VIBRATION RESEARCH AT THE R.N.E.C.

BY

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ABSTRACT

This article describes the vibration research activities of the Structural Dynamics Laboratory of the R.N.E.C. It traces the origins and evolution of this work to the present day and discusses current projects in progress.

Introduction

Engineers in the Navy have for many years been concerned with the effects of vibration in the machinery and systems with which they have to contend and is a subject which transcends all physical boundaries, since it is unlikely that there is any branch of engineering in which this phenomenon does not play an important role. However, knowledge of the factors influencing vibration still remain in many cases imprecise and, with machines becoming ever more complex and operating at greater speeds, the analysis and solution of vibration problems is one of increasing importance.

Consequently, considerable research is being carried out in this area by scientific establishments encompassed by MOD, often in liaison with externally contracted academic and consultant establishments at great financial cost.

Vibration research is well established in the Structural Dynamics Laboratory of the R.N.E.C. and has gained recognition at national and international levels. APPENDIX I gives selected examples of papers published by staff past and present in recent years. However, surprisingly little use is made of the extensive range of equipment and expertise within the vibrations group by naval/MOD sections engaged in this field. This may in part be due to a lack of knowledge or a misunderstanding of these facilities and which this article is hoped in some measure to remedy.

Origins of Vibration Research at the RNEC

The Advanced Marine Engineering Course (AMEC) grew out of the long established 'Dagger Course' in Advanced Marine Engineering previously run at the RNEC and before that at the Royal Naval College, Greenwich. By 1976 the course had been redesigned to meet the needs of the modern Navy in the light of advancing technology and was submitted to and approved by the Council for National Academic Awards (CNAA) for the award of M.Sc. in Marine Engineering. One of the conditions of the award was that the 'Council expects that staff teaching to Masters or Post-graduate level will be actively engaged in research . . .'.

As in every other similar establishment of higher education, research effort had to be costed and evaluated. However there was freedom in research. There was certainly no dictation in the choice of vibration topic by the Navy itself or by MOD establishments. The staff who lectured to the M.Sc. accredited AMEC course during the initial years were officers of the Instructor Specialization who had been seconded to a designated university to read for a vibration-biased M.Sc. degree. The research they embarked upon was invariably a reflection and extension of the knowledge and expertise gained in obtaining their higher degree. It also reflected the specialist area of vibration research of their designated university, links which still remain. Also, great efforts were made to establish links and collaboration with naval research groups and as time evolved certain research areas became based upon topics which were likely to become increasingly important in meeting naval needs. Selected members of staff were sent to ARE Portland for a period of two years in order to increase research experience in naval-related vibration problems, a process which still continues.

Research Staff

Initially, apart from naval staff who were prime movers of research and who spend longer recurrent periods at the R.N.E.C., the main source of investigative support was the AMEC student during the project phase of his course. Originally, this was seen as a problem area insomuch that there could have been a lack of continuity in progressing a particular research theme. This was because from the projects offered it did not necessarily follow that all would be adopted, and in any case the project phase is of only six months duration. As events have proved this did not present an insurmountable obstacle and vibration themes are progressive. Credit for this is also due to the civilian staff who as co-research workers have provided valuable continuity and technical expertise. Summaries of all completed student research projects are now published in the *Journal*[1, 2, 3, 4].

Evolution of Research

APPENDIX II lists the projects completed by AMEC students since M.Sc. accreditation and not only shows the continuity of research themes but also reflects the evolution of staff research from which the projects were derived.

