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Analysis of Technical Trend of Electric Agricultural Field Machinery

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Abstract As basic research to develop HEV and EV agricultural field machinery, the present study analyzes the technical trend of electric agricultural field machinery through product analysis, paper analysis, and patent analysis concerning HEV and EV in the automobile, construction machinery, and agricultural machinery sectors. For product analysis, the homepages of companies in these sectors were consulted to analyze the number of products of each company. For paper analysis, key words related to HEV and EV were selected, a search formula was drawn up, and articles search sites were consulted. And for patent analysis too, key words were selected and then a search formula was drawn up to examine published patent applications or registered patent applications, and trends were analyzed by structure, country, and year. The number of HEV and EV products were 17 in the automobile area, 8 in construction machinery, and 4 in agricultural machinery. Notably, in the agricultural machinery area, all HEV and EV products were from advanced companies overseas. In terms of papers, papers published in the past 5 years were searched and 33,195 papers were from the automobile area, 3,806 were from construction machinery, and 2,687, the fewest papers, were from the agricultural machinery area. A search of patents in the electric drive technology area in Korea, USA, and Japan, and Europe showed 1,927 valid patents, with 1,120 in Japan, 497 in USA, 193 in Korea, and 117 in Europe. Analysis of the trend of research on electric agricultural field machinery by product, paper, and patent shows the development of HEV and EV technology in Korea is insufficient compared to USA, Japan, and Europe, which means rapid technological development is needed.

Keywords Hybrid Electric Vehicle, Electric Vehicle, Product, Paper, Patent, Agricultural field machinery

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1 Introduction

Recently, with the rise in international oil prices (KNOC, 2010) and tightened regulations on exhaust gas, the demand for environment-friendly and high-efficiency technology is increasing. To meet this challenge, electric drive technology (Yeo, 2008) has already been applied to the automotive sector for the active development of products including HEV (hybrid electric vehicle) and EV (electric vehicle), and the technology is also increasingly being spread and applied to the sectors of construction machinery and agricultural machinery (RDA, 2008).

HEV electric drive technology is a method of using two power sources of the internal combustion engine and the electric motor for the vehicle, and is an environment-friendly and high-efficiency technology that enables energy efficiency and reduction of exhaust gas through optimum power distribution according to the way of running or performance (Hochgraf et al., 1996). Today the technology is mainly applied to the automotive industry, and is used for the purpose of improving fuel efficiency and dealing with

environmental regulations centered on energy recovery, including deceleration during driving and reusing the energy loss at the time of braking (Kim et al., 1996; Lee et al., 2008). And depending on how the power source is connected, there are serial type HEV, parallel type HEV, and power-split type HEV which is a combination of serial and parallel types, as well as EV which is driven only by an electric motor. Depending on the nature of the subject to which technology is applied, there is a wide technical scope of the electric drive type used. In the construction machinery sector, Komatsu developed a parallel hybrid type excavator to improve the efficiency of hydraulic drive systems (Kanezawa et al., 2001), and this is reported as having produced an annual energy savings of 35% through the use of the hybrid drive for the turning operation.

In the agricultural machinery sector, research has mainly been conducted on the development of high-efficiency tractors, and most of the research is focused on task-specific load analysis for efficient analysis of existing work.

In the agricultural sector, an electric drive system to improve high efficiency has mainly been developed and commercialized by John Deere, an advanced company. But in Korea, research on electric drive technology is incomplete and product development is nonexistent.

Therefore, as basic research to develop HEV and EV agricultural field machinery, the present study aims to analyze the technical trend of electric agricultural field machinery through product analysis, paper analysis, and patent analysis on HEV and EV in the automobile, construction machinery, and agricultural machinery sectors.

