Journal of Advanced Marine Engineering and Technology, Vol. 46, No. 5, pp. 290~301, 2022
J. Advanced Marine Engineering and Technology (JAMET)
https://doi.org/10.5916/jamet.2022.46.5.290

ISSN 2234-7925 (Print)
ISSN 2765-4796 (Online)
Review Paper

Propulsion system of Republic of Korea naval vessels and prospects for future changes: A Review

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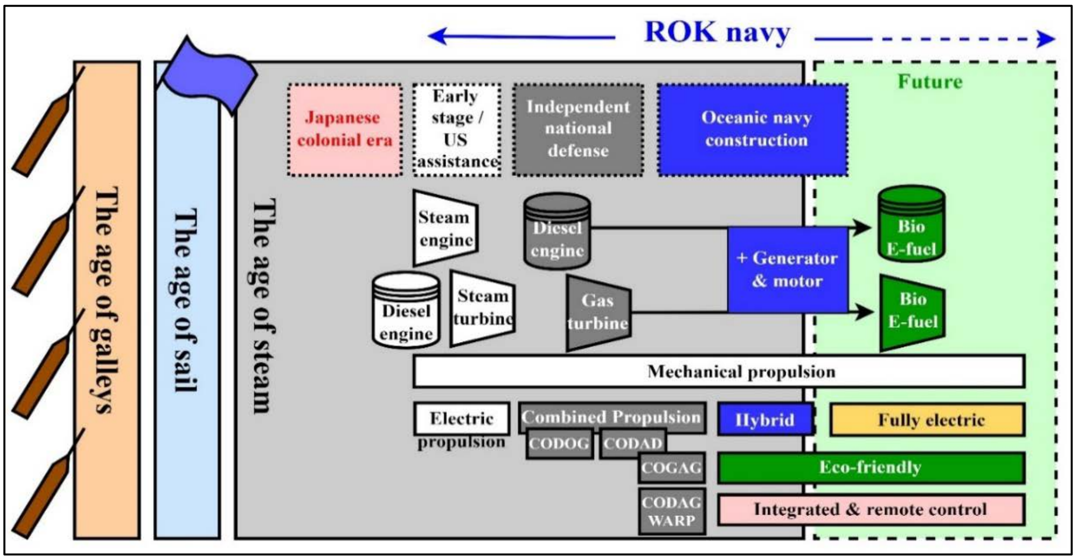
(Received August 29, 2022 ; Revised September 12, 2022 ; Accepted September 22, 2022)

Abstract:



This paper reviews the development and changes in the propulsion systems of naval vessels in the Republic of Korea(ROK), considering the capabilities required for recent vessels and examines the characteristics required for the propulsion systems of the future naval vessels. The history of warships can be divided into three distinct periods: the age of galleys, which used manpower, hand-to-hand combat, and ram; the age of sails, which used wind power, redundant space and cannons; and the age of steam, which began with steam engines and ironclad. The history of ROK naval vessels, which began in the age of steam, was relatively short. However, after the US assistance period and independent national defense capability period, the ROK Navy, which is preparing for an oceanic navy, has many vessels with advanced technology. In this process, the ROK Navy gained operational expertise and technical capabilities for various engines and propulsion systems and is now preparing to respond to the future changes. The conventional relationship in which the propulsion system affects the weapon system has been reversed in modern times, and now the propulsion system will be changed to an electric propulsion system to support the weapon system. In this process, the operational performance and environmental requirements are simultaneously satisfied. The declining population also affects the number of vessel crews, and to overcome this issue, system advancement, system integration, and space integration based on automation and unmanned technology will be carried out. In the process of upgrading the system, real-time monitoring and data-sharing functions on the main devices, such as engines between the vessels and the ground support units, will be added, and vessels will be managed remotely. Furthermore, military actions and concerns about the environment and global warming will continue to be emphasized, and vessels that use fossil fuels are expected reduce fuel usage, use alternative fuels, and actively apply measures to reduce greenhouse gases.

Keywords: Republic of Korea Navy, Propulsion system, Age of the naval vessels, Future prospection, History

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Abbreviations

DD	Destroyer
DDG	Destroyer guided missile
DDH	Destroyer guided missile helicopter
DE	Destroyer escort
DPRK	Democratic people's republic of Korea
FFK	Frigate Korean
IFEP	Integrated fully electric propulsion
IMO	International maritime organization
PC	Patrol craft
PCC	Patrol combat coastal
PF	Patrol frigate
PG	Patrol gunboat
PGM	Patrol guided missile medium
PK	Patrol killer
ROKS	Requirement of Korea navy ship

1. Introduction

The Republic of Korea Navy, founded on November 11, 1945, has undergone continuous development over a period of 76 years and has become a remarkable navy today. The ship building technology and operation know-how for naval vessels, which are the main bodies of naval forces, reached their peak in the middle of the 20th century through several growth steps during the US military assistance period, the independent national defense capability period and oceanic navy construction period. Now, it has reached the stage of exporting combat vessels and teaching naval tactics and technologies based on its own ship-building capabilities and know-how. In this process, not only the weapon system, but also the propulsion system, which is an essential structural component of the naval vessel system, has been diversified and technologically developed.

The ROK Navy has continuously developed vessels' propulsion systems to satisfy the high-speed response capabilities and quietness against submarines, considering the conflict situation with the Democratic People's Republic of Korea **(**DPRK) Navy, coastal environmental characteristics, and environmental friendliness. In this process, the navy has ensured engine operation technology from external combustion engines, such as steam turbines, to internal combustion engines, such as gas turbines, and has gained sufficient experience in combined propulsion and hybrid propulsion. Currently, the ROK Navy is proceeding with the changeover to a fully electric propulsion linked with a weapon system. Through various studies of the changes in the propulsion systems of ROK naval vessels, it is possible to present the necessary background for foreseeing the characteristics and development directions of future ROK naval vessels.

By studying warship history, we first analyzed the changes in the relationship between the propulsion system and the weapon system, which are the two essential components that constitute a naval vessel. Subsequently, we examined and introduced changes in the propulsion system of vessels in the ROK Navy, which began in the age of steam, and grew in the US assistance, independent national defense capability, and oceanic navy construction period. Finally, we evaluated the recent trend of changes in the ROK naval vessels and examined the changes in the propulsion systems and necessary capabilities required of the future naval vessels.

