ROYAL NAVAL ENGINEERING COLLEGE POST-GRADUATE PROJECTS 1994–1995

As part of the final Advanced Marine Engineering Course (MSc Course in Marine Engineering) at the Royal Naval Engineering College, Manadon, each student spent 17 weeks working at a particular research project. A summary of each project completed is printed below.

Robust control methodology applied to ship roll stabilization
by LIEUTENANT A.A. GARWAL, B(TECH), MSC, MCGI, Indian Navy

The effectiveness of a rudder roll stabilization system has been recognized for sometime. A measure of roll reduction can be achieved using the existing rudder systems. The use of the existing rudder system to assist rather than to replace fin stabilizers appears to provide an inexpensive method for enhancing the roll reduction presently achieved. The success of this combined roll reduction strategy depends on controller design.

This report describes the development of the rudder roll controller and autopilot using the H∞ optimization technique and compares their performance with the classical counterparts. The advantage of using H∞ design method is that it guarantees robust stability. Simulation studies are described that quantify the performance characteristics of the designed controllers. The report also examines the interaction present between the yaw and roll control loops.

This study concludes that the overall performance of the H∞ rudder roll controller and autopilot is superior to that of the classical type. The level of interaction between the two loops can be suitably modified by varying the performance weighting functions. The study has concentrated on designing the controllers for the Type 23 frigate of the Royal Navy, but the approach is suitable to present and future warship designs.

The development of a numerical model to investigate the transient response of a tunable vibration absorber
by LIEUTENANT COMMANDER G.C. BULL, BENG, PGDIP, MSC, MCGI, AMIMECHE, RN

Semi active vibration absorbers provide one method by which the vibration levels of a parent system can be reduced over a range of frequencies. This is achieved by varying the physical properties of the absorber elements, to match their natural frequency to the frequency of the parent system excitation. The reduction in the vibration levels is dependent upon the accuracy with which the absorber control system conspire to introduce an error that leads to a reduction in the general performance. In some circumstances this effect can lead to the amplification of the parent system vibration. It follows that, where tunable vibration absorbers are to be used, the ability to predict its transient response is important if vibration targets are to be met over the operating range.

The aim of this project was to develop a model that could be used to determine the transient response of a tunable vibration absorber. This was achieved using the Newmark numerical integration technique to analyse the response of a 2 degree of freedom system subjected to sinusoidal excitation. The veracity of the model was demonstrated by comparing the model predictions with experimental results obtained from a pneumatically tunable absorber.

The value of the model as an analytical tool was demonstrated by investigating the effect of changes in absorber parameters and transient severity on the overall response. It was shown that by increasing the mass of the absorber, relative to the parent system, the transient response of the absorber can be improved. The variation of the alpha and beta parameters within the Newmark equations can be used to optimize the model prediction. Future versions of the model can be expected to use this facility to achieve greater accuracy in the prediction of system response.

Simulation of a pressurised water reactor using distributed processing in real time

by LIEUTENANT J.R. CORDEROY, BENG, PGDIP, MSC, AMIMECHE, MCGI, RN

In both the Royal Navy and the Nuclear Industry, simulators have been used to great effect for many years. The advent of cheap reliable digital processors and modern high level programming languages allows low cost 'Basic Principle Simulators' to be produced. A single loop Pressurised Water Reactor (PWR) model has been developed and implemented on a series of PCs using a mixed language Windows™ programming technique.

The PWR model is based on the one group neutron cycle and is described by a system of coupled, 1st order, nonlinear differential equations. The equations are solved using an innovative, variable time step, numerical integration method. The method developed continuously adjusts the integration time step to maintain numerical stability, minimizing the processor load and hardware requirements. A Microsoft Windows™ interface has been developed to provide an ergonomic 'front end' for the user. The fast solution of equations, required for a real time simulator, is achieved using Fortran code compiled as a dynamic link library.

The simulator shows the response of a PWR plant under a variety of conditions. Operation as a subcritical/critical reactor and throughout the power range are all simulated, enabling the load following and self regulating characteristics of the plant to be studied. The PWR model and the software produced show that the technique developed is an extremely powerful method of implementing simulations on a set of distributed digital processors.

Neural network modelling and controller design for an unmanned underwater vehicle in the seabed terrain following mode

by LIEUTENANT COMMANDER D.J. DEMERS, BENG, MSC, PENG, CD, MCGI, CAF

Remotely operated vehicles and unmanned underwater vehicles are valuable tools for the oceanographic researcher to conduct activities such as:

- Exploring undersea life.
- Inspecting pipe lines and cables.
- Ocean surveying.

Military aspects of these vehicles include:

- Underwater intelligence gathering.
- Mine laying.
- Mine countermeasures.

These types of vehicles are limited in their potential simply due to the requirement for human interaction, usually conducted via an umbilical cord such

as a tether or ultra sonic link, which restricts their operating range and manoeuvrability. These limitations could be overcome by using autonomous underwater vehicles, which do not require direct human interaction. However, underwater vehicle response is highly nonlinear and thus difficult to control.

