PROPULSION MACHINERY CONTROL SYSTEMS IN SURFACE WARSHIPS

PART II

SETTING TO WORK AND OPERATING EXPERIENCE

BY

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Introduction

This is the second in the series of three articles being published on propulsion machinery control systems in surface warships. The first article described the state of the art to date with particular emphasis on the Type 42 destroyer as the lead example; this second article covers the setting to work procedures for the current analogue systems previously described and also gives a feel for the operators' experience of them during the eight years service seen so far. The author is the officer in charge of The Machinery Controls Trials Team (MCTT) which is the specialist unit responsible for monitoring the installation and setting to work of the control systems during build and after refit, and for advising the Machinery Trials Unit (MTU) as to the acceptability of the COGOG/COGAG control systems trials results during basin and sea trials of new-construction ships. This article includes a brief description of the role of the MCTT.

In-service control system problems are usually handled by the C.-in-C. Fleet COGOG team but MCTT are available for further consultation if needed, and also for the implementation of major control system modifications required as a result of other plant changes, i.e. fitting of the uprated Tyne RM1C gas turbine in lieu of the Tyne RM1A engine.

Deep technical discussion and copious extracts of data are deliberately avoided throughout this article thereby hopefully avoiding at least some of the 'black box magic' aura which surrounds the subject of propulsion controls for many people.

The Setting to Work Process

The Machinery Controls Trials Team

The Machinery Controls Trials Team (MCTT) is the 'field' team of DG Ships Section D152 (Machinery Controls and Surveillance) and is staffed by R.N. personnel in a fifty/fifty mix of ME and ME(L) sub-specializations. It was formed initially to monitor trials on the pneumatic control system of the AMEE Haslar Y100 boiler but with the evolution of electronic controls in COGOG ships the involvement with pneumatics was gradually transferred to the Royal Dockyards and Fleet Maintenance Groups. MCTT's primary concern now is the determination of the first-of-class propulsion control system performance parameters and settings as defined in the build specification, proposing modifications where necessary to achieve acceptable machinery operation; this is then followed by monitoring the class follow-on builds in accordance with current *Naval Engineering Standards* requirements, including modification packages that are embodied. The team also carries out the control system Harbour Acceptance Trial (HAT) in COGOG ships after refit. In these roles, the MCTT spends some sixty per cent. of its time on-site in shipyards or royal dockyards, albeit with no direct authority for acceptance or trial conduct. The MCTT role is a supporting one but with a firm mandate to witness control system trials (as laid down in *General Marine Engineering Specifications*) advising the Principal Naval Overseers in the shipyards during the system installations and at each stage of setting to work, and then to the MTU (DG Ships, PD213) during basin trials and sea trials.

The team enjoys a close and somewhat unique liaison with the shipbuilders and the numerous sub-contractors that are connected with the main propulsion package and its control. This provides a rapid feedback network to the parent D152 section and other DSDE sections whenever a build programme may be threatened by the need for a design modification or advice on a performance specification. The details of the control system acceptance procedures are amplified in this article.

Organization and Test Forms

Until the build programme for Type 42 destroyers and Type 21 frigates was initiated, surface war ships were built and set to work without standard class test forms for trials procedures and standards to be achieved. Ships coming out of dockyard refit were similarly set to work using a plan devised by the MEO in conjunction with the dockyard planning office and trade centres. Without standard documentation for setting to work (STW) new-build or refitted ships, it was not surprising that the serials for marine engineering commissioning were at times muddled and rarely recorded properly, let alone updated for subsequent refits. All new-build COGOG/COGAG ships have their auxiliary and main propulsion machinery set to work by the shipbuilder's dockside test organization (DTO); this practice evolved from the Vickers nuclear submarine build experience. The DTO is a team of specialist test engineers who are separate from any production side of shipbuilding; their structure, acceptance procedures, and documentation are laid down by the MOD in *Naval Engineering Standards.* The documentation used consists of a volume of test forms drawn up for first of class by the lead shipyard in conjunction with the DG Ships project group. The test forms are a comprehensive guide to the logical step-by-step testing of a complete or sub-system; the simplest test forms describe, say, the test for a stop/start panel on the auxiliary machinery section of the console, while a more complex one tests the procedure, for example, for a gas-turbine remote-start sequence.