2 Materials and methods

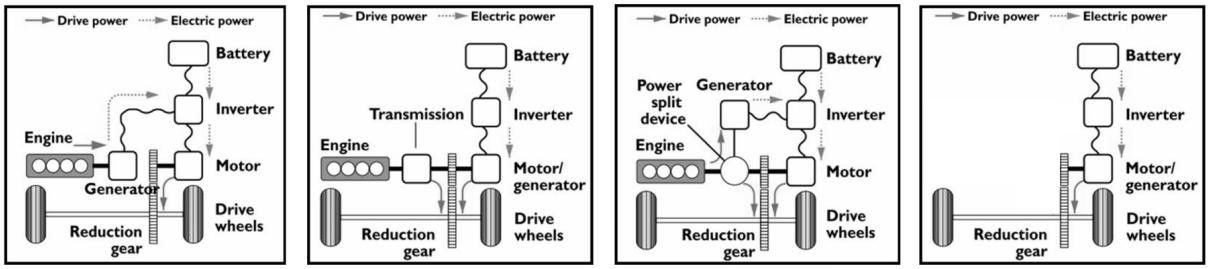
2.1 Electric drive technology

As shown in Figure 1, HEV and EV technology is divided into serial type, parallel type, power-split type, and electric drive type in accordance with the proportion of the electric energy used. As shown in Figure 1 (a), serial-type system consists of engine, motor, generator, and battery. As for the engine, it only serves to drive the motor through the generator, and the battery can be recharged using engine power and regenerative braking. Since the vehicle is driven by the power of the motor only, the drive is of high efficiency. But the energy conversion loss is very large and the drive needs a large capacity motor and battery, which requires a high price.

As shown in Figure 1 (b), the parallel-type system is a structure that adds hybrid core components such as the motor (generator) to the conventional internal combustion engine in parallel. It can use both motor and engine as the power source for the vehicle. At the same time, battery recharging is possible through driving the engine and regenerative braking. And since the motor and the battery can have a small capacity, the parallel type is cheaper than the serial type.

As shown in Figure 1 (c), the power-split type system is a mixture of serial type and parallel type with the power split device added. It is composed of at least one power split device and engine, motor, generator, and battery. It has the advantages of both serial and parallel types. But the structure of the power-split type system is mechanically very complex and difficult to control, and due to a monopoly on the technology by advanced Japanese companies, the system cannot be applied to other sectors.

As shown in Figure 1 (d), since the EV of the electrical drive system is composed of motor and battery only, without an internal combustion engine to drive the vehicle, it is a pollution-free vehicle with no emissions of carbon dioxide (CO2) during the drive. Compared to an internal combustion engine, it has the advantage of low noise and low maintenance costs. However, it has a short driving distance due to its battery capacity, and in terms of price it needs more work on development.



(a) Series (b) Parallel (c) Power-split (d) Electric

Fig. 1 Classification of electric driving technology.

2.2 Analysis Methods

2.2.1 Product Analysis

For product analysis, to analyze the products of the automobile, construction machinery, and agricultural machinery sectors with HEV and EV applied, the homepages of companies that released such products up to September 2013 were examined. Product analysis was carried out according to the area, the mode of application of electric drive, and the number of products for each company in Korea and overseas.

2.2.2 Paper Analysis

For paper analysis, key words related to HEV and EV were selected from automobile, construction machinery, and agricultural machinery and a search formula was drawn up as shown in Table 1. Search sites (sciencedirect, elsvier, scopus) were consulted for paper analysis to search papers in Korea and overseas, and the search period was the last 5 years. The number of papers for each sector and year were analyzed.

Table 1 Paper search formula using HEV and EV key word

hybrid car or hybrid vehicle*hybrid construction machinery* electric agricultural machinery or hybrid tractor* hybrid car*hybrid vehicle*EV*HEV*PHEV*series*parallel*tractor*bulldozer*drag-shovel truck*trailer*bus*loder*forklift*heavy*construct

2.2.3 Patent Analysis

For patent search, key words related to HEV and EV were selected from automobile, construction machinery, and agricultural machinery, and a search formula was drawn up as shown in Table 2. The range of patent search was patents in Korea, USA, Japan and Europe whose applications were published or registered by June 2013. Trends for each structure, country, and year were analyzed so that the structure of HEV and EV could be comprehended.

