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Research on the status quo of key core technology innovation in intelligent manufacturing enterprises

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Abstract: *The international situation is becoming increasingly fierce, and vigorously developing intelligent manufacturing is the main direction to promote the high-quality development of the national economy. However, as the core of the fourth industrial revolution, intelligent manufacturing enterprises are facing the problem of "stuck neck" in key core technologies. In terms of key core technology breakthroughs, although some areas have gradually approached the original innovation level of the technological frontier, many key core technologies in many industries are still subject to the situation of foreign technology monopoly and blockade, and no fundamental breakthroughs have been made. Whether we can achieve a breakthrough in the key core technologies of intelligent manufacturing enterprises will determine whether China can achieve sustainable development and high-quality growth in the future. This paper first briefly summarizes the research status of key core technology breakthrough, identifies the key core technology of intelligent manufacturing enterprises, then analyzes the innovation status of key core technology of intelligent manufacturing enterprises, and finally analyzes the problems existing in the endogenous breakthrough of key core technology of intelligent manufacturing enterprises.*

Keywords: *Intelligent manufacturing enterprises; key core technology; innovation status*

1. Overview of domestic and foreign research

Since the Sino-US trade war, the key core technologies of China's intelligent manufacturing enterprises have been subject to technical sanctions by other countries, posing a major threat to national security and economic development, and how to achieve a breakthrough in key core technologies has become a hot topic of research. There are few specialized researches on core technology research and development or breakthrough, and core technology capability training, among which domestic literature is more than foreign literature, which also reflects the difference of technological innovation status and demand between China and western developed countries from the side. Developed countries have a number of key core technologies, while China has been subject to the key core technologies for a long time, in order to obtain more initiative, we must break through the key core technologies, so Chinese scholars on the key core technology breakthrough research is also increasing.

Some scholars analyzed the factors of key core technology breakthrough from multiple perspectives. Zhang Jie et al. (2021) summarized the internal and external factors limiting China's key core technology breakthrough, and proposed the key breakthrough of scientific and technological research in the "14th Five-Year Plan", which is a general description at the national level. It cannot effectively solve problems such as the identification of influencing factors and specific implementation paths of key core technologies in specific industries and enterprise contexts [1]. Zhou et al. (2005) [2] and Lee et al. (2014) [3] emphasized the influence of internal factors on independent innovation, such as R&D investment level and strategic orientation. Lv Tie et al. (2019) [4] and Zhang Yongan et al. (2020) [5] believe that the external environment of an enterprise will affect its independent innovation ability, such as government intervention, external environmental pressure and regional institutional environment.

Some scholars analyzed the breakthrough paths of key core technologies in different industries. Wu Jianlong et al. (2014) constructed the breakthrough technological innovation paths of strategic emerging industries from a modular perspective: high-end penetration path of peripheral modules, key breakthrough path of key modules, subversion and reconstruction path of architecture rules, and module-architecture coupling upgrade path. The differences between different paths and their applicable conditions are also given [6]. Meng Donghui et al. (2018) [7] and Li Xianjun et al. (2020) [8] used the multi-case study method to find that the core technologies of the automobile industry and high-speed rail industry have experienced the evolution path from functional core technology to performance core technology and then to reliability core technology. Tang Zhiwei et al. (2021) took the electronic information industry as an example, identified 13 "bottleneck" technologies, and put forward policy suggestions from the perspectives of basic technology research, the main role of enterprise innovation, the rise of the industrial chain source, and the advantages of the socialist system [9]. Song Yan et al. (2022) discussed the evolution path of key core technology breakthroughs of leading equipment manufacturing enterprises from the integrated perspective of "breakthrough path - technological innovation capability - breakthrough result", from technology introduction to improvement and upgrading to independent innovation, and finally to realize the process of global leadership in technology and products [10]. Wang Ruiqi et al. (2022) selected 8 enterprises among China's top 500 manufacturing enterprises in 2020 as typical cases and identified 7 key success factors behind the breakthrough of key core technologies of China's leading manufacturing enterprises [11].