2. The age of the naval vessels

The age of naval vessels is roughly divided into the age of galleys, the age of sails, and the age of steam based on the propulsion power sources (the age of galleys-manpower, age of sail-natural energy, and age of steam-fossil energy). Based on the

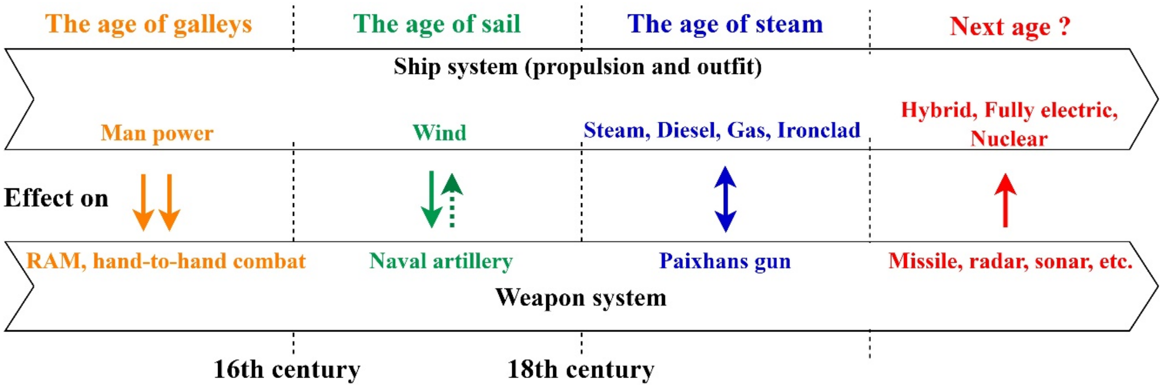

Figure 1: Change of the age of naval vessel

power supply method (propulsion systems) for ships, the history of ships can be roughly divided as follows: 1) vessels using human power (using oars); 2) wind-powered ships (sailboats); 3) steam-powered ships (after the steam turbine system, also known as the external combustion engine); 4) ships powered by internal combustion engines (after the invention of the internal combustion engine); 5) ships powered by electric propulsion systems (internal combustion engines and/or steam turbines were used to run electric generator; the generated electricity is used for the propulsion system of the ship using electric motors; the energy supplied to the boiler can be fossil fuel or nuclear).

From the beginning of human history until the age of the sail in the 16th century, the main source of power for naval vessels was manpower. Before 1000 B.C., during the age of galleys, when conventional weapons, such as swords, spears, and bows were relied upon, hand-to-hand combat was the main activity on the sea, as it was on land. Vessels were used as transport ships that transported these combatants. However, from 900 B.C., manpower, which was the main propulsion power source on galleys also worked as the vessels' weapon power source. From that period onwards, the vessels had the ram, and conventional weapon system to ram the enemy's vessel body. Although the galley was slow, it was easy to adjust the speed and direction in response to the commander’s intention. Therefore, the ram, which requires instantaneous acceleration and accuracy, was used effectively. And to increase the penetration power against enemy warships, warships got bigger and the number of rowers also increased. From this period, naval vessels began to be distinguished from ordinary ships in outward appearance.

With the advent of the age of sailing ships, the propulsion power sources of naval vessels changed from manpower to wind power. Sails, which are the main propulsion systems for sailing ships, have already been applied to ships since B.C., but the full-scale use of sails on the battlefield for naval vessels began in the 16th century. In this period, new navigation routes were opened, new continents were discovered, and wars to decide who the hegemonic nation was happened the ocean. For this reason, the development of large sailing vessels that were strong enough to carry out long-term voyages on the ocean and had excellent munition loading capacity were required. The sails grew in size, multiplied, and diversified to make the most of the wind power. Vessels were enlarged to support these sails, and the space for rowers(manpower) that produced propulsion was no longer required. As a result, the surplus space of enlarged vessels was used for new weapons called naval guns, and naval gun battles began. Victory or defeat in naval battles during this period depended on the maneuverability of vessels using sails and the power of naval artillery, highlighting the importance of crew training and command ability.

The invention of the steam engine, the industrial revolution in England in the 18th century, and the invention of the Paixhan gun in France in the 19th century served as the background for age of steam, which emerged following the age of sail. In the early 19th century, after manpower and wind power, steam engines and propellers began to be equipped on sailing vessels so that the energy of fossil fuels could be used in vessels. Later, in the middle of the 19th century, Paixhan gun, an explosive cannon with a delaying mechanism, was developed to cause fire damage by exploding inside wooden sailing vessels [1]. As a countermeasure against the Paixhans gun, the wooden hulls of sailing vessels were wrapped in iron plates, and through the invention of the steel manufacturing method and the mass production of steel based on the Industrial Revolution, the deck material used on naval vessels was eventually replaced by steel instead of wood. From this period onwards, naval vessels had an iron deck(outfit), naval guns (weapons system), and mechanical devices (propulsion system) powered by fossil fuels.

Even a single naval vessel with an ironclad acted as a huge threat to the nation that was behind in industrialization at that time. The Japanese empire quickly learned a lesson on this, and with an open door policy, promoted industrialization and military modernization, which eventually led to the Russo-Japanese War and Pacific War. Nuclear power, the new impetus for the age of steam, began its development during the Japanese-initiated Pacific War, and to this day, it has been used alongside fossil fuels as the main impetus for naval vessels in some countries. After industrialization, World Wars I and II, weapons systems have been a standard for national scientific and technological proficiency competition and have evolved to counter new weapon systems developed in competing nations, and again to incapacitate that counter measure.

It is considered that this process completely reversed the conventional influence relationship in which ship systems influenced the development of weapon systems and tactics in the age of the galleys and sails. Torpedoes and sonar detectors (weapon systems) were developed; therefore, faster and quieter vessels (propulsion system, counter measures) were required. Missiles and radars were developed; therefore, stealth hulls were required.

Aircrafts are used in naval warfare; therefore, flight decks are required. These are representative examples of reversed influence relationships.

Artificial intelligence (AI), data analysis, high-speed data communication using satellites, automation, unmanned systems, and electromagnetic principles have been applied to weapons systems. Because of these changes, naval vessels are required to produce large amounts of electricity **[2]**, and switching from mechanical propulsion systems to electric propulsion systems is one way to satisfy these requirements.

