Application and research of intelligent manufacturing in the aerospace manufacturing industry

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Abstract: In recent years, to promote the integration of industrialization and informatization in China's manufacturing industry, intelligent manufacturing technology has received widespread attention. The aerospace manufacturing industry, as the top end of the equipment manufacturing industry, is also facing the transformation to intelligence. This paper takes the key technology of aerospace intelligent manufacturing as the starting point, introduces the technical connotation and application direction of the digital clue, cyber-physical system (CPS) and intelligent artificial enhancement respectively, and also introduces the key process of intelligent manufacturing in aerospace manufacturing application, which provides reference for enterprises to realize intelligent transformation.

1. Introduction

Intelligent manufacturing is the product of the deep integration of industrialization and informatization. Currently, the Chinese government is promoting the strategic plan and action plan of "Made in China 2025", which should seize this favorable opportunity to build aerospace intelligent manufacturing based on the existing digital network design/manufacturing, and improve the overall capability and level of China's aerospace manufacturing industry[1].

As a typical high-tech industry, the aerospace manufacturing industry is at the top end of the advanced equipment manufacturing industry, with high technology content, large market capacity, extensive industry coverage, and other characteristics. It represents the development level of a country's overall manufacturing industry. The progress of the national aerospace manufacturing industry has greatly contributed to the construction of the national economy, the acceleration of national defense modernization and social science and technology forward, and the improvement of the country's comprehensive national power. Therefore, contemporary countries in the world, especially the developed countries are sparing no effort to develop the aerospace industry. After more than 60 years of hard struggles and independent innovation, China's aerospace manufacturing industry independent industrial system has been constructed, and its development speed and achievements have attracted worldwide attention. In recent years, China's aerospace industry has entered a period of rapid development, and the level of aerospace research and production has developed by leaps and bounds. However, with the rise of intelligent manufacturing technology, the manufacturing industry needs to transform and upgrade from automation to intelligence. And China's aerospace manufacturing industry also ushers in a more demanding challenge [2] [3].

With the continuous development of aviation products, the manufacturing technology of aviation products is also changing and progressing. In order to meet the high demand of aviation enterprises for the increasing development of products, new technologies must be actively introduced and developed [4] [5]. Intelligent manufacturing technology is the inevitable development trend in the field of machinery manufacturing, which means that mechanical equipment autonomously drives and controls the mechanical equipment original parts, and automatically controls the mechanical production system[6] [7].

At present, the global manufacturing industry is forming intelligent manufacturing systems around value relationships to achieve intelligent transformation [8] [9]. Intelligent manufacturing technology integrates disciplines and technologies such as artificial intelligence, flexible manufacturing, virtual manufacturing, system control, network integration, information processing. It is an important way for the transformation and upgrading of traditional industries to realize the automation, intelligence, leanness and greenness of the manufacturing process by intelligent equipment, intelligent control, and intelligent information man-machine integrated manufacturing system [10]. Therefore, intelligent manufacturing has become one of the main directions of the new round of industrial technology change in China's aerospace manufacturing industry. This paper takes three core technologies of intelligent manufacturing as the starting point and introduces the application direction of intelligent manufacturing technology in the aerospace manufacturing industry.