Table 2 Patent search formula using HEV and EV key word

Search expression	
Korean	(((((하이브* 하이부* 하이브리드* 에이치이브* hev* hybrid* ((plug* adj2 in*)플러그인*) (직렬* series* 시리즈* serial*) (병렬* parallel* 페러럴*)) NEAR2((트랙터* 트렉터* 농기계* 농기기* 농작업기* 농업용기기* 농업용기계*작업기* (농업* adj2 (기기* 기계*)) 작업차* (작업* adj2 (자동차* 차량*))) OR(건설기계* 건설기기* (건설* adj (기계* 기기*)) 중장비* 불도저* 로더*굴삭기* 포크레인* 지게차* 포크리프트* 착암기* 레미콘* 크레인* 백호우*)OR (자동차* 차량* 비클* 비이클* 오토모빌* 휠*) OR (트럭* 화물차*화물자동차* 트레일러* 상용차* 버스* 특장차* 특수차량* 전차* 탱크*무한궤도* 캐터필러* 견인차*)))
English	((((hybrid* hev* hibrid* (plug* adj2 in*) series* serial* parallel*) NEAR2((tractor* ((farm* agricultur* work*) near2 (machine* vehicle*))) OR (loder*forklift* excavator* crane* ((heavy* construct*) near2(equipment *machine*)) ready-mix* ((ready* truck*) near2 mix*) bulldozer* backhoe*(back* near2 hoe*) dragshovel* drag-shovel* (drag* near2 shovel*)) OR(car* vehicle* automobile* wheel*) OR (truck* trailer* bus* (commercial*near vehicle) tank* caterpillar* (track* near2 link*))))

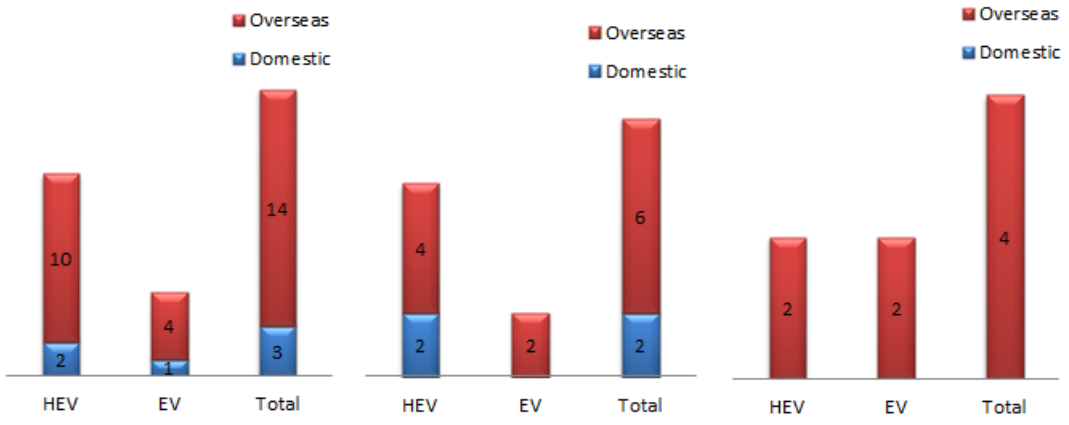
3 Results and Discussion

3.1 Results of Analysis

3.1.1 Results of Product Analysis

The electric drive technology in the automobile, construction machinery, and agricultural machinery sectors is shown in Figure 2, and analysis was performed on the number of products related to HEV and EV in Korea and overseas. The number of HEV and EV products for each sector was 12 HEV and 5 EV in the automobile sector (17 commercialized products in total), 6 HEV and 2 EV in the construction machinery sector (8 in total), and 2

HEV and 2 EV in the agricultural machinery sector (4 in total). In terms of the number of technologies applied, 20 of the 29 electric drive technology applications were HEV technology applications, and there were 9 EV technology applications, which means development was underway concentrating on HEV technology. And the number of products in the automotive sector to which electric drive technology was applied was 14 in Korea, 3 overseas; in construction machinery, 6 in Korea, and 3 overseas showing some cases of commercialization in Korea; while in agricultural machinery, 4 overseas, but no products in Korea, which means the development of electric drive technology is urgent in this area.

