

Technology Analysis of Permanent Magnet Synchronous Motor Based on Patent Information

Zhang Jie, Cui Jing⁺ and Zhai Dongsheng

Department of Management Science and Engineering, Beijing University of Technology

Beijing, 100124, China

Abstract—Under global economic growth, the industrial technologies keep renovating at an unprecedented high speed. How to use the effective information to investigate the technology development status and future trend that help the government and enterprises reasonably formulate R&D strategies, the patent analysis has been proven a good method and tool to solve the problem. This paper analyzes the permanent magnet synchronous motor technology with the data of 2216 patents in 1976-2009 from United States Patent and Trademark Office. First, the author introduces the brief of PMSM technology, then brings out a analysis framework based on patent information, several current patent analysis methods are used in the research, such as technology life cycle, IPC classification analysis, patent citation analysis, application tendency analysis and patent visualization analysis. Through comparison between the study result and the actual situation, it has proven patent analysis is good tool for technology research. And the status, the hotspot, the development roadmap of the permanent magnet synchronous motor technology has revealed at last.

Key words-Patent; Technology Analysis; PMSM

1. Introduction

According to the statistics report from world intellectual property organization (WIPO), there are over 80% of Sci-tech information appeared in patent documents firstly in the world. The patent document entails abundant technical, legal, economic information, it can reveal the industry technology trend, reflect the competitive dynamic, and predict the market development opportunity and risk, especially for provide the reliable support for make decisions in technology research, technology introduction, technology application and technology transfer. As playing the vital role in view of the patent information application on the scientific research and technology development many aspects, making good use of patent information may enhances the research efficiency and reduces the funds investment greatly. Therefore, patent information is an important prerequisite and basis for technical analysis.

Permanent magnet synchronous motor (PMSM) is a kind of rotating machine by using permanent magnet to establish magnetic field excitation, its stator generates rotating magnetic field and the rotor made by permanent magnetic material. International studies on PMSM started from the beginning of the 70's last century, as the prospect is promising, PMSM and related technology developed rapidly. Nowadays, there are hundreds of manufacturers and institutions are engaging in the research of the PMSM technology, and several thousands of achievements applied for patent. Based on this point, the paper use statistical classification and data mining methods to analyze PMSM technology by the point of view of patent analysis, from which we can investigate the performance, the distribution, the future development and the research hotspot of the PMSM technology.

2. A brief introduction of permanent magnet synchronous motor

⁺ Corresponding author.

E-mail address: shanjialiren@163.com

Permanent magnet synchronous motor (PMSM) can operate in complicated working conditions: petroleum, Coal Mine, fan and water pump, and other large engineering projects. It has many merits of small volume, high efficiency and low power consumption, etc. According to the different position of permanent magnet in the rotor, the permanent magnet synchronous motors are classified into surface and interior two types.^[1] In surface PMSM, permanent magnet usually placed at the outer surface of rotor iron core like a tile. The main characteristic of this motor is the inductance of the direct-axis and quadrature-axis to be equal. But in interior PMSM, permanent magnet is located in rotor internal, the pole shoe between outer surface of permanent magnet and inner circle of stator iron core can protect permanent magnet, and the main characteristic of this motor is the inductance of the direct-axis and quadrature-axis not be equal.

In recent years, the application of PMSM has been quickly extended in various complex mechanical systems for energy saving advantages. From induction motor to PMSM and energy-saving interior PMSM, the power factor greatly improved, the Copper Loss decreased significantly, and the effective rate increased by 2%-8% compared to the same specification induction motor. Now the permanent magnet synchronous motor keeps high power and high efficiency in a nominal load range of between 25-120%, especially has remarkable energy-saving effect while in light running^[2], followed that, the paper will make a further research on PMSM technology.

3. Theoretical framework

As main manifestation of technical achievements, patent represents the output of technical research, and is considered to be the best data source of excavating technology information and its internal relations. As patent databases open to public, acquiring patent information is easier than before, so more and more technology analysis based on patent information analysis. Therefore, in this paper, we propose an analysis framework of PMSM technology based on the theory and methods of patent analysis, as shown in Fig 1.

