Research on key technology of intelligent production line of aircraft structural parts based on intelligent manufacturing

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Abstract. The rapid development of new generation information technology and artificial intelligence and its integration in the manufacturing field have spurred advanced manufacturing countries to actively explore the development strategy of intelligent manufacturing, in order to realize the interconnection and interoperability of manufacturing processes and life cycle data. And the dynamic optimization of decision-making, ultimately achieving manufacturing automation, flexibility, intelligence, and synergy. Starting from the characteristics of intelligent manufacturing, combined with technical practice and theory, it mainly analyzes the key technologies of intelligent production lines for aircraft structural parts to improve the intelligent manufacturing of aircraft structural parts, from equipment technology, intelligent production technology, intelligent production execution technology, intelligent management technology. In one aspect, the technologies involved in the production line are interpreted, namely, data acquisition technology, intelligent equipment technology, intelligent process design technology, production line modeling and simulation technology, production line maintenance guarantee technology, and intelligent management and control technology.

1. Introduction
Intelligence mainly includes three aspects, namely, perception, thinking ability and behavior ability. Artificial intelligence [1] refers to the intelligent behavior exhibited by the "machine" made by human beings, that is, using mechanical and electronic equipment to imitate, extend and expand human intelligence, and carry out intelligent activities such as solving, reasoning, analysis, decision-making, etc. To make the machine capable of complex tasks that usually require human intelligence to complete [1-2].

Aircraft structural parts belong to many varieties and small batches of production. The requirements for processing, parts precision and product customization are high. Building intelligent production lines is the only way for aviation companies to realize small-volume customized processing of aircraft structural parts. The intelligent production line can store, extract, analyze and process various manufacturing data such as process and tooling, as well as process data such as operating parameters and operating status of the equipment, and adjust the operating parameters of the equipment and monitor the health status of the equipment in real time through analysis of the data.
According to this, fault diagnosis, maintenance alarm and other behaviors can be carried out. For the case that it is difficult to handle automatically in the production line, it can be transmitted upward to the central control system of the workshop [3-4].

2. Research Status of Intelligent Production Line Technology and Domestic and Foreign Gap

2.1. Research Status of Intelligent Production Line Technology

Since the introduction of intelligent manufacturing, intelligent production lines have become the key development direction of domestic and foreign aviation companies. Domestic and foreign aviation companies have introduced a large number of automated flexible equipment to prepare for the development of digital, automation, flexible and intelligent production lines, and in order to comply with the pace of development, aircraft structural parts production represented by flexible automated production lines has begun at home and abroad Mode [5].

For the JSF35 aircraft, the United States Loma Company has built a cockpit production line based on measurement technology and processing integration technology to realize the automated production of large and complex military parts. The German AER-OTECH company has established a flexible production line to realize the flexibility of multi-variety and large-volume civil aircraft parts. Production equipment utilization rate of up to 90% [6].

2.2. Intelligent processing line challenges

For aircraft structural parts, its processing characteristics are typical small batch and multi-variety production, and the automation and intelligence level of China's equipment has not been high for a long time. Therefore, the challenges faced by China in the realization of intelligent production lines for aircraft structural components are as follows:

- Logistics: The level of automation and intelligence is low. There are not many warehouses and automated warehouses. The material distribution at the production site and the automation of material transfer between processes are low.
- Equipment: The level of digitization and intelligence is not high, and the networking rate is low, which seriously hinders the construction of digital and intelligent production lines.
- MES: The proportion of workshops implementing MES is low, resulting in extensive workshop production operations, uneven equipment load, and poor material supply coordination. There is also confusion in the material management of the workshop and poor monitoring of the progress of the workshop.
- Data: Data collection is seriously insufficient, and information such as production schedule, part quality status, equipment operation status, and material distribution status cannot be timely feedback, resulting in low transparency and visualization of the entire production system.
- Integration: The integration of the system is poor for automated production lines.

Combining the intelligent production line that has been implemented and the existing problems in the manufacture of aircraft structural parts in China, this paper mainly studies the key technologies of intelligent production lines based on the characteristics of intelligent manufacturing of aircraft structural parts.