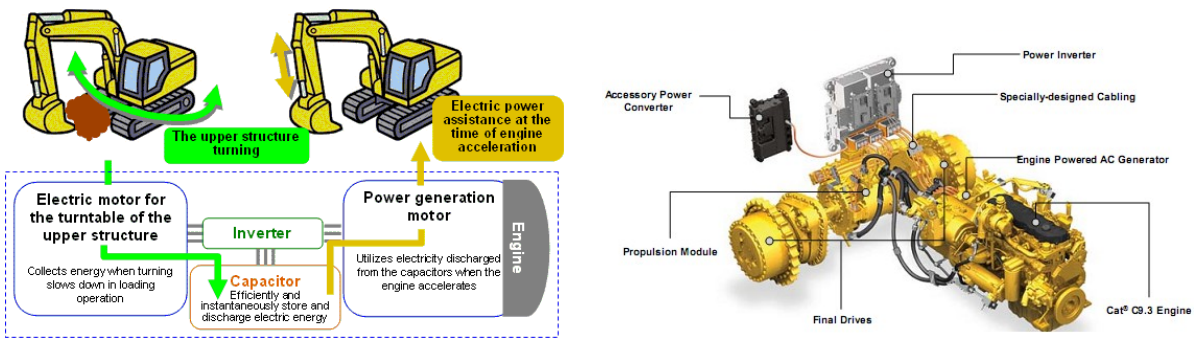


(a) Vehicles (b) Construction machinery (c) Agricultural machinery

Fig. 2 Result of product analysis for HEV and EV

In the automotive sector, Toyota commercialized the Prius in 2009, which accounts for more than about 80% of the hybrid car market, and recently expanded its production to more than 1 million cars. Ford also produces hybrid cars, while GM released the electrically-driven Volt, which is capable of about 100km per 1 L. More recently, Tesla succeeded in mass producing an electric car that can run about 150 km with one recharge at 200 km per hour. It is popular as a representative electric drive vehicle in the US market, which gives government subsidies to environment-friendly vehicles.

As shown in Figure 3 (a), in the construction machinery sector, Komatsu (Japan) developed HEV excavators making use of the 3 core parts of electric swing motor (instead of hydraulic rotary motor), ultra capacitor, and generator motor. HEV excavators have the advantage of can reducing fuel consumption by 25-40% by electrifying the swing motion, which consumes the most power. As shown in Figure 3 (b), Caterpillar developed a bulldozer (D7E) directly driven by the electrical energy generated in the engine, with no separate electric battery. D7E does not need an expensive transmission and has the advantage of reducing fuel consumption by up to 40%.



(a) Excavators (b) Dozer

Fig. 3 HEV and EV construction machinery.

Unlike with automobiles, regenerative braking is not possible in agricultural machinery, as in general, its operation speed under 10 km/h. So as shown in Figure 4, the system is composed of engine, motor/generator, inverter, and battery-BMS system. Drive mode is divided into engine drive, engine and motor drive, engine and generator drive mode. Engine drive refers to driving the tractor with the power of the engine, as with existing tractors. To explain the engine and motor drive mode, when the load is generated and engine speed falls below target engine speed, the electric energy saved in the battery drives the driving engine to assist the torque and relieve the load. Lastly, to explain the engine and generator drive mode, when engine speed is higher than target engine speed, the generator is operated to produce electrical energy, and this energy is saved in the battery.