Royal Dockyards—Propulsion Test Groups

Three Type 21s and three Type 42s have now been refitted in the dockyards of Devonport and Portsmouth using a setting-to-work organization similar to the shipbuilders DTO.

Test forms based on those of the lead-build shipyard are indexed to suit the nature of the refit and often re-designed to suit the A. and A. or modification package, a typical example being the uprating of the primary gearing and the control system changes for the Tyne RM1C gas-turbine fit.

The preface sheet of each test form has to be signed off by the MEO, the Dockyard Test Group member, and the local CSO(E) representative and from thereon deviation from the agreed test form procedure can only be approved by all three signatories.

All aspects of the test form, namely the prerequisites, procedures, machinery limitations, and standards to be achieved are therefore discussed well before the STW programme commences.

For example, the test form to achieve the remote start of a gas turbine will have been vetted some weeks before the test day to check on the prerequisites: in this case the availability of the engine, power supplies, the console and surveillance system, fuel and HP air, lubricating oil system, for the power turbine and gearbox, and compartment security. The conduct of the trial must always be agreed between the ship's staff (who have charge of the machinery throughout the refit) and test group personnel, especially if sub-contractors are involved and there is to be joint operation of machinery and systems. Standards achieved are judged by comparing the performance to the Class standard, but often a modification incorporated during refit for the first time in the Class does not have complete documentation on its expected or desired behaviour. MCTT will then decide on the acceptability of the results on site for final ratification with their parent design Section D152 in due course. Technical queries raised during setting to work are handled by the local CSO(E) or by DG Ships; most of the queries are similar to those raised by the shipbuilders or naval overseers and are promptly handled by ship sections at Foxhill. Machinery control system 'field problems' are passed to MCTT at AMTE Haslar from the parent specialist section D152 at Foxhill.

The preliminary stages of COGOG plant setting to work are not completely without pain despite the formal acceptance procedure and clear definition of standards that are to be achieved. Dummy runs at certain test forms are inevitably carried out, if only to show up the lack of prerequisite conditions; in the dockyards as in shipyards, it is sometimes difficult to clear production trades away from a compartment under test or prevent the integrity of previously tested systems being invalidated by disturbance or removal in wake of some late fitting out work.

The overall setting-to-work documentation for main propulsion machinery in COGOG ships is the most comprehensive available for surface ships; it enables a realistic and easy-read programme to be planned, and in general provides the dockyard line management with clear milestone targets.

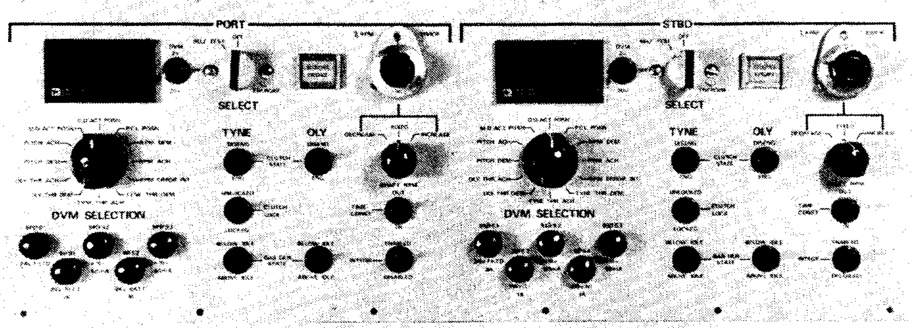

FIG. 1—MAIN MACHINERY CONTROL CONSOLE MOUNTED BITS PANEL

Type 21/42 Ships

The initial setting to work of the propulsion control system in all COGOG ships requires the SCC/MCR console to be powered-up and linked with the numerous sensors, transmitters, and feed-back loops on the engines, gearbox, and CPP system.