3. Key technology of intelligent production line for aircraft structural parts

The key technologies involved in the construction and operation of intelligent production lines include: data acquisition technology, intelligent equipment technology, intelligent process design technology, production line modeling and simulation technology, production line maintenance guarantee technology, and intelligent management and control technology. These key technologies are an important part of Cyber physics system technology and are the core technology for building self-organizing, self-learning, adaptive and self-optimizing production systems.
3.1. Intelligent Equipment Technology

Intelligent equipment [3] mainly includes intelligent machining centers, intelligent robots, intelligent control devices and detection systems, sensor identification and information acquisition devices, intelligent decision-making units and intelligent logistics systems. It is the movement, power, torque, and Real-time monitoring of information and other conditions, and based on advanced technology for autonomous decision-making and adaptive control. Intelligent equipment is based on numerical control equipment, which enables self-sensing, self-learning, self-decision, self-execution, self-adaptation and other functions to achieve integration and deep integration of next-generation information technology and advanced manufacturing technology [7].

![Intelligent device technology integration system](image)

In the intelligent processing of aircraft structural parts, we focus on building automation, flexible, intelligent production lines, intelligent control systems, etc., to achieve automation, digitization and intelligence of the production process, and to improve the manufacturing level of the machine-added production line [8]. The intelligent equipment set will perform the conversion and processing of various equipment communication protocols. Intelligent equipment integration mainly realizes two functions: First, real-time collection and transmission of equipment operation status, energy consumption information, logistics status, production schedule and quality information in the manufacturing process, so as to ensure that the upper-level workshop management information system such as MES can grasp the workshop in time. The production situation; the second is to reach the equipment layer under the control command of the upper management information system through the on-site network of the workshop. The intelligent equipment information interaction of aircraft structural parts is shown in Figure 1.

![Aircraft structural parts intelligent equipment information interaction](image)

In general CNC machining centers, data cannot be directly shared between processing equipment. Once a processing operation is issued, once a
processing equipment fails, the entire operation plan cannot be successfully completed; and the intelligent processing system can sense the processing status and equipment status in real time. In the event of a failure, feedback and decision-making will be made, and communication will be associated with other relevant intelligent machines to redistribute operations as quickly as possible, with the utmost effort to ensure that the production is carried out smoothly. Therefore, the intelligent machining center and its environment are required to perform knowledge sharing and negotiation on the work tasks, and it is possible to smoothly obtain or transmit relevant information from the other party.

2) Robot technology: Based on traditional robots, intelligent machines embed perception, decision, effect and other functions, and simulate human machine systems in behavior, emotion and thinking [10]. They have a fairly well-developed "brain" that can listen to human instructions, perform tasks according to procedures, interact with people friendly, and continuously learn and improve in the process of interaction. Technically, robot technology evolves from traditional industrial technologies such as controllers, servo motors, and reducers to artificial intelligence technologies such as computer vision, natural language processing, and deep learning. In applications, robots are used from industrial users to commercial, home, and personal. The gradual promotion of other fields will be more deeply integrated into human society; in terms of human-computer interaction, human beings and robots will be separated from each other and developed into full human-machine collaboration and interaction [11].

3) Data acquisition device: Data is a kind of signal that transmits signals. The action command is determined based on the judgment of the "signal". The manufacturing process data is collected by the execution unit and parsed and processed by the intelligent decision unit and encapsulated and transmitted via the data interface. Manufacturing process data mainly includes equipment operation records, product manufacturing data, and fault maintenance records.

4) Intelligent control device and detection system: The control device of the intelligent production line can store, extract, analyze and process all kinds of manufacturing data such as process and tooling, as well as process data such as operating parameters and running status of the device, and can pass data to Analyze real-time adjustment of equipment operating parameters, monitoring equipment health status, etc., and perform fault diagnosis and maintenance alarms accordingly. Real-time analysis can realize the analysis of the perceived state information, and realize the analysis and calculation of position deviation, I/O abnormality, abnormal working condition and workpiece error; the decision-making process makes decision-making according to the analysis result, realizes position compensation, Autonomous processing decisions such as working condition analysis, parameter adjustment, and processing instruction adjustment; and related control based on decision results in precise execution.

5) Intelligent decision-making unit: The intelligent decision-making unit is the core component of the intelligent device. It is used to complete the device operation process control, operation parameter calculation, device detection and maintenance, etc. during the operation of the device. From the business logic, the intelligent decision-making unit encapsulates the automatic operation. The control system, the process parameter optimization system, and the equipment health monitoring and maintenance system, from the business implementation level, the intelligent decision unit includes a logic control unit and a numerical operation unit.

