# **MARINE ENGINEERING**

# Energy Storage Systems: Fuel Cells for surface warship applications by LIEUTENANT G.H. ADAMS RN

The current drives towards cheaper and more efficient propulsion systems and the reduction of noxious engine emissions are forcing major navies to reconsider their policy on propulsion selection. This has resulted in the concepts of Integrated Full Electric Propulsion (IFEP), single prime mover operation and all gas turbine systems. The operation of only one engine at any time has forced designers to consider an energy storage system, and current proposal is for the use of lead-acid batteries. However this is a system with little development potential (amongst other disadvantages) and would result in the fitting of a large system which may be little used.

Widely considered to be the energy source of the future, the emerging technology of fuel cells offers, in the author's view, a better and more flexible approach to energy storage. Although an energy conversion, rather than storage, device the fuel cell offers numerous advantages over existing and proposed storage systems. Indeed it has considerable potential to become a ship propulsion system in its own right.

This project reviews the current and future development of the fuel cell and discusses the potential applications of fuel cell propulsion systems for surface warships. It also investigates the design considerations for such systems, including fuel selection, operational aspects, potential efficiencies and development hurdles. Comparisons are made with existing gas turbine/diesel propulsion systems and proposals are offered for integration of fuel cells into IFEP and other future propulsion systems.

#### Sulphuric acid attack on marine recuperators by LIEUTENANT C.B.J. ANIYI RN

Exhaust heat recovery exchangers (Recuperators) employed with gas turbines enable a step improvement in specific consumption, with particular benefits experienced at part load under certain operating conditions, experience on other similar fields suggests that sulphuric acid attack may be a problem in engines that burn sulphur containing fuel. The topic of study was suggested by Rolls Royce (Ansty) and studies were carried out during a 3 month placement with the company.

The theory surrounding the production of sulphuric acid was investigated and predictions made as to the operating conditions under which acid corrosion can be expected. The design and manufacturing techniques and materials used in the 'Spiral Recuperator' are examined, and the type and extent of expected corrosion investigated.

Based on the findings of this study it is concluded that under certain operating conditions sulphuric acid attack is a problem. A proposal is made for the rig testing of a Spiral Recuperator under specified conditions to ascertain if practice concurs with theoretical predictions. Finally, methods and costs of preventing sulphuric acid corrosion are considered.

# An investigation into the use of remotely operated vehicles for underwater engineering students

#### by LIEUTENANT G.T.M. BURGESS RN

The use of Remotely Operated Vehicles (ROV's) to carry out undersea work in the offshore oil and gas industry is widespread. ROV's offer great improvements in safety and cost effectiveness. This project investigated the extent to which this technology could be utilized as part of the underwater engineering package for the Royal Navy's submarines. One particular area studied was ballast tank intervention with the submarine still afloat.

It was discovered that the cost of this technology is inhibitive and few improvements on the current methodology could be demonstrated. The report concludes that the clear advantages offered to the Offshore Industry cannot be enjoyed and therefore ROV's will make a very limited contribution to underwater engineering in the Royal Navy.

# The future of classification societies

by P. CONSTANTINIDES, Private Student, Greece

Classification societies have been through an unparalleled period of scrutiny after being subjected to heavy criticism in the past years. There is a general problem of confidence today and each partner in the shipping community reacts by viewing things from his own particular view point. However, safety is of prime concern for the whole shipping community and should not be liable to any political or economical circumstances. After all, the main objective of all parties involved is:

'The promotion of safety of life, property and the natural environment both at sea and on land.'

It appears that the role of classification societies will have to be reassessed in order to adapt to the rigorously changing shipping environment. The intent of this paper is to examine the impact of such changing circumstances in the classification societies activities and discuss possible future directions.

The first part of the paper reviews the organizational changes of classification societies, from their establishment up to the present, in historical perspective. Then the current state is examined by analysing the facts and statistics of the societies for the last years, and addressing the main economical and technical issues.

Finally, by taking under consideration a wide range of interests including classification societies, shipowners, shipbuilders, underwriters, P&I clubs, charterers and both Flag State and Port State administrators, the areas of future development are identified.

