ROYAL NAVAL ENGINEERING COLLEGE POST-GRADUATE PROJECTS 1993-1994

As part of the Advanced Marine Engineering Course (MSc Course in Marine Engineering) at the Royal Naval Engineering College, Manadon, each student spends 17 weeks working at a particular research project. A summary of each project completed by the course of 1993-94 (AMEC 29) is printed below.

AC/AC tandem generators feasibility study
by LIEUTENANT G.T. LITTLE MSc RN

The ever increasing use of electric propulsion schemes has resulted in much greater demands being placed on existing power generation arrangements. Tandem generators have been proposed as a possible solution to satisfy the requirements of both propulsive and ship service electrical loads; they provide the greatest system flexibility with reduced system complexity. A tandem generator comprises 2 synchronous AC generators connected to a single prime mover shaft; each generator operates at a different rated voltage, frequency and power. The project develops and validates a computer simulation of tandem generators within the Interactive Power System Analysis Package (IPSA), with Matlab and Simulink used to evaluate controller effectiveness. Complex models of practical marine power systems are developed to assess fully the performance of tandem generators in parallel. A practical test rig has also been developed to replicate the operation of a single tandem generator.

A study into the use of an Inter-Cooled Regenerative (ICR) radial gas turbine for small marine applications
by LIEUTENANT F.S. MORGAN BENG (HONS) MSC CENG MIMARE RN

This project was to conduct a thorough literature survey for radical turbomachinery and to investigate the relevant theory for radial compressors and radial inflow turbines. Once an understanding was achieved, radial inflow turbine tip clearance losses and size limitations were analysed. The knowledge gained in designing turbomachinery was then used to propose a preliminary design for a radial compressor and a radial inflow turbine for use in a small ICR radial gas turbine. The gas turbine was designed to produce 2 MW, with the same thermal efficiency, about 40%, of a high-speed diesel.

Initial modelling proved most promising for the compressor and inflow turbine, resulting in a highly efficient ICR radial gas generator with a projected thermal efficiency of 43%. It is proposed that a Computional Fluid Dynamics analysis is conducted on the inflow turbine to clarify turbine losses. Also an enhanced turbine/compressor matching programme is required to enable more accurate off-design performance prediction to be made.

The need for cleaner emissions to meet the future MARPOL requirements has meant that small efficient gas turbines are a safer option to diesels engines. The requirement to carry ammonia to clean the diesel exhaust is not an attractive proposition, small intercooled-regenerative gas turbines may be the better option.

Identification and modelling of power control parameters for marine gas turbines
by LIEUTENANT J.A. MARKUS MSC Royal Netherlands Navy

This report investigates possible combinations of readily measurable parameters to control the power output of marine gas turbines without the need for expensive and unreliable torque measurements. A literature survey of current marine gas turbine power control systems was conducted with emphasis on limitations in relation to the intercooled and recuperated gas turbine. It was concluded that currently applied analogue (hydromechanical) control systems would not meet the stringent environmental climate. It was postulated that a digitally based control would fulfil this objective.

Performance calculations on a simple cycle, twin spool engine under variable conditions showed a combination of input parameters were suitable for controlling the power output of the engine. These were then used as the basis of a modelling process in order to design a digital controller.

After eliminating the existing fuel control system from TRANS (a simple cycle transient gas turbine simulation programme), the transfer function of the gas turbine model incorporated in TRANS, was determined. This was achieved by applying numerical system identification techniques based on an autoregressive model and the input-output relationship of fuel flow and temperature difference over the power turbine respectively. A digital controller was designed via application of the direct digital design method.

After analysing the performance of the system in the time domain, it was concluded that this was a feasible method of designing controllers for marine gas turbines. Further investigation in parameter robustness is recommended.

The active filtering of multiple non-integer harmonic currents
by LIEUTENANT T.J. ROBERTS BENG (HONS) MSC RN

The use of cycloconverters is becoming increasingly widespread in the provision of variable speed AC drives. This type of drive is very flexible and provides control of both output frequency and voltage. The most significant disadvantage of such systems is the harmonic distortion created in both output current and output voltage waveforms. The most difficult type to eliminate are those referred to as inter-harmonics, because the frequency of the harmonic is dependent upon both input and output frequencies. Thus the frequency of all inter-harmonics will change throughout the speed range of the drive.