3. The history of propulsion system advance for Republic of Korea naval vessels

The modern ROK navy sought ideological sources from the 16th century Joseon dynasty's navy and commander, Admiral Chungmugong Yi Sun-sin. The Turtle ship operated by the Joseon dynasty's navy was a pioneering work in the history of the Korean peninsula, with the characteristics of the propulsion system (manpower) and the weapon system (ram) of the galleys' age, as well as the weapon system (naval artillery) of the age of sail and the weapon system (beeguekjinchoenroe, a type of time bomb with a small cannon used in 1592) in the age of steam. (Some literature also describes the characteristics of ironclad, but the facts about this have not been definitively proven **[3]**.)

However, after this period, the naval vessels of Joseon and the Korean empire did not develop enough to represent the age of sail and steam. From 1903 to 1904, Gojong, the emperor of the Korean empire, introduced the iron steamships Yang Mu and Gwangje, but these were not naval vessels, and were exploited by the Japanese empire **[4]**. Later, with the liberation of Korea in 1945, the Republic of Korea began building naval vessels in the middle of the steam age.

3.1 Early stage and US assistance period of Republic of Korea Navy

The first ROK naval vessel operated in 1947 was a 287-ton iron boat with two diesel engines and two shaft propulsion systems (up to 13 knots) and was a captured boat after the Japanese Empire defeat. However, the boat had retired in 10 years owing to maintenance limitations of the main equipment, such as engines.

The ROK Navy's first naval vessel for combat was the ROKS Baekdusan, which was purchased from the United States in 1950 through naval self-fundraising and national donations. ROKS Baekdusan was a patrol craft (PC) with a full load of approximately 450 tons and a maximum speed of 20 kts. It used two RB-99DA diesel engines (2,560 HP) of Hooven, Owens & Rentschler (HOR) company. The RB-99DA diesel engine installed on ROKS Baekdusan is believed to be the first propulsion engine directly introduced by the ROK Navy for naval construction. ROKS Baekdusan served during the Korean War and was disassembled in 1960.

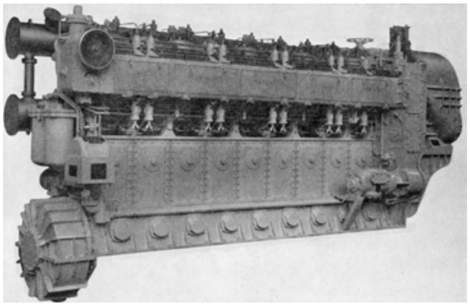

Figure 2: ROKN's first own diesel engine (RB-99DA) **[5]**

Four months after the outbreak of the Korean War, the Tacoma-class Patrol Frigates (PF) transferred from the US Navy between the year 1950 and 1951 were named Taedong, Imchin, Nae Tong, Apnok, and Duman. With a full displacement of approximately 2,200 tons, the vessels could achieve speeds of up to 20 kts using two external combustion vertical triple-expansion steam engines (compound steam engines) (Figure 3). The compound steam engine unit is a type of steam engine in which steam is expanded in two or more stages [6]. A typical arrangement for a compound engine is that the steam is first expanded in a high-pressure cylinder, then having given up heat and losing pressure, it exhausts directly into one or more larger-volume low-pressure cylinders. These vessels were decommissioned in the early 1970s after service.

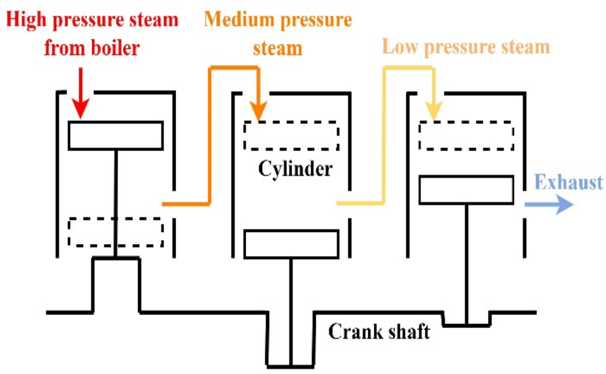

Figure 3: Principle of vertical triple-expansion steam engine

After the Korean War, Canon class Destroyer Escorts (DE) (full displacement of 1,620 tons, maximum speed of 20 kts) were introduced by the US Navy in 1956 as part of the five-year naval reinforcement plan from 1954 to 1958. These naval vessels were named ROKS Kyongki, and Kangwon and these vessels carried out the task of escorting the fleet against the U-boat during World War II and operated an early-stage electric propulsion system with two electric motor drives and four diesel engines (**Figure 4**) **[7]**. The electric propulsion system that modern naval forces are increasingly adopting is not a new technology propulsion system. When sophisticated reduction gear manufacturing technology could not be developed, an electric drive was used to adjust the torque. For the DE, whose main mission was to detect submarines, electric propulsion system would have been an effective option for noise control. The US Navy has been applying electric propulsion to vessels since 1917 **[8]**.

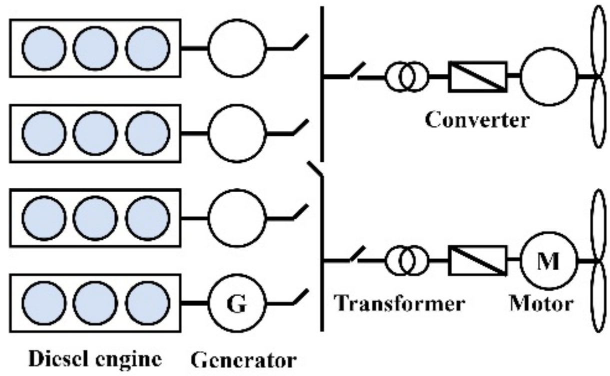

Figure 4: Configuration of diesel-electric tandem propulsion system

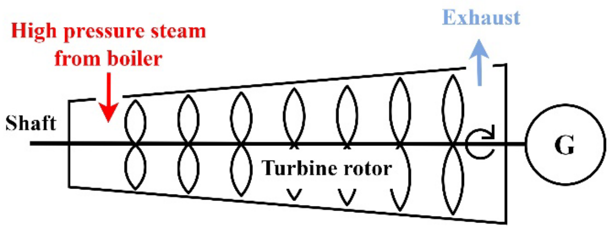

Figure 5: Principle of steam turbine generator

The newly introduced Rudderow-class DE (full displacement of 1,770 tons, maximum speed 24 kts) was named ROKS Chungnam and used a steam turbine-electric system instead of a diesel-electric system to secure increased tonnage and higher speed than the Canon-class. A steam turbine (**Figure 5**) is a machine that extracts thermal energy from pressurized steam and uses it to perform mechanical work on a rotating output shaft. Its modern manifestation was invented by Charles Parsons in 1884 **[9]**. Unlike the expansion steam engine (**Figure 3**), which uses high-pressure steam to create a reciprocating motion and a crank to switch to torque, the steam turbine engine is an external combustion engine that creates torque directly.

