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Research Article

Layout Optimization of Mechanical Automation Production Line Under the Background of Intelligent Manufacturing

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Abstract

Under the background of the rapid iteration of intelligent manufacturing technology and the transformation and upgrading of the manufacturing industry, the mechanical automation production line, as the core carrier of intelligent manufacturing, its layout rationality directly affects production efficiency, product quality and the market competitiveness of enterprises. The traditional layout mode has problems such as insufficient flexibility, unbalanced resource allocation and excessive logistics loss, which can no longer adapt to the production needs of multi-variety and small-batch and intelligent production scenarios. Combined with the technical characteristics of intelligent manufacturing, this paper analyzes the current situation and existing problems of the layout of mechanical automation production lines, explores the core principles and key influencing factors of layout optimization, puts forward targeted optimization strategies, verifies the feasibility of the optimization scheme combined with the actual application effect, and finally summarizes the optimization experience and development trend, so as to provide theoretical reference and practical guidance for manufacturing enterprises to realize the upgrading of production line layout and improve the level of intelligent manufacturing.

Keywords

Intelligent manufacturing, Mechanical automation, Production line, Layout optimization, Resource allocation

1. Introduction

With the in-depth advancement of the Industry 4.0 concept, intelligent manufacturing has

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become the core direction for the high-quality development of the manufacturing industry. As a key link connecting the manufacturing process and intelligent technology, the mechanical automation production line is facing new challenges and opportunities in its layout design. At present, most manufacturing enterprises still adopt the traditional layout mode for their automated production lines, which have problems such as poor process connection, insufficient equipment coordination and low flexibility, restricting the exertion of the efficiency of intelligent manufacturing technology. Optimizing the layout of mechanical automation production lines and realizing the optimal allocation of equipment, materials, human resources and other resources can effectively reduce production costs, improve production efficiency, enhance the flexibility of production lines, and help enterprises realize digital and intelligent transformation. This paper focuses on the layout optimization of mechanical automation production lines under the background of intelligent manufacturing, and combines industry practice and relevant theories to provide a feasible path for enterprise layout optimization.

2. Relevant Basis for the Layout of Mechanical Automation Production Lines Under the Background of Intelligent Manufacturing

2.1. The core relationship between intelligent manufacturing and mechanical automation production lines

Intelligent manufacturing is supported by a new generation of information technologies such as the Internet of Things, big data and artificial intelligence, and its core is to realize the automation, intelligence, flexibility and collaboration of the production process. The mechanical automation production line is the core carrier for the implementation of intelligent manufacturing, and there is an inseparable collaborative relationship between the two. Intelligent manufacturing technology provides technical support for the layout optimization of mechanical automation production lines. Through the Internet of Things, real-time interconnection of equipment, materials and personnel is realized; through big data analysis, various parameters in the production process are accurately grasped; and relying on artificial intelligence technology, autonomous decision-making of production scheduling is realized, breaking the rigid constraints of traditional layouts. At the same time, a reasonable production line layout can provide a good hardware foundation for the application of intelligent manufacturing technology, enabling the efficient exertion of functions such as intelligent equipment, intelligent detection and intelligent scheduling, and reducing resource waste and efficiency loss in the process of technology application. The two empower each other and jointly promote the transformation of the manufacturing industry from traditional large-scale

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production to personalized and intelligent production. Among them, layout optimization, as a key link connecting the two, directly determines the application effect of intelligent manufacturing technology and the overall operation efficiency of the production line. This close connection requires that the layout optimization of mechanical automation production lines must be carried out under the guidance of intelligent manufacturing concepts, and fully integrate various intelligent technologies to maximize the overall efficiency of the production system.