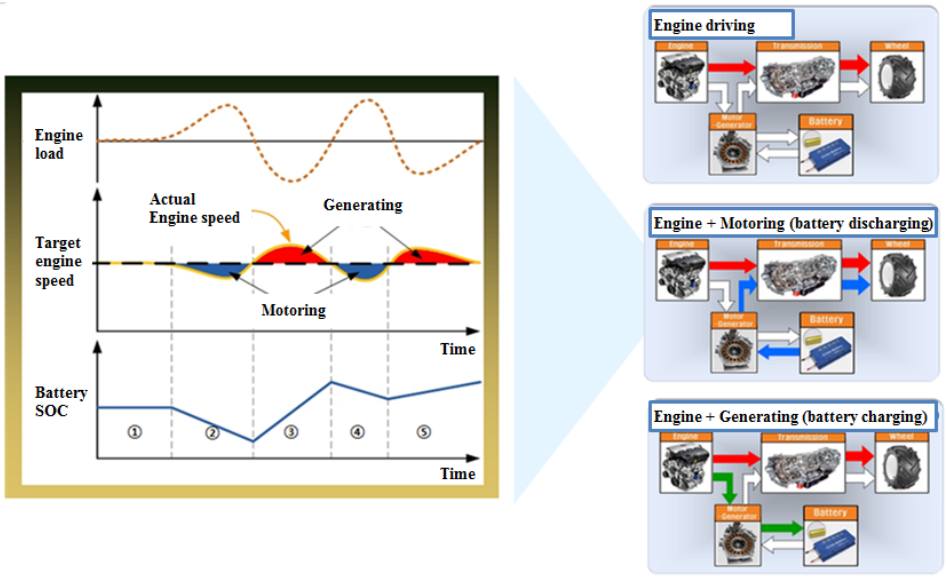


Fig. 4 System configuration and mechanism of hybrid and electric driving system for agricultural machinery.

Products released in the agricultural machinery sector are mostly from John Deere as shown in Figure 5. It has an HEV product, the 7030E, which motor driving ancillary devices of the engine, such as air-con compressor and cooling system. The 7030E has a generator equipped in the flywheel of the engine to save electric energy in the battery when the engine rotates, and when needed, provides energy to the ancillary devices of the engine by making use of electrical energy. Compared to existing tractors, it offers the advantages of a 15% improvement in the reaction speed of the engine and a 10% improvement in fuel efficiency. And as for electrically-driven products, electric mowers such as the X304 and 8500E have been released to the market. Electric mowers have the advantage of producing less noise compared to existing engine drive products, and can be continuously operated on a single charge.

(a) Composition of 7030E (b) X304 (c) 8500E

Fig. 5 HEV and EV agricultural field machinery.

3.1.2 Results of Paper Analysis

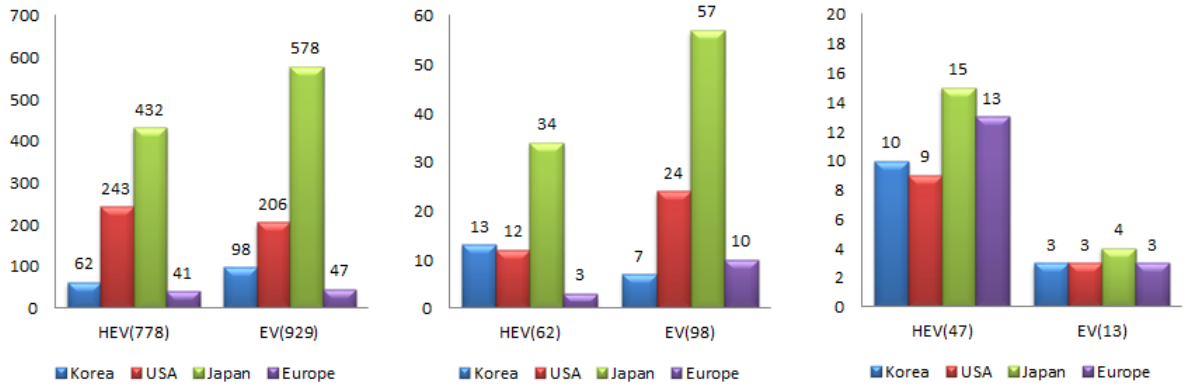
The number of journal articles on electric drive technology in the three sectors from 2010 to 2014 was 39,688, as shown in Table 3. A total of 33,195 papers were on the automotive sector, accounting for 84% of the total, 3,806 papers were on the construction machinery accounting for 9%, and 2,687 papers were on agricultural machinery accounting for 7%, the least papers of the three sectors. Significantly, papers on agricultural machinery have continuously increased, showing a 146% increase during 5 years. But the number of articles published was 720, only 7.5% the number of papers in the automotive sector, which indicates the need for continuous research and development.