The build-in test system (BITS), dynamic data retrieval (DDR) system, and some commercial test equipment enable setting to work and trials to be achieved to the test form programme and trials procedures for new-build ships. Procedures laid down in BR 6605 (401) *Main Propulsion Installation Control and Surveillance Systems Setting to Work for the T42/21* and BR 6605 (402) *Main Propulsion Installation Tests and Trials for the T42/21* are used thereafter with the BITS, DDR, and some items of common range electrical test equipment (CRETE). BITS and DDR are shown in FIGS. 1 and 2.

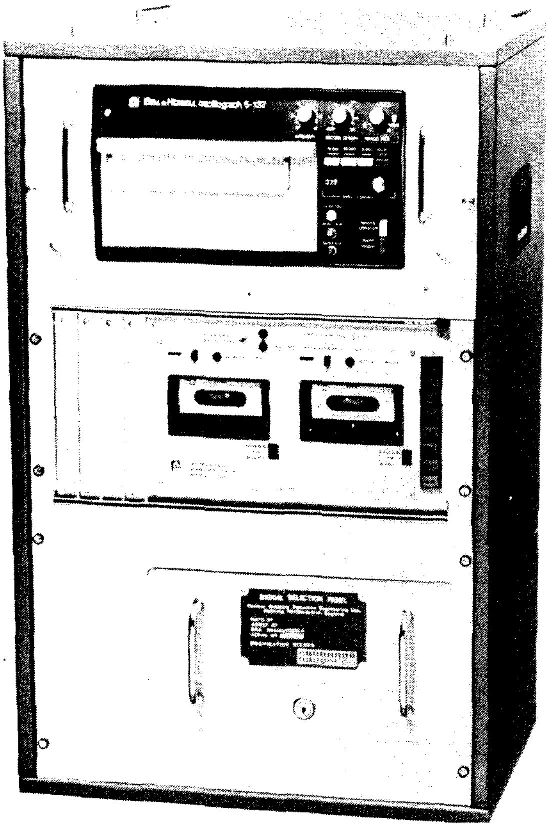

FIG. 2—DDR SYSTEM FOR TYPE 21 AND 42 SHIPS

An aid to fault-finding during setting to work and in service is the functionally identified diagnostic aid (FIDA) panel of test points in the back of the console which is used with the FIDA document to identify faults down to module/mini-module level.

All this test equipment and documentation also allows ships in service to identify any control system problems independently of specialist teams, and to monitor their system's performance when carrying out manoeuvres during regular mandatory system performance trials. BR 6605 (402) was largely derived from the original first-of-class trials procedures but was written for ship's staff use. It is a clearly written BR which describes the two phases of harbour acceptance trails, i.e. shafts stationary, shafts turning, and details the procedures and standards required for sea acceptance trials (SAT).

The results of contractor's sea trials and subsequent SATs are always recorded on the multi-channel DDR system U/V recorders using designated channel allocations and scales. Analysis of the traces obtained enables results to be compared with the class peformance traces shown in BRs and the classified book reference *Main Propulsion Installation Performance T42/21,* and with the ship's CST/final machinery trials reports which are held onboard for reference purposes. A typical ahead-to-astern manoeuvre U/V trace is shown in FIG. 3. The C.-in-C. Fleet COGOG team or MCTT will always ask for the appropriate DDR trace, or a repeat serial to obtain a trace for analysis before recommending any control or CPP system adjustment.

CPP System Commissioning

The pitch and power sub-systems are set to work individually. First of all the pitch is cycled ahead and astern using the motor-driven CPP swash