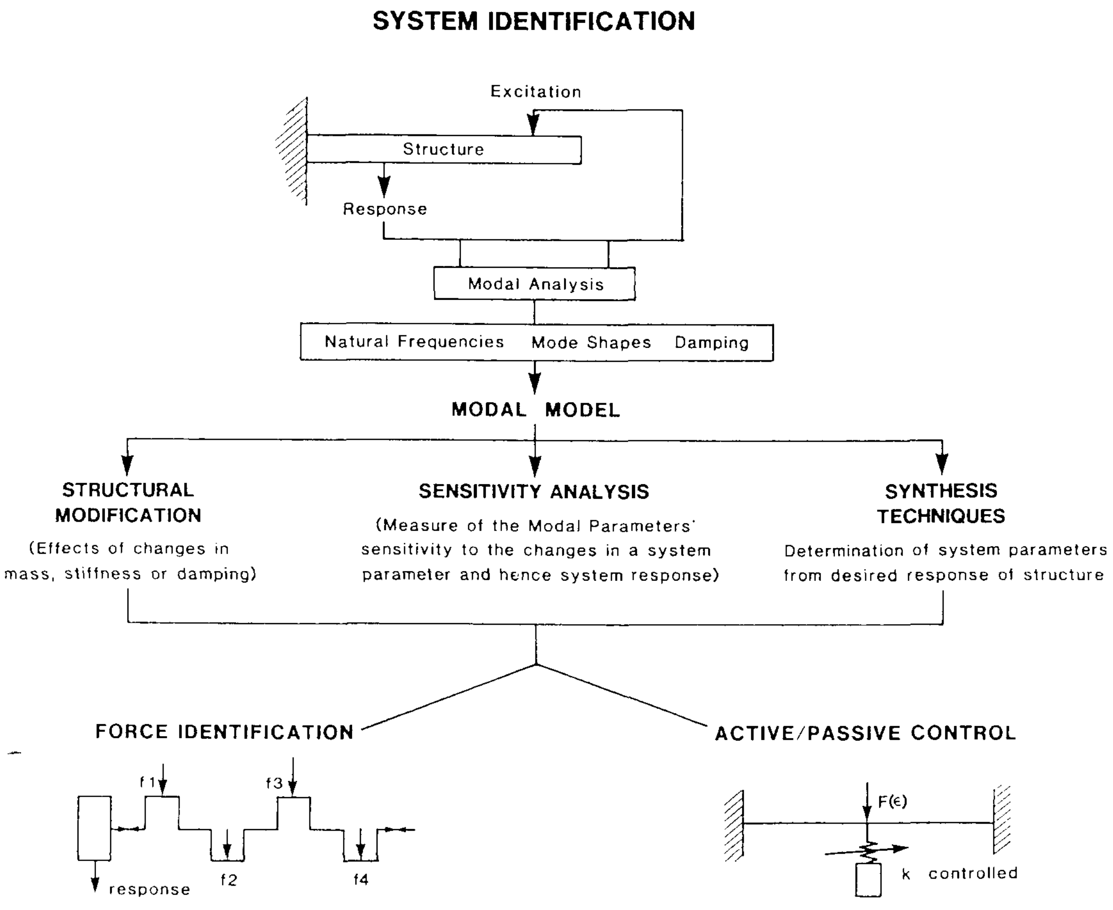

FIG. 1—GENERAL RESEARCH MODEL

Indeed, the transition from staff research topic to AMEC course input is through the student project. An important contribution has also been made by the many undergraduate projects formulated from these topics. FIG. 1 shows the general research model which evolved and reflects the research themes of APPENDIX II. It shows how, using experimental data from a structure, a model is derived. Using this model the response of the structure to internal parameter and input variation can be predicted and control exercised.

Current Research

The research model of FIG. 1 has further evolved and distinct areas have been defined. FIG. 2 shows the current research topics grouped under the general headings of Fundamental and Applied research.

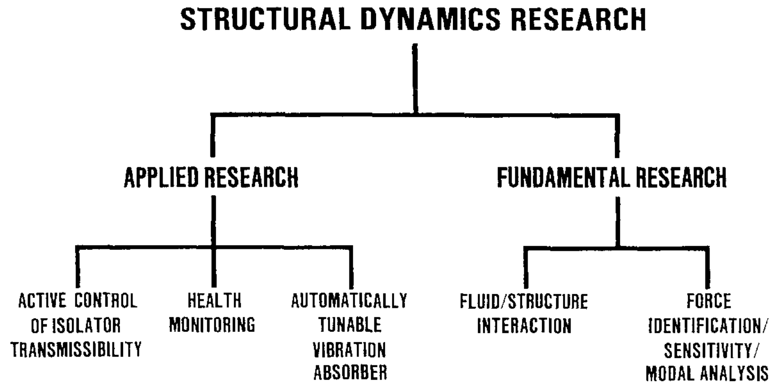

FIG. 2—CURRENT RESEARCH TOPICS

Fundamental Research—Investigations carried on without regard for immediate practical value, to establish the principles upon which certain vibration phenomena occur.