6) Intelligent logistics system: Intelligent logistics system is to improve the automation and intelligence level of logistics system through intelligent technologies and means such as big data, cloud computing and intelligent hardware. The intelligent logistics system mainly achieves two objectives. One is interconnection and data-driven, that is, all logistics elements are interconnected and digitized, and “data” is used to drive all perceptions, decisions, and actions. Second, deep coordination and efficient execution, that is, integration is different. The deep coordination between enterprises and factories, based on the global optimization of intelligent algorithms, scheduling the various modules in the entire logistics system to work together efficiently.
The key technologies extracted from the technical aspects of intelligent equipment: data acquisition technology and intelligent equipment technology.

3.2. Intelligent production technology

In the production of products and parts, the manufacturing process is the method and process of transforming raw materials into finished parts by using processing equipment, processing tools, human skills, etc. It is also based on human intelligence and physical labor to transform the design drawings and their technical requirements into The knowledge and ability of the actual product. The intelligent production process function module mainly includes ten modules of process database management, process feasibility assessment, process review, process plan formulation, process planning, process design, process analysis, process simulation and optimization, manufacturing instruction generation, and process intelligent decision making. Figure 2). The process data management module will import data from the CAD system, manage the input products, parts, resource models, and production data in a distributed manner, and unify and manage the data in different formats and types [12]. Review the technicality of specific components, exchange feedback with the design department, and make changes to the unreasonable 3D model. The process plan development module will create a PBOM based on the design of the 3D model, reorganize the parts according to the process, determine the special materials, special processing methods, and the standards and basic specifications of the design process, production, quality, testing, etc. The process planning module is the process of continuously enriching the PBOM. Mainly to process the division of the process and the allocation of resources, the main work of the process planning module is summarized as: "fix the benchmark, the process, the allocation of resources, the parameters." The process design module is mainly for the establishment of the process model, and needs to complete the blanking guidance documents, the operation instructions of the process, the clamping guidance documents, the tooling combination guidance documents, and the numerical control programming.

Figure 2. Intelligent production process function module

1) Intelligent process design: Intelligent process design includes two aspects: first, process design process is explicit, process and modular; second, process design activities are intelligent and closed-loop. Simulation verification and closed-loop optimization of the process design to achieve knowledge integration process and knowledge integration into the design. The process design method based on full digital expression, intelligent recognition of MBD model and information acquisition and processing capability is used to realize knowledge-driven decision-making and optimization of integrated process design [13]. In the intelligent process design, it mainly includes four aspects: feature processing plan decision, resource selection decision, process order division, cutting parameter decision, and Figure 3 shows the intelligent process design method. Based on the processing feature information as the main entrance, the processing method corresponding to the processing features is extracted from the rule base, and the feature-based processing method is formed based on the
information matching of feature type, precision and roughness. On the basis of obtaining the feature processing scheme, it is necessary to carry out process activities such as resource selection decision, process sorting and division, cutting parameter decision, etc. Since the resource selection decision and the process ordering are mutually constrained and interact, it is necessary to make parallel decision, which can be judged according to the definition. Standards to meet the process's preference, in the decision-making, through the constraints of the process constraints and integrated information model, the selection of resources and the ordering of processes in units of processing units. The selection of the cutting parameters is usually the parameter information such as the cutting depth, the cutting speed and the feed amount obtained according to a certain target under the condition that the machining requirements are guaranteed and the resource conditions such as the machine tool and the tool are known. After completing the four steps of intelligent process design, the final process design information is obtained to form a complete process route.

2) Manufacturing instruction generation: based on part features and process knowledge base, automatically select appropriate processing equipment, tools, tooling and other manufacturing resources, automatically generate part processing methods, machining trajectories, machining strategies, machining instructions, and automatically generate according to processing equipment and tools. The optimized cutting parameters based on the rule knowledge base is the key to the adaptive processing of the production line. The automatic detection path planning based on part detection features is realized by using part digital model. For complex parts, high-precision and high-speed on-machine measurement can be realized, and the surface size and shape tolerance of parts can be accurately obtained, and the test results can be feedback and intelligently analyzed in real time.

3) Process simulation optimization: With the aid of machining simulation analysis tools, through simulation verification and optimization, to obtain the optimal processing technology plan, based on the intelligent decision-making push in the decision-making knowledge base, quickly infer and predict the defects of the parts manufacturing process, and achieve the precise execution of the manufacturing process.