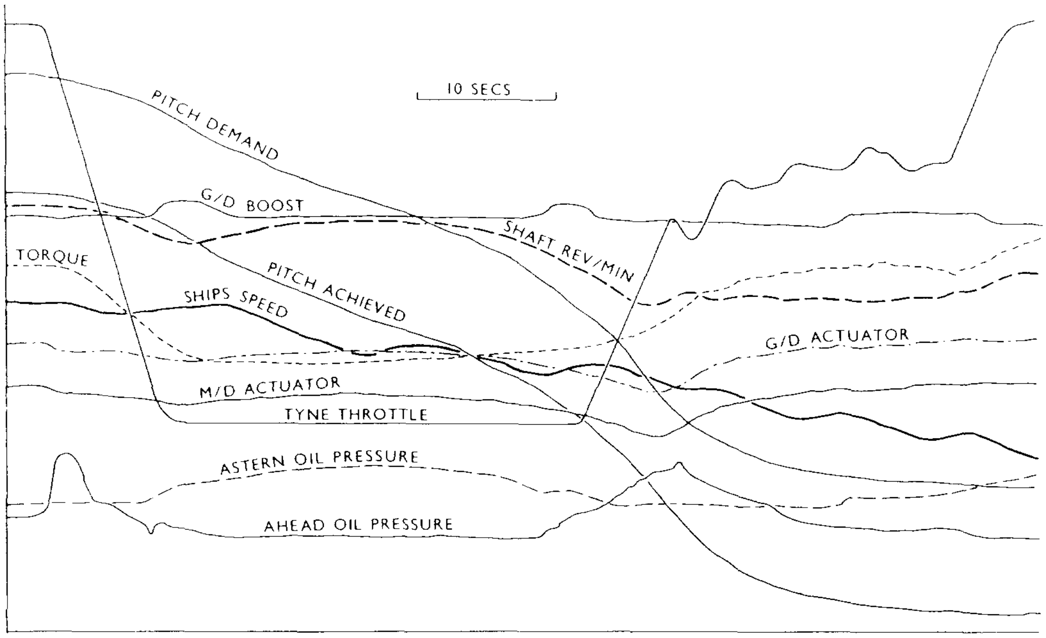

FIG. 3—TYNE ENGINE FULL AHEAD TO FULL ASTERN MANOEUVRE

pumps. This dynamic serial (albeit with shafts stationary) requires the hydraulic operation of the CPP system to be correct and hand control of the motor-driven swash pumps to be available. Before the pitch can be cycled by PCL (a closed-loop operation) propeller-hub calibration must be complete, since positional feedback of the blades' pitch achieved position closes the loop. Recently-revised procedures now calibrate the blades' angle to the axial movement of the hub servo piston by bumping between ahead and astern 'stops'. This revised method saves the need for any laborious calibration serial involving a team in the dock bottom (or divers), the after engine-room, and the MCR; the operation is now completely inboard and well within the ability of ships' staff to check after defect rectification, before periodic performance trials, or whenever the ahead pitch achieved readout is in doubt.

The initital commissioning and setting to work of the CPP system in refitting and DED ships is a ship's staff responsibility; it is analogous to the opening out of a boiler to a steam range and will therefore depend upon careful planning and a thorough knowledge of the system for its success. The dockyard Propulsion Test Groups do not commission systems.

In COGOG ships some very high-quality actuation gear is interfaced to traditional valve spindles and levers; unfortunately part of the interface was often a mild-steel pin in a mild-steel, ever-enlarging oval hole, or a taper pin in a parallel hole. The quality of the electro-mechanical interfacing in the CPP system has been the commonly accepted weakness in all COGOG ships, in particular between the actuator drive and swash-pump servo head; hopefully this will improve from now on following a recent modification. There have been countless hours lost needlessly looking inside high-quality actuator units with the consequent disturbance of factory-set positional sensors. Degraded CPP system performance, for example in the response of the hub to the pitch demanded and its stability under varying loads, can be attributed to the following causes:

(*a*) Malfunction of the CPP hydraulic circuit due to a defective or dirty composite valve unit (CVU) or incorrectly set relief and dump valves.

(*b*) Mismatch between the 'hydraulic neutral' of the variable swash pumps and the 'electrical neutral' of the pump actuators.

(*c*) Inconsistent feedback signals from the OT box pick-off units.

The problems in (*a*) are not always solved in a few minutes since the instrumentation does not always indicate a sluggish valve operation or a lightly-set relief valve; analysis of DDR traces is needed. As some valve settings are masked by others, it is best to start again from first principles and declare a 'hands off' policy towards the control system and its calibrations. The system flushing procedures vary from shipyard to shipyard, and some parts of the system can accept debris permanently 'in transit' during the pitch reversal operations whilst other parts demand a high CHA(RN) cleanliness standard for successful operation. (*b*) and (*c*) are identified during the STW HAT programme using the DDR to monitor pitch demanded, pitch achieved, actuator stroke, ahead line pressure, and astern line pressure.