2. Overview of aerospace smart manufacturing technology

Smart manufacturing refers to a system formed by manufacturing-related links, activities, and resources, whose main parts have the ability of autonomous sensing, learning, analysis, decision-making, and coordination control capabilities, and can dynamically adapt to the changes in the manufacturing environment to achieve the corresponding goals [11]. At present, according to the development process and characteristics of aerospace products, after analyzing the requirements of aerospace manufacturing for intelligent manufacturing, a preliminary intelligent manufacturing architecture model with aerospace characteristics is initially formed, as shown in Fig1 This architecture model is proposed to establish an intelligent manufacturing system with the characteristics of dynamic perception, real-time analysis, autonomous decision-making and precise execution at four levels, including enterprise alliance, enterprise management, production management, and control execution. Note that this model is mainly to establish a new manufacturing model with dynamic perception, real-time analysis, autonomous decision making, and precise execution. Among them, dynamic perception refers to the comprehensive perception and monitoring of the real-time operational status of the supply chain, enterprises, production lines, equipment, and products. Real-time analysis is a timely and rapid analysis of the collected real-time operating status data. Autonomous decision-making is to make judgmental decisions independently according to the set rules and based on the analysis results. Precise execution is to execute the decision and control the operation of products, equipment, production lines, enterprises, and supply chains to achieve adaptive adjustment.
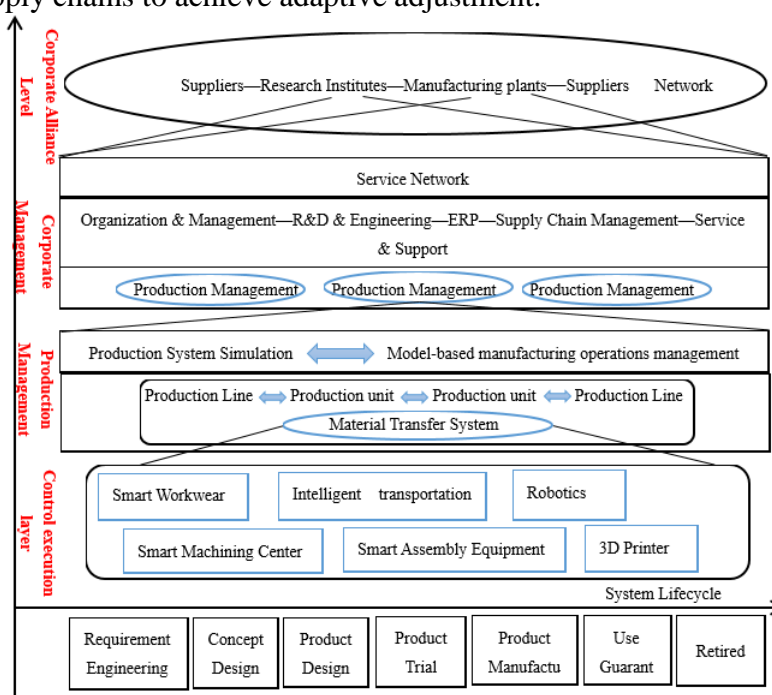

Fig 1. Aerospace intelligent manufacturing architecture model.

3. The application of intelligent manufacturing in aerospace manufacturing

The key technologies of intelligent manufacturing mainly include identification technology, real-time positioning technology, information-physical fusion technology, cybersecurity technology, and system collaboration technology [12]. According to the manufacturing characteristics in the aerospace field, aerospace intelligent manufacturing technologies can be summarized into three types of core technologies, namely, Digital Thread technology, Cyber-Physical Production Technology (i.e., CPPS, also known as Information Physics Production System Technology), and Intelligent Artificial Augmentation System Technology. In brief, Digital Thread is a life-cycle management architecture that integrates software, information transfer, and model building to achieve a seamless "data-information-knowledge" connection. The information-physical production system is the most important core technology of the intelligent manufacturing system, with real-time sensing and analysis of state information, and according to this, it makes independent decisions for precise actions, and finally feeds back to the whole system for its learning and improvement according to the execution process and results. Intelligent artificial augmentation technology is mainly supported by digital cue technology, through the decomposition and refinement of complex systems and operational processes, to assist in enhancing human understanding and mastery of their system processes, and ensure the efficient and accurate execution of complex tasks.

3.1 Digital Cues Technology

The process of intelligent manufacturing is a management process from end to end, and each process is managed to correspond up and down. Otherwise, it will cause the processing chain to break down and fail to achieve a precise embodiment. The digital trial technology has a very prominent role in the direction of the whole life cycle management of products [13]. Digital trail aims to establish technical processes through advanced modeling and simulation tools to provide the ability to access, synthesize, and to analyze data at all stages of the system life cycle, enabling the military and industry to complete real-time analysis and dynamic assessment of project cost, schedule, performance, and risk-based on a high fidelity system model that leverages seamless interaction and integrated analysis of all types of technical data, information, and engineering knowledge. The digital twin technology realized by the digital trail technology can realize the new product production mode of "design-virtual synthesis-digital manufacturing-physical manufacturing". It is an integrated simulation of the real system, through the perception of the real state and the collection of data, to establish a more reasonable data model to reflect and predict the corresponding "physical twin" state and performance characteristics in its life cycle process.