4) Process intelligent decision-making: establish a process decision knowledge base including process design, CNC machining process decision rules, etc., combined with process design knowledge,
CNC machining strategy, tool cutting parameters, tooling/tooling/equipment/machine tool manufacturing resources, process design, CNC Intelligent process design such as programming, process simulation, inspection, assembly, etc. Process intelligent decision-making is based on process knowledge and resource library, facing new process requirements, adopting appropriate process reasoning methods, and simulating the human thinking reasoning process in the process of process design to construct an optimized manufacturing process. The key theories and methodologies involved in process intelligent decision making include process knowledge reasoning and process parameter optimization. Under the support of these technical foundations, rapid process decision-making based on templates can be realized, and intelligent process decision-making combining process templates and manufacturing resources can be further realized.

The key technology extracted from the technical aspects of intelligent production technology: intelligent process design technology.

3.3. Intelligent production execution technology

The whole process of production intelligence is to interconnect and integrate the data of “human, machine, material, law and ring” to form a complete closed-loop system, through the collection, transmission, analysis and decision making of the whole process data. Optimize resource dynamic configuration and improve product quality control. The intelligentization of the whole process of production requires enterprises to have a good foundation in personnel, automation equipment, equipment connection, and environmental awareness. On this basis, the key work of the whole process of intelligent production is to open up various data streams, including data flow from production planning to production execution (ERP and MES), data flow between MES and control equipment and monitoring equipment, and on-site The flow of data between the device and the control device. By realizing the interconnection of data streams, the implementation process will be more transparent and concise, and the application of data flow for design and manufacturing will be realized by using advanced intelligent technology to realize intelligent production execution. Figure 4 shows the production process control function model.

![Figure 4. Production process control function model](image-url)
the process flow, personnel operation, equipment operation status and various production decision data models in actual production. The logic model can realize the control of the production line simulation and the input and output of the data flow, ensuring that the model operation conforms to various conditions in the actual production; then the simulation analysis of the overall layout of the production line and the logistics system, and the production capacity of the production line can be analyzed based on the simulation of the production line model. According to the data, the bottleneck, production capacity, fault distribution and other indicators of the production line are judged according to the data, and the data is optimized for further optimization of the production line. Therefore, the production process is evaluated before the production line is put into production, the process route is verified, the layout design is measured, the resource allocation is optimized, the production capacity and utilization rate are improved, the productivity is improved, the energy saving is enhanced, and the production flexibility is improved.

2) Intelligent plan management: Undertake ERP production plan, apply advanced scheduling technology, meet the needs of multiple varieties, small batches, and frequent changes in production lines, and analyze the matching between production plan and production schedule in real time, when abnormal conditions occur (such as Material shortage, etc.) Enter the automatic calculation mode to dynamically schedule the current task queue to minimize the impact and impact of production changes on the plan.

3) Intelligent Manufacturing Execution: Through production site information terminals, production workers can know what to do, how to do, what to do, and how to do it in an integrated way; some typical CNC machining parts based on working conditions, rapid decision making and on-machine process The detection can be adaptively processed; the production management personnel can timely understand the operation of the production site through the intelligent management and control platform, as shown in the figure.

4) Just-in-time material distribution: Through the association management of production planning and materials, automated feeding equipment delivers materials to the required locations at the required time.

5) Automatic material clamping: The robot is controlled by the PLC to transport the parts on the upper station to the processing station. The intelligent tooling realizes automatic positioning and clamping. After the parts are processed, the intelligent detection is performed, and the handling robot completes the blanking operation of the parts.

6) Intelligent detection: automatically generate the main measurement program by acquiring the identified features of the part to be inspected, determine the measurement trajectory, the number of measurement points, the layout of the measurement points, and compensate the error generated by the measurement process in real time, and complete the measurement of the main program and the called macro program. Sending and receiving coordinate information of the measuring point; based on the on-line detection and simulation of the numerical control machine tool, analyzing the position information of the contact point between the measuring head and the part to be tested, and checking the detection path through simulation, and continuing the processing after correcting the program error. The machining process is based on the internal inspection of the parts on the CNC machine tool to realize the self-sensing machining allowance during the machining process, and adaptively adjust the machining allowance to ensure the machining stability and machining quality.

7) Production line maintenance technology: Production line maintenance and support technology begins with equipment reliability assessment and preventive maintenance and equipment fault diagnosis and early warning [4]. Predictive maintenance quickly captures information from multiple systems such as critical equipment sensors, enterprise resource planning systems (ERPs), computer maintenance management systems (CMMS), and production data. After processing, analyzing, and visualizing the signal, you ultimately need to convert the analysis into behavior. Or intelligent production lines with higher integration and capacity requirements, single-point failures and unplanned shutdowns may lead to overall flaws in the production line, so intelligent maintenance technology is an important technical means to ensure the operation of the production line. The
maintenance support of the production line includes online monitoring, fault diagnosis and early warning for a single device, as well as statistics, analysis and optimization for the overall operation of the production line. Intelligent maintenance is an active on-demand monitoring and maintenance mode, which needs to focus on intelligent prediction and maintenance optimization of information analysis and performance degradation.

