SUBMARINE HYBRID PROPULSION SYSTEMS

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Summary. Basic information about hybrid propulsion systems installed on conventional submarines in latest years is presented in this paper. This paper does not draw on any funded study and all data is from open literature.

1. Introduction

Taking into account types of propulsion system, submarines are classified as nuclear powered or conventionally powered ships. Conventionally powered submarines are divided into three categories:

- Category "A" – classic submarine with diesel-electric propulsion system;
- Category "B" – classic submarine with diesel-electric propulsion system additionally supplied with air independent propulsion system – "hybrid propulsion system"
- Category "C" - submarine equipped only with air independent propulsion system.

Submarine with hybrid propulsion system has, except from conventional diesel-electric propulsion unit, additional source of electric energy based on air independent heat engine which drive generator or electrochemical system, for example fuel cells (Fig.1).

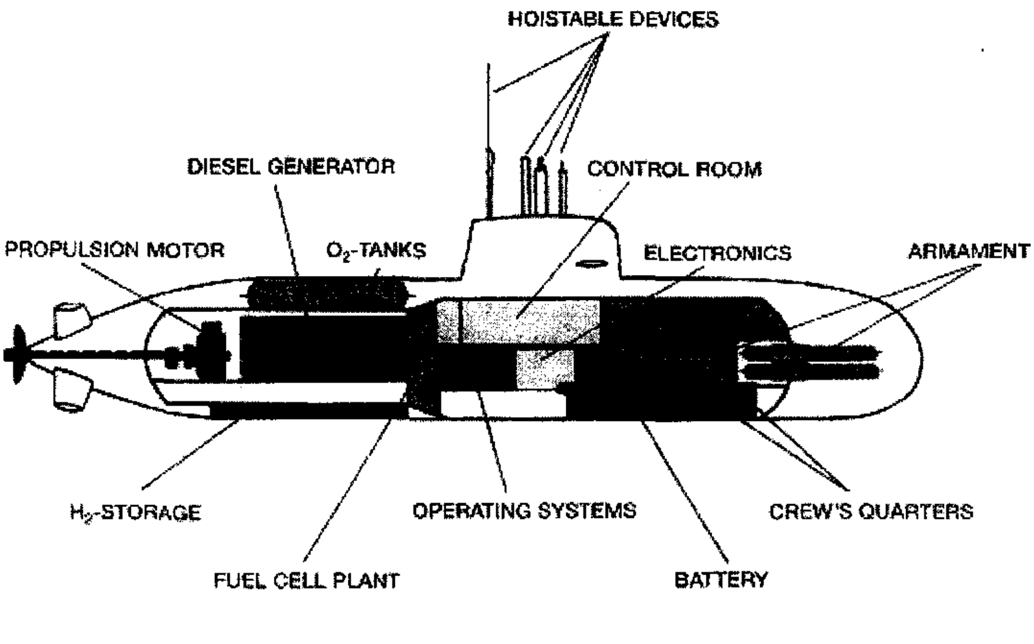

Fig. 1 Submarine with hybrid propulsion system

Hybrid propulsion system gives submarine possibility of diving and of moving with five knots speed for several days longer than classic submarine of category "A" can. In Germany, Helmut Walther in 1935 introduced his turbine project for U-boats working in closed cycle [5]. This system, called Walther's turbine, was installed on several German U-boats during the Second World War. Research on power plants working in closed cycle started before the last war also in the Soviet Union. After the war, from 50's, main constructing works were involved in nuclear powered submarines. During the last two decades research on AIP – air-independent non-nuclear power system gathered speed. Systems called "nuclear power systems for poor fleets" are used in 11 countries [17]. Nowadays, we generally distinguish four types of such systems mounted on submarines, namely: *semi-closed cycle diesel engine*, *semi-closed cycle Stirling engine*, *semi-closed cycle gas turbine* supplied with ethanol as fuel and *fuel cells*. The first three systems are AIP heat engines, which convert chemical energy from fuel into electric energy driving generators. The fourth system, fuel cells, is an electro-chemical AIP in which chemical energy of the fuel is converted directly into electric energy. Fuel cells are not engines, they are energy converters so they are not limited in efficiency by thermodynamic lows like heat engines.

It is mentioned [24] that some day different combinations of AIP systems might be installed on more than one hundred submarines. Some of the AIP systems which were introduced on fleet submarines will be presented in that work.

