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Research
Smart Process Manufacturing—Perspective

Fundamental Theories and Key Technologies for Smart and Optimal Manufacturing in the Process Industry

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ABSTRACT

Given the significant requirements for transforming and promoting the process industry, we present the major limitations of current petrochemical enterprises, including limitations in decision-making, production operation, efficiency and security, information integration, and so forth. To promote a vision of the process industry with efficient, green, and smart production, modern information technology should be utilized throughout the entire optimization process for production, management, and marketing. To focus on smart equipment in manufacturing processes, as well as on the adaptive intelligent optimization of the manufacturing process, operating mode, and supply chain management, we put forward several key scientific problems in engineering in a demand-driven and application-oriented manner, namely: ① intelligent sensing and integration of all process information, including production and management information; ② collaborative decision-making in the supply chain, industry chain, and value chain, driven by knowledge; ③ cooperative control and optimization of plant-wide production processes via human-cyber-physical interaction; and ④ life-cycle assessments for safety and environmental footprint monitoring, in addition to tracing analysis and risk control. In order to solve these limitations and core scientific problems, we further present fundamental theories and key technologies for smart and optimal manufacturing in the process industry. Although this paper discusses the process industry in China, the conclusions in this paper can be extended to the process industry around the world.

1. Introduction

The term “process industry” refers to elementary raw material industries such as petroleum, chemical engineering, steel, nonferrous metals, and building materials; these are fundamental industries for the national economy, and are important in supporting momentum for the sustainable growth of the economy of the world’s manufacturing power. After decades of development, the level of manufacturing techniques, equipment, and automation in Chinese process industries has been greatly improved. China has now become one of the largest manufacturing countries in the world, with the most comprehensive range of categories and the largest scale of production. In China, the equipment used in some industrial units is comparable to or even more advanced than that used in developed countries.

Although significant developments and improvements have been made in the Chinese process industry in recent decades, a gap still exists between the domestic and international advanced levels in terms of overall production effectiveness. In addition, our innovation ability needs to be promoted due to restrictions in resources, energy, and environmental protection, which are manifested in the following aspects: ① severe structural overproduction problems (oversupply of some products); ② a lack of knowledge-based automation in management and marketing; ③ a low utilization rate of resources and energy; ④ a lack of high-end production (i.e., equipment, technique, and production); and ⑤ high pressure in efficiency and environmental safety. In general, the Chinese process industry exists on a large

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scale, and has a huge consumption of resources and energy, making it one of the main battlefields for supply-side structural reform and for green development in the manufacturing industry.

The manufacturing industry has shown a recent tendency to merge with information technology [1]. A number of developed and developing countries are accelerating their strategic plan for and layout of smart and optimal manufacturing (Fig. 1). For example, the US Smart Manufacturing Leadership Coalition presented the Smart Process Manufacturing roadmap, a framework and route to implement smart process manufacturing in the 21st century [2]; this roadmap aims to realize industrial upgrading and transformation via the optimization of manufacturing processes, driven by knowledge. Germany has proposed the concept of smart manufacturing to realize the Fourth Industrial Revolution, that is, Industry 4.0—a revolution that deeply integrates information and communication technology with manufacturing technology [1], and aims to achieve seamless integration and cooperation among products, equipment, humans, and organizations [3]. In this context, in order to realize innovation and revolution in the manufacturing industry in the era of the "new industrial revolution," China presented the Made in China 2025 strategy [4], and proposed the idea of "innovative, coordinative, green, open, and shared development." Then, in 2016, Chinese Premier Li Keqiang clearly pointed out in the Report on the Work of the Government: "In the course of economic development, it is only natural that old drivers of growth are replaced by new ones" [5]. As the process industry is an important component in the national economy, this is a crucial period for its development. As pointed out in Ref. [5], we should "use network-based information technology and other modern technologies to drive changes in models of production, management, and marketing, create new industry chains, supply chains, and value chains, and transform and upgrade conventional drivers, thus injecting them with new vitality" [5].

