Achieving improved fuel efficiency with waste heat recovery

MARKUS VIRTASALO, KLAUS VÄNSKÄ - Using a waste heat recovery system is becoming an increasingly viable means of reducing fuel costs by increasing the energy output from combustion engines. This article describes the technology and its application in a marine environment and sets out some of the savings that can be achieved.

Waste heat recovery has significant potential for use in marine propulsion systems. Even with current conventional two-stroke propulsion power plant, approximately 50 percent of the energy content of the fuel is lost, mainly to heat, without being used for mechanical work. By supplementing the ship's main propulsion plant with a waste heat recovery system (WHRS), the fuel can be utilised more efficiently, because less energy is lost in the exhaust gas flow. As a further environmentally-beneficial consequence, the amount of CO_2 emissions in relation to the engine's mechanical power output can be decreased.

Through the WHRS, the recovered energy, which typically amounts to about 10 percent of main propulsion's shaft power, is converted back for mechanical work. When the WHRS is provided with a propeller shaft generator/motor, a further saving is gained by improving the main engine's loading condition at various points within the ship's operating profile. In addition, energy recovered from the main engine exhaust can be converted to mechanical work and added back to the propeller shaft as well.

What is a WHRS?

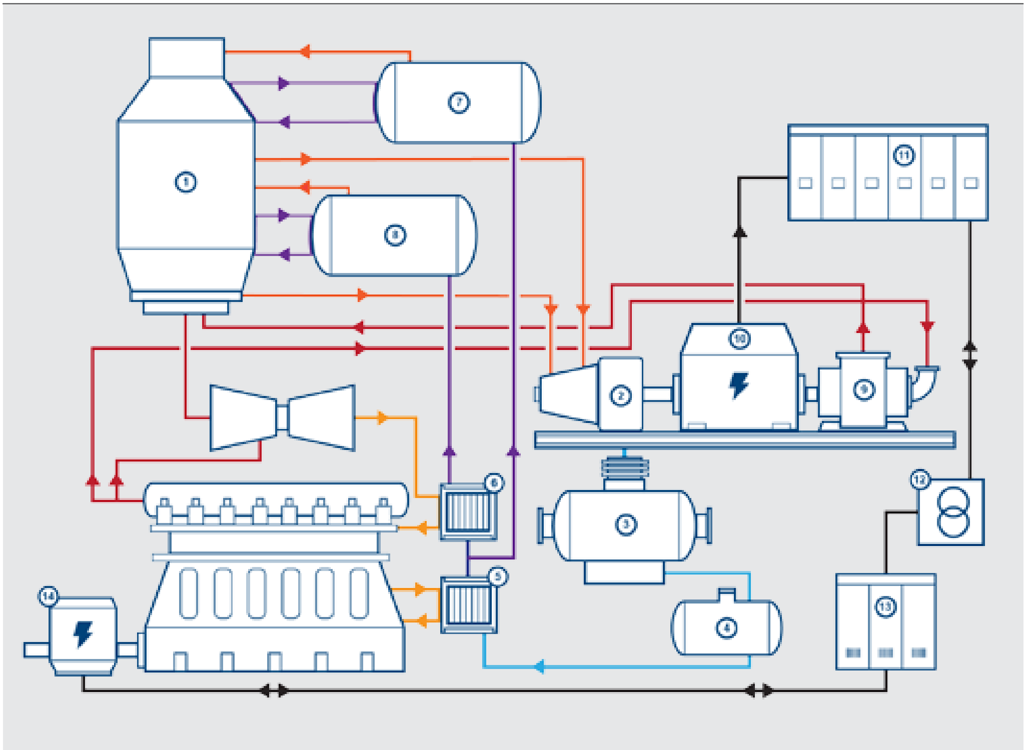
A WHRS is a combination of equipment installed on board to assist the ship's main propulsion machinery recover a part of the energy contained in the fuel that cannot be efficiently utilised by the main engine. Without the WHRS, that energy would be lost as heat into the atmosphere and sea water. The technical details of the WHRS can be tailored to suit each application, but typically the following main components are provided (details shown in Figure 1):

- Dual pressure exhaust gas boiler
- Steam turbine generator unit with vacuum condenser
- Exhaust gas power turbine
- Boiler feed water heater(s) from main engine scavenging air and/or jacket water
- Propeller shaft generator/motor with frequency converter
- An electric system and power management system for distribution and control of the power generation and flow

How does the WHRS work?