In 1963, the ROK Navy began operating fully fledged destroyers. The ROK Navy acquired three fletcher-class destroyers (DD) (one in 1963 and two in 1968) commissioned in the United States during World War II. The first vessel was named ROKS Chungmu (full displacement of 2,500 tons, maximum speed of 36.5 kts) in honor of Admiral Yi Sun-sin, an iconic man of the navy, and operated until 1993. At that time, the ROKS Chungmu was 45% smaller in size than the destroyers currently in service with the ROK Navy (full displacement of 5,500 tons, maximum speed 30 kts) but approximately 1.2 times faster. When estimating the shaft horsepower using the propeller law with tonnage and speed as variables, it was determined that an equal shaft horsepower produced by the propulsion system installed on modern destroyers is necessary. Therefore, considering the limitations in terms of insufficient electric motor output and insufficient energy conversion efficiency, it seems that a mechanical propulsion connecting a reduction gear to the steam turbine was adopted. To this end, two 60,000 HP steam turbines with four oil-fired boilers producing 600 psi steam were operated for propulsion, and two 350 kW steam turbine generators and a 100 kW diesel engine generator (backup) produced electricity for weapon systems and cabins **[10]**. From 1972 to 1981, two Allen Melancthon Sumner-class DDs (full displacement of 3,535 tons, maximum speed 34kts) named ROKS Daegu and Incheon, and seven gearing-class DDs (full displacement 3,500 tons, maximum speed of 37kts) were acquired. These destroyers operated with mechanical propulsion systems with steam turbine-reduction gears, such as the Fletcher-class DD.

3.2 The independent national defense capability period

In the Middle East War of 1967, Israel's newly commissioned DD Eilat was sunk by a Styx surface to surface missile (SSM) launched from an Egyptian patrol guided (PG) missile boat. At that time, the DPRK Navy possessed more than 50 Osa-class PGs equipped with the Styx missile that sank the Eliat. The lesson learnt from the Middle East War made the ROK Navy aware of the need to change its naval power. In 1970, a ROKS broadcasting boat (120 tons) was kidnapped by a high-speed patrol boat of the DPRK Navy, further emphasizing its necessity.

Thus, in collaboration with the Korea Institute of Science and Technology (KIST), the ROK Navy built and operated two KIST-class boats, which were the first domestically produced high-speed boats, in 1972, followed by Baekgu-class patrol guided missile medium (PGM) and Haksaeng-class patrol killer (PK). The ROK Navy mass-produced 25 swallow-class PK (full displacement 76 tons, maximum speed 40kts) through technology accumulation during this period. These PKs were equipped with two German Motoren and Turbinen-Union (MTU) 16-cylinder V-type diesel engines for propulsion.

Sea eagle-class patrol killer medium (PKM) (full displacement 141 tons, maximum speed of 38kts, a total of 105 vessels produced), which is still in operation today, is equipped with improved MTU diesel engines and uses the same two-shaft propulsion system (Figure 6) as the conventional patrol boat's propulsion system.

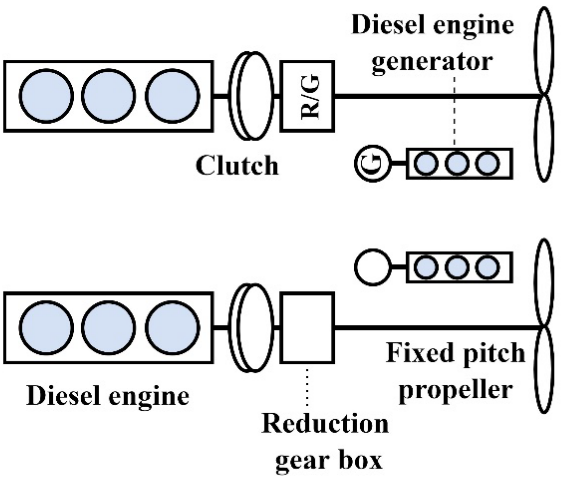

Figure 6: Configuration of typical diesel propulsion system with power generation system in ROKN sea eagle-class PKM

Subsequently, the naval power of the ROK and ship building capability of naval ship builders developed dramatically. In 1980, the ROK Navy built an Ulsan-class Frigate Korean (FFK) based on its own technology. The Ulsan class with full displacement of 2,215 tons and maximum speed of 36 kts is equipped with two MTU diesel engines for patrol mode and two GE LM-2500 gas turbines for battle mode. These two types of prime movers were configured as the combined diesel engine or gas (CODOG) turbine propulsion system, which operates prime movers independently at each operation mode of the vessel.

Starting from the Ulsan-class FFK, the gas turbine (**Figure 7**) has operated as the main propulsion prime mover for the high-speed propulsion of ROKN's medium and large vessels for approximately 30 years. And now, the CODOG propulsion system (**Figure 8**) is the representative propulsion system for the ROK Navy combat vessels; such as the Pohang-class patrol combat coastal (PCC)(commissioned on the year 1983), the great Kwanggaeto-class destroyer helicopter (DDH) (commissioned on the year 1996), the Chungmugong Yi Sunsin-class DDH (commissioned on 2003) and the Incheon-class frigate guided missile (FFG) (commissioned on the year 2012).