Some scholars have conducted relevant studies from other perspectives. Zhang Yuanyuan (2020) explained the path to break through the bottleneck of key core technologies from the perspective of the synergy of basic research, science and technology and institutional innovation [12]. Wang Zhe et al. (2020) [13] and Zhang Jie et al. (2021) [1] emphasized that state-owned enterprises should play an active role in overcoming key core technologies and should fully build a new innovation system with organic integration of "enterprise + government". Cao Yougen et al. (2023) constructed an integration framework for key core technology breakthroughs, and clarified the future path from five systematic dimensions of key core technology breakthroughs: target system construction, main attack direction selection, offensive force deployment, activation mechanism remodeling, and steady progress of offensive [14].

2. Intelligent manufacturing enterprise key core technology identification

2.1 Data source

In order to identify the key core technologies of intelligent manufacturing enterprises, this paper selects the intelligent bud patent database as the research data source. The retrieval time is September 2023, and the time span is from 2000 to 2023. The search enterprise is based on the list of 17 intelligent manufacturing benchmarking enterprises issued by the Ministry of Industry and Information Technology and the list of Top 50 intelligent manufacturing enterprises in 2022 issued by Internet Weekly, and 31 listed intelligent manufacturing enterprises are selected. Through manual screening of the search data, there are 306,561 data of the patentee as the enterprise.

2.2 Key core patent identification

2.2.1 Establish an index system for identifying key core patents

Table 1: Key core patent identification index system

Identification dimension	Index	Index interpretation
Patent technicality	Patent type	Express innovative value
	Cited frequency	The higher the number of citations, the higher the value
	Quantity of claim	Indicates the technical protection scope
	IPC Classification Number (patent width)	Indicates the size of the coverage area
Economy	Number of patents in the same family	Patent potential technology market
	Applicant country	Patent quality representation
	PCT application	Patented technology market scope
legality	Assignment of patent	Marketability of patented technology
	Patent litigation	Whether they encountered and successfully fought a lawsuit
	Patent payment and life	The longer the life, the higher the fee, the higher the quality

Because of the close correlation between high-quality key core patents and key core technologies, finding high-quality key core patents from a large number of patent data is a prerequisite for evaluating key core technologies. As for the identification of key core patents, the existing methods include single index identification, index grouping, index system identification and social network analysis. With reference to Zheng Sijia et al. (2021), this paper selects the index system of high-quality key core patents [15] from the three dimensions of patent technology, economy and legality, and constructs the index system as shown in Table 1.

2.2.2 Key core patent identification steps

The patent data obtained were screened through the screening steps in Table 2, and 1,993 key core patents were finally obtained.

Table 2: Key core patent screening steps

Screening procedure	Index content	Threshold value	Number of patents
	Patent total	-	306561
1	Patent-accepting country	Seven countries and two organizations	284769
2	Patent type	Invention patent	217994
3	Quantity of claim	>10	167268
4	Citation frequency	>0	95724
5	Breadth of patented technology	>1	35461
6	Legal status of patent	Opposition, assignment and litigation	3250
7	Duplicate removal	Remove patents with the same patent application number	1993

2.2.3 Key core technology identification

(1) Key core technology identification indicators

This paper refers to Cao Qianwen et al. (2023) to identify key core technologies from the two aspects of technology network and technology importance [16]. Technical network-ness includes degree centrality and intermediate centrality of patent code in the co-occurrence relationship network, while technical importance includes the popularity of patent code and the frequency of technical code assigned to the main class number in Table 3.

Table 3: Key core technology identification indicators

Primary index	Secondary index	Three-level index
Technical core degree	Technical network-ness	Degree centrality
		Intermediation centrality
	Technological importance	Popularity
		Primary class number frequency