Table 3 Result of search for papers from the past 5 years

Sector	Year					
	2010	2011	2012	2013	2014	Total
Vehicles	4,403	5,367	6,131	7,718	9,576	33,195 (84%)
Construction machinery	557	645	748	898	958	3,806 (9%)
Agricultural achinery	385	441	516	625	720	2,687 (7%)
Total	5,345	6,453	7,395	9,241	11,254	39,688 (100%)

3.1.3 Results of Patent Analysis

Based on the patent data published up to June 2013, a search of patents related to electric drive technology showed a total of 1,927 patents. Patents related to automobiles in major countries are shown in Figure 6 (a). Japan had the most patents on HEV with 432, followed by the USA with 243, Korea with 62, and Europe with 41. As for patents on EV, Japan also had the most patents with 578, followed by the USA, Korea, and Europe, with 206, 98, and 47, respectively. As shown in Figure 6 (b) which deals with patents in the construction machinery sector, there were 34 HEV-related patents in Japan, 12 in the USA, 13 in Korea, and 3 in Europe; EV-related patents were 57, 24, 7, and 10 each. The search result shows Japan has the greatest number of patents on HEV and EV. As shown in Figure 6 (c) about patents on agricultural machinery, Japan had the most patents on HEV and EV with 15 and 4, respectively, followed by Europe with 13 patents on HEV, Korea with 10, and USA with 9. As for EV-related patents, USA, Korea, and Europe had 3 patents each. As for electric drive technology, there were 778 HEV-related patents and 929 EV-related patents in the automobile sector; 62 HEV-related patents and 98 EV-related patents in the construction machinery sector; and 47 HEV-related patents and 13 EV-related patents in the agricultural machinery sector. Compared to other sectors, the percentage of HEV-related patents in the agricultural machinery sector was higher at 80%, showing active research and development in the agricultural machinery sector.



(a) Vehicles (b) Construction machinery (c) Agricultural machinery

Fig. 6 The number of HEV and EV patent registrations for major countries and technologies.

The results of our analysis of the trend of HEV and EV technology by year are shown in Figure 7. It was analyzed that in 2004 research and development was led by Japan, which had a high share in patents related to electric drive technology, and since then patent applications have been on the rise in the USA, Korea, and Europe. This shows research has been actively conducted into the related technology. Between 2008 and 2010, patent applications decreased compared to the previous year, which is thought to reflect the worldwide recession. 2011 saw an increase in the number of patents, while 2012 shows fewer patent registrations due to insufficient aggregation of data since the analysis was carried out on the patents published up to June 2013.

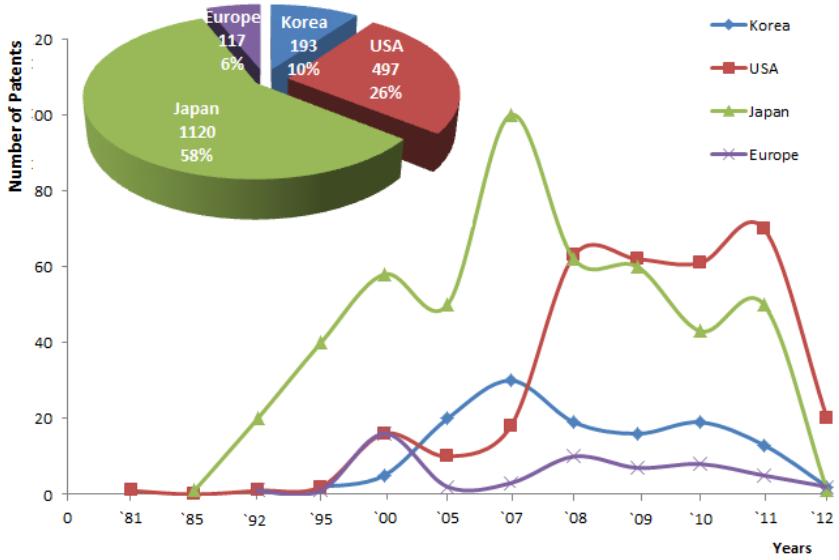


Fig. 7 Trend of patent registration for major countries and technologies.

The number of patent applications by year in the HEV and EV-related automobile sector in major countries is shown in Figure 8, with 1,010 (59%) in Japan, 449 (26%) in USA, 160 (10%) in Korea, and 88 (5%) in Europe. HEV-related patents continuously increased from 9 in 1992 to 68 in 2008, reaching a peak. EV-related patents also show a trend similar to that of HEV-related patents, with 16 in 1992 showing somewhat higher number than that of HEV-related patents, and have increased since then, reaching a peak in 2008 with 76 patents. The development of HEV and EV technology in the automobile sector shows a similar tendency, but patents on EV-related technology were higher than HEV-related patents in all cases.