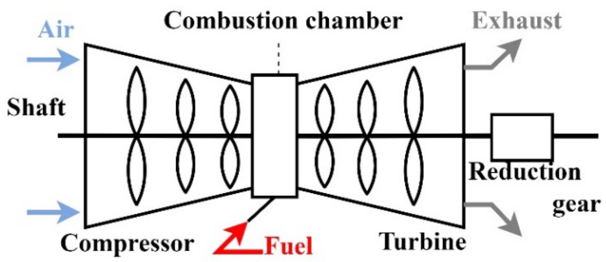

Figure 7: Principle of gas turbine for propulsion

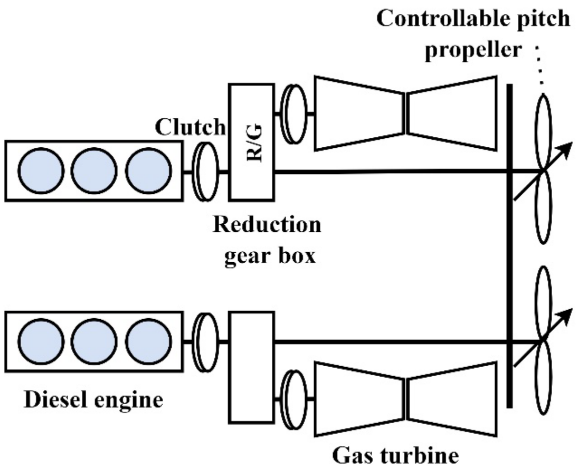

Figure 8: Configuration of CODOG propulsion system

During this period, for independent national defense capabilities, the ROK Navy expanded its missions in diverse domains. Therefore, the ROK Navy acquired amphibious warfare vessels, such as the landing ship tank (LST), landing platform helicopter (LPH), and combatant assistant vessels, such as surface ship rescue ships, submarine rescue ships, and salvage ships to subdivide vessel missions. In addition, the Aux. oiler (AOE) was acquired to improve the sustainability of naval operations. These vessels are primarily driven by diesel propulsion, and is combined with a diesel engine on each of the two shafts. In addition, these vessels have a sufficient margin for internal space compared to combat vessels. Therefore, they usually adopt a commercial diesel engine with improved economic efficiency instead of a gas turbine with high specific power or an expensive diesel engine for the military.

The ROK Navy submarine force was also established as a foundation at this time. Submarines operated by the ROK Navy in the past and present have used electric motors with diesel engine generators and batteries. In particular, the air-independent propulsion (AIP) mechanism using fuel cells has been applied to the Son won-il class submarine.

3.3 The oceanic navy construction period –I (~year 2010)

The ROK Navy, which has accumulated the technologies and know-how of naval ship building and operating through the independent national defense capability period, has built a balanced naval power with the coastal mission vessels against the DPRK Navy and the oceanic mission vessels for ballistic missile tracking, interception, merchant ship escorts, etc.

First, a Yoon Yeongha-class patrol killer-guided (PKG) missile (full displacement of 570 tons, maximum speed 44 kts) and a new type of sea eagle-class patrol killer medium rocket (PKMR) (full displacement of 250 tons, maximum speed of 40 kts) have been operating since 2008. These vessels are replacement vessels for the gradually aging sea eagle-class PKM to maintain the overwhelming naval power against the DPRK Navy on the coast and have increased displacement compared to conventional PKM owing to the guided missiles or rockets. In addition, these new combat vessels were equipped with water-jet-refined propellers (Figure 9). It is a choice to solve the problem of screw and rudder damage caused by floating objects and fishing nets on these vessels, which have many coastal voyages owing to the mission.

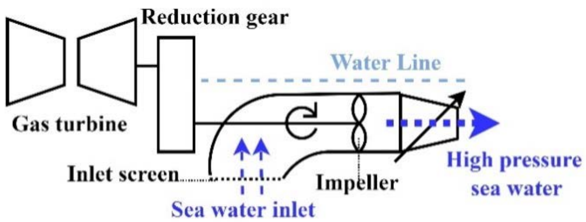

Figure 9: Principle of water jet refined propeller propulsion

These vessels are additionally fitted with one shaft driven by a gas turbine and two shafts driven by diesel engines. This measure satisfies the conditions of increased displacement and top speed. The propulsion system of these new vessels is called combined diesel engine and gas turbine–waterjet refined propeller (CODAG-WARP) in patrol mode. Only the left and right propulsion shafts that are directly connected to the diesel engine are activated, and when switching to battle mode, the central propulsion shaft that is directly connected to the gas turbine is additionally activated. These vessels are propelled by the pressure of seawater jetted by three water jets. By performing steering function in the seawater injection direction of the left and right water jet nozzles, the turning performance was improved when compared with the conventional PKM.

The great Sejong-class Aegis Destroyer-guided missile (DDG) (full displacement:of 10,600 tons, maximum speed of 30 kts), which carries out the mission of tracking and intercepting ballistic missiles, was introduced in 2007. To ensure a top speed of 30 kts and increased displacement of DDG, the combined gas turbine and gas turbine (COGAG) propulsion system that uses four gas turbines instead of diesel engines with low specific power was selected. This propulsion system operates one or two gas turbines in patrol mode (low speed) and operates all four gas turbines in battle mode at maximum speed.

During the period of independent national defense capability, the ROK Navy operated a diesel propulsion system on small combat vessels and combat assistant vessels, and the CODOG propulsion system on medium and large combat vessels. Later, it was confirmed that as the vessel spectrum was expanded to counter diversified threats. New propulsion systems, such as CODAG-WARP and COGAG were introduced to meet the various requirements of the operational capability (ROC) of the vessels. The propulsion system of the ROK Navy vessels up to this period corresponded to typical mechanical propulsion.

3.4 The oceanic navy construction period–II (year 2010~)

In 2010, the ROKS Cheonan (PCC) was sunk by the DPRK Navy submarine. Subsequently, radiated noise from the vessels emerged as an issue during the ROK Navy vessel building project. Submarines detect radiated underwater noise from the surface vessels. Therefore, the propulsion system for anti-submarine mission vessels, such as FFG and DDH operating in the sea area adjacent to DPRK must ensure a high level of quietness in the low-speed range. Therefore, an electric propulsion system with electric motors could be used as an alternative.