2. Semi closed - cycle Diesel engine

Germany

The MTU 8V 183 SE52 diesel engine working in semi closed-cycle (CCD – closed-cycle diesel) has been tested and is offered as a hybrid propulsion system by German shipyard in Tyssen. There is an additional hull section together with all needed auxiliaries for diesel engine working under water. Six-meter long section was mounted on ex U-1 in March 1996 [15]. Engine worked in open cycle as full rated when boat was in surface or near surface position and when boat was in submerge position engine worked in closed-cycle. According to German specialists' opinion such system gives opportunity to lengthen boats range in submerge position five times. In closed-cycle mode exhaust gasses are cooled from 300-400 °C to approximately 80°C by a spray cooling system. Then they are fed into CO_2 absorber. The absorber mixes exhaust gasses with seawater. Maximum engine power in this mode, together with the absorber, is about 400 kW and seawater flow through the absorber totals 50 l/s. When oxygen and neutral gas (argon) are added in mixing chamber, gasses cleaned in the absorber return as a new charge to the engine. The advantage of this system might be, as constructors regard, that main system components such as diesel engines are standard and reliable. High-energy concentration in diesel fuel and liquid oxygen is also advantageous. On the other side, high noise level and low system efficiency – about 30-35 % might be relatively disadvantageous. Exists report [13] about tests of that system in submerge position with engine working, without stopping, for 14 days. German shipyard TNSW together with engine manufacturer firm MTU offer this system (CCD) as especially attractive in cases when older boats are retrofitting and modernized. The additional hull section with oxygen storage system might be easily implemented in existing hull. The length of this section is approximately equal to the hull diameter. After such modernization hydrodynamic characteristics of the boat and her maneuverability stay on comparable level as it was proven on ex U-1. For boats of 1500-ton displacement, 250 kW engine working in closed-cycle is sufficient to get speedy 5-7 knots in submerge position. Higher engine power, for example for battery charging in a buffer mode, is not necessary because of energy losses during conversion.

Netherlands

Netherlands RDM shipyard worked out and tested hybrid propulsion system for boat type "Moray 1400"[7]. This boat, except from three diesel generators, each 2000 kW rated power, might be supplied with special section with closed-cycle diesel engine. There might be one or two units, each 300 kW rated power, according to a needed submerged boat's speed. Declared speed only on AIP system is 8-10 knots. Oxygen is stored in two tanks in liquid form. Tanks are mounted in the bottom part of the section with the absorption unit and cooling systems for engine exhaust gasses. Propulsion system has been tested on laboratory stand and in sea trails. The noise level measured during sea trails in AIP mode was close to the noise level of the conventional electric mode, according to what Netherlands' specialist stated.

3. External combustion stirling closed - cycle engine

Sweden

Stirling engine has been tested and successfully introduced by Swedish Navy. Prototype plant has been installed in 1988 [21] on boat of type A14 "Nacken". After that experiment decision about Stirling engine installation on submarines A19 has been taken. On that boat, except conventional diesel engines, two Stirling engines each 75 kW made by firm Kockums type V4-275R has been mounted. The first of the A19 type boats - HMS "Gotland" - finished sea trails in December 1996. Stirling engines, working during submerge trails, gave boats five knots speed and lengthened their operating range. Thanks to that engines boats might be several times longer in submerge position than without AIP system [3]. Fuel burning in Stirling engine takes place in semi closed-cycle. Exhaust gases outlet system gives boat possibility of diving for several hundred meters. Disadvantages of AIP Stirling systems are high technological demands in manufacturing processes of not typical piston engines, high fuel quality demands, low efficiency and low energy concentration.

Sweden is the only example of the country where AIP system is fully implemented on navy (not shipyard) boat. R & D works on new generation boats – "Submarine 2000" started in 1990 as a common Swedish, Danish and Norwegian project [2,3,4]. Hull of that ship is to be similar to the American project "Albacore", which has relation length to width as 7:1. Such relations give very low noise level. Propulsion system with Stirling engine gives possibility of being under water for a fortnight.

