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Air Independent Propulsion; Silent Submarines with Stirling Engines

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***Abstract*- Air Independent propulsion deals with powering a submarine without access to atmosphere or air. As we know that every diesel engine needs access to an air supply to work. So, a submarine using diesel engine stores air in tanks to maneuver underwater. So, the submarine has to resurface after every fixed interval in order to refill the air(oxygen) supply. This makes it difficult to have long stealthy operations under water in a submarine. It is true that a nuclear submarine can stay underwater for months. But, a nuclear powered submarine needs constant pumping of cooling water inside out, causing a lot of pumps to run which in turn causes a lot of vibration. Also the installation of an entire nuclear reactor makes the whole submarine a significantly large in size. So, it cannot be used for silent and stealthy operations. The paper deals with the application of stirling engine, one of the important AIP system, in a submarine.**

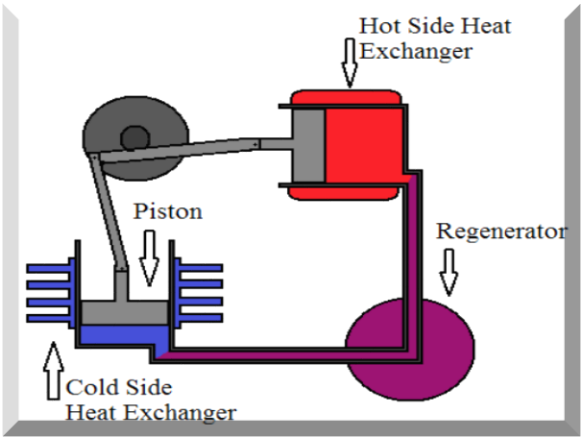
Keywords—Submarine, AIP, Stirling Cycle, Stirling Engine.

INTRODUCTION

A submarine is a watercraft which has the capability to maneuver under water. It has a basic structure which is a long cylindrical tube with conical or hemispherical ends. A submarine uses typical principle of buoyancy to move on the surface of water and beneath the water surface in the depths of sea. The submarine design is a long and elaborate process with a lot of constraints. The design involves the optimization of a lot of factors like propulsion technology, carrying capacity, weapon capacity, maneuvering capacity and design aspects. All these factors has to be optimized without compromising the size of the whole system.

STIRLING ENGINE

A stirling engine is an engine that utilizes the stirling cycle as its working cycle. It is a combination of a refrigeration system and an IC engine with the merits of both the systems. A stirling system is best known for its high efficiency which is so close to the ideal value of almost 50 percent.



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The working of any stirling cycle is a four step process as of any other cycle like the Otto or Diesel cycle. But the processes are different and the greatest difference is that all the processes are practically reversible. Initially, the working fluid will have a greater contact with the hot side heat exchanger. Since the hot side heat exchanger is a high heat source, it will provide heat which is absorbed by the working fluid. This absorption of heat makes the working fluid to expand and thereby occupy more volume. This expansion will push the pistons further move outwards from the cylinder. It is to be noted that the regenerator absorbs the heat from the hot gas going into the cold cylinder. The expansion of hot working fluid makes the fluid to fill the cold cylinder too.

Now, the flywheel motion makes the hot side piston to move inwards compressing the fluid a little bit. The second thing that the flywheel does is reducing the area of contact between hot side heat exchanger and working fluid leaving the working fluid to have a greater contact with the cold side heat exchanger. This will lead to the heat loss from the working fluid into the sink. The heat loss will lead to a drop in temperature and thereby a drop in the volume. The drop in volume provides a compressing effect and will force the pistons to move inwards. The movement of pistons inwards is same as the upward stroke in an IC engine. The reduction in volume or the compression of working fluid continues as long as the contact between working fluid and cold side heat exchanger is higher than that of working fluid and hot side heat exchanger.

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The flywheel, which is still rotating will make the hot side piston to move outward again or in other words, the flywheel will force the piston outwards leaving the working fluid to have more contact with the walls of the hot side heat exchanger. This will cause the gas to expand again and this process continues. It may also be noted that the working fluid will take up heat from the regenerator along with the heat from the heat source in order to expand. In short, the stirling engine uses the temperature difference between the heat source and heat sink as input in order to produce the output work.

