The Electric Warship: Using Energy More Efficiently

by ***Professor Chris Hodge***

As Chief Electrical Engineer of BMT Defence Services Ltd, Chris Hodge is involved in surface warship and submarine programmes examining the future of power and propulsion systems. In the 1990s he was Head of Power Systems at the MoD where he co-initiated the UK's Electric Ship programme. In this article, he outlines the energy-saving and other benefits of electric propulsion in warships.

The twin challenges of declining oil reserves and growing CO_2 emissions inevitably mean that the world must burn less fossil fuel in the future. Whether we're forced by scarcity or persuaded by environmental concerns, the issue is unavoidable.

There are two ways of responding. One is to make greater use of alternative energy sources (of which there are not many – primarily renewables and nuclear energy). The other is to treat all fuels, fossil and otherwise, as a far more valuable resource than we have done to date and develop technologies to make them go further.

One technology of particular interest to the defence industry is electric propulsion for warships. Given that electricity is not a source of energy, simply a method of transmitting it, electric propulsion is clearly part of the second strategy. As I hope to show, it can make an important contribution to conserving energy and cutting defence costs without compromising operational effectiveness.

Nearly all current warships use mechanical transmission whereby the main engine (a diesel or gas turbine, also known as a prime mover) drives a gearbox which in turn powers the shaft and propeller. Such systems are most efficient at full power and indeed are designed to operate at full load for the best possible power-to-space ratio. They're well suited, therefore, to vessels such as oil tankers that leave port and build up to a constant passage speed which is then maintained for what can be a matter of weeks. In those circumstances it's feasible – indeed easy – to optimise the mechanical transmission system to give the best possible fuel economy for the operating speed in question.

Maximum Efficiency at Variable Speeds

A warship behaves very differently. It might cruise at 15 knots and perform a few bursts at 30 knots, but also spend long periods at four knots while searching with sonar, for example. Optimising the system for one particular speed obviously makes it less efficient at other speeds. Just as a car designed for optimum fuel consumption at, say, 60mph wastes fuel when it's driven at 5mph, a ship's prime mover is increasingly inefficient as the loading drops away from the maximum.

The difficulty is exacerbated by physics in that the amount of power needed to drive a ship goes up by the cube of the speed. Moving from three knots to 30 can mean an increase in power from 20 kilowatts (equivalent to a few electric room heaters) to 20 megawatts (the output of a small power station). Producing power over such a range is clearly not conducive to high fuel efficiency.

Warships have traditionally met the problem by using a small engine for cruising and a bigger one for boost or sprint propulsion. This 'little and large' solution offers three points of optimum efficiency, namely when one or other engine or the two combined are running at full power. But that's still only three. To be efficient at other speeds, naval designers have sometimes added more engines – up to four per shaft on a frigate – with the aim of connecting them progressively in order to go faster. The problem, then, is physically linking so many prime movers to one shaft, not to mention the inherent unreliability of having so many.

Given the need for warships to be fuel-efficient at all speeds, there's growing interest in electrifying the transmission system. Instead of the engine-gearbox configuration, the prime movers in an electric system each drive an alternator from which power is fed to electric motors that in turn drive the shafts. This way, each motor can take as much or as little power as it needs from one or more prime movers. The result is a flexible, easily connected system in which the prime movers can be optimally loaded and can handle a range of speeds without losing efficiency to the extent that a mechanical equivalent would.

Under a mechanical system, for example, you might have four prime movers, two on the port shaft and two on the starboard. If these are to operate efficiently, you're limited to a two-step operation – running one main engine up to its full load, then switching to two to build up to the combined full load for a faster speed. Under an electric system with its more flexible connections, one prime mover can be made to power both shafts. Four main engines therefore give you a four-step operation as each is connected in turn. If you also adopt the 'little and large' solution, the increments possible without significant loss of efficiency become smaller still.

The Ship Service Benefit

Further advantages follow. A typical frigate with mechanical transmission has four prime movers to propel the vessel and

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four to power its non-propulsion 'ship service' – its heating, lighting, ventilation, radar, sonar, computer systems and so on. With electric transmission, the same prime movers can be used flexibly for both duties under a system known as Integrated Full Electrical Propulsion (IFEP). Not only can the number of main engines therefore be reduced, but those in place can be made to run more efficiently. That's because ship service power typically requires up to 2 megawatts, 24 hours a day. Using this demand as a permanent baseload for the prime movers avoids having to run them at fuel-squandering low loads.

Another benefit of an electric drive system is the possibility of running just one prime mover in certain conditions – for example, when the ship is travelling slowly and is unlikely to need a sudden burst of power. There are risks, obviously, in running a warship on just one engine, but the technical feasibility offers at least the potential for further economies.

While the primary advantage of the electric warship is its greater fuel efficiency, the system offers numerous operational advantages.

One is the opportunity for a more flexible internal layout. By definition, a mechanical transmission system requires prime movers and gearboxes to be aligned with the shaft. In an electric warship, the only interconnection is a cable. Prime movers can therefore be located wherever is most convenient and where they're least likely to cause noise and vibration or be damaged in action. With the right design, electric transmission also offers the potential to build quieter warships – an advantage in tracking submarines, for example.

In addition, the ability to connect prime movers to shafts in flexible ways can make the propulsion system more robust. Using Integrated Fight Through Power (IFTP) technology, the system can recognise damage or gaps in the transmission, isolate the fault and restore power to the shafts by another route. A shell hitting a primary mover need not necessarily put the ship out of action.

Deployment

The concept of electric transmission is not new. Cruise liners have been using the technology for some time with the modern form deployed ever since the re-engining of the QE2 in the 1980s. Like warships, liners spend long periods at less than full power and need to be able to do so efficiently. As floating hotels, they also have a heavy ship service requirement which it makes sense to use as a base load for the main engines. The difference – and the reason why passenger ships are so far ahead – is that liners have plenty of space for the relatively bulky equipment. Until recently, the limited confines of a frigate or destroyer made it difficult to use electric transmission in warships.

The situation changed, however, with the revolution in power electronics in the 1990s. In a process led by the US Integrated Propulsion System Program, technologies such as the Insulated Gate Bipolar Transistor (IGBT) were used to reduce the size of converters by a factor of up to 4:1. Prime movers and electric motors have also become smaller, albeit less dramatically.

The UK contributed by building the Electric Ship Technology Demonstrator at Whetstone, Leicestershire, as part of a collaborative international programme. Run by the power and propulsion supplier, Converteam, the demonstrator proved all the operational advantages of electrification and went on to test the equipment for the Type 45 anti-aircraft destroyer.

The first warship to deploy electric drive in this fully modern style was the Type 45 HMS *Daring*, which followed on from the electrically driven Landing Platform Docks *Albion* and *Bulwark* and was formally handed over to the UK Ministry of Defence in December 2008. Recognising the advantages of electric propulsion, the MoD has accepted as its default position that future warships should incorporate IFEP as opposed to direct drive mechanical transmission. The Royal Navy remains at the forefront of new developments with plans to extend this remarkably fuel-efficient technology to aircraft carriers and submarines.

Looking wider, one can also see the technology being used in land vehicles, tanks and aircraft. The future, I believe, is electric. ■