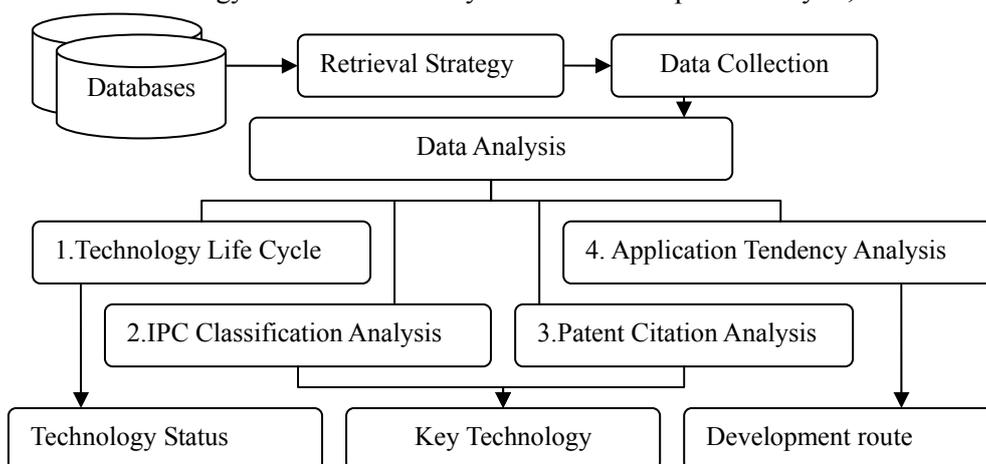


Fig.1. PMSM technology analysis framework based on patent information

Among them, patent data is downloaded from USPTO Patent Databases (<http://www.uspto.gov/>). And the analysis tools are Microsoft Excel and PatentEX. First, according to the keyword list recommended by experts, making retrieval strategy and searching for PMSM patents in USPTO database with the time span from 1976 to 2010, totally 2216 patent documents are collected, then using the methods of data cleaning, sorting, screening, classifying and drawing to complete data analysis work. The analysis content mainly includes: technology life cycle, IPC classification analysis, patent citation analysis, and time series analysis. Through technology life cycle analysis, we can know technology development status; From IPC Classification and patent citation analysis, we can find key technology and developmental focuses in this field; And by application tendency analysis of the key technology, its development route can be drawn in a roadmap.

4. Analysis and results

4.1. Technology life cycle

Technology development complies four periodic variation in theory: introducing stage, growing stage, mature stage, and decline stage^[3]. In the introducing stage, most of patents are theoretical and basic patent, the quantity is less, only a few manufacturers and institutions participate in industrial R&D. With the market expansion and technical progresses, the quantity of patent and patent application increase rapidly, it means the technology began to enter growing stage. When the technology in the mature stage, the patent increase easing up, the market participants gradually decreased, and with the coming of decline stage, patent quantity no longer increases and tend to decrease continuously, lots of applicants withdrawal from market. In view of this, the patent application volume and the number of applicants two dimensions should be considered together in judging technology life cycle. Hereby, using the patent data, the technology life cycle graph of PMSM are plotted with “application volume“ as ordinate against “applicants number“ as abscissa, as shown in Fig 2.