Phase Six Testing

With the CPP system working correctly and the engine-throttle control loops set to work, the complete control system is presented for static and dynamic checks as 'phase six' of the setting-to-work procedure; this phase is best described as the HAT of the bridge controls, SCC/MCR control console, and the M/D CPP pumps and engine throttle actuators. MCTT witness and report on the trial on behalf of the Principal Naval Overseer (PNO) or CSO(E) staff as appropriate. The phase-six test checks the correct functioning and calibration of every feature of the system and takes about three days to complete. The outcome of a successful phase-six trial is that the propulsion control system is 'passed' for use during the Official Basin Trials.

The Type 22 Frigate

The main propulsion plant and control system in the Type 22 is essentially the same as that in the Type 42/21, with the exception of the built-in test facilities; there are therefore some differences in the setting-to-work procedures. An improvement in the options for overall control of the machinery is the provision of console-mounted servo-manual overrides on pitch control and engine throttles.

BITS in the T42/21 console is replaced in the Type 22 by an arrangement of built-in test equipment (BITE) and pre-start integrity check (PSIC); this change supported a revised concept of console fault diagnosis, a subject that is still constantly in debate among console maintainers and setting-to-work teams.

The PSIC enables a simple pre-sail check to be made on pitch and throttle actuators following PCL, as does BITS in the Type 42/21. PSIC, however, does not have the depth of simulation required for test-group setting to work. The BITE/PSIC panel is shown in FIG. 4.

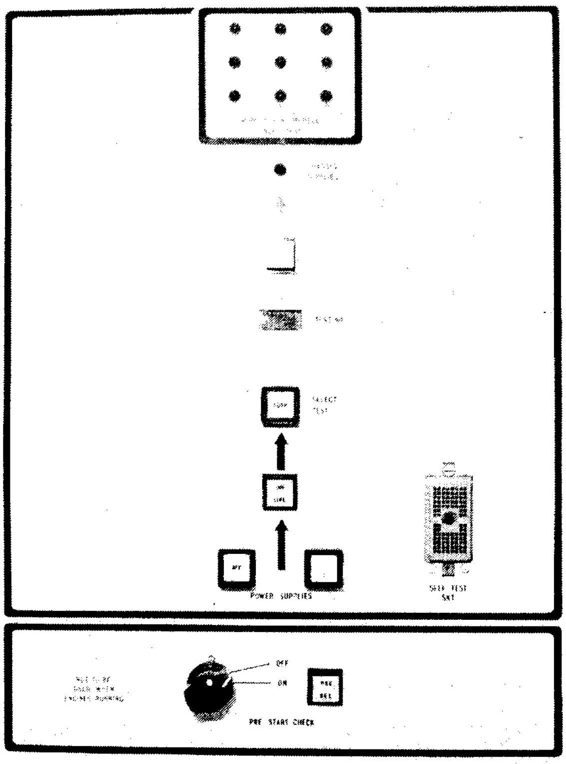

FIG. 4—BITE/PSIC PANEL IN A TYPE 22 FRIGATE

BITE is the off-line test facility that applies some thirty programmed functional tests to key control modules and is normally operated by the console maintainer before the preparation of main machinery for trial or sea. Interpretation of an indicated failure is not 'black or white' however: a test that has failed may immediately point the console maintainer to the faulty module, but the test may have failed because of incorrect test parameters applied to the module under test. The scope and shortfalls of BITE are still under review but with module failures comparatively rare in all COGOG/COGAG ships, test cases for analysis are in short supply to DG Ships. In addition to the BITE itself, a BITE expander box is used for on-line monitoring at points within the control chassis during setting to work and for fault diagnosis. The Type 22 FIDA shows the test points and expected results.

The principles involved in setting to work the Type 22 are the same as those for the T21/42 but, as the test hardware is different, there are considerable differences in practice. Shipyards and sub-contractors use their own test equipment consisting of logic-switching boxes and oscillator units as well as the BITE expander box; the test forms are written to suit.