The mechanical efficiency of the main engine is close to 50 percent. The rest of the energy contained in the

1 **Waste heat recovery system process flow and main component diagram**



The following units are shown: 1. Exhaust gas boiler, 2. Steam turbine, 3. Vacuum condense, 4. De-aerating feed water tank, 5. Feed water heater (ME jacket water), 6. Feed water heater (ME scavenging air), 7. Boiler steam drum, low pressure, 8. Boiler steam drum, high pressure, 9. Exhaust gas power turbine, 10. Turbine unit generator, 11. Switchboard, 12. Transformer, 13. Shaft generator/motor frequency converter, 14. Shaft generator/motor

fuel consumed by the engine is not converted into shaft power, but is lost, mainly to heat and friction. The WHRS is designed to recover as much energy from these losses as is economically viable.

Recovery of the waste heat begins in the exhaust gas boiler (Figure 2). Compared with conventional exhaust gas boilers, the WHRS' dual pressure exhaust gas boiler is designed to efficiently generate steam with characteristics that make it suitable for electricity generation.

For optimum efficiency, steam is generated at two pressure levels - high and low. Both high and low pressure steam flows are then led through the ship's steam piping system to a condensing steam turbine, which is connected to a generator. The turbine will then convert the thermal energy of the steam into mechanical energy to run the generator. When the thermal energy has been used, steam will exit from

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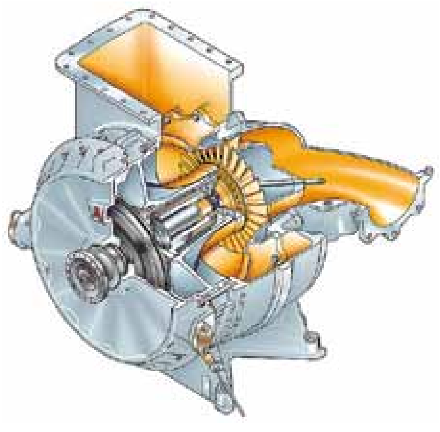


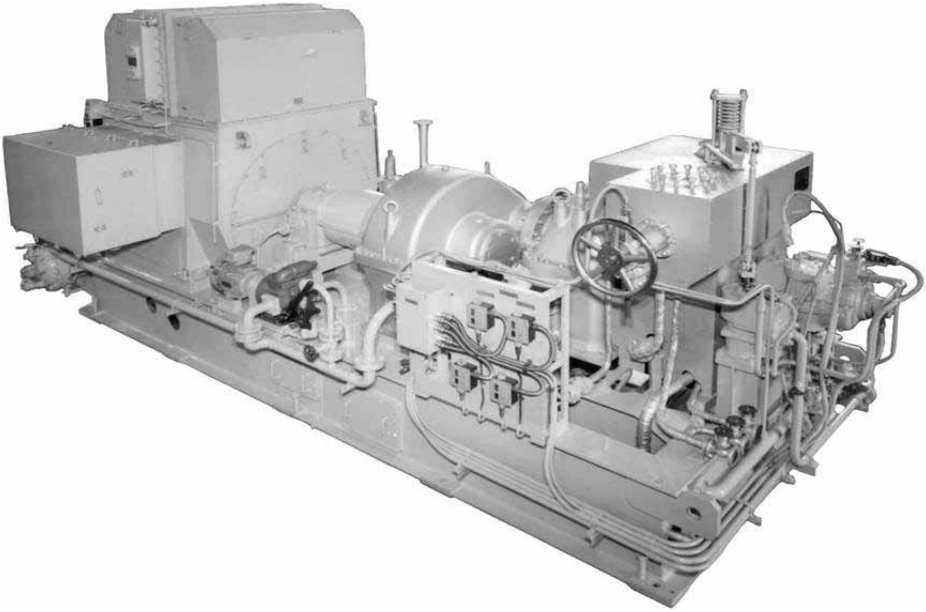
the turbine and condense in the sea water-cooled vacuum condenser attached below the steam turbine. This condensate water is collected into a deaerating feed water tank and pumped back into the exhaust gas boiler. On its way there, the condensate will recover heat from the main engine jacket, cooling water and/or the main engine scavenging air by flowing through the respective heat exchangers. This part of the process is called feed water heating. The entire circulation process of the steam and condensate water is closed, and the quality of steam/condensate is monitored.