(*a*) *Fluid/Structure Interaction*

An area of work which was instigated by ARE (Southwell) at Portland in collaboration with Brunel University, studying hydroelasticity which is that branch of science concerned with the motion of deformable bodies through liquids. A general three-dimensional hydroelasticity theory is being developed which is applicable to marine structures which may be moving or fixed in regular sinusoidal waves.

The particular aspect being investigated is the application of this novel approach to the behaviour of flexible shell structures in a submarine environment. The frequency response characteristics of a plain unreinforced cylinder have been measured in both 'wet' and 'dry' states (FIG. 3). The dry analysis identifies mode shapes and natural frequencies which are the basis for calculating the fluid loading. For a stationary submarine body in still water the external fluid loading consists of hydrostatic pressure and the radiated pressure field which surrounds the vibrating structure and is the source of computational difficulty as it is not only caused by but also causes the deformation of the structure.

The experience gained in performing these calculations will enable further work to be completed on the responses to transient or shock loading.

FIG. 3—'WET' TESTING OF UNREINFORCED CYLINDERS

(*b*) *Force Identification/Sensitivity/Modal Analysis*

The dynamic properties of a vibrating structure are encompassed in the natural frequencies and mode shapes of its free motion. These characteristics can be determined by experimental modal analysis and used to predict the response of the structure to a set of applied forces whose magnitude and location are known. The measured and theoretically predicted responses compare very favourably.

Often the applied forcing function is not completely specified; in particular its magnitude and location may not be known. It would seem logical to reverse the analytical procedure by measuring the system response and using the predetermined free response characteristics to determine the magnitude and location of forces causing the measured response. This is an attractive proposition especially as far as health monitoring is concerned. The development of force prediction however, using this technique, is not as simple as theory suggests. Force prediction has been shown to be extremely sensitive to small errors in the free response characteristics and measured response data. Research is continuing in these areas in an attempt to overcome the sensitivity, numerical and measurement problems (FIG. 4).

