterion of selecting fitness function. When all candidate solutions are tabu, release the best state tabu object in the tabu table to solve the optimal solution. The termination criterion used in this paper is the maximum number of iterations. When the maximum number of iterations is reached, the algorithm stops.

3.3 Model solving

According to the logistics volume of the parts provided by the enterprise between the equipment, the handling cost between the equipment, the size of the equipment in the cell and the minimum safe distance matrix between the equipment[9], as well as the mathematical model established above, the tabu search algorithm is used to solve the problem. First, use the insertion method to find the initial solution through the equipment number, and use MATLAB 2020a as the tool to program, set the tabu length:T=7, and the maximum number of iterations:I=200。 After calculation, the algorithm calculates the best objective function value at the 54th iteration as E=22693, that is, the minimum maximum logistics cost is 22693. The optimal layout of the equipment is P=[7, 5, 2, 3, 4, 1, 6].

4. RESULT

According to the solution results, the position of each processing equipment can be determined preliminarily. According to the results of the field survey, combined with the minimum safety distance between the equipment and other information, the actual layout of the flexible manufacturing cell of the aluminum magnesium casing is determined, and the cell layout is shown in Figure 2.

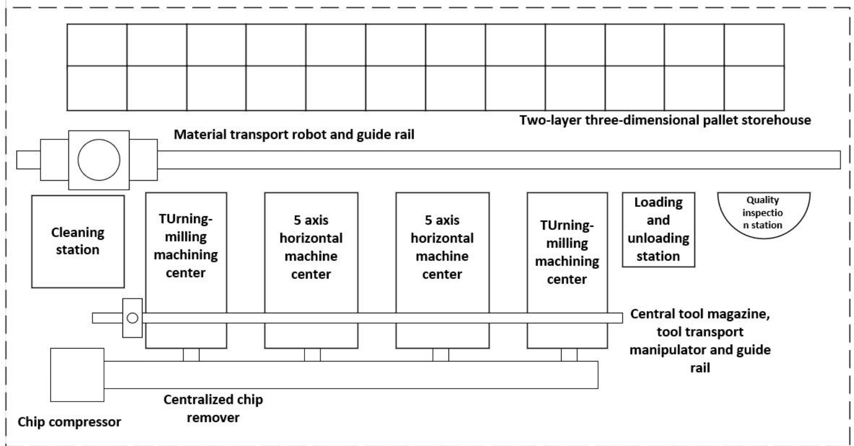

Figure 2. Layout of flexible manufacturing cell for aluminum magnesium casing

The flexible manufacturing cell of aluminum magnesium casing completed in this paper is composed of two turn-milling composite machining centers, two horizontal five-axis machining centers, one automatic loading and unloading logistics system (including material transportation robot, material warehouse, loading and unloading station), one set of tool magazine system (including tool loading and unloading station, central tool magazine and tool transportation manipulator) and production management system, which can realize the mass processing and manufacturing of aluminum magnesium casing parts, and the cell covers an area of 32m × 10m, (6m high) about 320 square meters.

5. CONCLUSION

The construction of the flexible manufacturing cell for aluminum magnesium casing has realized the mixed production of multiple types and multiple processes of the casing parts, which can effectively improve the production efficiency and the controllability of the production process[10]; At the same time, the machining quality of aluminum magnesium casing parts is improved. The flexible manufacturing cell of aluminum magnesium case is an important research direction for traditional case manufacturing workshop to move towards automation, digitalization and intelligence, and has great significance for promoting the transformation of traditional case manufacturing workshop to digital workshop.

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