2.2. Core types and characteristics of mechanical automation production line layout

At present, the layout of mechanical automation production lines is mainly divided into three core types, each with its own characteristics and applicable scenarios, adapting to different production needs. The first is the linear layout, which arranges production equipment in a straight line according to the process sequence. The process connection is simple and intuitive, and equipment debugging and maintenance are convenient. It is suitable for standardized production of single variety and large batch. However, its flexibility is poor, it is difficult to adapt to the production needs of multiple varieties, and the material handling distance is long, which is likely to cause logistics loss. The second is the U-shaped layout, which arranges the production line in a U-shape to realize the closed-loop connection of processes. The material handling distance is greatly shortened, which is convenient for collaborative operation between equipment. At the same time, it can reduce the occupation of production space and adapt to the production mode of multi-variety and small-batch. However, its layout design is more difficult, and the equipment arrangement needs precise planning. The third is the modular layout. Based on the flexible needs of intelligent manufacturing, the production line is divided into multiple independent modules, each of which is responsible for specific processes. The modules can be flexibly combined and adjusted according to production needs. It has strong flexibility and expansibility, and can quickly adapt to product iteration and changes in production plans. It is the most promising layout type under the background of intelligent manufacturing. However, its initial investment cost is high, and it has strict requirements on equipment compatibility. Understanding the characteristics of these three layout types is the basis for enterprises to carry out layout optimization, and it is necessary to select and combine them according to their own production conditions and development needs.

2.3. Core objectives of production line layout optimization under the background of intelligent manufacturing

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Under the background of intelligent manufacturing, the core objectives of the layout optimization of mechanical automation production lines focus on four dimensions: efficiency, cost, flexibility and quality. Compared with traditional layout optimization, it pays more attention to the improvement of intelligence and collaboration. Firstly, the efficiency objective: by optimizing process connection, shortening material handling distance and improving equipment coordination efficiency, reduce the waiting time and invalid loss in the production process, maximize the overall production efficiency of the production line, and realize the reasonable release of production capacity. Secondly, the cost objective: by optimizing resource allocation, reduce equipment idleness, material waste and site occupation, reduce production costs and operating costs, and improve the economic benefits of enterprises. Thirdly, the flexibility objective: adapt to the production needs of multi-variety and small-batch, realize the rapid adjustment and iteration of the production line, flexibly respond to changes in product specifications, order fluctuations and other situations, and enhance the market adaptability of enterprises. Finally, the quality objective: reduce the interference between processes by optimizing the layout, improve the stability of the production process, cooperate with intelligent detection technology to reduce the product defect rate, ensure the consistency of product quality, and at the same time provide guarantee for safe production and reduce potential safety hazards in the production process. These four objectives are interrelated and mutually restrictive. The layout optimization work needs to balance the relationship between various objectives to achieve the comprehensive improvement of the production line's operation level.

3. Existing Problems in the Layout of Mechanical Automation Production Lines Under the Background of Intelligent Manufacturing

3.1. Lack of intelligent concept support in layout design

At present, when most manufacturing enterprises carry out the layout design of mechanical automation production lines, they still adopt the traditional design concept, lacking in-depth integration of intelligent manufacturing technology, leading to the disconnection between the layout and the needs of intelligent production. Some enterprises only pay attention to the automation upgrading of equipment, but ignore the coordination and rationality of the layout, and fail to fully consider the application needs of technologies such as the Internet of Things and big data, resulting in the inability of intelligent equipment to achieve efficient interconnection, difficulty in real-time collection and analysis of production data, and failure to give play to the collaborative advantages of intelligent manufacturing. For example, the layout of the production lines of some enterprises still adopts the traditional

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linear type, and there is a lack of data interaction interfaces between equipment, so it is impossible to realize intelligent decision-making of production scheduling, and only manual scheduling can be relied on, which is not only inefficient, but also prone to scheduling errors, leading to chaotic production rhythm. In addition, the layout design lacks foresight, and fails to consider the needs of future product iteration, production capacity expansion and technological upgrading, resulting in a rigid production line layout, high cost and difficulty in later adjustment, which is difficult to adapt to the long-term development needs of intelligent manufacturing and restricts the digital transformation process of enterprises. This problem has become a key bottleneck restricting the integration of intelligent manufacturing technology and production lines, and must be solved in the layout optimization work.