Incheon-class FFG, for which exploratory development was started before the ROKS Cheonan sinking, adopted the conventional CODOG system. However, Daegu-class FFG, for which exploratory development was started after Cheonan sinking, adopted the combined diesel electric or gas turbine (CODLOG)

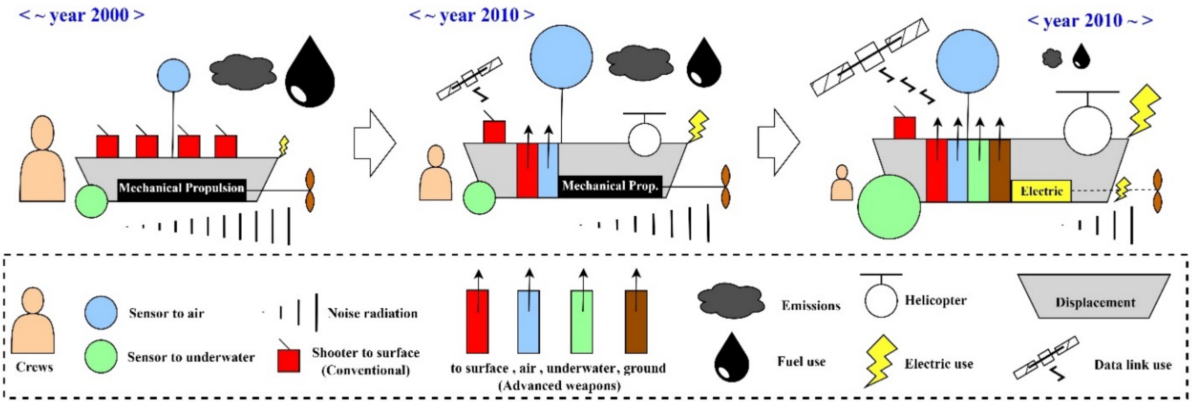

Figure 11: Change of ROK naval combat vessel's paradigm

hybrid system (**Figure 10**) to minimize radiated noise. The CODLOG hybrid system drives two electric motors with electricity produced by four diesel engine generators in the patrol mode. In battle mode, the motors stop and a large gas turbine engine is activated and takes charge of all speed ranges from 0 to 30 kts. The ROK Navy operates eight Daegu-class FFG vessels.

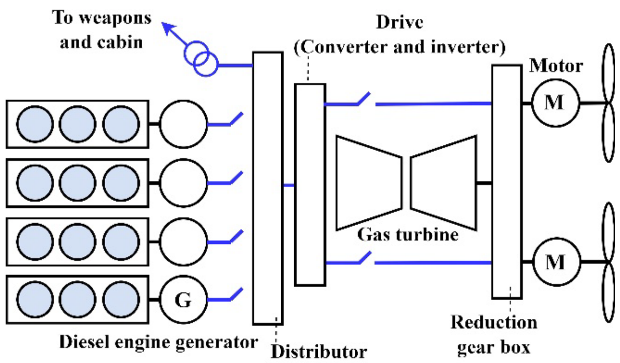

Figure 10: Configuration of CODLOG hybrid system

With the exception of the vessels introduced during the US assistance period, the power generation and propulsion systems were clearly separated before the Daegu-class FFG. In other words, the purpose of the prime movers for power generation and the prime movers for propulsion was clearly distinguished. However, after the Daegu-class FFG, the power produced by the generator began to be used for low-speed propulsion of the vessel, and gradually, the vessel's entire mechanical system begins to be integrated without being divided into a generation system and a propulsion system. Subsequently, electric propulsion was applied to combat assistant vessels. Soyang-class AOE adopts (combined diesel electric and diesel engine (CODLAD) hybrid system. The Soyang-class AOE's CODLAD drives the propulsion motors with electric power produced by four diesel engine generators in the low-speed mode, and two diesel engines are additionally activated for the high-speed propulsion mode.

Another feature that can be identified with the propulsion and power generation system of vessels introduced since 2010 is the improved environmental friendliness of the system's prime mover. IMO emission regulation tier II came into effect on January 1st, 2011, making environmental friendliness mandatory in the marine engine market. The engine market for naval vessels was also affected by this, and diesel engines adopted technologies, such as electronic control with common-rail injection, two-stage turbo charging, and variable valve timing to improve the environmental friendliness of ROKS.

4. Prospection of propulsion system for the future Republic of Korea navy vessels

Figure 11 shows the paradigm change of naval combat vessels, which is qualitatively illustrated by analyzing the characteristics of various vessels in the past and present for the ROK Navy. The changing features of the ROK Navy vessels that can be confirmed through observation are summarized as follows:

1. The displacement would be increased to load more weapon systems but rather the space for engine systems and crew accommodation would be decreased.
2. The conventional weapon system centered on naval guns would be switch to advanced weapon systems, such as missiles and electromagnetic weapons.
3. Operating crews for the naval vessel would be continually decreased and demand of automation systems would be increased.
4. The naval vessel's anti-air and anti-submarine detection capabilities would expand and the missions of a vessel would be diversified.

5. As the amount of electric power required for the vessel increases, the propulsion system would be changed from mechanical to electrical.
6. Lower fuel consumption, lower exhaust emissions and lower underwater radiated noise would be required, continuously.
7. The amount of data to process in a vessel would be increased.

In the course of this change, the future of naval vessel propulsion systems can be predicted as follows:

4.1 Electric propulsion

ROKS Sejong, the great-class DDG, which was commissioned in 2007, operates more weapon systems, such as the Aegis combat system and an expanded vertical launch system (VLS), unlike the conventional combat vessels operated by the ROK Navy. The DDG was equipped with 3 MW gas turbine generators to produce electric power needed to increase the weapon system operations. Typical combat vessels utilize highly economical (SFOC, g/kW) diesel engine generators to produce a maximum power requirements of 3-4 MW. However, if the DDG uses diesel engine generators, such as, typical combat vessels, very large diesel engines must be equipped to produce the required power of up to 9 MW. Thus, the design displacement could not be satisfied. Therefore, the ROKS Sejong, the great-class DDG falls under the category of vessels in which all prime movers mounted on the vessel are gas turbines only and is considerably disadvantageous in terms of economy (fuel consumption).

To overcome these shortcomings, Jeongjo, the great-class DDG launched in 2022, selected combined gas turbine electric or gas turbine (COGLOG) hybrid system. It maintains the optimum load (75-85%) of the gas turbine generators as much as possible, and a considerable amount of surplus electric power from the generators is used to drive propulsion motors in the patrol mode. In the battle mode, propulsion gas turbines are driven.

This change is also reflected in the Korean destroyer experimental (KDDX) program, and it is expected that the new DDH to be delivered in the next term will use an integrated fully electric propulsion system. The introduction of electric propulsion for ROK naval vessels has already begun.