#### The Matrix Converter

by Lieutenant T. Drywood RN

The concept and development of direct AC to AC frequency conversion using forced commutated devices was investigated to establish the advances made on the Matrix Converter since it's inception in the late 1970's. Its advantages and limitations assessed.

Simulation models, using MATLAB-Simulink, were then developed to produce synthesised waveforms for both output voltage and input current. These models were then extended to address one of the basic converter's limitations—voltage transfer ratio. The simulated matrix converter was then loaded to see the effects of loading on the voltage and current waveforms. A failure mode effects analysis was carried out to establish the damaged states of a practical matrix converter. The implications of single device failures were then investigated using Simulink. Output voltage waveforms and expected induction motor stator current waveforms were generated to illustrate these effects of device failure. Ways of overcoming the effects of these failures were also investigated.

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#### Material Stress Memory Unit by LIEUTENANT B.J. HALL RN

The mechanism of fatigue is the largest single cause of long term deterioration of structural components. At present there is no self contained and non-obtrusive method of measuring the fatigue crack initiation damage of an in-service component; instead 'safe-life and fail-safe' design approaches based upon typical service load spectra are used to prevent catastrophic failures. A knowledge of a components actual stress history would be beneficial in determining the fitness-for-purpose of a structural component. Potential applications include pressure vessels, bridges and offshore structures.

The project entailed the formulation of a statement of requirements for an ideal Material Stress Memory Unit and the design and build of a development unit. This involved the integration of a strain gauge bridge, amplifier, micro-controller and software to create an operational unit capable of performing stress calculations and rainflow variable amplitude cycle counting algorithms. The performance envelope of the development device was ascertained by dynamic mechanical testing of a beam under four point loading. Stress was determined to within an accuracy of  $\pm 4\%$  up to a frequency of 8 Hz, typical of oscillations experienced in engineering structures.

The recorded in-service stress and cyclic data can be used directly in fatigue crack initiation and propagation prediction models, instead of using probabilistic estimates of structural loading. This would provide a highly accurate evaluation of remaining life, allowing a more informed decision on the fitness for further service.

#### Active vibration isolation using smart materials by LIEUTENANT D.C. HALLIWELL RN

The successful suppression of vibration transmissions from rigidly mounted machinery in ships and submarines would reduce underwater signatures. This project investigates the application of smart materials technology to the active attenuation of vibrations from rigidly mounted machines. A laboratory test rig comprising of an unbalanced electric motor, rigidly mounted on 3 magnetostrictive actuators provides a suitable focus for study. The dynamics of the system are first analysed and computer models are developed that demonstrate the behaviour of the motor and its base plate. An asynchronous active controller is designed and implemented utilizing a PC based digital signal processor. Good attenuation (15dB) of forces transmitted to the foundation, in the vertical direction and at shaft frequency, were obtained. A truly smart mount would exhibit both actuating and sensing characteristics. This project demonstrates the ability of magnetostrictive Terfenol-D to sense and discusses current strategies for the implementation of a combined actuator/ sensor.

#### Design of active magnetic bearings for high speed alternators by Lieutenant S.P. Henderson Royal Navy

Operating electrical machines at high speeds results in dramatic reductions in size and mass, making their use more attractive in more applications. Higher speeds put increasing demands on the machine bearings and lubricants, resulting in greater interest in magnetic bearings. Although still viewed by many as a novel technology, Active magnetic bearings are gaining acceptance rapidly, in many more applications. Although larger with a higher unit price cost than conventional bearings, they offer unprecedented scope for reliability, vibration control and lower running costs. Because they levitate the rotor of a machine, there is no wear and no life restriction, redundancy design is straightforward and reliability very high. An investigation into the world-wide manufacture and use of active magnetic bearings was undertaken, with an assessment of their application to electrical machines. A radial bearing system was designed, including consideration of machine rotor dynamics, power amplifier type, control and matching, and sensor type and placement. The system was modelled and a PID controller designed with the aid of MATLAB SIMULINK. It was concluded that magnetic bearings are viable technology for the future high speed electrical machines.