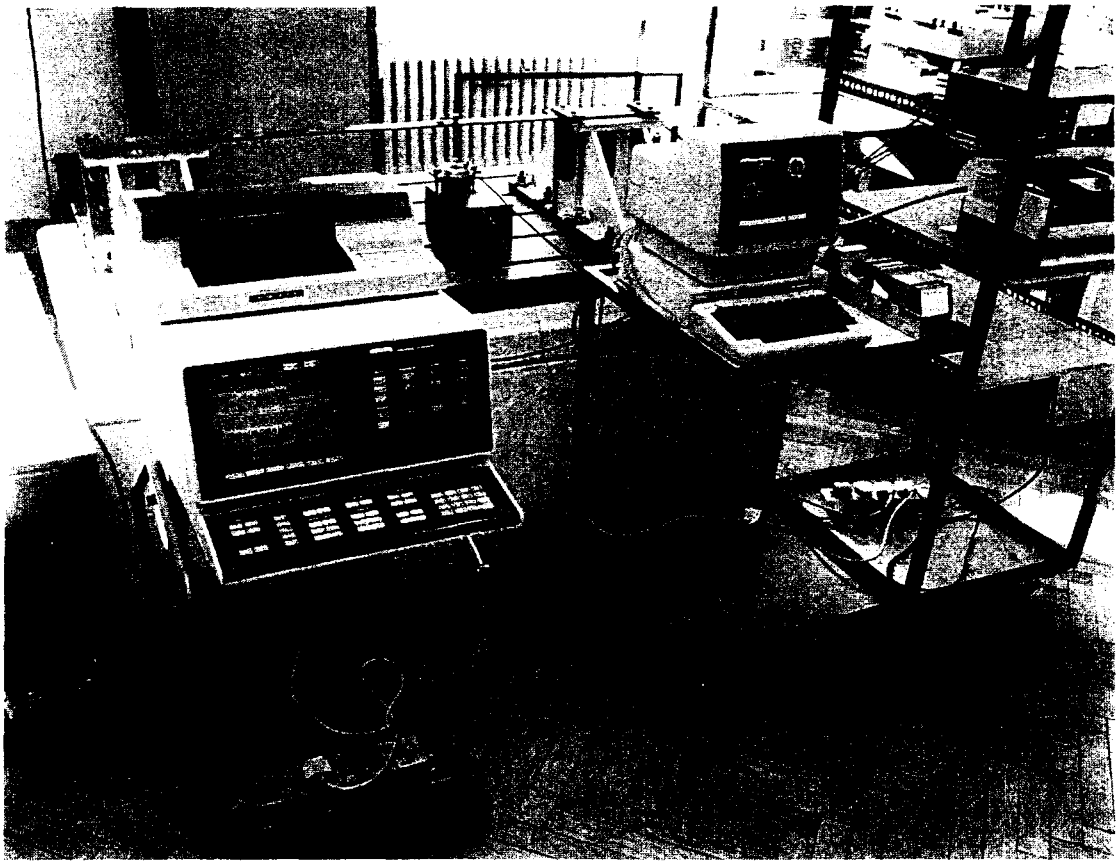

FIG. 4—NUMERICAL MODELLING IN FORCE DETERMINATION OF A STRUCTURE USING EXPERIMENTAL RESULTS

Applied Research—Investigations which are based on established principles which are put to practical use.

(*a*) *Automatically Tunable Rectilinear Vibration Absorbers*

One of the main causes of vibration in naval equipment is the imbalance in rotating machinery, directly speed-related and illustrated by large displacements at the machinery mountings. This results in the premature failure of machinery components and in a high underwater noise signature. The conventional mass/spring dynamic vibration absorber offers good vibration reduction but only over a very limited frequency range.

An alternative method of extending the operating range whilst still maintaining its full effectiveness is to employ an active element in the absorber system. Thus the absorber can be tuned to the frequency of the rotating imbalance and thereby provide the maximum reduction in vibration levels. Extending this further, if the governing parameters of the absorber are known this tuning process may be automated.

A prototype has been built and tested satisfactorily and a patent licence granted. Work continues in the optimization of the control unit and the micro-miniaturization of the micro-processor/measurement circuit has been achieved and is under test (FIG. 5). Further operational tests are scheduled on a G and M Power Plant diesel generator set (48 kW) using a Perkins 6.354.4 prime mover. Future work will extend the principle to active torsional absorbers.