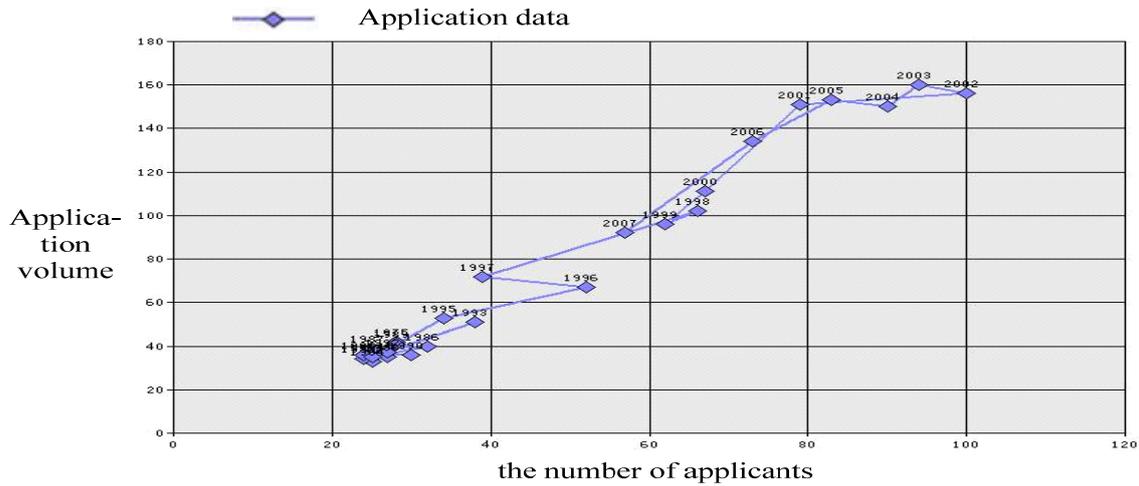


Fig.2. Graph of PMSM technology life cycle

From the Graph of PMSM technology life cycle(Fig 2), we can see that the change of patent application volume is basically in accordance with the number of applicants. In the year of 1975-1995, patent quantity is few, only remained 40 or so, and the market participants of between 20-40. But from 1995 to 2003, both them dramatically increased. And through the research on the development history of motor, we found that 80-90's of 20th century just in the rapidly extension period of rare earth permanent magnet material, especially the thermal stability and the corrosion resistance of nd-fe-b permanent magnetic material have been improved, and the cost price was reduced. this makes PMSM applied widely in national defense, industrial, agricultural and other industries^[4]. Its related research of design theory, algorithm, structure process and control technology get a brand-new room. So a wealth of academic papers and scientific research achievements come forth, and resulting the patent applications quickly increase. This means that the PMSM technology enter in a rapid growth stage. After 2003, both the patent application volume and the number of applicants are decreased slightly, but the quantity decrease amplitude of the applicants was smaller than that of patent application. This suggests that the PMSM technology begin to enter mature period.

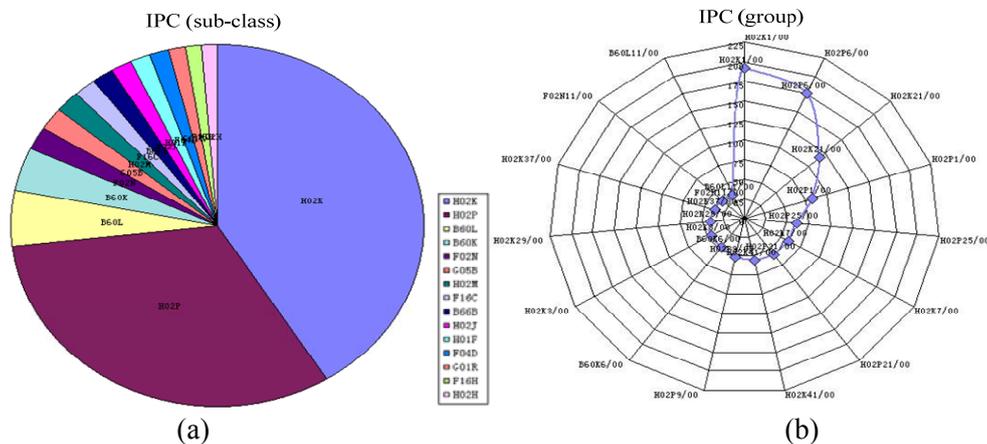


Fig.3. Technical composition by IPC

TABLE I. IPC & TECHNOLOGY TOPIC COMPARISON TABLE [5]