In its 2013 Global Horizon top-level science and technology planning document, the U.S. Air Force identified digital cues and digital twins as disruptive opportunities for "game-changing". Since FY 2014, Lockheed Martin, Boeing, Northrop Grumman, General Electric, Pratt & Whitney, and other companies have under taken on a series of applied research projects that are already yielding results. The U.S. Air Force plans to promote the use of digital cues in key acquisition programs such as the E-8 Ground Surveillance and Strike Command aircraft replacement, the T-X advanced trainer, and the long-range, out-of-area air-launched nuclear cruise missile. Besides, Northrop Grumman has applied digital clue technology and digital twin technology to the F-35 medium fuselage production, building a digital clue system by improving the information collection of non-conforming products, and then building a three-dimensional (3D) visual model through digital twin technology to achieve rapid and accurate automatic analysis, significantly reducing the processing time of defective products. The feedback from the non-conforming product characteristics has also enabled improvements to the manufacturing process and fixtures to reduce later changes to the product [14]. The company has now shortened the time to solve the F-35 intake machining defects by 33 percent. In collaboration with the U.S. Air Force, Boeing has created a digital dual-model of the F-15C airframe by using advanced 3D modeling and simulation software, which can simulate the structural dimensions of the product, predict residual stresses, operating loads, boundary conditions, material microscopic defects, and remaining

life, and help the company adjust the timing of structural inspections, modifications, overhauls, and replacements promptly.

3.2 CPS Technology

CPS is a complex system containing computing, network, and physical entities. Through the organic integration and deep collaboration of 3C (i.e., Computing, Communication, Control) technology, the interaction with the physical processes is realized through the human-computer interaction interface, enabling Cyberspace to manipulate a physical entity in a remote, reliable, real-time, secure, collaborative, and intelligent manner. Its technical architecture includes connection layer, conversion layer, network layer, cognitive layer, and configuration layer, and its capability framework is divided into five layers: resource liquefaction capability, data value-added capability, resource integration capability, intelligent analysis capability and resource deployment capability. The corresponding application framework is divided into five aspects: equipment digitization, equipment self-monitoring, factory networking, factory self-decision, and factory self-configuration.

Germany's "Industry 4.0" high-tech strategic plan and the "Industrial Internet" proposed by the U.S. General Electric (GE) have a different understanding of CPS technology. Germany takes production equipment as an important object of CPS, and makes the equipment most sensitive to product categories, and adjusts process parameters and control parameters automatically accordingly. For example, aircraft engines can collect operational data and send it to the cloud, which will analyze the operation and give suggestions and feedback to optimize the operation. However, smart manufacturing needs to CPS not only the physical entity of the equipment but also the 5M1E (i.e., human, machine, material, method, environment, and measurement) involved in the production of products should be fully CPS. For example, by collecting and analyzing the movement of people carrying RFID, we can propose leaner operating procedures and provide them to employees through wearable devices, such as material distribution personnel on-site. Besides, there is also the real-time collection of process parameters (such as the heat treatment temperature) on-site, and through big data analysis, guidance for optimization of process parameters is given.

In this wave of transformation and upgrading of Chinese enterprises, CPSing some complex and high value-added products (e.g. remote monitoring system, equipment health maintenance management system, etc.) is a feasible direction. As for the manufacturing process, it is necessary to determine which production resources can be CPSized (transformed) according to the industry's equipment level, sensing level, and input and output, and then realize the intelligent transformation and upgrading of the production process step by step.

3.3 Intelligent human enhancement technology

Human-beings in the intelligent manufacturing process still play a decisive role, but in the face of complex, boring, and repetitive work and harsh working environment, it is impossible to achieve automation, the use of robot operations is too costly, while the human work efficiency and accuracy are difficult to be guaranteed. For example, the work of thousands of wiring actions in a small space in the aircraft manufacturing process, therefore, intelligent artificial enhancement technology came into being, which can greatly improve the efficiency and quality of this process. Intelligent artificial augmentation technology aims to enhance human perception, analysis, decision-making, and execution capabilities, which connects people to the intelligent manufacturing environment and enhances their ability to access and use the information and is a core technical component of intelligent manufacturing. Virtual reality technology is an important support for intelligent artificial augmentation systems, with virtual reality (VR) and augmented reality (AR) technologies being the top priority for development.