Many different methods have been explored to control underwater vehicles which have only offered limited success. Recent advances in neural networks technology however, have the potential to succeed where other control methods have failed.

In this study, neural networks were used to first model the depth dynamics of an Autonomous Underwater Vehicle (AUV). This model was used to develop a neural network controller to provide suitable AUV control for sea bed profiling. To model the AUV depth dynamics, a recurrent type Elman network was used and was successful at modelling the AUV, but only within a narrow operating bandwidth. Fortunately for this study, this bandwidth corresponded to that which is likely to be required of the AUV.

The network model was then used, in what is commonly called an identification network, to train a feedforward type neural network controller. The controller was to provide suitable AUV control over any seabed profile. Though different types of controllers were studied, it was found that by inputting the AUV's gradient velocity into the controller and using the height error over the profile as a bias into the AUV, a marginally suitable controller could be obtained. Although the controller was not completely successful, there is much scope for improvement and ultimately, a suitable neural network controller could be developed.

The development and practical investigation of tandem generators using micro machines

by LIEUTENANt G.F. HILL, MSc, MCGI, RN

The increasing uses of marine electrical propulsion systems in ships have inevitably placed greater demands on the electrical generating plant. Large marine drive systems usually require a high voltage supply whereas the ship's service equipment generally needs a 'clean' low voltage supply.

A recent feasibility study of tandem generators, identified that two electrically independent AC synchronous generators could be connected to a single prime mover to provide both the high and low voltage supplied. Tandem generators would offer advantages in terms of space, weight, and cost. They would provide electrical isolation between the high and low voltage supplies, ensuring that any electrical distortion generated by the propulsion power converter equipment is prevented from contaminating the 'clean' service supply.

The behaviour of tandem generators has been investigated by modifying two existing laboratory micro-machines and by designing suitable governor and automatic voltage regulator control algorithms within the digital signal processing software. The performance of the machines has been monitored by a computer based data acquisition system, developed to record the changes in the alternator parameters during transient load and symmetrical fault conditions. The results of these tests have satisfied the generator voltage and frequency requirements defined in the Naval Engineering Standard, and have shown the ability of the tandem generator to provide electric power to two independent voltage systems.

The vibrational behaviour of high power, high speed single helical gears with and without thrust cones

by LIEUTENANT G.R. HOPE, BENG, MSc, MCGI, RN

Both single and double helical gears are used in main marine propulsion gearing. Neither has been shown to be significantly superior for gear noise and vibration, although the higher alignment accuracy achievable with single helical gears offers the potential for reduced noise levels. The fitting of thrust cones to single helical

gears offers a further theoretical advantage in terms of noise and vibration reduction, when compared to the use of single helical gears with thrust bearings. The development of a theoretical model is required to investigate the dynamic behaviour of single helical gears both with and without thrust cones fitted.

Using model summation techniques, a dynamic model of a wide facewidth, single helical, gear pair is established. The model is formed using data from experimental model analysis and the results of a finite element analysis of the individual unconstrained gears. All the identified modes of vibration below the calculated fundamental frequency of vibration of the gear pair are included. Excitation is provided as a result of time varying gear tooth stiffness and is derived from an established finite element analysis of the elastic mesh under static conditions.

The decoupled equations of motion for the constrained gears, in model coordinates, are derived. The solution, of the resulting 63 degree of freedom model, is by standard numerical technique using PC driven software, allowing prediction of dynamic mesh forces. Initial results from the dynamic model have been compared with experimental data from a test gearbox at the Design Unit, University of Newcastle upon Tyne and provide a preliminary validation of the model and the theoretical technique employed. Further work is required to fully validate the model, to directly predict dynamic bearing forces and to include the effects of fitting thrust cones to the gears. A full development of this modelling technique will enable investigation of the dynamic behaviour of marine gears to take place at the design stage, with the aim of improving both the design and the noise characteristics of wide facewidth gears.

Condition monitoring of a static power inverter using visual basic software
by LIEUTENANT R.A. LOBLEY, BENG, MSC, MCGI, RN

The increasing uses of power electronics in engineering applications has highlighted the requirement for effective circuit monitoring techniques. Both the efficient operation and maintenance of power converters are dependent on the condition of the individual power electronic devices and associated input and output signals. The level of sophistication of monitoring is determined by a Reliability Centred Maintenance (RCM) analysis of a typical static power inverter circuit.

A low power static power inverter, and associated control circuitry has been constructed and configured to form a test rig. RCM methodology has been carried out to determine the applicability of, and reasoning for, condition monitoring various elements of the inverter. A software program has been written using Visual Basic to monitor the condition of both devices and waveforms, at specific points within the inverter. This provides the operator with relevant information in a usable format. Prompts are provided to highlight the onset, or possible cause, of failure.

Recommendations are given as to the relevance of the RCM process when applied to an electronic circuit and to the effective use of monitoring techniques and maintenance programmes for static power inverters and associated circuitry. This is of particular relevance, as industry is increasingly adopting the RCM process.