STIRLING ENGINE IN SUBMARINES

Design

The design aspects includes the housing of a stirling engine which can work toe to toe or rather instead of the main diesel engine in driving the submarine. As shown in the figure, the design constitutes working fluid tanks which provide the fluid or gas which transfers the energy between hot and cold reservoirs.

There is a fuel tank and an oxygen tank provided so that their mixing can provide the heat energy for the hot reservoir. It may be noted that the fuel requirement is much less than that of a diesel

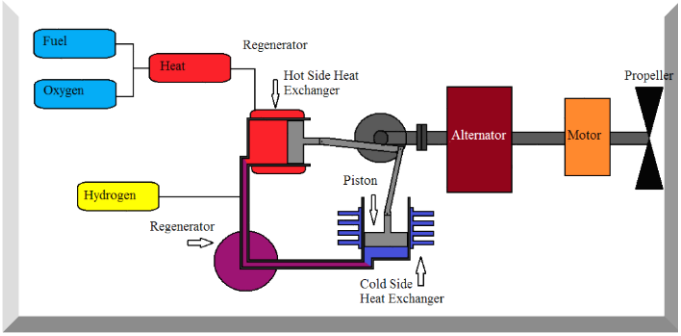

Image Reference: Wikipedia

engine. The fuel is used to provide a certain temperature for the hot reservoir. These inputs are given into the engine. Since the working is done in deep sea, where the temperature is very low, we don't need a cold reservoir. But, as a backup, a liquid nitrogen tank is also given for the cases of emergency or when high power requirement comes. The oxygen required for combustion can also act as a sink if carried as liquid oxygen. The engine is connected to the alternator by a coupling to transfer the torque produced. This alternator produces the required energy for the propulsion motor. The design is compatible to work both alongside and instead of the main diesel engine. The engine can also power the motors to control the air and water levels in the trim tank which in turn allows the depth control in a submarine.

Operation

The operation of the submarine with a stirling engine is basically the working of the stirling cycle. The combustion of oxygen and fuel provides the necessary heat required. So, the combustion chamber acts as the heat source. The heat is taken up by the hot side heat exchanger in order to give the heat into the system. Using LSHS(Low Sulphur Heavy Stock) instead of diesel as fuel for combustion can be profitable from an economical point of view. The cold sea water can act as the heat sink to absorb all the heat. The working is basically stirling cycle, that is the timely expansion and contraction of the working gas causes the piston movements inwards and outwards. The output is taken from the shaft connected with the crank disc. This output is used to rotate the alternator which produces the necessary electrical energy to charge the batteries and to run the
motors and thereby pumps and propeller. Also, the pressure of combustion is higher than the pressure of sea water outside. So, the exhaust will be sent out without any extra work leaving no compressor work causing very low infrared signature. The overall process involves very low or in other words, negligible vibration and noise. So, the submarine will be almost impossible to detect underwater.

Comparison with Diesel Engine

A Stirling engine can theoretically be more efficient than a conventional internal combustion engine (ICE) or a steam engine. But in practical application, the diesel engines outrun stirling engine in terms of power output. The power to weight ratio of stirling engine is lower than that of a diesel engine. It means the stirling engines are practically heavy. So, it can't be used in smaller locomotives like cars or trucks as the added weight creates drag. The system of stirling engine does have an advantage of being very silent, unlike IC engines which are noisy.

Also, unlike a diesel or petrol engine, the pollutant output is very low. The fuel used can be virtually anything as the combustion products doesn't interact with the engine directly. But, the rapid cooling and heating can sometimes damage the heat exchanger materials. In short, a stirling engine is a highly efficient engine with a limited number of application as of the current development in comparison with a typical IC engine like diesel engine.

CONCLUSION

The use of stirling engine or any other AIP methods is never an alternative for the mammoth nuclear submarines. But, it is a drive that can assist the conventional engines both by working together and working instead of engines like typical diesel engines. The AIP bargains for stealth by compromising speed . The internal noise and vibration are very low as compared to any other propulsion methods. At the end of the day, Stirling Engine compensates for all its drawbacks when seen through an eco-friendly point of view.

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