3.2. Unbalanced resource allocation and low logistics efficiency

Unbalanced resource allocation is one of the core problems existing in the current layout of mechanical automation production lines, which is mainly reflected in the unreasonable allocation of equipment, materials, human resources and other resources, directly affecting the operation efficiency of the production line. In terms of equipment configuration, some enterprises blindly pursue the level of automation, introducing a large number of high-end intelligent equipment, but fail to carry out reasonable layout according to production needs and process characteristics, resulting in excessive idleness rate of some equipment, while insufficient equipment configuration in key processes forms production bottlenecks and affects overall production capacity. In terms of material configuration, the layout design fails to fully consider the flow path of materials, the material storage area is too far from the production process, the handling route is cumbersome, and the lack of coordination of intelligent logistics equipment leads to long material handling time and large loss, increasing production costs. In terms of human resource allocation, the layout design fails to take into account the coordination between manual operation and intelligent equipment, resulting in redundant personnel in some positions, while a shortage of professional personnel in positions such as intelligent equipment operation and maintenance, leading to the coexistence of human resource waste and insufficient post adaptation. At the same time, the logistics system is disconnected from the production line layout, and there is a lack of unified intelligent scheduling, leading to untimely material supply and long process waiting time, which further reduces the overall operation efficiency of the production line. Solving the problem of unbalanced resource allocation is the key to improving the operation efficiency of the production line and reducing production costs.

3.3. Insufficient flexibility, difficult to adapt to changes in market demand

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With the transformation of market demand to personalization and diversification, the production mode of multi-variety and small-batch has become the mainstream, while the current layout of most mechanical automation production lines has insufficient flexibility, making it difficult to adapt to the rapid changes in market demand. The traditional production line layout mostly adopts rigid design, with fixed processes and fixed equipment arrangement. Once the product specifications change or the order is adjusted, large-scale transformation of the production line is required, with long adjustment cycle and high cost, which cannot quickly respond to market demand. For example, the production lines of some auto parts manufacturing enterprises can only adapt to the production of a single type of auto parts. When the market demand turns to new types of auto parts, the production line layout cannot be adjusted quickly, leading to enterprises missing market opportunities. In addition, the layout of the production lines of some enterprises lacks modular design, and the correlation between various processes is too strong to achieve independent adjustment. When a certain process fails, it will affect the normal operation of the entire production line, reducing the stability and fault tolerance of the production line. At the same time, the layout design fails to fully consider the flexible application of intelligent technology, and cannot realize dynamic adjustment of processes through intelligent scheduling, which further restricts the flexibility level of the production line. In the context of increasingly fierce market competition, insufficient flexibility will seriously affect the market competitiveness of enterprises, so improving the flexibility of the production line layout is an important direction of layout optimization.

4. Layout Optimization Strategies of Mechanical Automation Production Lines Under the Background of Intelligent Manufacturing

4.1. Integrate intelligent concepts and optimize layout design ideas

To solve the problem of lack of intelligent concepts in layout design, enterprises should change their design ideas, deeply integrate intelligent manufacturing technology with layout design, and build an intelligent and collaborative layout system. Firstly, in the early stage of layout design, combined with the enterprise's production needs, product characteristics and intelligent manufacturing development plan, conduct a comprehensive demand analysis, clarify the needs of intelligent equipment, data interaction, intelligent scheduling and other aspects, and formulate a scientific and reasonable layout plan. Secondly, introduce digital design technology, use 3D modeling, digital twin and other technologies to build a digital model of the production line layout, simulate the equipment operation, material flow, process connection and other scenarios in the production process, find out the problems in the layout

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design in advance, optimize the layout plan, and reduce the later adjustment cost. At the same time, reserve space for intelligent technology upgrading, consider the installation and layout of Internet of Things equipment, intelligent sensors, data interaction interfaces and other in the layout design, and provide hardware support for subsequent intelligent upgrading. In addition, strengthen the foresight of layout design, combine the needs of product iteration and production capacity expansion, design an adjustable and expandable layout structure, ensure that the production line layout can adapt to the long-term development needs of intelligent manufacturing, and give full play to the collaborative efficiency of intelligent technology. By integrating intelligent concepts into the whole process of layout design, the production line layout can be closely combined with intelligent manufacturing technology, laying a solid foundation for the efficient operation of the production line.