Heat transfer enhancement from a rib roughened surface
by LIEUTENANT C. MCCARTNEY, BA, MSC, AMIMECHE, MCGI, RN

The use of rib roughening as a turbulence promoter is a well-established method of heat transfer enhancement in forced convection heat transfer, at the expense of some pressure loss. This effect has been used in the nuclear industry and in gas turbine blading. A recent paper by S.R. MULLER investigated this effect experimentally, using a wind tunnel to model a gas turbine combustion chamber.

The present work seeks to validate the Fluent Computational Fluid Dynamics (CFD) package with MULLER's results, and continues to conduct a parametric study of heat transfer in this configuration. The parametric study includes the effects of increased turbulence intensity, rib size and decreased annulus size. The working fluid is air, mimicking MULLER's conditions. In addition, some realistic gas turbine conditions are also investigated. Some difficulties were found with the CFD capacity in the 3D case, but it is found valid when using an axisymmetric 2 D model of the flow field. A k-ε turbulence model is used in the analysis, and for the gas turbine combustion chamber flow conditions, enhancement of up to 8% is found to be available. Increasing turbulent intensity causes an increase in heat transfer enhancement, although the analysis finds a limit to the applicability of the k-ε model in this case.

This work finds CFD to be a useful and powerful tool for parametric studies, but it's validity for preliminary analysis in such a large flowfield is limited. A principle recommendation from this work is for further studies of the flow regime using modified turbulence models, thus providing greater accuracy and allowing more wide ranging parametric comparisons.

The detection of local tooth defects in gearing by vibration analysis
by LIEUTENANT A.G. REYNOLDS, BENG, MSC, MCGI, RN

Local tooth defects, affecting only one tooth on a gear, are difficult to detect by established vibration analysis techniques: They are in mesh for only a small time in the rotation of the gear and their effect on vibration is therefore spread across a wide range of frequencies. This study seeks to detect such defects using a range of techniques including:

- Synchronous time averaging (to reduce noise and extract the vibration of the gear of interest).
- Hilbert transform-based demodulation (to reveal small phase variations in the meshing vibration due to a damaged tooth).
- The relatively new Wavelet Transform (WT) (a variable-resolution time-frequency analysis method).

Software is developed to implement these techniques using the MATLAB™ programming language, and simulation studies show their use. The simulations show, with increasing likeness to 'real' gear vibration, the diagnostic features and limitations of the techniques.

The techniques are then validated by application to real data from gearing test rig developed at the University of Manchester. The rig was found to give a poorer signal than might be expected from a high quality marine gearbox, with structural resonances, misalignment and amplitude and frequency modulation impeding analysis. No single technique (other than visual inspection) was found to give a reliable diagnosis, but all methods could be included in the diagnostic engineer's toolbox. In particular, a simple and robust gearbox monitoring system could be based on statistical analysis of a synchronously-averaged stress wave sensor signal. Further work is recommended, particularly in matching the ideal type of WT to the impulses produced by local tooth defects.

Power augmentation of marine gas turbines for pulsed power applications
by LIEUTENANT M.J. TOXOPEUS, BE(HONS), MSC, MCGI, RNZN

Future weapon systems such as Electro-Thermal Chemical (ETC), rail and coil guns will require power of an instantaneous, relatively random nature but of high magnitude (10 MW). Provision of such a power source on board a naval vessel could be met from using the main propulsion gas turbines and extracting power either from the main reduction gearbox through use of a dedicated power take-off

generator, or from the main propulsion generators associated with future full electric ships.

This project has undertaken a study into suitable power augmentation techniques for marine gas turbines that could be applicable for a pulsed power application. An extensive literature search revealed many technologies that could be used. Use of closed cycle gas turbines, application of reheat, steam injection, water injection, increased fuelling rates within the primary combustor, and turbo or super charging have been discussed and analysed.

Initial modelling has shown that the following can offer significant power increases:

Steam injection

Would require installation of a waste heat recovery steam generator in the exhaust ducting of the gas turbine, which causes additional pressure losses and hence reduced efficiency when steam is not injected. It is considered unsuitable for pulsed power application, due to delays in steam generation response times.

Turbo-charging

Would require incorporating an auxiliary compressor and turbine into the system with associated ducting and valve arrangements for pulsed applications. The scale of the ducting makes this system unsuitable for a main propulsion engine system, but may find favour on smaller turbines.

Water Injection

Causes a reduction in efficiency, but can be of an instantaneous nature, and is therefore recommended as the preferred method. Analysis has shown that increases in power output of more than 50% could be achieved by injecting water at 15% of the air mass flow rate into the combustor region of the turbine.

SUCCESSOR TO THE AMEC

With the demise of the RNEC, it has been necessary to find an alternate MSc course in Marine Engineering. This is to meet the continuing requirement for a few officers of the ME and MESM specializations to be educated to post-graduate level. The decision has been taken to join the existing MSc course in Marine Engineering run by University College, London from September 1995. As at the RNEC, electrical and mechanical options are available.

This course operates alongside the MSc in Naval Architecture, attended by MoD sponsored students of the Defence Engineering Service. The Marine Engineering MSc will share a ship design exercise with these students and attend a number of their keynote addresses/lectures.