#### Bending to membrane ratio in tubular 'T' welded joints by D.S. Katsanos, Private Student, Greece

Tubular welded joints are most commonly found in offshore platforms. They are made of medium or high strength steels and they are welded together in order to form frames. Severe stress fields develop during their service due to a variety of loading modes. These are axial loading, in plane bending and out of plane bending. In addition these frames are designed to withstand a harsh sea environment and are subjected to fatigue.

In order to predict the joints life several methods have been developed and these are mainly empirical and analytical solutions.

The aim of this project is to determine which one is more suitable and copes with the majority of the life affecting parameters. It is seen that most of these methods take into account the Hot Spot Stress (HSS) as the major life affecting parameter. Regardless of its extreme importance, HSS is not the only one. Bending and membrane stresses which are formed have a major significance in the life of tubular joints. A proper dimensioning of such a component should take into account B/M ratio if maximum life is to observed.

The project is based on the FACTS software which was developed in UCL and provides the basis for a proper design. All methods were evaluated and compared to each other and several test cases were analysed. The main conclusion was that the B/M ratio is of extreme importance as well.

#### Trimaran propulsion options: A parametric study by A.C. MOODY, Private Student, UK

#### Since 1990, when Nigel IRENS' *llan Voyager* captured the round Britain powerboat record, interest in the trimaran hull form has grown in intensity both in civilian and military circles. A great deal of recent research has been carried out on the potential advantages of the trimaran hull form which include superior powering characteristics, improved intact and damage stability and good seakeeping. For the marine engineer, however, the trimaran is a mixed blessing from a design point of view. The favourable powering characteristics of trimarans which result from the decreased wavemaking by the slender hulls suggests that less powerful and by implication, less expensive propulsion machinery may be utilized. Also increased flexibility arises from the possibilities of locating propulsion machinery in the outriggers and the box decks, above waterline. However, the slender nature of the hulls leads to restricted space available within them and may cause the designer problems in the installation of the machinery.

The aim of this study is to explore the extent to which the propulsion system of a trimaran is driven by its dimensional parameters and role. Information on equipment has been collected from the MoD, industry and previous UCL ship designs. Size and shape parameters have been systematically varied and the extent to which they determine the choice of propulsion machinery has been discussed. The effect of the ships design speed and the position of the outriggers has also been explored because of the importance of **t**he inter-

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ference between the three hulls to the overall resistance of a trimaran. Consideration has been given to the role of the ship and to features such as outrigger propulsion, which are unique to the trimaran.

#### Application of composite materials to high speed vessels by I. PSARRAS, Private Student, Greece

Since their appearance onto the marine world, reinforced plastics have been successfully used for the fabrication of boats and other marine structures. In the early days overdesign made it possible to use inexpensive systems which were not necessarily the best for the job. However, as composite marine structures have increased in size or where performance is the major criterion, a significant step has been made towards the use of advanced composite materials.

During the last decade, high performance raceboats have been constructed from advanced composite materials, and they have come to dominate the market to the virtual exclusion of all other forms of construction. The development of advanced fibres and resins, and the further understanding of polymer composite structures behaviour enhanced this dominance, however, a consideration for using other types of composites such as metal matrix ones (MMC), in specific structural areas, is discussed.

The importance of sandwich construction for high speed craft is examined quite extensively since the majority of high performance craft follow this particular method of construction, while it has been shown to offer the most efficient construction with the highest potentials. Although our knowledge of sandwich construction is quite adequate, further investigation is required in order to understand fully the behaviour of sandwich structures under various loading modes.

Weight is always a key consideration when designing high performance craft. The construction of high speed small craft increasingly involves light weight FRP and FRP sandwich material structures. High speed craft are subjected to repeated dynamic loads caused by slamming. High speeds lead to higher dynamic loading, such that impact loading is often the dominant factor in structural design. Extreme slamming loads can lead to structure failure, with the failure mode to be predominantly core shear cracking followed by delamination.