As yet dockyard test groups and ships' staff do not have setting-to-work BRs and are therefore also using shipbuilder's test forms. Other hardware needed is obtained from CRETE and specially procured manufacturer's test equipment. A full setting-to-work programme of a Type 22 system after refit has yet to be undertaken.

The Carrier (CVS)

The propulsion control system of the COGAG arrangement in the CVS where there is no CPP or engine 'mix' is less complex than that of the COGOG plant but uses more logic circuits. The shafts are driven through large reversing gearboxes which have fluid couplings for manoeuvring drive and SSS clutches for high-speed drive. The setting to work of the complete propulsion package of gas turbines, gearboxes, and surveillance equipment is a long but well-documented evolution using class test forms. During build, the SCC console is set to work by the sub-contractor using a special test box and the BITE expander boxes. The relative BRs containing setting-to-work procedures are still in draft form but when available to the fleet will detail setting-to-work/system checking to be carried out by ship's staff using simulation and BITE expander boxes. The special test box will be held by the dockyard propulsion test group.

The propulsion control console and gearboxes have numerous electro-mechanical interfaces with inherent problems due to the design arrangements of the many microswitches, levers, and plungers used to operate electrical and hydraulic circuits. This 'switching' concept provides the logic input to the console for permitting or inhibiting drive mode change or engine selection. The fail-safe features of the control system are based on probable combinations of incorrect logic due to a mechanical line-up failure, or loss of logic input through faulty electro/mechanical/hydraulic interfacing. However, the system is not foolproof and a loss of propulsion due to control system failure is possible.

A secondary control position for each shaft is the gearbox local control console (GLCC) situated in each gearing room. This control position allows engine and drive mode selection with a mimic flow of clutches and fluid couplings identical to the SCC.

A very sophisticated PSIC system enables the movement of the power demand lever (PDL) to line up the gearbox servo hydraulics and clutches for the drive mode selected on the console. The gearboxes can be cycled through the various combinations of engine selection and drive mode selection for varying amounts of power demand with the console mimic flow following the movements of the SSS clutches and fluid couplings. The throttle opening and closing rates can be recorded on the DDR.

PSIC provides an excellent training facility when used in conjunction with the DDR monitoring facilities and DVM readout, provided the gearbox is available in an operational state. In harbour, ship's staff can conduct their own basin trials and mark up the DDR traces for comparison with setting-to-work records without actually running the engines.

The CVS BITE fit is designed and installed on the same principle as that in the Type 22 frigate, BITE expander boxes being used to 'look' into each chassis for setting to work and fault diagnosis. The programme of BITE is again dependent on the propulsion system modification state and will need re-programming when certain parameters or limits are changed, i.e. fuel schedule or power limits.

Basin Trials

During the official basin trials in a COGOG ship the power/pitch control of both shafts is checked using both sets of engines; this is followed by witnessing the engine changeover operation which is the only true test of SSS clutch operation and engine throttles constraints. The exact procedures to be followed are again detailed in the shipbuilder's dockyard trials procedures and in the BRs already mentioned. Control system performance throughout is monitored by MCTT using DDR primarily as the means of analysing results.

The CPP systems as a whole come under close scrutiny as the gear-driven (G/D) CPP pumps are for the first time running in parallel with the M/D units; pitch stability is only obtained when the 'hydraulic neutral' both of M/D and G/D pumps is correctly set—a state achieved by monitoring pitch demanded and achieved, ahead and astern line pressures, and pump swash angles, followed by adjustment where necessary whilst shafts are turning.

Included in the basin trial serials is the setting of the zero thrust position at zero PCL; this is achieved by adjusting a control system potentiometer which increases pitch to between one and two degrees ahead in most ships. The zero thrust position is assumed correct when there is no visible propeller wash in either the ahead or astern direction—the mark one eyeball test!

The procedures for basin trials in the CVS ships follow the same format with tests of drive modes and engine changeovers, etc. again being fully analysed from DDR traces.