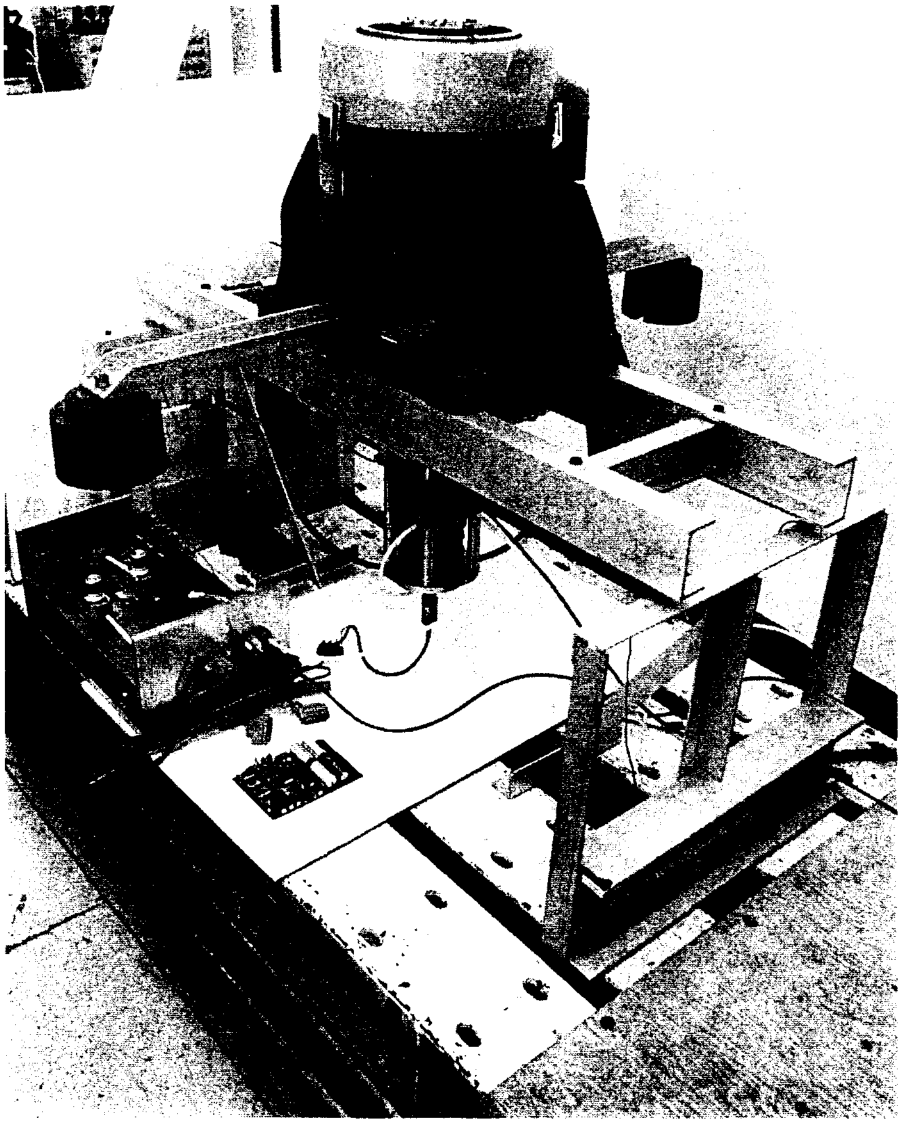

FIG. 5—AUTOMATICALLY TUNEABLE VIBRATION ABSORBER WITH CONTROL SYSTEM

(*b*) *Active Control of Isolator Transmissibility*

The use of air springs for vibration isolation is now well established. Such air springs, or pneumatic isolators, provide excellent isolation and a simple means of height control, and a typical installation has a natural frequency below 10 Hz. Unfortunately many large machines have their fundamental frequency below this or sweep relatively slowly through that frequency range on start-up. Therefore if air springs are to be used for such machines some means of reducing the amplitude of vibration at resonance must be provided.

One method is to introduce damping by pneumatically coupling a fixed air receiver to the air spring through a capilliary restrictor but, as with a conventional damped spring system, not only is the amplitude of vibration at resonance decreased but also the degree of isolation.

Depending on the degree of isolation required, this relatively simple system may be quite acceptable; however, for many applications a far higher performance is required. Work is currently being undertaken to optimize the air spring isolation system using active control.