IPC(Num)		Technology Topic	
H02K(695)	dynamo-electric machine	H02K1/00(192)	Details of the magnetic circuit
		H02K21/00(117)	Synchronous motors having permanent magnet; Synchronous generators having permanent magnet
		H02K7/00(58)	Arrangements for handling mechanical energy structurally associated with the machine, e.g. structural association with mechanical driving motor or auxiliary dynamo-electric machine
H02P(543)	Control or regulation of electric motors, generators, or dynamo-electric converters; Controlling transformers, reactors or choke coils	H02P6/00(175)	Arrangements for controlling synchronous motors or other dynamo-electric motors with electronic commutators in dependence on the rotor position; Electronic commutators therefor
		H02P1/00(82)	Arrangements for starting electric motors or dynamo-electric converters
		H02P25/00(60)	Arrangements or methods for the control of ac- motors characterised by the kind of ac- motor or by structural details
		H02P21/00(58)	Arrangements or methods for the control of electric machines by vector control, e.g. by control of field orientation
B60L(84)	Electric equipment or propulsion of electrically-propelled vehicles; magnetic suspension or levitation for vehicles; electrodynamic brake systems for vehicles, in general		
B60K(65)	Arrangement or mounting of propulsion units or of transmissions in vehicles; Arrangement or mounting of plural diverse prime-movers; Auxiliary drives; instrumentation or dashboards for vehicles; Arrangements in connection with cooling, air intake, gas exhaust, or fuel supply, of propulsion units, in vehicles		
F02N(35)	Starting of combustion; Starting AIDS for such engines, not otherwise provided for		
G05B(34)	Control or regulating systems in general; Functional elements of such systems; Monitoring or testing arrangements for such systems or elements		
H02M(32)	Apparatus for conversion between AC and AC, between AC and DC, or between DC and DC, and for use with mains or similar power supply systems; conversion of DC or AC input power into surge output power; control or regulation thereof		
F16C(31)	Shafts; flexible shafts; elements of crankshaft mechanisms; rotary bodies other than gearing elements; bearings		
B66B(28)	Elevators; Escalators or moving walkways		
H02J(28)	Circuit arrangements or systems for supplying or distributing electric power; systems for storing electric energy		

From the Fig 3 and Table 1, we can conclude that the PMSM patent is mainly concerned with structural details, control systems and methods, arrangement and mounting, equipments and devices, and motor bearings, which the “control systems and methods” and the “application in various equipments and devices” are mainly topics, also present research emphasis. The sub-class G05B and the group H02K7/00, H02P6/00, H02P25/00, H02P21/00 show that the controlling and driving technology are the key point of PMSM research. The sub-class B60L, B60K, B66B show that PMSM as electric equipment can be applied in electrically- propelled vehicles, elevators and Escalators.

4.2. Patent citation

For corroborate the judgment of IPC Classification analysis, this part introduce the patent citation analysis, the citation information from patent documents can recognize the most actively patent, if one patent is cited by the many later patents, it may be has important influential force or high value^[6]. The class it belonged more probably are the key technology in the field. Hereby, we sorted the 2216 patents by forward citation, selecting the forward citation(≥50)(see table 2)

TABLE II. FORWARD CITATION RANKING OF PMSM PATENTS

Ranking	IPC	patent Num	Forward Citation	Ranking	IPC	patent Num	Forward Citation
1	B60K	US6161640	87	10	H02K	US5917248	54
2	H02K	US6049153	77	11	H02M	US5038092	54
3	H02K	US5879375	67	12	H02K	US4924125	53
4	H02K	US4433261	65	13	H02P	US4321518	53
5	F16C	US4763032	64	14	H02K	US4315171	53
6	H02K	US4645961	60	15	F02N	US4481459	52
7	F02N	US5818116	57	16	H02K	US5334898	51
8	H02P	US4447771	56	17	B60G	US5060959	50
9	H02P	US4134055	55	18	H02K	US5010266	50

Table 2 shows that the top 18 of forward citation in the ranking list are more and than 50, these patents are especially important to the thoughts and theories of later inventor. So they have a higher value and play a core

role in PMSM technology field. Refer to their IPC sub-class, we found that there are 17 in 18 patents are belong to the top 10 of IPC sub-class (only US50609594 not contained, its IPC code is B60G17/015, means “the regulating means comprising electric or electronic elements”). In all, the patent citation analysis about the main technology is basically identical with the IPC classification analysis.

4.3. Application Tendency

According to the analysis results from 4.2 and 4.3, the top 10 of IPC sub-class in table 1 can be regarded as the key technology in PMSM field. For investigate their development routes, we plot the application tendency graph of PMSM patents by annual applications, as shown in Fig 4.