Sea Trials

For contractor's sea trials (CSTs) of new construction ships the acceptance authority is the Machinery Trials Unit with the MCTT in support for monitoring the control and surveillance systems performance. Trials to be carried out are detailed in yet another series of agreed procedures and comprehensive records are taken using the DDR system. During final machinery trials before the ship is accepted into service, a final set of U/V traces is recorded for inclusion in the final report that is compiled by MCTT, a copy of which is held by the ship as a datum reference document for the control system performance thereafter.

Post-refit COGOG ships carry out the SAT(ME) serials as laid down in BR 6605 (402), the acceptance authority being the local CSO(E) staff. MCTT are sometimes asked to witness preliminary manoeuvring trials if there has been difficulty in the setting-to-work phase with any control system modifications.

Reports

MCTT raise reports where necessary after each stage of setting to work and trials of the control systems; the reports are circulated both to design and post-design sections at Foxhill, and to the relevant naval overseer, shipbuilder, and sub-contractor. These reports highlight any specific defects, and also raise items needing further discussion within the Ministry for possible official modification action in the future.

If during the setting to work and trials programme a problem arises with the control system which needs resolving quickly in order to make a system work correctly without disrupting the ship programme, a temporary modification procedure exists which has to be jointly authorized by DG Ships (MCTT/D152 and the relevant PNO), and the controls sub-contractor.

Operating Experience

It is undoubtedly true to say that the current analogue systems work well and are very tolerant of being 'out of tune'. Since the inclusion of a 50-hour heat soak test during manufacture, module/mini-module reliability is high with failures averaging less than four per operational ship year. The situation with actuators has not been so impressive so far but matters are improving.

The CPP pump actuators have always suffered from water-tightness problems with the inevitable results—particularly on those pumps sited in the engine-room bilges. Sealed actuators used to have to be opened in order to connect the electrical supply cables and were then never watertight again; a wiring arrangement modification has since been made which overcomes the problem and the number of CPP pump actuator defects has fallen correspondingly.

A COGOG control system design shortcoming in allowing the engine throttle actuators to bear a demand signal in excess of 100 per cent. open has resulted at times in the actuator drive bouncing against the mechanical stops fitted and causing serious damage to the actuator gearing. A solution to this particular problem is still being sought.

Having said that the systems are very tolerant of being 'out of tune' is no reason for allowing them to remain so and therefore, in addition to the mandatory periodical system performance checks laid down by C.-in-C. Fleet, there are also now six-monthly planned maintenance routines to be carried out on the controls—hopefully with the result of even better system performance and reliability.

Opinions vary considerably about the quality of the support documentation and test equipment for system upkeep but the majority opinion is that it is very adequate for a skilled properly-trained maintainer. The problem of actually realizing that the system is degraded in some way can be a real one in itself, and this is an area where MEOs/maintainers have lacked guidance in the past; a revised and much improved version of the classified datum performance document which is now in course of publication will provide a better basis for performance analysis and defect identification. As more operational experience of the control systems has been accumulated, the quality of training of maintainers has improved with obvious results in the fleet, but standards in the use of test equipment is one area in which there is currently still some concern.

The situation as regards spares was referred to in the previous article but bears repeating briefly as it is an essential part of the scene. Systems were designed to meet a repair-by-replacement philosophy down to module, mini-module, and actuator level. Unfortunately though, there have been problems in having the correct spare unit to the correct modification state readily available onboard for fitting, and this has led in some quarters to a call for onboard repair down to component level. The existing policy is being maintained however, and the spares situation is steadily improving as a number of anomalies associated with modifications (currently 30-odd in number in each of the T21/42, T22 and CVS systems) are sorted out; this is not to say though that ships never *do* repair at component level!

In Conclusion

The need to use disciplined setting-to-work procedures for the COGOG/ COGAG propulsion plant and their analogue control systems was recognized at the outset and they are now well established in all shipyards and royal dockyards. The use of these procedures with the console built-in test facilities, data retrieval systems, and supporting documentation, results in the timely and successful introduction into service of the propulsion controls.

The current generation analogue systems are proving successful in service and cause few real headaches for ships' MEOs and maintainers—surely the true accolade?