4. Steam rankine cycle - module

France

Module d'Energie Sous – Marine Autonome (MESMA) installation has been ordered for one of third Pakistan's Agosta 90B class boats maiden in Kharachi under France license. Test module MESMA (weight of 30 tones) has been built by DCN shipyard in Inderet, near Nantes [22]. System working principle (Fig.2) based on closed-cycle, where ethanol and oxygen are burned which allows conventional boat to be in submerged position for 5 days. Liquid oxygen and ethanol are stored in separated tanks located in different parts of a ship to upgrade safety. Power in the basic ethanol circuit differs from 150 to 600 kW and output on the generator driven by a steam turbine in the second steam Rankine circuit gets to 200 kW. This gives boat possibility of moving with 4 knots speed or to charge battery. The whole oxygen and ethanol transfer processes are monitored and depend on a needed energy level. Heat energy from burning ethanol is used for steam generation and for auxiliary circuit heating. Steam pressure in this circuit is about 1.8 MPa and temperature ~ 500°C. The auxiliary circuit works on the Rankine principle (steam generator, turbine, condenser, pump). Total system efficiency is about 24%.

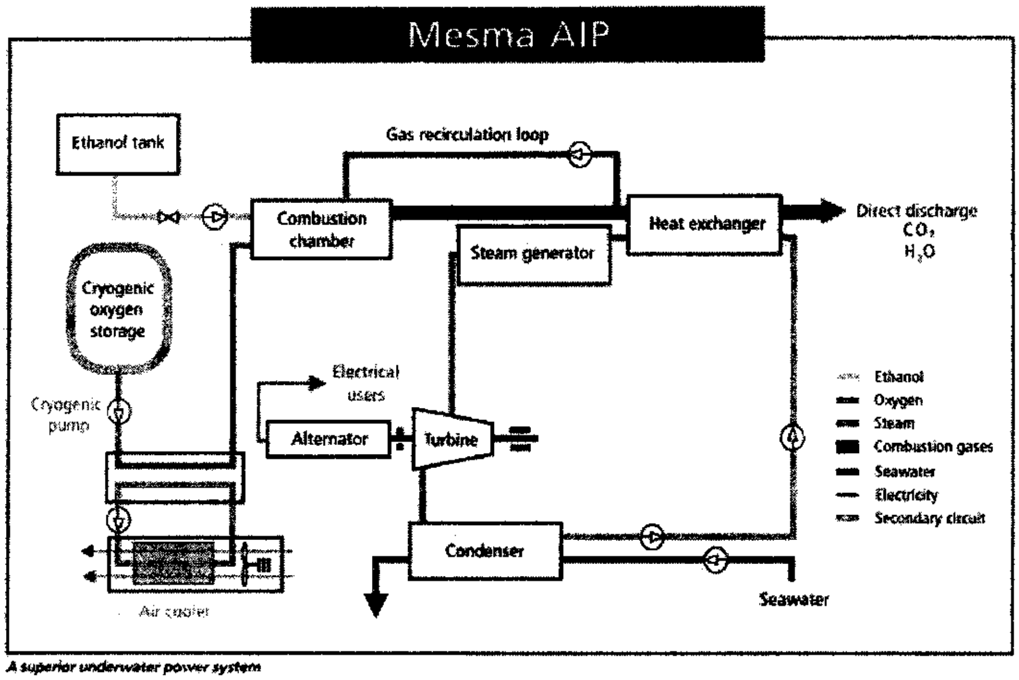

Fig.2 Module MESMA

Oxygen consumption in the MESMA system is bigger than in (comparable in power) CCD or Stirling systems, and tanks for ethanol should be two times bigger for the same boat's range.

5. Fuell cells

Germany

German shipyard HDW offers fuel cell technology in which separate fuel cell unit (Fig. 3) has electric power from 30 to 50 kW [24]. As they mentioned, boat type U-212 will be supplied with fuel cell battery with 300 kW power. Such energy source gives boats submerge speed up to 8 knots. Boat type U-214 will be supplied with hybrid propulsion system which consists of conventional MTU 16V396 diesel engine (2000 kW) and two fuel cells batteries (120 kW each). Fuel cells are enough to get 2 to 6 knots submerge speed and fuel (oxygen and hydrogen) resources give boat ability to be 3 weeks in submerge position constantly.