Energy is also mechanically recovered from the main engine exhaust gas flow. Part of the main exhaust gas flow is diverted into a power turbine (Figure 3), which is connected to a generator. This part of the process runs the power turbine, which is similar to the turbine side of a main engine turbocharger, and thereby complements the steam turbine's generating capacity.

The steam turbine and the power turbine can be installed in two different configurations. They can either be on the same bed frame with one common generator or on separate bed frames with dedicated generators (Figure 4). The choice between the two options can be made on the basis of the ship's engine room layout, as well as what is technically the optimum and most feasible approach. In all configurations the turbines are connected to the generator through a reduction gear. With the common generator configuration, the power turbine and generator connection are also provided with a special freewheeling clutch, enabling automatic engagement/disengagement depending on operating conditions.

On ships with two main engines, a configuration with two power turbines, one for each main engine, can be considered. In special cases, a WHRS with only a steam turbine and generator or only a power turbine and generator, can be provided, but with consequentially a lower heat recovery capability.

The propeller shaft generator/motor will maximise the utilization of the recovered energy. When provided with a highly flexible variable frequency drive, the shaft generator/motor can convert electricity into additional propulsion shaft power, as well as propulsion shaft power into electricity, a change in functionality that is achieved seamlessly without any interruption to the operation. This flexibility is due primarily to utilizing a frequency converter between the shaft



generator/motor and the ship's electric network. As a result, the energy recovered in the steam turbine and power turbine can be directly utilized as mechanical power on the propeller shaft. On the other hand, in slow speed situations where the ship's consumption of electricity exceeds the amount recoverable from waste heat, the shaft generator/motor will feed the ship's main network, thereby utilizing the main engine's increased efficiency.

Where and when can the WHRS be used?

The WHRS can be applied to any propulsion plant with sufficient power output to make the investment economically viable. There is a clear economy of scale here, and the bigger the main engine output, the more waste heat can be recovered. The power level above which the WHRS becomes economical depends on the price of fuel, as well as required payback time, and should be validated by making detailed calculations as to system efficiency. As an indication, however, given various parameters prevailing at the beginning of 2012, ABB estimates it would be economically feasible to use WHRS on board container ships with main propulsion machinery with a mechanical output of 20 MW or more.

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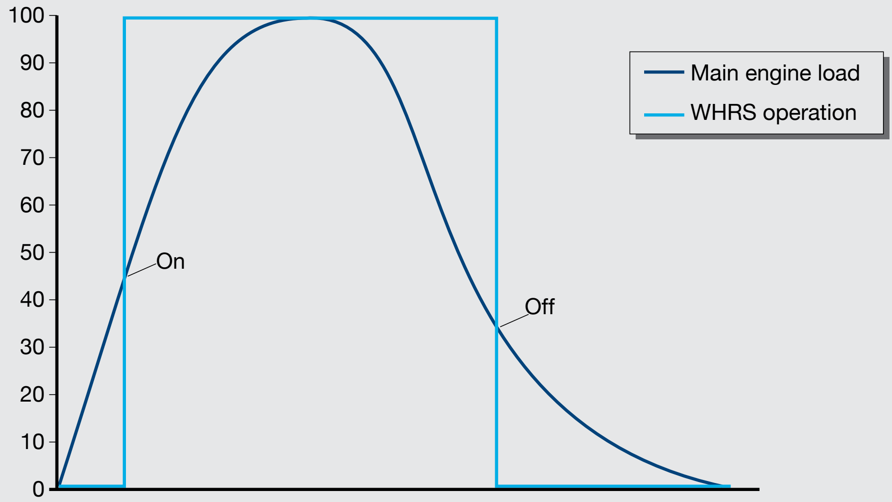
5 Economical operating range of the WHRS



