TROUBLE-SHOOTING IN PNEUMATIC COMBUSTION CONTROL SYSTEMS

BY

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The snag with trouble-shooting in control systems is that it is basically an art born mainly of experience, and experience is directly dependent on time and opportunity.

In small measure, however, it is possible to pass on some of the lessons learned from experience and this article is an attempt to do this. If it succeeds in preventing even a handful of M.E.O.s from having sleepless nights, its writing will have been worth while.

The experience drawn on is mainly first-hand resulting from setting-to-work and acceptance trials in *Tiger* Class cruisers, G.P. frigates and G.M. destroyers, and operation of the Y.102 prototype systems at the Admiralty Fuel Experimental Station. The second-hand experience has been gleaned from past and current members of the Machinery Controls Trials Team and ship and shore technical staffs.

THE ESSENTIAL REQUIREMENTS

Diagnosing and curing machinery system troubles is analogous to diagnosing and curing ill-health in children. The patients are fairly new and are designed to a rigorous specification, although congenital disorders can exist. Performance falls within certain limits or tolerances but allowances have to be made for varying environmental conditions. The child cannot help verbally with the diagnosis, neither can the machinery system, but if feeling poorly each will exhibit symptoms which are seen as departures from the original performance specification.

Before a doctor starts practising his profession he must acquire a thorough knowledge of the various systems and components which comprise the human body. He then must learn what constitutes good health (optimum performance) in order that he can recognize ill health. Having done this he must diagnose the exact trouble using recognized techniques and instrumentation, and then, and only then, can he carry out treatment to effect a cure. If the cause of ill health cannot be firmly established in spite of exhaustive tests, it is normal to call upon a second opinion or the services of a consultant.

There are of course weakness and divergencies in the control engineer/doctor analogy. A dead control system can often be resuscitated whereas a dead body cannot. Repair by replacement is easily and commonly done in control systems but it is in its infancy in the medical world. Control systems and instruments can be supplied in a myriad of basic designs, humans in only two. However, on the main points the analogy is considered good. In

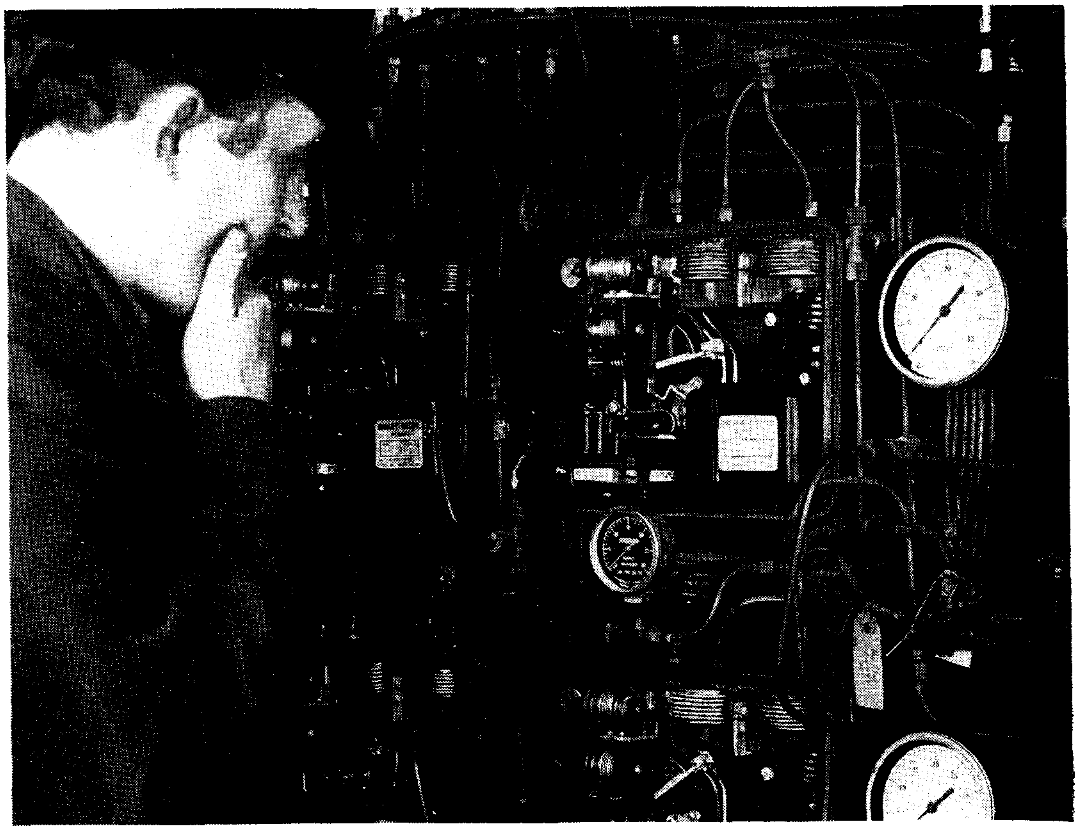

FIG. 1—'THE PATIENTS ARE FAIRLY NEW'

order these are:

(*i*) Knowledge of the system being *controlled*
(*ii*) Knowledge of the *control* system
(*iii*) Knowledge of optimum performance achievable under various conditions
(*iv*) Recognition of poor performance by eye, ear or instruments
(*v*) Diagnosis of exact trouble, using special instruments if necessary. (Specialists to be called in if diagnosis is found to be impossible)
(*vi*) Treatment to effect the cure: involving repair/replacement of *controlled* system components, or recalibration/repair/replacement of *control* system components
(*vii*) Performance check(s) under varying conditions to establish the efficacy of the cure and whether there are any side effects.

Knowledge of System Being Controlled

It is a fact gained from bitter experience that the majority of machinery faults which are initially attributed to control instruments are finally found to be due to defects elsewhere. It is therefore essential to be completely familiar with the construction, layout and operation of the system being controlled. Some of these systems may be very simple (e.g. the F.F.O. heating system), and some complex (e.g. the fuel spill system), but complete familiarity with every part of them is essential.

Knowledge of the Control System

Once the *controlled* system is understood the *control* system must be tackled.

This comprises the valves, linkages, operators, positioners, controllers, control stations, transmitters, gauges and indicators as well as the inter-connecting pipework and sensing arrangements. In addition to their arrangement in the system, their individual mechanisms must be thoroughly understood. It is also helpful to have knowledge of the design philosophy.

Knowledge of Optimum Performance

This article pre-supposes that all the systems have been optimized with regard to efficiency, stability and response during the builder's sea trials and that the ship has been given a full set of performance readings, and instrument settings and calibrations. Until ships are equipped with continuous pen recorders it is not easy to supply meaningful records of response and stability, but the ships' E.O.s can bear witness to performance achieved during sea trials. Unfortunately, time and turn-overs often distort these subjective recollections and too often one hears comments like, 'Oh! that has always been on the blink', or, 'That blower has always been unstable', which are untrue. The knowledge of optimum performance therefore comprises two main parts: the written records in handbooks, reports and registers, and the recollections of previous trials and operation. In small part it is possible to add to this knowledge from experience gained in ships of other classes but knowledge based on such experience should be used with caution. It is not always directly applicable.

Recognition of Poor Performance

The ease with which poor performance is recognizable is proportional both to the divergence of the performance from the optimum and to the impact of the poor performance on the senses. Thus black smoke, cold bath water and burnt toast are easily recognized as markedly poor performance. With automatic control systems poor performance is not always so readily recognizable and so the following must be continually observed as a matter of normal watchkeeping and dealt with directly they deviate from the optimum: stability, response and accuracy. The longer that poor performance is suffered the worse it becomes and the more difficult it is to rectify.

Diagnosis of Exact Trouble

This is where experience really starts to count, but nevertheless a few golden rules can be laid down:

(*i*) Examine the symptoms for yourself. There is of course value in making the medical approach, 'What seems to be the matter?', but it is essential to carry out your own examination if a confident diagnosis is to be made.

(*ii*) Troubles which manifest themselves in one system can have their root cause in another system, which may only be remotely inter-related, e.g., combustion control instability can originate from unstable deaerator level control.

(*iii*) If the system cannot be operated in hand control it will never operate in automatic control.

(*iv*) Keep your test equipment in a safe place and handle it carefully. The accuracy of a control system cannot be greater than that of the instrumentation used to check it and calibrate it.

(*v*) If the control system is giving no trouble, leave it alone. Do not take it apart just to see why it is working so well. (Routine maintenance, such as the greasing of associated rod gearing, is of course necessary.)

(*vi*) If the trouble cannot be diagnosed, do not in desperation make random adjustments in the pious hope that the situation will magically right itself. It will not.

In addition to these rules, trouble-shooting schedules are of great value. Typical ones which detail some of the more common faults in combustion control systems are shown later.

The special instrumentation normally supplied to ships to assist diagnosis (Ref. 1) consists of:

(*a*) A pneumatic calibrator for supplying and accurately measuring inputs and signals over the range 0–30 lb/sq in.

(*b*) A dead-weight tester, for accurately supplying input signals over the ranges 100–1,000 lb/sq in. and 0–100 lb/sq in. in steps of 10 and 1 lb/sq in. respectively.