Russia

R & D works on fuel cells had been done in construction bureau Rubin Central Design Bureau in St. Petersburg since 60's [8]. It is planned to introduce in Russian Navy, in these years, boat of forth generation "Amur" class (project 1850) in which fuel cell section is installed. Export versions of boat that class will be without fuel cells. The first experiments and sea tests with fuel cells were conducted on experimental boat "Kratan" of "Whiskey" class (project 613). In 1996 a completed fuel cell plant worked in a land installation. Fuel cell section lengthens boat type "Amur" hull for 8 meters, up to approximately 62 meters. Fuel cells section might be offered also for exported versions of the third generation boats type "Kilo" (proj. 877EKM) and the newest version "Kilo" (proj. 636). The fuel cell made by Rubin bureau is very similar to those of SIMENS company for boat U-212. German fuel cells are rectangular and Russian are cylindrical. Output of fuel cells battery is from 100 to 250 kW and depends on the number of battery units.

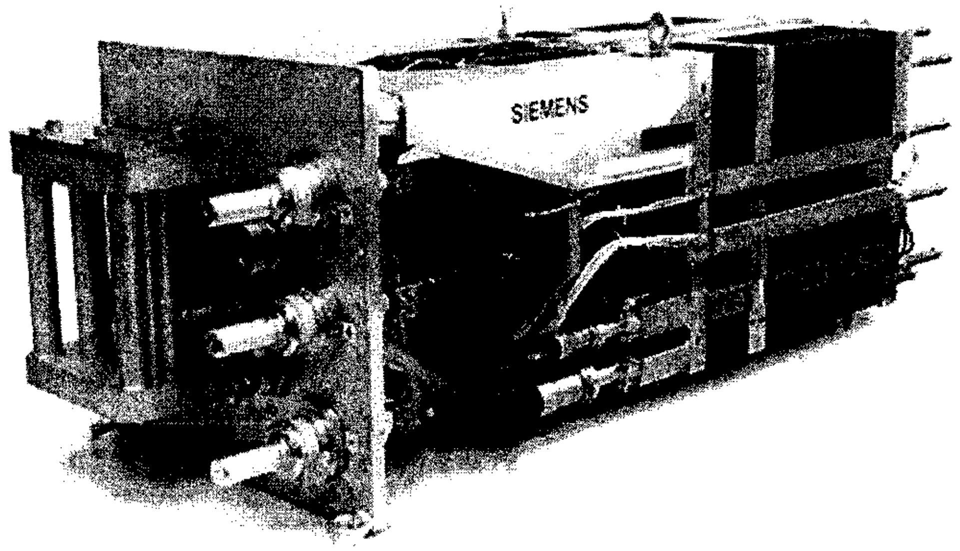

Fig. 3 Fuel cell SIEMENS unit

For fuel cell following parameters are determined [9]: output, mass power index, fuel consumption, oxygen consumption, reaction products, modularity construction and independence in working process of depth. Fuel cells can be divided in view of such factors as electrolyte type, membrane type and working temperature. Working temperature range is from 50 to 1000°C. Efficiency of fuel cell varies between 50 – 70%.

6. Conclusions

Nuclear powered submarines have some limitations in their operations in shallow or in closed waters because of their definite noise level and increasingly sensitive antisubmarine warfare (ASW) systems. Moreover, nuclear subs are very expensive in building and maintenance processes [18]. Only the richest countries may afford to operate such ships. However, the majority of the navies most of their tasks connect with submarines. There is about 550 subs in the world navies and 384 of them are subs with a conventional propulsion system. Shipyards have in their portfolio orders for about 200 new subs worth more than 109 billion dollars. Taking into account that average sub period in service lasts 30 years and that in the future number of submarines will be on the same level, we may expect yearly subs production on 20 units level.

Many small navies want to buy conventional subs because of their high efficacy and usefulness in different type of warfare operations [1]. The most of orders (about 90) for conventional boats have German shipyards. Also in the USA decisions about building conventional subs for export have been taken. Excellent situations for the future have producers of the armament and materials for old subs being in service, because of a need to lengthen their service period in navies. Modernization and retrofitting of older subs may be connected with their equipping with additional AIP module – or with hybrid propulsion system.

Present works on modern submarines and AIP systems may be divided into following directions: high capacity and efficiency battery units, diesel engines in closed cycle in different configurations, turbines in closed cycle, Stirling engines and fuel cells. Fuel cells seem to be the most promising technology because of the reached efficiency. Apart from profitable technical indexes in comparison with traditionally used heat engines, essential are also environmental aspects of using fuel cells which are often called "clean energy sources" [29]. Nevertheless, in opinion of some specialists [8], boats built with fuel cell technology, cannot be attractive for developing countries because of high costs.

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