In patent code co-occurrence network, degree centrality and intermediate centrality are two commonly used indexes, which can represent technical network-ness. In this paper, python language is used to construct a patent code co-occurrence network. Degree centrality measures the degree of connection between patent code and other nodes in the network. The higher the degree centrality, the more times the patent code appears in the co-occurrence relationship, and the patent has higher attention and importance in the technical field. The calculation formula is:

$$C_D(N_i) = \sum_{j=1}^{g} x_{ij}\ (i \neq j) \tag{1}$$

Formula, $C_D(N_i)$ patent code N_i degree centrality; g represents the number of patent codes;$\sum_{j=1}^{g} x_{ij}$ patent code N_i the number of direct connections to other patent codes. Degree centrality is also related to network scale. In order to eliminate the influence of network scale on it, Standardize $C_D(N_i)$,the calculation formula is:

$$C'_D(N_i) = \frac{C_D(N_i)}{g-1} \tag{2}$$

Intermediary centrality measures the ability of nodes as intermediaries in the network, that is, the importance of transferring information or resources between nodes, reflecting the criticality and core of technology patent code. The higher the intermediation centrality of a node, it means that it plays an important role as a bridge of information transmission in the network. The calculation formula is:

$$g(v)=\sum_{j\neq v\neq i}\frac{\sigma_{ij}(v)}{\sigma_{ij}} \tag{3}$$

Formula, σ_{ij} is the number of shortest paths from patent code i to patent code j;$\sigma_{ij}(v)$ represents the number of times these paths pass through v.

The popularity of patent code and the frequency of main classification number in technical importance are indicators used to measure the importance and attention of patents. Popularity can be measured by the number of citations of patents. A patent that is frequently cited by other patents may have a high degree of popularity because it has an important impact on subsequent technical research and innovation. The calculation formula is:

$$K(N_i)=\frac{(y_i+q_i*0.5)}{2023-T_i+1} \tag{4}$$

Formula, K_i Indicates the popularity of the patent code Ni;y_i Represents the number of cited patents with patent code Ni;q_i Represents the number of simple family members of the patent code N_i; T_i Indicates when the patent code Ni was issued.

The main classification number is an identifier used in patent literature to classify and organize the field of patented technology. The number of major class numbers refers to the number of times that the corresponding major class number of a patent code appears in the entire patent code list. The patent code with a higher number of main classification numbers indicates that the technical field to which it belongs has a higher frequency in the patent data set, indicating that the technical field involved in the patent has greater research and application importance. The calculation formula is:

$$f_m=\frac{p_m}{w} \tag{5}$$

Formula, f_m represents the frequency of occurrence of the primary class number m; p_m represents the number of occurrences of the main classification number m;w indicates the total number of occurrences of the primary class number.

The technical core degree is the score obtained by weighted summation of the scores of the three indexes, which can evaluate the technical core degree more pertinently. Based on the existing studies, weights were assigned to indicators, with the weight of degree centrality being 0.4, the weight of intermediate centrality being 0.3, the weight of popularity being 0.2 and the weight of main classification number frequency being 0.1. The calculation formula is:

$$CTP=C'_D(N_i)*0.4+g(v)*0.3+\ K(N_i)*0.2+f_m*0.1 \tag{6}$$

(2)Key core technology identification

According to the method described above, a patent code co-occurrence network is constructed with python language, and the degree centrality, intermediate centrality, popularity and main classification number frequency of each patent code node in the network are calculated. The data results of some patent code indicators of intelligent manufacturing enterprises are shown in Table 4.

Table 4: Patent code index data results of intelligent manufacturing enterprises (Part)

Patent code	Degree centrality	Intermediation centrality	Popularity	Primary class number frequency
CN105513499A	0.002065	277	4.5625	0.702459
CN103558714B	0.000192	0	0.0625	0.200702
CN106531579A	0.000288	8	0.357143	0.301054
CN103454808A	0.001777	330	2.045455	1.354742
CN102600750B	0.000144	0	0.055556	0.050176
CN101915237B	0	0	0.083333	0.050176
CN104377086B	9.61E-05	0	0.071429	0.050176
CN106510605A	0.000528	24	0.5	0.050176
CN102494221B	0.000384	0	0.1	0.050176
CN103369422A	0.00072	54	0.863636	1.304566
CN104465253A	0.000288	5	0.166667	0.050176
CN102857853A	0.000913	84	1.590909	0.250878
CN104118299B	0.00048	0	0.0625	0.050176
CN102865275B	0.000192	0	0.05	0.100351
CN104612152B	0.000192	0	0.25	0.050176

According to patent code index data and index weights, the core degree of each patent code is calculated. In this paper, patent codes with the top 10 weighted scores are selected as core technology patent codes, as shown in Table 5.