Pratt and Whitney, using VR technology, developed a VR training simulator in 2017 to train the maintenance process of its latest GTF-type engine, which makes it easier for trainees to grasp the working principle of the engine and the operation structure of each component, and intuitively simulate the problems and solutions that may arise in the operation of the engine, greatly shortening the training time and reducing the difficulty of training. GE developed the Saltus MWR-85 TA intelligent torque

wrench for aero-engine bolt installation, supplemented by augmented reality technology and equipped with smart glasses with Skylight software for installation engineers. With the system, the rate of assembly errors was significantly reduced and the efficiency was increased by about 10 percent. Airbus developed the Smart Augmented Reality Tool (SART) for quality management of the tube positioning brackets in the assembly process, which reduced the inspection time of more than 80,000 tube positioning brackets in the aircraft fuselage to one-seventh of the original time.

4. Key processes of intelligent manufacturing in aerospace manufacturing applications

4.1 Optimize the process using process grouping technology

Based on the existing product manufacturing process, production resources, and the application of computer-aided manufacturing technology, focused on the manufacturing process of parts, optimize the process route and manufacturing resources, standardized process protocols, tool series, and tooling structures based on grouping technology are formed. Thus, it meets the different levels of production management, process control, and operation management, forms the optimized production process and manufacturing resource configuration, adapts to the current situation of the enterprise, and emphasizes the availability.

4.2 Realize fast work piece loading and unloading with automatic exchangeable table technology

To meet the high-efficiency requirements of the intelligent production line, the exchangeable workbench can be configured and the existing numerical control equipment can be transformed into the form of exchangeable workbench. In the processing process of a workbench, the machine tool, the machine tool can clamp the parts of another workbench, so that the workpiece clamping time and machine processing time coincide, thus greatly reducing the auxiliary work time of the machine tool and improving processing efficiency. The intelligent production line uses two workstations for single-machine operation and multiple workstations for multi-machine operation.

The configuration of exchanging tables can greatly save the auxiliary time of loading and positioning clamping of complex parts, improve the machine start-up rate, and thus shorten the machining cycle of parts.

4.3 Establish data acquisition and analysis system to realize dynamic monitoring of production site visualization

The data acquisition and analysis system is developed to realize equipment data acquisition and monitoring, quality data acquisition and feedback, tool data acquisition and planning, material data acquisition and monitoring of the production line, and fast and timely analysis of the acquired implementation of operational status data.

4.4 Use of modern logistics and storage automation technology to achieve automatic material transfer

In the processing and production of parts, there are many problems in the storage and use of many materials such as blank materials, semi-finished and finished products, processing tools and fixtures, etc. The use of modern logistics warehousing automation technology can be a good solution to this problem.

Establish the automatic storage station of tooling, cutter and work pieces, and analyze the size of the storage area, the layout of the inlet and outlet process, and the quantity specifications of the cargo space, and to determine a reasonable distribution of cargo space and realize the automatic storage of tooling, tools, and work pieces.

The automatic transportation rail is laid on the intelligent production line and connected with the automatic warehouse station, and the automatic transportation of tooling and work pieces between the warehouse and the machine tool, and between the machine tool and the machine tool is realized by using the Automated Guided Vehicle (AGV).

Barcode technology and Radio Frequency Identification (RFID) technology are used to mark the tools and work pieces and other materials, and establish an information collection system to realize the whole data collection and status monitoring of tools and work pieces and other materials.

4.5 Realize automatic scheduling with APS system

Advanced Planning and Scheduling System (APS system) can automatically schedule production according to product processing route, material, process, equipment, personnel, delivery time, etc. It has the ability of synchronous real-time constraint and simulation for all resources, and integrates APS system with production equipment, field network, and hardware so that APS system can play the most effective role.

5. Conclusion

With the continuous development of intelligent manufacturing and the transformation of the manufacturing industry, the application of intelligent manufacturing in the aerospace field will continue to expand. As a complex system, aerospace manufacturing needs not only "intelligence" but also "manufacturing" to realize intelligent manufacturing. Therefore, in the process of enterprise transformation and upgrading, we should adhere to the practical problems and demand-oriented policies, and remember not to blindly pursue intelligence. Taking three core technologies of intelligent manufacturing as the starting point, this paper introduces the technical connotation, application direction of digital clues, CPS and intelligent artificial enhancement and examples respectively, and introduces the key process of intelligent manufacturing in an aviation manufacturing application, which provides reference for enterprises to realize intelligent transformation.

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