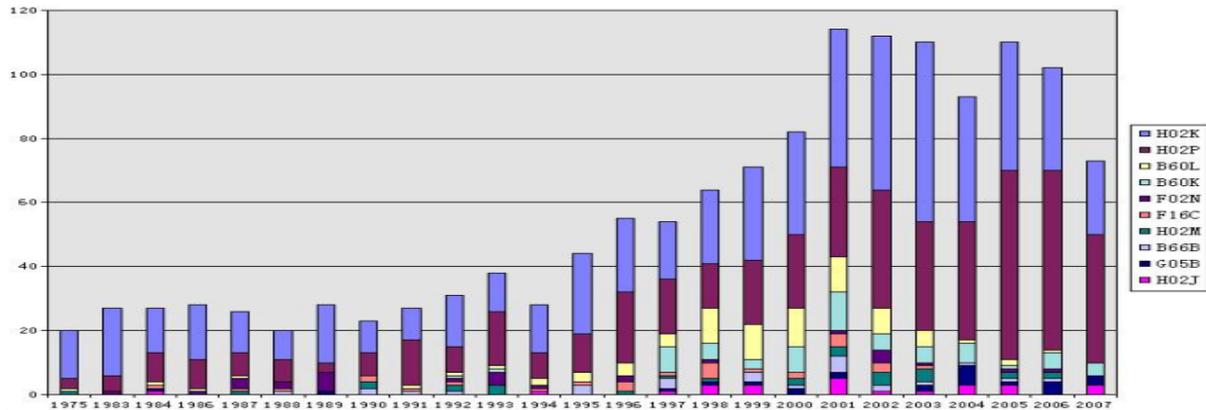


Fig.4. Application tendency of PMSM patents

To observe Fig 4, the patent applications of IPC sub-class H02K, H02P that basic contents of PMSM technology still remained stable growth with time process. Comparing with H02K, the growth tendency of H02P (with the keyword “controlling”) is more obviously. The main reasons for the phenomenon may be the requirements for controlling and electric conversion become higher and higher, while the development of the electron industry, the constant improvement of magnet material properties, and the detrusion of motor energy efficiency standard in many countries.

In addition, the proportion of B60L, B60K, G05B in annual application are gradually increased that supposed to be the research focuses in PMSM technological innovation, and the technology topics they represented may be the hotspot in future research. The increasing trend of B60L, B60K seem more significantly, which the definition in IPC classification is respectively “Electric equipment or propulsion of electrically-propelled vehicles” and “Arrangement or mounting of propulsion units or of transmissions in vehicles”, that's just inosculate the recent research hotspot of “electric vehicle PMSM [7]”. So, the PMSM for electric vehicles may be one of the research hotspot in future technology development.

5. Discussion and conclusions

This study established a patent analysis framework to investigate the development status, research focuses, and future trend of PMSM technology. For complete the analysis work, the data 2216 patent documents in PMSM technology field for 1975–2010 was downloaded from USPTO, and several patent analysis methods are used in the research: technology life cycle, IPC classification, patent citation, and application tendency analysis. Furthermore, the patent visualization also be used to explain the above analysis results. The results show that:

- The PMSM technology is in the industrial mature period;
- The structural details, control systems and methods, arrangement and mounting, equipments and devices, and motor bearings are the main technology in PMSM Technical composition. And the “controlling” and the “application” are the key technology among them;
- The PMSM for electric vehicles is one of the recent research hotspot in PMSM technology field;
- The PMSM technology is expected to higher energy efficiency, lower loss, more flexibly control in future.

6. Acknowledgment

The work was supported by Natural Science Foundation of Beijing (9092002); Project support of Beijing Municipal Commission of Education (KM200910005027); The Talent Deepening Plan of Beijing Municipal Commission of Education (J2011212200901).

7. References

- [1] Jing L, Xiaohua C, “The Development Trend of PM Synchronous Machine”. *Explosion-proof Electric Machine*, vol. 44, May. 2009, pp. 1-4.
- [2] Liang Q, Jin L, Lichan T, Zhenbing W, “The Application and Development of PMSM”. *Equipment&Machine*, Mar. 2007, pp.15-17.
- [3] Andersen, B., “The hunt for S-shaped growth paths in technological innovation: a patent study”. *Journal of Evolutionary Economics*, Sep. 1999, pp. 487–526.
- [4] Renyuan T, “Summary of Development of Rare Earth Permanent Magnet”. *Electrical Engineering*, Apr. 2005, pp. 1-6.
- [5] WIPO website. Available at <http://www.wipo.int/classifications/ipc/ipc8/?lang=en>
- [6] Jinsheng M, Xiaobing F, Yan C, “Practice of Patent Analysis and Early-Warning”. Beijing: Tsinghua university press, 2009, pp.62–63.
- [7] Dingxian H, Jingqi L, Peng Y, Yuhui L, Weidong G, “Development of Technology on Small and Medium Electric Machine”. *Electric Machines & Control Application*, vol. 34, Aug. 2007, pp.1-5.