Through the analysis of the patent data of listed intelligent manufacturing enterprises, it can be seen that most of the key core technologies of enterprises are chips, mobile phone RF devices, haptic sensors and so on.

Table 5: Intelligent manufacturing enterprise key core technology patent code

Patent code	Technical core degree	Technical field
CN104267498A	310.28	Core algorithm, display system
CN106299627A	289.75	Core components, mobile phone RF devices
CN106205394A	289.38	Core components, chips
CN103747398A	214.50	Core components, mobile phone RF devices
CN103208255A	173.64	Core components, chips
CN106298859A	166.55	Core components, tactile sensors
CN106022324A	166.16	Core algorithm, line recognition technology
CN103957486A	123.82	Core components, chips
CN109469479A	117.55	Core algorithm, geological exploration technology
CN103024638A	110.38	Core components, electroacoustic transducer

3. Current status of key core technology innovation in intelligent manufacturing enterprises

3.1 Current status of key core technology innovation in intelligent manufacturing enterprises

Science and Technology Daily published a list of 35 key core technologies in 2018, which is the most authoritative report on the key core technologies in the field of intelligent manufacturing, involving multiple links of product production of intelligent manufacturing enterprises, such as core components, core raw materials, core equipment, etc., combined with the qualitative analysis above and the patent data of 31 listed companies. The innovation status of 35 key core technologies is analyzed, as shown in Table 6.

After summary, at least 21 of the 35 key core technologies have broken through, and the remaining 14 technologies are in the process of breaking through or have not been disclosed for some reason. The key core technologies that have not been broken through are mainly core equipment such as lithography machine and transmission electron microscope, core components such as aero-engine pods, high-end capacitors and resistors, milling cutters, and medical imaging equipment components, and core raw materials such as photoresist, epoxy resin, and high-strength stainless steel. The above parts and raw materials are difficult to independently develop, design and manufacture, or the performance and function of the parts and components independently developed and manufactured, the purity, strength, hardness and other indicators of the material, the precision of the equipment and the maturity of the process can not be compared with other countries. In addition, the lack of key core technology of intelligent manufacturing enterprises is also reflected in core algorithms such as core industrial software and robot core algorithms, due to the lack of code development ability and experience accumulation, which also indirectly weakens the operating efficiency and stability of intelligent hardware equipment.

Taking metal materials as an example, China is a steel country, but can not produce high-strength stainless steel and other special steels; For example, high-end capacitors and resistors, most of the products of intelligent manufacturing enterprises are used in the low-end market, and the consistency of capacitance and resistance in mass production is difficult to meet the needs of high-end products, and how to maintain the consistency of mass production has become the problem of high-end capacitor and resistance production in intelligent manufacturing enterprises. Taking core industrial software as an example, at present, only business management software UFida and Kingdee have initially gained the right to speak in the industrial chain, and there is still a big gap in the performance of other industrial software.

From the perspective of the industry, the key core technologies that have not been broken through are mainly the new generation of information technology, high-end equipment manufacturing, new materials and other strategic emerging industries, such as core industrial software, robot core algorithms, photoresist, transmission electron microscopy and so on. In the field of high-end equipment manufacturing, 90% of China's high-end medical devices, 80% of integrated circuit chip manufacturing equipment, 70% of automotive manufacturing key equipment and advanced intensive agricultural equipment still rely on imports. High-end equipment manufacturing is closely connected with traditional manufacturing enterprises, and the lack of key core technologies is also, to a certain extent, the technology cannot be independent in the transformation process of traditional manufacturing enterprises to intelligent manufacturing enterprises.