Motivated by the context discussed above, this paper reviews the problems in the existing manufacturing mode of the process industry. In order to solve the restriction problem of resources, energy, and environmental protection, and to increase efficiency in manufacturing, we propose that the process industry must implement the Made in China 2025 development strategy [4]. In other words, the Chinese process industry must make use of modern information technology, with the goal of achieving efficient, green, and smart processes in manufacturing and marketing. In addition, based on technological process optimization and the whole-process optimization of production, management, and marketing, we must promote smart, optimal, green, and high-end manufacturing, which is of great importance in accelerating improvements in quality and effectiveness. It is also important toward transformational development in the Chinese manufacturing industry, and especially in the Chinese process industry.

This paper is composed of the following sections: Section 2 introduces the background and current status and challenges for smart and optimal manufacturing in the process industry. Section 3 provides a vision for smart and optimal manufacturing in the process industry. Section 4 describes the scientific problems and key technologies for smart and optimal manufacturing in the process industry, and Section 5 provides conclusions and prospects.

2. Background and current status and challenges for smart and optimal manufacturing in the process industry

2.1. Background

Several industrial revolutions have occurred in human history (Fig. 2) [6]; each revolution greatly improved productivity and promoted economic development. The First Industrial Revolution was based on the technologies of steam engines and mechanical feedback speed controllers. In the Second Industrial Revolution, electric power replaced traditional power, and the electrical control system was developed as the core technology. In the Third Industrial Revolution, engineering technologies such as the programmable logic controller and the distributed control system promoted industrial production [7].

Today, developed countries such as Germany have proposed a Fourth Industrial Revolution: Industry 4.0. One of the key points of Industry 4.0 is the construction of cyber-physical systems (CPSs) [7–10]. A CPS is a multi-dimensional, complicated system in a computing, networking, and physical environment that realizes real-time sensing, dynamic control, and the information service of large engineering systems. It is based on the inherent natural integration and cooperation of the "3C" technologies: computers, communication, and control [7–10]. CPS realization can achieve the integration of computing, communication, and physical systems, thus enhancing the reliability, efficiency, and timeliness of large engineering systems. Therefore, the CPS presents a wide-ranging and significant prospect for practical applications. Specifically, a CPS includes ubiquitous environmental awareness and embedded computing, communication, and networked control; these factors grant physical systems the capabilities of computing, communication, precise control, remote cooperation, and autonomy. In addition, a CPS focuses on the close integration and coordination of computing and physical resources; such integration and coordination have been widely applied to various intelligent systems, such as device interconnection, smart homes, robots, intelligent navigation, and so forth [7–10].

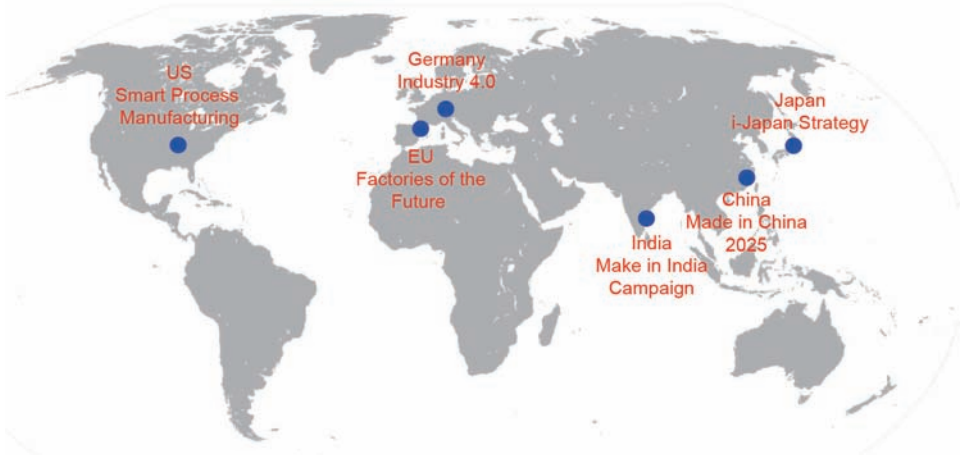

Fig. 1. Revitalization programs for the manufacturing industry proposed by several countries around the world.