Although the most common failure mode for a sandwich structure concerns delamination between core and skin, several other failure modes can occur in the skin, leading to overall failure of the structure. Sandwich panel tests have contributed greatly to the understanding of the behaviour of sandwich structures under impact loading, which are the dominant ones, and the results and conclusions derived from these, have been successfully adapted into the modern high performance craft. Nowadays, the use of particular core materials and fibres in specific areas, is the major design practice for an efficient design.

# Hybrid DC switchgear

#### by Lieutenant A. Sansford RN

Over the past decade the rapid advances in power semiconductors and permanent magnet technology have resulted in the concept of an Integrated Full Electrical Propulsion (IFEP) system becoming an attractive proposition for future warships. Electrical propulsion systems, although initially more expensive than conventional mechanical systems, offer:

- Increased system flexibility
- A low noise signature

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- Improved efficiency
- Reduced running costs.

Furthermore, electrical propulsion systems are extremely reliable and, with the exception of the primemovers, are virtually maintenance free. This report evaluates the most suitable form of bulk power distribution for a typical Frigate-sized IFEP system, and compares the current proposed topology with a novel, high voltage dc distribution system. In addition, the advantages, disadvantages and practical limitations of both ac and dc circuit breakers are also reviewed. This review highlighted a shortfall in the availability of compact dc switchgear for use in ringmain distribution architectures. Consequently, this led to a change in emphasis of the project to the design, construction and performance evaluation of hybrid dc switchgear utilizing advanced semiconductor devices. MATLAB computer models were then developed to simulate the response of a hybrid dc circuit breaker under normal operation and short-circuit fault conditions. This was followed by the detailed design of a 500 Volt, 600 Amp, technology demonstrator, using Insulated Gate Bipolar Transistors (IGBT's) in parallel with a conventional vacuum contractor. Finally, the hybrid circuit breaker was assembled and a number of tests were carried out to assess the breaker's performance characteristics against the theoretical results obtained from computer simulations.

# Improving tanker machinery reliability through redundancy by I.P. ZOULAKIS, Private Student, Greece

Concerns about the reliability of propulsion machinery for tankers, as a response to then new challenges in the shipping environment, has resulted in a call for alternative options. One key feature of these alternatives is propulsion machinery redundancy. Having defined fire, flooding and mechanical failure as the main machinery related causes of the tanker losses, the author investigates the implementation of redundancy on the minimization of these failure modes by developing full redundant alternatives of a typical Aframax double hull tankers machinery.

Four machinery schemes including slow speed single and twin screwed, medium speed and diesel electric were considered. They are compared to the basic machinery using the availability that they provide, as well as, the initial equipment purchase cost, installation cost, through life cycle cost (including fuel and lub oil cost, maintenance and spare cost, harbour dues, insurance and NOx emission cost, tugs and pilot cost) in order to build up a total cost of ownership for the ship throughout the anticipated operational profile over 25 years and the payback period. The message of this project is that ships, such as tankers, should not be built with machinery concepts containing many components in order to insure reliability, because the failure rate of the whole propulsion plant increases and therefore becomes more critical for propulsion, manoeuvring the whole ship, persons onboard and environment. Furthermore from this comparison it is obvious that the layout and general arrangement of machinery spaces have a significant influence on propulsion redundancy especially in incidents involving fire, collision or flooding.

The redundancy of tanker propulsion machinery can therefore be improved by:

- Providing a minimum of two independent propulsion motors/units, main generating sets and auxiliary systems capable of operating after a failure on one system.
- Placing the propulsion motors in separate compartments.
- Separating the power station into a minimum of two decks.

- Separating all essential equipment (cabling, piping etc.) to maintain operability in case of fire or flooding in one compartment.
- Extinguishing systems as high pressure water sprinklers positioning at more risky areas of the machinery (e.g. spaces containing electrical equipment) working together with the existing fire fighting systems for a more effective solution in the first minutes of ignition.

The full reports are held at the University and further information may be obtained from:

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The Professor of Naval Architecture,

Naval Architecture and Marine Engineering Office, Department of Mechanical Engineering, University College London, Torrington Place, London, WC1E 7JE