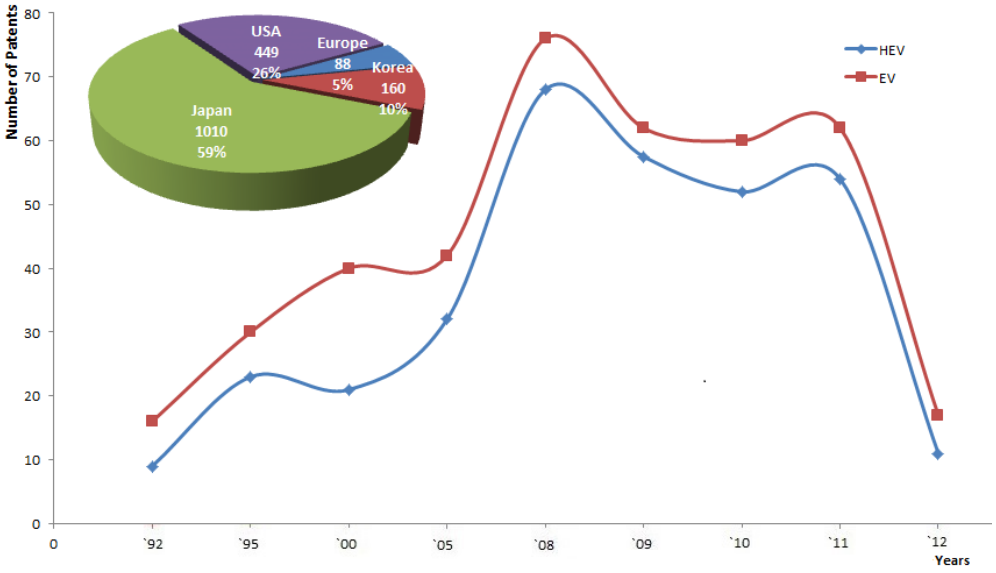


Fig. 8 Trend of patent registration for major countries in the automotive industry.

The number of patent applications by year on HEV and EV technology in the construction machinery sector is shown in Figure 9, with 91 (57%) for Japan, 36 (23%) for USA, 20 (12%) for Korea, and 13 (8%) for Europe. HEV-related patents increased from 2 in 1996 to 16 in 2009, and EV-related patents were 2 in 2005 (showing a late start in research and development compared to HEV technology) and reached a peak with 14 in 2010. The development of HEV and EV-related technology in the construction machinery sector was focused on HEV before 2010, but it can be seen that from 2010 EV-related technology has been on the rise, indicating that technical development is gradually transferring from HEV to EV.

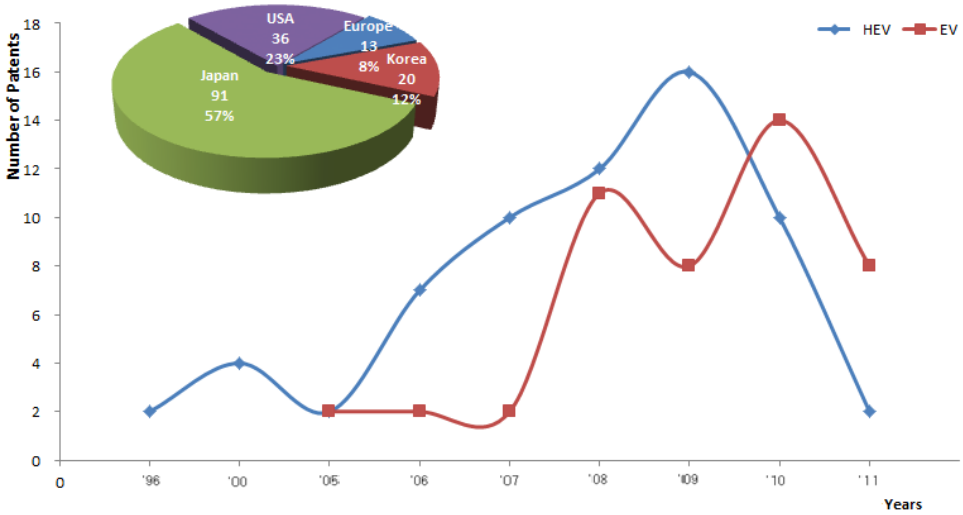


Fig. 9 Trend of patent registration for major countries in the construction machine field.