Table 6: Current status of key core technology innovation

Key core technology	Technology type	Breakthrough or not	Research and development unit
Photoetching machine	Microelectronic technology, core equipment	no	-
chip	Microelectronic technology, core components	yes	Huawei, SMIC
Operating system	Software, core algorithm	yes	Huawei HarmonyOS
Aeroengine nacelle	Aviation technology, core components	no	-
Tactile sensor	Microelectronic technology, core components	yes	Zhejiang University, Beijing Soft Robot Technology Co., LTD
Vacuum still	Core equipment	yes	Hefei Ryder equipment, Hefei Xinyihua, Zhongshan Triumph
Radio frequency device for mobile phone	Microelectronic technology, core components	yes	China Mobile, Huawei, Fuman Micro
iCLIP technique	Medical biotechnology	no	-
Heavy-duty gas turbine	Metal materials, core equipment	yes	Dongfang Electric Group
Laser radar	Microelectronic technology, core components	yes	Shandong Furui Optical Technology Co., LTD
Airworthiness standard	Space technology	no	-
High end capacitance resistance	Microelectronic technology, core components	no	-
Core industrial software	Software, core algorithm	no	-
ITO target	Core raw material	yes	He Jilin Academician, Zhengzhou University
Robot core algorithm	Software, core algorithm	no	-
Aviation steel	Metal materials, core raw materials	no	-
Milling cutter	Metal materials, core parts	no	-
High end bearing steel	Metal materials, core raw materials	yes	Xingcheng special steel
High pressure plunger pump	System, core components	yes	Heavy Group Yuci hydraulic industry Co., LTD
Aeronautical design software	Software, core algorithm	no	-
photoresist	Chemicals, core raw materials	no	-
High pressure common rail system	System, core components	yes	Dalian University of Technology, Chengdu Witt Electric Spray Co., LTD
Transmission electron microscope	Instruments, core equipment	no	-
Boring machine main bearing	Metal materials, core parts	yes	China Railway Construction Heavy Industry Group
microsphere	Core raw material	yes	Suzhou Nawei Technology Co., LTD
Underwater connector	Electronic components, core components	yes	Harbin Engineering University, CNOOC Offshore Oil Engineering Co., LTD
Key materials for fuel cells	Nuclear and hydrogen energy, core raw materials	yes	Suzhou Kerun, Suzhou engine, Himalaya
High-end welding power supply	Power system and equipment, core components	no	-
Lithium battery separator	Ability to transform storage technology and core raw materials	yes	China Lucet
Medical imaging equipment components	Microelectronic technology, core components	no	-
Ultra-precision polishing process	Production process control technology, core technology	yes	Xi 'an Science and Technology Bureau
Epoxy resin	Polymer materials, core raw materials	no	-
High strength stainless steel	Metal materials, core raw materials	no	-
Database management system	Software, core algorithm	yes	Alibaba, Huawei, ZTE
Scanning electron microscope	Instruments, core equipment	yes	Anhui Zeyou Technology Co., LTD

Note: Collated according to relevant information

From the perspective of scientific theory, the lack of key core technologies of intelligent manufacturing is mainly in basic sciences such as physics, mathematics and chemistry. At present, the theoretical research required for key core technologies is not thorough, and a large number of long-term repeated experiments have not been carried out. For example, the development of comprehensive mathematical models requires a deep understanding of basic physics, mathematics and calculation methods. Intelligent manufacturing often requires the integration of multiple scientific disciplines, and shortcomings arise when there are gaps or limited cooperation between different categories of scientific theory.

3.2 Intelligent manufacturing enterprise key core technology breakthrough problems

3.2.1 The innovation mechanism is not sound

The key core technology breakthrough of intelligent manufacturing enterprises is a long and complex process, which requires the integration of resources in multiple fields, such as technology, talent, equipment, capital, etc. Due to the lack of power and resources, it is difficult for a single enterprise to complete a breakthrough in key core technologies, so it is necessary to have a perfect innovation mechanism. The existing innovation mechanisms for breakthroughs in key core technologies are mainly the new nationwide system and the industry-university-research collaborative innovation system. The new nationwide system is mainly to give play to the guiding role of the government, integrate resources, integrate resources, improve the national innovation ecological mentality, and form a long-term mechanism for key core technology breakthroughs. The industry-university-research collaboration mechanism means that enterprises, universities and research institutions share benefits and risks over a period of time, jointly carry out scientific and technological innovation, and promote the transformation of achievements. At present, the specific details of the two mechanisms have not been perfected, such as the ownership of intellectual property rights, resource investment and benefit distribution, which often produce different opinions, resulting in the failure of the innovation mechanism, or the lack of effective cooperation, and the inability to focus on the breakthrough of key core technologies.