(*c*) A test set for checking the operation of Telektron motors.

(*d*) Various pressure regulating valves for simulating L.P. signals.

(*e*) Assorted hoses and tubing for connecting test equipment into the systems.

With only a little ingenuity however, some of these can be easily supplemented by ships' staffs if the need arises. L.P. air supplies and even the lungs of an enthusiastic trumpet player (up to 30 inches W.G!) will provide low pressure inputs and signals. These can be measured on accurate test gauges or, for the lower pressures, on a water manometer which can be simply manufactured from a piece of wooden board and some plastic tube. L.P. and H.P. air supplies will cover the dead-weight tester range but must of course be used in conjunction with accurate test gauges.

If eventually it is found impossible to diagnose the exact trouble, a very small band of people does exist who can help (Ref. 2). If its members are called in, however, it is important to ensure that the symptoms can be demonstrated. It is of little value wasting their time and yours by summoning them to a ship which, for instance, is going to be shut down for three weeks or is engaged on other trials which preclude going up to the power where the trouble occurs. This is akin to calling the specialist and then not allowing him to see the patient.

Treatment

Particular treatment for some particular troubles are shown in the trouble-shooting schedules. The general principles are however just good common sense:

(*i*) Avoid cannibalization of other systems/instruments.

(*ii*) If possible make the following checks on spare gear some time before it is required to fit:

(*a*) *Pressure and flow transmitters*—Type No., range and zero. Settings of any limit stops.

(*b*) *Controllers*—Balance and null point (Bailey Meter). Zero (A.E.I.). Input/output relationship in proportional only control, over the whole range of P.B. settings.

These checks in most cases will prove to be a formality, but occasionally they will enable an incorrectly calibrated or a damaged spare instrument to be put right before it is required urgently to fit.

(*iii*) Although repair-by-replacement of instruments is recommended if time is short, even if the 'repair' entailed only amounts to re-calibration, it is important first to ensure that the instrument really is at fault. Often instruments are needlessly changed when the trouble lies in a leaking connection or a blocked sensing point.

Performance Checks

The only acid test after the repair/re-calibration of a control system component is a live one over the entire range of loads and rates of load change. It is possible however, to approach the final check in a methodical way which consists of:

(*i*) *'Dead' Checks*—Controlled systems dead but servo air available. Limited to checking calibration of instruments using test equipment, freedom of movement and length of stroke of control valves, clearness of sensing connections and absence of servo-air leaks.

(*ii*) *Limited Live Checks*—Some controlled systems live but operating range of plant limited. Enables sensing lines to be vented and checked for leaks, and combination of control and controlled systems to be partially checked. In some cases these limited live checks can very closely duplicate the whole range of steaming conditions. For example, a 'cold blow', with the blower and fuel pump both in servo-manual control and the fuel being re-circulated, using steam from another unit, can provide a close simulation of actual steaming over the whole power range.

(*iii*) *Live Checks*—All systems live. Whole power range of plant available. These divide into two main parts:

(*a*) Steady state—which are live calibration and stability checks carried out at steady powers

(*b*) Dynamic—which are response and stability checks to ensure that the systems are lively enough to meet the maximum rate of load change demanded of them.

Whether the whole sequence of performance checks is embarked upon or only the final ones will depend on the nature of the original fault and the action taken to cure it.

TROUBLE-SHOOTING SCHEDULES

Below are four typical schedules prepared by the author for the G.M. destroyer combustion control systems in an attempt to document experience. Such schedules always look more involved than they are in practice because, after a short time, a number of the checks are carried out almost without thinking and result in the control engineer taking a swift look around and then saying, 'The spill controller is probably out of balance', or, 'The pump is running on its governor'.

The preparation of such schedules is a good mental exercise and, particularly when a ship encounters and corrects unusual faults, it is considered well worth while for the ship's staff to prepare its own. This legislates against any changes of complement or dulling of memory with time, and also leads to a better understanding of the instruments and systems.

Symptom 'A'—Minimum Boiler Power Cannot Be Obtained Without Taking Off a Burner

Check (1)—That the designed minimum supply/spill relationship exists at at burner test gauges.

If it does

Check (2)—That F.F.O. temperature at manifold is correct (190 $\pm$ 10 degrees F.). If it is too low, more fuel than designed is burnt.

Check (3)—Atomizers if F.F.O. temperature is correct:

(*a*) Visually, particularly supply holes in feed plate and tangential holes in swirl plate. When spilling, if one of these holes is blocked, an increase of 20 per cent in fuel burnt can result. If two are blocked this rises to over 40 per cent.