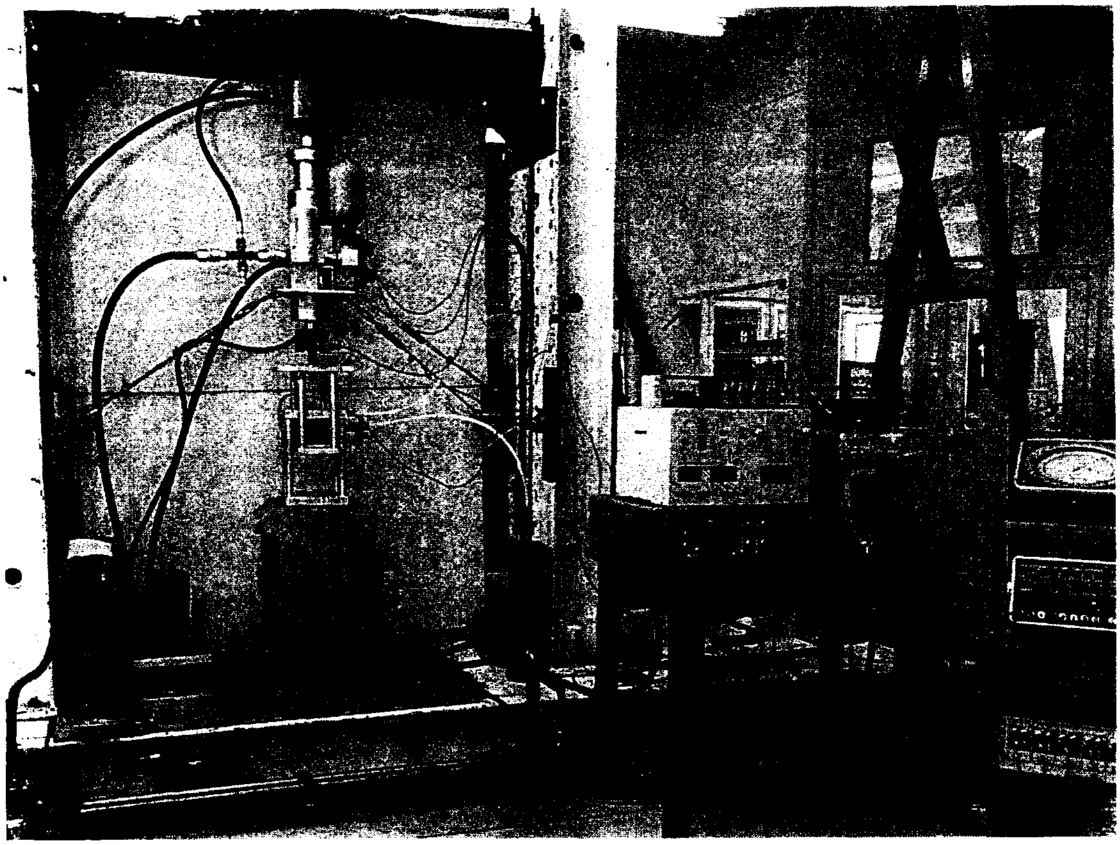

FIG. 6—ACTIVE CONTROL OF TRANSMISSIBILITY RIG

In this system an air spring and fixed receiver are connected through a controllable orifice (FIG. 6). At low frequencies the orifice is closed, pneumatically isolating the spring from the receiver and affording relatively high dynamic stiffness. At higher frequencies the orifice is open and the dynamic stiffness is reduced. If a control system is arranged to open the orifice automatically at the crossover point between high and low dynamic stiffness, the system transmissibility characteristics can be considerably improved without affecting the static performance and thus the mean position of the machine. Much of the initial experimental evaluation has been completed. A computer simulation and optimization package has already shown good correlation between the predicted and experimental results. The eventual aim is to produce a single- or multi-mount, microprocessor-controlled isolation system capable of providing the optimum transmissibility characteristic over the widest possible range of operating frequencies.

(*c*) *Health Monitoring*

The Navy has a requirement to reduce machinery noise with a view to reducing overall transmitted ship noise and ultimately reducing the detectability of both surface and sub-surface vessels. If this is to be possible and reliable, an improved understanding is required of the vibration signatures produced by machinery and of methods for the interpretation of these signals. Condition monitoring systems are already used for the detection of incipient failure and the diagnosis of the nature of faults in operating machinery. Work is due to commence to investigate the possibility of using these same signatures to identify machinery health operating away from their optimum.

The Future

1988 saw the commissioning of the Keyham Building at the RNEC. This is a new mechanical engineering laboratory second to none, of which the Structural Dynamics laboratory forms a major part (FIG. 7).