The relationships between input and output frequency and inter-harmonic frequency can be predicted accurately using mathematical relationships. This project further developed an adaptable control system for an active filter, using these relationships, such that the system was capable of accurately tracking and attenuating multiple inter-harmonic components of the supply current. The effect of varying harmonic attenuation found in the previous study, was investigated, and the actual behaviour of the unfiltered harmonics compared with the mathematical predictions. Using an active filter developed in a preceding research project, which had its control algorithms implemented using DISPLAY XL, new software was developed which tracked and attenuated multiple inter-harmonics, under varying cycloconverter output conditions. It was recommended that this technique be applied to a three phase cycloconverter operating at a higher voltage.

Piezoelectric actuators and sensors for active vibration control
by LIEUTENANT (N) C.S. WARDLE BENG(RMC) PENG C D Canadian Navy

Traditionally, passive vibration isolation measures have been used to control the transmission of vibration in practical engineering structures. More recently, new techniques involving the active control of unwanted vibrations have been developed. These methods require sensors and actuators to be incorporated into

the structure to be controlled and this project was concerned with the way in which these transducers couple into, and control, vibrations. Two types of material were used; piezopolymers as sensors and piezoceramics as actuators. An experimental rig consisting of a long, slender beam was designed and built and the sensors and actuators fitted. Theoretical models were developed which coupled the transducers to the beam and simple experiments were conducted to validate the theory. The results demonstrated the effectiveness of the sensors and actuators in suppressing vibration on a simple structure.

Heat transfer enhancement from a rib-roughened surface
by LIEUTENANT S.R. MULLER BE(M) MSC Royal Australian Navy

Recent development in the fields of gas turbines, nuclear reactors, and heat exchangers has provided the impetus for research into heat transfer enhancement from turbulence promoters. These units offer a simple and effective means of enhancing single-phase heat transfer by generating a locally accelerated flow field with a significant level of turbulent activity in their wake.

The work presented was motivated from a need to improve gas turbine thermal efficiency, power density and component life. Subsequently, the aim was to study heat transfer enhancement from a rib-roughened annual passage modelled on the Rolls-Royce SPEY SMIC gas turbine tubo-annular combustion chamber. The present study focused on qualifying the phenomenon of rib-roughened heat transfer enhancement in entrance regions as this was considered to bear great practical significance.

The working fluid was air and seven pitch-to-height ratios were investigated across four different Reynolds numbers. Results indicated an optimum pitch-to-height ratio of nine, and showed that the effect of Reynolds number on the ribbed passage Nusselt number was stronger than for the smooth derivative. This indicated a decrease in enhancement with increased Reynolds number. The distribution of local heat transfer coefficient in successive inter-rib pitches demonstrated the strong influence of entrance effects and suggested that hot-spots (negative enhancement) did not occur in this region. Flow visualisation techniques were employed to indicate the mechanisms of flow separation and reattachment over a surface mounted obstacle, and results clearly defined a reattachment point at one to two rib heights downstream of the point of maximum heat transfer coefficient.

The benefit of gas turbine engine design was examined, and specific application to the Rolls-Royce SPEY SMIC combustion chamber indicated that rib-roughening could maintain the combustion chamber liner at a significantly lower temperature and induce longer life. This would also protect components in the downstream gas path (blades) due to a reduction in debris damage from liner deterioration. Furthermore, rib-roughening was found to generate versatility when apportioning air flows for greater efficiency and reduced emissions.

The effects of TAYLOR vortices on local heat transfer in a narrow eccentric horizontal annulus
by LIEUTENANT M.J. CAMPBELL CD BESC MSC PENG Canadian Forces

The circumferential flow of a fluid in the annular space between two concentric cylinders, either or both rotating, is referred to as COUETTE flow or TAYLOR vortex flow. COUETTE flow occurs at low speeds and consists of laminar flow with circular streamlines. Above a certain critical speed a transition to TAYLOR vortex flow occurs, and the flow then consists of pairs of counter-rotating toroidal vortices.

Research into TAYLOR vortex flow has linked an increase in heat transfer to the transition from COUETTE flow to TAYLOR vortex flow. Other research has shown that the transition occurs in two phases when the cylinders are placed eccentrically.