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Another consideration, which determines the economic viability of the WHRS, is the operating profile of the propulsion plant. Ships with a relatively stable operating profile, especially with higher propulsion loads, have the biggest potential for savings. The more the vessel has a high-load operation, the shorter the payback time for the WHRS will be. The WHRS is not run in port or manoeuvring situations, so the smaller these are as a portion of a ship's overall operating profile, the greater the economical potential of the WHRS.

To date, WHRS have typically been installed on deep sea container vessels and very large crude oil carriers (VLCCs), equipped with a two-stroke engine propulsion plant.

The WHRS will function only when the main engine load is above a certain limit. That limit depends on the system design for each project, but is typically about 40 percent of the main engine MCR for an ABB WHRS. The propeller shaft generator/motor is functional from any low load, the main engine can run up to 100 percent of the main engine MCR and the shaft generator/motor can be optimised to give 100 percent output power at a specified main engine load, for example 80 percent of the main engine MCR. Optimising specifications during the design phase allows for maximum flexibility in the recovery and utilisation of waste energy during the ship's operation.

Is the WHRS complicated and does it require special skills?

The basic technologies used in the WHRS have existed for decades and no new technologies, for instance, fuel cells, are incorporated in the systems being offered on the market today. The reason it has now become more feasible to make use of WHRS technology is primarily down to improvements in component design, as well as increases in fuel cost and a greater awareness of the importance of energy efficiency and the need to reduce emissions. What allows a conventional auxiliary steam system to become a modern WHRS is basically the increased capacity of the auxiliary steam production and the conversion of the steam's thermal energy into electricity instead of other purposes like heating.

Exhaust gas boilers and auxiliary steam systems are standard on practically every ship. The steam turbine is installed on an integrated standalone bed frame and requires little maintenance between scheduled overhauls. The power turbine is similar technology to the main engine turbochargers, and so maintenance procedures are also basically equivalent. The overhauling period of the propulsion machinery is not affected and the WHRS components need only similar intervals between overhauls.

Since ABB offers the WHRS as a single integrated package, the functionality of the complete system can be optimised at the design phase. The operation of the WHRS after startup is controlled by local and centralised automation systems and the loading of the units is controlled and adjusted automatically by the power management system. In addition, an advisory system is available to make a thorough evaluation of and if necessary adapt the WHRS when faced with any new operating conditions.

Why start using WHRS now?

The use of WHRS has become more economically viable due to the rise in fuel costs over the past decade. As a result, the payback time for the system has reduced and future restrictions and penalties for CO_2 emissions will enhance the attractiveness of having WHRS even further. The improved efficiency of propulsion machinery with WHRS gives the operators a competitive edge over those with conventional propulsion machinery and provides them with a reduced carbon footprint and other environmental benefits.

The WHRS package offered by ABB uses well-proven technology that customers have had experience with for many years. The steam system-related components have been selected from manufacturers that are equally well respected in their field of expertise. In delivering a complete package, ABB provides a single point of contact for all customer communication during a WHRS project. In addition to the WHRS package, ABB can also supply the power management system, integrated automation system, main electric network and propulsors required for the project.

How much does it cost?

There is no one simple answer to this to cover all applications. The initial cost of the WHRS will eventually be covered by the fuel savings made during the operation of the vessel. The WHRS system can be optimised to meet a required level of efficiency and tailored for the specified propulsion plant. Based on these main parameters, a payback time can be estimated in advance, relative to the prevailing cost of fuel and the operational profile of the ship.

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