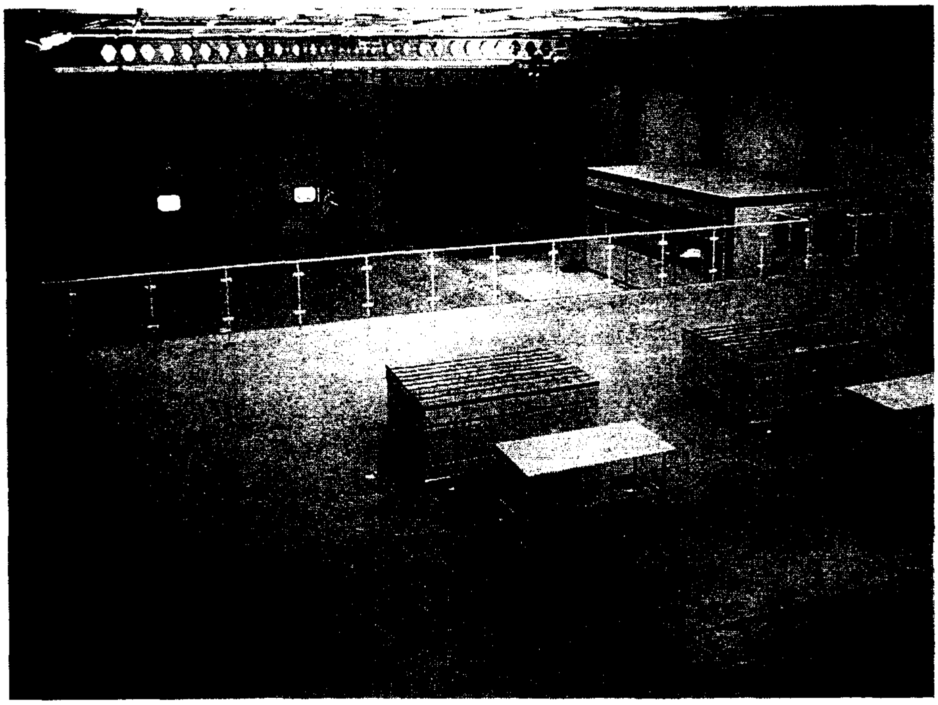

FIG. 7—THE STRUCTURAL DYNAMICS LABORATORY OF THE NEW KEYHAM BUILDING

This new location enhances and expands the vibration research facilities and capabilities. Consequently research effort is increasing, with a continuous influx of new talent and expertise. It would be highly desirable, not least from a naval financial aspect, that the work was directly related to naval procurement needs, sponsored both collaboratively and contractually by MOD departments.

APPENDIX I—SELECTED STAFF PUBLICATIONS

1982 RATCLIFFE, C.P.: Dynamic structural modelling and time domain analysis; Internal report in conjunction with Institute of Sound and Vibration (ISVR) Southampton University. RNEC-TR-82014 (October).

1984 RATCLIFFE, C.P.: The measurement of spatial properties of a structure using modal analysis techniques; *Mechanique Materiaux Electricité*, No. 404 (March-April).

1985 DOBSON, B.J., DUBOWSKI, D.G.: Computation of excitation forces using structural response data; *56th Shock and Vibration Symposium. Monterey, California. October*

1986 DOBSON, B.J.: Modal parameter estimation using difference equations; *IMAC Los Angeles, California. February.*

1986 DOBSON, B.J.: A straight line technique for extracting modal properties from frequency response data; *Mechanical Systems and Signal Processing*, vol. 1, no. 1.

1986 LONGBOTTOM, C., RIDER E., DAY, M.J.: An on-line self-tuning vibration absorber; *2nd International Conference on On-Line Surveillance and Monitoring. Venice, May 12-14.*

1987 RIDER, E., DAY, M.J.: The use of pneumatic springs in vibration control; Seminar delivered to ISVR Southampton University, November. RNEC-RR-002.

1987 RIDER, E., DAY, M.J., LONGBOTTOM, C.: Vibration control—a new look; *Journal of Naval Engineering*, vol. 30, no. 3, December.

1987 RANDALL, R.J.: Problems of modelling shell type structures for fluid/structure interaction; *Finite Element South West Research Seminar, Plymouth Polytechnic, December.*

in press RIDER, E., DOBSON, B.J.: The calculation of excitation forces from measured structural response data; *Proc. Institution of Mechanical Engineers.*

APPENDIX II—AMEC RESEARCH PROJECTS IN STRUCTURAL DYNAMICS

	Project Title	*Supervisor*
1977	1. The Assessment of Wear in Plain Journal Bearings by examination of Shaft Signature Student: LT. M. J. DUCKWORTH, R.N. Allied topic: *HEALTH MONITORING*	LT-CDR. E. RIDER
	2. Synthesis of Mode Shapes of Vibrating Beams Student: LT. F. MUNGO, R.N. Allied topic: *SYNTHESIS/SENSITIVITY*	LT-CDR. E. RIDER
	3. The Use of Impedance Testing to Evaluate Mounting System Effectiveness Student: LT. P. MITCHELL, R.N. Allied topic: *MODAL ANALYSIS*	LT-CDR. M. K. NORTH
1978	4. An Algorithm for the Synthesis of Active Modal Vibration Controllers by Complete Eigenstructure Assignment Student: LT. A. COOPER, R.N. Allied topic: *SYNTHESIS/ACTIVE CONTROL*	LT-CDR. E. RIDER
	5. An Investigation of Transient Modal Analysis Testing of Engineering Structures Student: LT. R. C. PELLY, R.N. Allied topic: *TRANSIENT MODAL ANALYSIS*	LT-CDR. E. RIDER
1979	6. A Criterion of Vibration Isolator Effectiveness Student. LT. C. R. ENGLISH, R.N. Allied topic: *Passive vibration control*	LT-CDR. M. K. NORTH