The key technologies extracted from the technical aspects of intelligent production execution: production line modeling and simulation technology, and maintenance support technology for production lines.

3.4. Intelligent management technology
The operation of the intelligent production line is characterized by flexibility, self-adaptation and self-decision. The intelligent management of the production line includes intelligent scheduling, automatic delivery of material tools, instant push of manufacturing instructions, and real-time collection and processing of manufacturing process data. The definition of decision-making rules supporting intelligent production and accurate real-time collection of decision-making basis are the basis for the normal operation of intelligent production lines; dynamic production scheduling based on production line resource occupancy, production plan execution feedback and production plan adjustment It is the prerequisite for ensuring the normal operation of the production line. For the production line with high degree of automation, the synergy between human and machine in the production process, such as material distribution, clamping, process inspection, etc., the synergy and integration of possible artificial links and equipment automation production is the key to ensure on-time production, and production The error prevention and quality assurance measures of the link, online detection of intelligent, and the real-time accurate collection and processing of detection data can effectively improve production efficiency and quality [4]. In addition to the integration of production line materials, personnel, equipment and tools, and the integration of information flow and logistics, the production line intelligent management and control system must also realize information interaction and integration with workshop-level information systems and enterprise-level information systems [13].

1) Production line command and dispatch center: Intelligent dispatching refers to the use of artificial intelligence technology, relying on intelligent equipment with independent perception, learning, analysis, decision-making and coordinated control, combined with the Internet to carry out dynamic collaborative adaptive management activities of manufacturing enterprises [13]. The production line command and dispatch center is oriented to the production task. Through the comprehensive analysis of the processing capacity of the production line and the product process characteristics, the production task is balanced. The command and dispatch center of the production line is the bridge of the entire production line. From the production task of the management to the production and processing of the execution layer, the operation route of the production line and the real-time status are operated under the control of the dispatch center.

2) Intelligent decision-making in production line: The decision-making system consists of a language system and a problem-solving system, consisting of a database management system and a database, and consists of a model library management system and a model library. The knowledge base is an important part of intelligent decision-making. It consists of three parts: knowledge base management system, knowledge base and inference engine. Through intelligent management of production lines, customized information sharing and interaction paths can be provided for leaders, process personnel, production planners, equipment maintenance personnel, etc. according to personnel role constraints, thereby providing decision support for the precision and transparency of the production process.

3) Information sharing and interaction: The resource layer provides equipment, technology, knowledge resources, all data information and resource information in the process of processing and production process and the management layer in the production process. On the server side, the enterprise management layer can upload the work tasks, equipment resource information, parts
assembly drawings and other data to the server, and have a unified management of the server, which is uniformly sent to the information terminal, for example, the task of the production workshop is issued, as long as The enterprise manager uploads today's tasks to the server, so the client can download the task processing book, the task processing drawings and the technical requirements of the processing from the server by applying. After the processing is completed, the production workshop producer can transmit the processing information to the server, and the upper management can understand the processing information at any time. Realized the informatization of processing tasks from management to production level [14].

The key technology extracted from the intelligent management technology level: intelligent management and control technology.

4. Summary
With the application of a new generation of information technology and artificial intelligence in the manufacturing field, the manufacturing industry is developing in the direction of intelligence, synergy, transparency and green. Germany proposed Industry 4.0, the United States proposed intelligent manufacturing, and the key technologies of intelligent manufacturing have developed rapidly. They all paint a beautiful blueprint for the future manufacturing plant. Smart Manufacturing in the United States emphasizes the information physics fusion system, while German Industry 4.0 emphasizes the Internet of Things technology and sees the future factory as an IoT plant. This paper firstly describes the development status and challenges of intelligent production lines. Secondly, through the four aspects of equipment technology, intelligent production technology, intelligent production execution technology and intelligent management technology, the intelligent production line technology involved in the production line is interpreted. From the perspective of extracting the key technologies for implementing intelligent production lines, namely data acquisition technology, intelligent equipment technology, intelligent process design technology, production line modeling and simulation technology, production line maintenance guarantee technology, and intelligent management and control technology.

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