All the requirements in the recent development process of ROK naval vessels can be satisfied with the electric propulsion system of the vessels. The enhancement of sensors, the increase in new weapon systems with extended range and improved accuracy, the decrease in human resources and the accompanying automation of vessels, improvements in computing technology, the increase in tactical information handled by a vessel, etc., make the naval vessel need higher electric power. In view of the future, introduction of electromagnetic weapon systems, in conditions with high instantaneous power demands, the electric propulsion system can provide high-density energy that can be produced by the prime movers of all vessels.

In addition, as the number of missions assigned to a future naval vessel increases, the space required for many weapons systems increases. In this situation, electric propulsion of vessels is an effective alternative that can respond to changes. Changing the propulsion system from mechanical to electric reduces the number of prime movers by up to 50% and eliminates the dependency between the prime mover and the shaft, thus increasing the flexibility of the propulsion system arrangement and saving space.

Furthermore, when applying an electric propulsion system, it is possible to shield the noise of the prime mover, which can improve the quietness of the vessel that emerged after Cheonan sinking in 2010.

However, electric propulsion system in the vessel is a strategy suitable for medium- and large-sized vessels, and its application to small vessels, such as PKMR, which is mainly used for high-speed operation and has a simple propulsion system, would increase the weight of the vessel and reduce its economic efficiency **[11]**. Therefore, a thorough review and analysis are required.

4.2 Eco-friendly propulsion

Second, the application of environmentally friendly technology to the propulsion systems of naval vessels is predicted. Global warming is a supranational and nonmilitary threat, and the response to greenhouse gases, the main cause of global warming, has become a global issue. The IMO's greenhouse gas emission regulations were applied to general ships in the process of promoting regulations and promotion issues for major greenhouse gas emission sectors, such as industries, power generation, and transportation. Naval vessels were not included in the scope of regulation. This is believed to be due to the restrictions on the monitoring of naval vessels, which are military assets.

However, countries that operate so-called advanced navies, such as the United States, the United Kingdom, and the European Union, have gradually sympathized with the need to reduce greenhouse gas emissions in the military sector and promote greenhouse gas mitigation policies **[12][13]**. The Ministry of Defense of the Republic of Korea has also promoted carbon neutrality tasks since 2021 to realize the government's carbon neutrality policy **[14]**. Practical tasks for the military sector, including energy conversion of military weapon systems, such as vessels and minimization of greenhouse gas emissions, are likely to be promoted.

For this reason, the necessity of applying alternative fuels, such as biodiesel and e-fuel, is increasing as a countermeasure for energy conversion in the military sector **[15][16]**. Unlike alternative fuels, such as hydrogen and ammonia, biodiesel and e-fuel have high applicability and can be operated within a range that does not significantly change the fuel storage and supply system currently operated in vessels. In addition, it is expected that active reduction measures, such as selective catalytic reduction (SCR) for the purpose of adsorption and removal of nitrogen oxides on general ships and exhaust gas recirculation (EGR), will limit the generation of nitrogen oxides in diesel engines.

Furthermore, the Navy will continue to reduce carbon emissions by minimizing vessel fuel usage through economy-enhancing technologies, such as electric propulsion and hull optimization. The electric propulsion vessel, which consists only of the prime mover for power generation, optimally distributes the power load between the prime movers and continues to operate under the most economical conditions. Techniques to satisfy the energy efficiency design index (EEDI) for general ships will gradually be applied to naval vessels.

4.3 Sensor monitoring and remote control

The third change is the application of remote monitoring and control technologies for mechanical systems. As the various systems that constitute the vessels become automated and unmanned, advanced maintenance technology is required. The decrease in the number of vessel crews worsens, so self-unit maintenance in the naval vessel meets realistic limitations. To complement this, the navy actively uses data communication technology between the vessels and the onshore support forces. Onshore monitoring units that have field maintenance functions receive and analyze information, such as temperature, pressure, and flow collected in real time by various sensors in the vessel's main devices to support condition-based management using AI technology. For this purpose, data collection technology is used for the vessel's main engines, generators, electric motors, and aux. machineries, etc., will be developed, and a function to integrate and share them onshore will be installed in the vessel in real time. This technology is now in operation by a large merchant shipping company, and the new vessels of the ROK navy are also introduced to early stage functionality. After these kick into high gear, when a failure occurs, remote system checks and status diagnosis are first performed by the onshore monitoring unit supervisor, and self-unit maintenance by crews in the site proceeds by exchanging information with the onshore monitoring unit supervisor. As the situation worsens and limits the failure process of the site, the vessel enters the homeport and quickly turns into field maintenance. The onshore maintenance support unit that conducts remote monitoring applies life cycle support (LCS) to the vessels. The LCS method manages the main devices, such as the weapon system and propulsion system of the naval vessel, from the perspective of the total life cycle, improves the efficiency of field maintenance, and enhances the availability of the vessels. For these, modular maintenance concepts, such as the maintenance float (M/F) repair method, will be extended.

4.4 Integrated control

The fourth change is the integration of the weapon system and fully electric propulsion system. This was the ultimate electric warship. Owing to multiple factors, such as the decrease in military personnel, the development of automation and unmanned technology, and the development of remote monitoring and control technology, the number of vessel operators will continue to decrease. In the case of naval vessels built before 2010, three or four people were on duty in the engine room, but for vessels built after 2010, the number of people on duty was reduced to one or two people. Owing to this trend, the conventional three-station configuration is divided into three main stations, such as the bridge, the combat information center and mechanical control room will be turned over to one or two station configurations by integrating the functions of the mechanical control room into the bridge or combat information center. This change had already begun. Personnel operating the combat information center, especially officers, will required to have a broader range of job performance capabilities with additional duties, such as machine control and failure processes added to the navigation and combat information duties.

System integration, along with the remote management technology explained earlier, will become an indispensable core technology for powering and operating unmanned vessels in the future.

5. Conclusion

The age of the naval vessels is divided into the age of the galleys, age of sail, and age of steam. Most modern naval vessels use internal combustion engines and gas turbines rather than steam engines and turbines, but modern naval vessels still have the features of steam age, direct power transmission, ironclad hulls, and iron naval guns. Therefore, in this study, it is believed that the modern naval vessels still belong to the steam age. However, it is clear that the ROK naval vessels are currently evolving from the age of steam to the next stage, which is the hybrid propulsion with fully electric propulsion for the integration of the weapon system, the propulsion system, and nuclear propulsion.