3.2.2 Weak basic research

The most basic feature of key core technology is its knowledge embeddedness and accumulation of experience, in which experience refers to the knowledge formed through a large number of practices in daily work, and the source of science, that is, theoretical knowledge, is the starting point of scientific and technological innovation, relying on basic research. The weakness of basic research will cause a lack of original achievements in important areas, resulting in the lack of key core technologies for intelligent manufacturing enterprises.

The weakness of basic research is mainly reflected in the unbalanced proportion of basic research investment and insufficient investment in basic research. As a developing country, R&D expenditure should pay more attention to the application-oriented model, but the data in the "Statistical Bulletin of National Science and Technology Funding Investment in 2022" released by the National Bureau of Statistics shows that the proportion of experimental development investment is the highest, accounting for 82.1%. Research funding is divided into three categories: experimental development investment, applied research investment and basic research investment, of which the proportion of applied research investment is 11.3%, the proportion of basic research is 6.57%, basic research investment is the least. The main reason for this is that technology is rapidly accumulated in the form of introduction and cooperation over a long period of time, while the introduced technology is perfected through experimental development and other forms, and innovation is gradually carried out on the existing technological route. Although this imbalance not only achieved rapid industrialization for us and produced significant economic effects, but also achieved successful cases of technological catch-up in some areas. However, in the long run, this imbalance will make it difficult to innovate and spread quickly and effectively in terms of in-depth theoretical knowledge and original technology acquisition, and key core technologies generally have strong theoretical and high knowledge level, so the imbalance of research and development structure will make it difficult to break through. For example, integrated system technology involving mathematical modeling requires an understanding of basic physics, mathematics and computational methods.

3.2.3 The innovation subject is absent

To a certain extent, the breakthrough of key core technologies is an economic behavior of enterprises in pursuit of technological progress, so as to obtain competitive advantages and technological dividends. As the main body of the market economy, enterprises are most aware of technological needs and difficulties, and their sensitivity to market demand can be reflected in the demand for technological breakthrough research. Therefore, enterprises should be in the main position of key core technology breakthrough. Key core technology has the characteristics of long-term uncertainty, intelligent manufacturing enterprises to carry out research on key core technology, need to invest large costs, but also need to bear many uncertain risks such as whether the technology can be broken through, whether the results can be converted into benefits, and so on. At present, most intelligent manufacturing enterprises lack of accumulation in capital and talent due to their own weak capacity. The operating pressure is relatively large, it is difficult to bear the cost of continuous investment in research, and it is impossible to carry out key core technology breakthroughs. Intelligent manufacturing enterprises lack of strategic planning and long-term investment in technological breakthroughs, and the innovation atmosphere and innovation culture of technological breakthroughs cannot be formed within the enterprise, which is also a factor in the key core technology breakthrough.

3.2.4 Shortage of high-quality personnel

In the report of the Party's 20th Congress, talent is the first resource, talent is the main body of scientific and technological innovation, so whether the key core technology of the enterprise can make a breakthrough ultimately depends on whether the talent can play a role. First of all, universities are too rigid in the setting of disciplines, and the key core technologies of intelligent manufacturing enterprises involve the cross-integration of knowledge from multiple disciplines, such as mechanical engineering, electronic engineering, and computer science. Colleges and universities lack of science and technology innovation interdisciplinary integration trend and scientific frontier grasp, in the interdisciplinary and frontier areas of talent training is not enough, which directly affects whether the quality of talent can be matched with the composite background of key core technology breakthroughs, intelligent manufacturing enterprises also need to train graduates to adapt to the integration of multidisciplinary key core technology breakthroughs. Secondly, intelligent manufacturing enterprises lack of incentives for high-quality talents, and the salary of existing employees is mostly related to the position, education, and length of service, and is not linked to technical contributions, which leads to the lack of motivation for independent innovation of high-quality talents, and the inability to retain excellent technical talents, resulting in the inability to improve the core technical level of enterprises.

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