4.2. Optimize resource allocation and improve logistics collaboration efficiency

To solve the problems of unbalanced resource allocation and low logistics efficiency, we should start with equipment, materials, human resources and other aspects, optimize resource allocation, build an intelligent and collaborative logistics system, and improve the overall operation efficiency of the production line. In terms of equipment configuration, according to the characteristics of production processes and production capacity needs, reasonably plan the type and quantity of intelligent equipment, avoid equipment idleness and bottleneck problems, and at the same time optimize the equipment layout, shorten the distance between equipment, improve equipment coordination efficiency, and realize the optimal use of equipment resources. In terms of material configuration, adopt the “proximity layout” principle, set the material storage area near the relevant processes, shorten the material handling distance, introduce AGV intelligent handling robots, intelligent warehousing systems, etc., to realize the automation and intelligence of material handling and storage, and reduce material loss and handling time. In terms of human resource allocation, optimize the post setting, clarify the responsibilities and needs of each post, strengthen the training of professional personnel such as intelligent equipment operation and maintenance, improve the professional quality of personnel, realize the collaborative adaptation of human resources and equipment, and reduce the waste of human resources. At the same time, build an intelligent logistics scheduling system to realize real-time monitoring and dynamic scheduling of material supply, handling and storage, ensure timely material supply, reduce process waiting time, and improve logistics collaboration efficiency. Through the comprehensive optimization of various resources, the overall operation efficiency of the production line can be significantly improved, and the production cost can be effectively reduced.

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4.3. Build a flexible layout and enhance market adaptability

To solve the problem of insufficient flexibility of the production line, we should build a flexible layout system, improve the flexible adjustment ability of the production line, and adapt to the production needs of multi-variety and small-batch. Firstly, adopt modular layout design, divide the production line into multiple independent production modules, each of which is responsible for specific processes. The modules realize data interaction and collaborative operation through intelligent interfaces. When the product specifications change or the order is adjusted, the combination mode of modules can be quickly adjusted to realize flexible switching of the production line, shorten the adjustment cycle and reduce the adjustment cost. Secondly, introduce flexible manufacturing technology, combine artificial intelligence, big data and other technologies to realize the intelligence and dynamism of production scheduling, and automatically adjust the process sequence and equipment operation parameters according to the production plan, order changes and other situations to realize flexible control of the production process. At the same time, optimize the process connection, reduce the correlation between various processes, realize the independent operation of each process. When a certain process fails, the standby module can be quickly switched or the production plan can be adjusted to ensure the normal operation of the production line and improve the stability and fault tolerance of the production line. In addition, strengthen the intelligent upgrading of the production line, introduce intelligent detection, intelligent diagnosis and other technologies to realize real-time monitoring and abnormal early warning of the production process, further improve the flexibility and intelligence level of the production line, and enhance the market adaptability of enterprises. A flexible layout can help enterprises quickly respond to market changes and gain an advantage in market competition.

5. Conclusion

Under the background of intelligent manufacturing, the layout optimization of mechanical automation production lines is a key link for enterprises to realize digital and intelligent transformation, which is of great significance for improving production efficiency, reducing production costs and enhancing market competitiveness. Through research, this paper finds that the current layout of mechanical automation production lines has problems such as lack of intelligent concepts in layout design, unbalanced resource allocation and insufficient flexibility, which restrict the application effect of intelligent manufacturing technology and the development of enterprises. To address these problems, this paper puts

forward optimization strategies such as integrating intelligent concepts to optimize layout design, optimizing resource allocation to improve logistics collaboration efficiency, and building a flexible layout to enhance market adaptability. These strategies can effectively solve the existing problems and realize the intelligent, collaborative and flexible upgrading of the production line layout. In the future, with the continuous iteration of intelligent manufacturing technology, the layout optimization of mechanical automation production lines will develop in a more intelligent, efficient and flexible direction. Enterprises should combine their own actual situation, constantly explore new methods and paths for layout optimization, continuously optimize resource allocation, improve the overall operation efficiency of the production line, and promote the high-quality development of the manufacturing industry.

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Author contributions

Qingjiang Zhang individually undertook all roles including conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, original draft writing, review & editing, visualization, supervision and project administration for this study, and has read and agreed to the published version of the manuscript.

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