The ROK Navy, which started with a 287ton boat acquired after liberation, has now grown into a cutting-edge navy that operates state-of-the-art large combat vessels, such as Aegis destroyers and landing platform helicopter vessels. During the navy's 70-year development process, the propulsion system plays the role of producing the driving force for the navy's core and naval vessels and develops in response to changes in technology, environment, tactics, and weapon systems.

Through the US assistance period and independent national defense capability period, the ROK Navy operates not only on internal combustion engines, such as diesel engines and gas turbines, but also on external combustion engines, such as vertical triple-expansion steam engines and steam turbines, that utilized the power of steam and also experienced the power transmission method using electricity, which is the current propulsion system change trend.

Since 1990, after the independent national defense capability period, the combined propulsion method, which switches or combines prime movers according to the speed of the naval vessel, has been fully adopted for naval vessels. Currently, CODOG, COGAG, CODAG-WARP, and CODAD mechanical combined propulsion systems are primarily used in ROK naval vessels.

The year 2010 was a turning point for the ROK naval vessels' propulsion system. The ROKS Cheonan sinking and changes in the engine market due to IMO environmental regulations have emphasized quietness, eco-friendliness, and economic efficiency in naval propulsion systems since 2010. As an alternative to meet this, electric propulsion has been on the rise again. The electric propulsion method is divided into the hybrid propulsion method, which combines mechanical propulsion and electric propulsion, and the fully electric propulsion method, which is driven only by electricity over the entire speed range. The ROK Navy has accumulated knowledge through hybrid propulsion vessel operation, and currently reviews how to build fully electric propulsion vessels. Environment-friendly engine technology has been introduced to naval vessels since 2010, in response to the demand to satisfy environmental regulations in the engine market. It is believed that these environmental techniques have intangible effects, such as reduction of oil usage and emissions, and participation in government policy by proper harmony with the introduction of electric propulsion.

Future ROK naval vessels will carry more weapon systems, sail longer distances, and perform a variety of missions, but they should solve the problem of reduced manpower, fuel saving, exhaust emission reduction, and noise. In addition, an increase in the state-of-the-art weapon systems and improved surveillance, reconnaissance, and detection capabilities, increased data throughput, the use of AI technology, active automation, and unmanned technology will require more electric power for naval vessels.

In the face of these changes, the ROK Navy should expand the application of electric propulsion systems to vessels and adopt methods for integrating mechanical systems with weapon systems. These changes require large combat vessels, such as destroyers. Furthermore, in line with the ongoing expansion of environmental regulations and participation of advanced naval forces in eco-friendly policies, the ROK Navy should adapt technology to mitigate global warming in the propulsion system of naval vessels. In addition, the reduction of vessel operation personnel should be complemented through the application of remote monitoring and failure processing by ultra-high-speed data communication technology with onshore assistant units, modularization for field maintenance units, and LCS concept expansion.

Acknowledgements

This study was supported by the 2022 Academic Research Project of the Naval Institute for Ocean Research of the Republic of Korea Naval Academy.

Author Contributions

Conceptualization, H. -M. Baek; Methodology, H. -M. Baek; Formal Analysis, H. Lee; Data Curation H. -M. Baek; Writing-Original Draft Preparation, H. -M. Baek; Writing-Review & Editing, H. Lee and H. -M. Baek.

References

[1] J. Kinard, Artillery: An illustrated History of Its Impact, Santa Barbara, California, USA: ABC CLIO, ISBN 9781851095568, 2007, pp 235-237.

[2] The Royal Institution of Naval Architects, Type 45 to get third diesel generator to overcome problems, https://www.rina.org.uk/Type_45_to_get_third_diesel_generator_to_overcome_problems.html, Accessed May 12, 2022.

[3] K. -H. Choi, The restoration of the Turtle Ship of the ROK Naval Academy, The Korea Defense Daily, https://kookbang.dema.mil.kr/newsWeb/20220818/3/BBSMSTR_000000010026/view.do, Accessed August 29, 2022 (in Korean).

[4] J. -I. Park, The bravado empire closed, The Chosun Ilbo, https://www.chosun.com/site/data/html_dir/2018/12/12/2018121200344.html, Accessed August 28, 2022 (in Korean)

[5] B. Daly, PC-1181, Reprinted from NavSource Online: Submarine Chaser Photo Archive, by Joseph M. Radigan, Copyright (1996-2022), Available: http://www.navsource.org/archives/12/010788.htm

[6] J. Brooks, Dreadnought Gunnery and the Battle of Jutland; The Question on Fire Control, 1st Edition, NY, USA: Routledge, 2005, p. 14.

[7] N. Friedman, U.S. Destroyers:An illustrated Design History, Revised Edition, Naval institute Press, Chapter 7, 2004.

[8] J. Czarnecki, Turboelectric Drive in American Capital Ships, The Naval Technical Board, NavWeaps, January 31, 2001 [Online], Available: https://www.warships.com.cn/navweaps/tech-038.htm

[9] A. Stodola, Steam and Gas Turbines: With a supplement on the prospects of the Thermal Prime Mover, 6th Edition: McGraw-Hill, 1927.

[10] Capt. G. Stewart, Life on a Fletcher class destroyer in the 1950's, Naval Historical Foundation, July 31, 2013 [Online], Available: Life on a Fletcher Class Destroyer in the 1950's Naval Historical Foundation (navyhistory.org)

[11] H. -M. Baek, K. -S. Jung, M. -H. Lee, and J. -S. Choi, “A study on the arrangement of integrated power system for warship,” Journal of the Korean Society of Marine Engineering, vol. 38, no. 9, pp. 1070-1074, 2014 (in Korean).

[12] S. Parkinson, “The Environmental Impacts of the UK Military Sector,” Scientists for Global Responsibility-Declassified UK, Halton, Lancaster, 2020.

[13] N. C. Crawford, “Pentagon fuel use, climate change, and the costs of war,” Watson Institute for International and Public Affairs, Brown University, 2019.

[14] Republic of Korea Ministry of National Defense, “2021 Government work report 「Recovery, Inclusion, Leap Forward 2021,” (Press Released January 21, 2021), 2021(in Korean).

[15] S. -P. Jung, Energy Platform News, http://www.e-platform.net/news/articleView.html?idxno=63483, Accessed July 18, 2022 (in Korean).

[16] S. -W. Park, Monthly Hydrogen Economy, https://www.h2news.kr/news/article.html?no=9528, Accessed July 18, 2022 (in Korean).