The number of patent applications on electric drive technology in agricultural machinery sectors is shown in Figure 10, with 19 (32%) for Japan, 16 (26%) for Europe, 13 (22%) for Korea, and 12 (20%) for USA. The trend of HEV and EV-related patent applications was similar to that of the automobile sector. The number of HEV-related patents alternately rose and fell, from 1 in 1995 to 14 in 2011, and EV-related patent applications started somewhat later than HEV-related patent applications, from 1 in 2000, to reach a peak with 6 in 2011. Overall, the agricultural machinery sector shows markedly more patents for HEV technology than for EV technology, reflecting the active technical development of HEV technology.

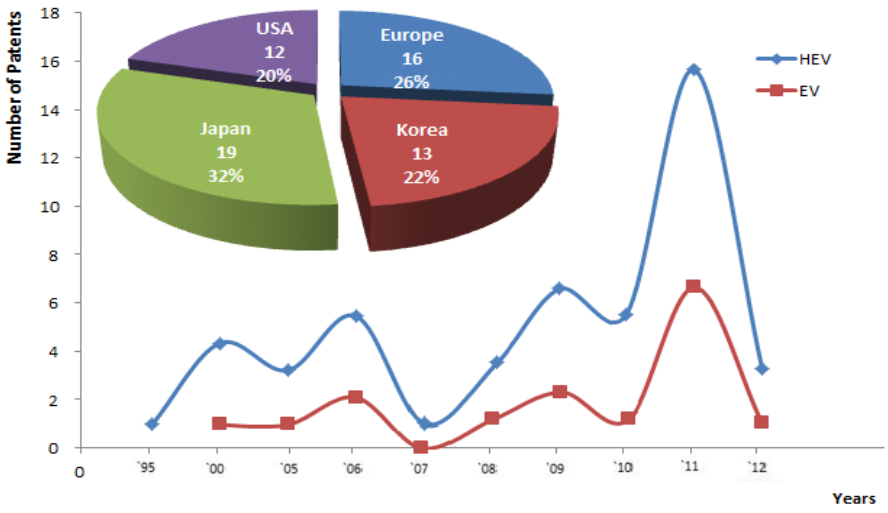


Fig. 10 Trend of patent registration for major countries in agricultural machine field.

4 Summary and Conclusions

The present study researched and analyzed products, papers, and patents in the automobile, construction machinery, and agricultural machinery sectors for the purpose of applying electric drive technology to agricultural machinery, and the results are as follows:

1) The research findings on products with applied electric drive technology can be divided into sector, technology, and country categories. In the sector category, the automobile sector had 12 products with HEV technology and 5 products with EV technology, for a total of 17 products commercialized; the construction machinery sector had 6 products with HEV technology and 2 products with EV technology, for a total of 8 products; the agricultural machinery sector had 2 products with HEV technology and 2 products with EV technology for a total of 4 products. As for technology with applied electric drive technology, 20 products had HEV technology and 9 products had EV technology of the 29 products in total, showing a concentration on HEV technology. Some countries have commercialized HEV and EV technologies in the automobile and construction machinery sectors. But in the agricultural machinery sector, there were no HEV and EV technologies commercialized, showing the urgent need to develop electric drive technology.

2) A search of papers by sector and year for the last 5 years shows that the automobile sector had a total of 33,195 papers over 5 years, accounting for 84% of the total number of papers; construction machinery had 3,806 papers accounting for 9%; and agricultural machinery had 2,687 papers accounting for 7%, the fewest papers. This indirectly shows that compared to the automobile and construction machinery sectors, the development of electric drive technology in agricultural machinery has been slow.

3) A search of patents on electric drive technology in Korea, USA, Japan, and Europe shows 1,927 valid patents; Japan had the most patents with 1,120 followed by the USA with 497, Korea with 193, and Europe with 117, showing that Korea's electric drive technology lags behind Japan and the USA.

The present paper provided information as objective data for deciding the direction of technical development in electric agricultural field machinery, and is expected to be used to offer a future direction for the agricultural machinery sector in Korea.

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