1980 7. Modal Vibration Control of a Submarine Raft by Eigenstructure Assignment
Student: Lt. T. C. Chittenden, R.N. — Lt-Cdr. E. Rider
Allied topic: *Active control*

8. The Modal Testing of Engineering Structures by Impact Transient Testing
Student: Lt. P. S. Gleave, R.N. — Lt-Cdr. E. Rider
Allied topic: *Transient modal analysis*

1981 9. The Building Block Approach to Structural Dynamics
Student: Lt. P. H. V. Kettle, R.N. — Lt-Cdr. E. Rider
Allied topic: *Modal analysis*

1982 10. Active Vibration Control of Machinery Support Systems
Student: Lt. M. Q. Janjua, P.N. — Lt-Cdr. E. Rider
Allied topic: *Active control*

11. An Investigation of the Vibration Characteristics of the Primary Wheel of a Y205 Gearbox
Student: Lt. F. C. E. Sherlock, R.N. — Lt-Cdr. C. P. Ratcliffe
Allied topic: *Transient testing*

12. Active Synthesis of the Stiffness of Flexible Bearings in the Control of Rotor Critical Speeds
Student: Mr J. L. Kirkwood, YARD Ltd. — Lt-Cdr. E. Rider
Allied topic: *Synthesis/active control*

1983 13. Shock Response of a Cantilever Beam using the Newmark-Beta Method
Student: Lt. R. A. Wall, C.F. — Lt-Cdr. B. J. Dobson
Allied topic: *Modal analysis*

1984 14. An Experimental and Numerical Investigation into the Base Excitation of a Structure
Student: Lt. T. M. Gaught, R.N. — Lt-Cdr. B. J. Dobson
Allied topic: *Modal analysis*

1985 15. Force Predictions for Measured Response Data
Student: Lt-Cdr. D. G. Dubowski, C.F. — Lt-Cdr. B. J. Dobson, Lt-Cdr. C. P. Ratcliffe
Allied topics: *Force prediction/modal analysis*

1986 16. Automatically Tunable Vibration Absorber[1,5]
Student: Lt. C. Longbottom, R.N. — Lt-Cdr. E. Rider
Allied topic: *Active control*

	17. Force Prediction in a Torsional System from Limited/Remote Response Data[2] Student: LT-CDR. C. F. HALLET, C.F. Allied topics: *FORCE PREDICTION/ SENSITIVITY/ MODAL ANALYSIS*	LT-CDR. E. RIDER
1987	18. An Assessment of Modal Analysis Techniques for Force Prediction in Open Coupled Systems[3] Student: LT. S. J. LLOYD, R.N. Allied topics: *FORCE PREDICTION/ SENSITIVITY/ MODAL ANALYSIS*	LT-CDR. E. RIDER
1988	19. Pressure Loading Effects on the Dynamic Behaviour of a Cylinder[4] Student: LT-CDR. P. OKPE, NG.N. Allied topic: *FLUID/STRUCTURE INTERACTION*	LT. R. J. RANDALL

References

1. *Journal of Naval Engineering*, vol. 30, no.2, June 1987, p. 426.
2. *Journal of Naval Engineering*, vol. 30, no.2, June 1987, p. 427.
3. *Journal of Naval Engineering*, vol. 30, no.3, Dec. 1987, p. 653.
4. *Journal of Naval Engineering*, vol. 31, no.2, Dec. 1988, p. 489.
5. Rider, E., Day, M.J., and Longbottom, C.J.: Vibration control—a new look; *Journal of Naval Engineering*, vol. 30, no.3, Dec. 1987, pp. 610–617.