This project developed an apparatus with $d/R_1 = 0.4$ and $L/d = 84$, variable eccentricity, a heated rotating inner cylinder and a stationary outer cylinder. The apparatus was capable of providing torque measurements and local heat flux measurements at five points around the cylinder. The apparatus was then used to investigate the local heat flux variation due to eccentricity around the circumference.

It was found that both instabilities could be detected through the measurement of local heat flux at the surface of the outer cylinder. It was further found that the torque increase due to the first instability could be detected at the outer cylinder in highly eccentric narrow annuli.

Numerical modelling of the SPEY gas turbine modified reflex air burner and primary combustion zone

by LIEUTENANT P.D. MAYER BE(MECH)(HONS) MSC Royal New Zealand Navy

The modified reflex air burner and primary combustion zone of the Rolls-Royce Spey SMIC gas turbine combustion chamber have been realistically modelled with the computational fluid dynamics code FLUENT Version 4.2. The flow and combustion characteristics in a 3D, 45° segment are predicted utilising turbulence, heat transfer, chemical species and dispersed phase computational submodels. Two different models of 17,000 and 33,000 cells have been created and solved, the latter with improved geometrical detail and increased grid density in critical areas.

The improved model has been used to investigate the effects of several design modifications, including fuel injection variation, the inclusion of an axial rib in the main injector flow channel and a major geometry alteration. The results of these investigations prompt several interesting questions on the design of the reflex air burner and Spey combustion chamber. Some encouraging validation of the modelling has been possible from comparisons made with water testing, empirical relations and with various experimental summaries. The application and scope of computational fluid dynamics to accurately predict combusting flows and assist in the design of gas turbine combustion chambers is clearly illustrated.

Determination of current capacity requirements for warship Impressed Current Cathodic Protection (ICCP) systems

by LIEUTENANT P.S. PARVIN BENG(HONS) MSC CENG PGDIP MIMARE AMIMECHE RN

Warship ICCP systems have been consistently under-rated, and hence systems presently in use do not protect the vessels adequately. Studies into the required current capacity have to date been simplistic, based upon the current densities for individual hull materials multiplied by the respective surface area, and added. Potentiodynamic and potentiostatic polarisation studies of the Protection Current Density requirements for the three components of a ship's hull (painted mild steel, bare mild steel & Nickel Aluminium Bronze (NAB)) were carried out under conditions of static and flowing electrolyte. The individual alloy components that comprise a warship's wetted hull area were examined singly, and galvanically coupled in the correct geometric ratio. Effects of surface condition, set potential and configuration were examined. Data extrapolation techniques were used to predict current requirements for materials under high speed flow.

The requirement for standardisation of techniques for determining Protection Current Density requirements is identified. Results are discussed in relation to the need to install ICCP systems with a current output capacity to meet maximum anticipated demand.

It has been confirmed that system capacity should not be determined by simple summation of the currents required to protect the individual components, but by examination of the coupled components. New proposals for the Naval

Engineering Specification have been forwarded, and recommendations for the determination of current capacity of new classes made.

Design criteria for two zone warship ICCP systems
by LIEUTENANT R.D. HUGHES BENG(HONS) MSC CENG MIMARE RN

Problems have been encountered at sea with the ICCP systems fitted to modern warships to minimize hull corrosion. Hull surveys suggest that it has not been possible to achieve acceptable levels of protection along the length of the hull as prescribed in the Naval Engineering Standard (NES 704). Problems stem from poor design due to a lack of understanding of the relationships governing the distribution of current and potential. This project determines the interactions between different ICCP systems and the hull components (bare steel, painted steel and NAB) and suggests improved design criteria for two zone systems.

For the first time, values of percentage current distribution to all hull components have been measured. Effects of anode location, size and shape have also been examined in relation to current output and potential distribution. Practical data has been compared with theoretical equations for anode 'throw'. The effect of propeller rotation has been determined and different ICCP systems were evaluated employing a 'design for damage' policy. Single and two zone systems showed that the relative contribution from each zone varied according to hull state and operational conditions.

A two zone, eight anode system configuration provided markedly better protection than the present six anode systems. Results are presented in the context of improved design criteria, the adoption of which should lead to improved future ICCP system designs.