(*b*) By calibration.

If it doesn't

Check (4)—That master signal after low load limiter falls to 3 lb/sq in. when signal before it is 3 lb/sq in. or less. Re-set low load limiting relay so that its output will fall to 3 lb/sq in.

Check (5)—That supply and spill pressure transmitter signals are 3 lb/sq in. when master signal is 3 lb/sq in. If both are 3 lb/sq in. one of the transmitters needs re-calibrating. Check calibration using burner gauges or dead-weight tester. If one is not 3 lb/sq in. trouble lies in its loop.

Check (6)—*Trouble in the supply loop.* Check controller output signal. If it is saturated confirm that fuel pump control valve is wide open. Check range and stop valves wide open, also that pump is not held on governor (make any alterations gently). If signal is not saturated balance actual and desired values on controller (if PB is greater than 80 per cent use CD beam adjustment; if PB is less than 80 per cent use AB beam adjustment).
Note: Strictly speaking the null point of the relay should be re-established. If, however, no alterations of PB are made subsequently this does not matter.

Check (7)—*Trouble in spill loop.* Check controller output signal. If it is saturated confirm that spill valve is wide open. Check fuel pump inter-stage pressure not too high (at low powers it should be approximately 20 lb/sq in.). Check fuel re-circulating valve shut. If signal is not saturated balance controller as in Check (6).

Symptom 'B'—Maximum Power Cannot Be Obtained on Clean Boiler

Check (1)—That designed maximum supply/spill relationship exists at burner test gauges.

If it does

Check (2)—Steam temperature.

Check (3)—Air/fuel ratio by noting R.D.L. Trim R.D.L. as necessary.

Check (4)—Atomizers for blockage.

If it doesn't

Check (5)—That master signal is 27 lb/sq in. If it is less check high load limiter setting.

Check (6)—That supply and spill pressure transmitter signals are 27 lb/sq in. when master signal is 27 lb/sq in. If both are 27 lb/sq in. one of the transmitters needs re-calibrating. Check calibration using burner gauges or dead-weight tester. If spill transmitter signal is not 27 lb/sq in. trouble lies in spill loop. If supply or both transmitter signals are not 27 lb/sq in. trouble lies in supply loop.

Check (7)—*Trouble in spill loop.* Check that signal to spill valve is saturated. If it is, check that spill valve is not leaking by shutting spill manifold burner valves and noting effect on boiler output. If not saturated, balance actual and desired values on controller (if PB is greater than 80 per cent use CD beam adjustment; if PB is less than 80 per cent use AB beam adjustment).

Check (8)—*Trouble in supply loop.* Check controller output signal. If it is saturated confirm that fuel pump control valve is wide open. Check range and stop valves wide open, also that pump is not held on governor (make any alterations gently). If these are correctly set check that service pump relief valve is not lifting. If signal is not saturated, balance controller as in Check (7).

Symptom 'C'—Over-Forcing of Boiler is Apparent

Check (1)—That F.F.O. temperature is correct (190 $\pm$10 degrees F.). If it is too low, over-fuelling can occur.

Check (2)—That designed maximum supply/spill relationship at burner test gauges is not exceeded.

If it is

Check (3)—(*a*) High spill pressure, but correct supply pressure can give over-fuelling (known as 'super-simplex' or 'augmenting'). Can only occur if re-circulating valve is open. Check that it is shut.

(*b*) High spill pressure and high supply pressure will give over-fuelling. Check high load limiter correctly set at 27 lb/sq in. If it is, trouble probably lies in both supply and spill loops. If supply and spill pressure transmitter signals are 27 lb/sq in., check transmitter calibrations. If they are greater than 27 lb/sq in., check balance of controllers.

If it is not

Check (4)—Atomizers:

(*a*) Visually. A turned reverse swirler in the feed plate can give up to 4 per cent increased output.

(*b*) By calibration.

Symptom 'D'—Combustion Control System Appears Unstable

Check (1)—That all burners are on. (System is tuned for all burners in use and gain of fuel system increases as burners are taken off). In reduced burner states,

Check (2)—that fuel recirculating valve is open sufficiently to give usual pump speed.

Check (3)—That fuel pump is not cavitating. This can be caused by too low an inter-stage pressure (less than 15 lb/sq in.) or too high a fuel temperature (greater than 200 degrees F.).

Check (4)—That fuel pump inter-stage pressure control valve is operating freely and that its bellows leak-off valve is shut.

Check (5)—That exhaust pressure control system is stable.

Check (6)—That various governors, controllers and regulators in the closed feed system are stable.

Check (7)—That steam temperature control is stable.

Check (8)—That blower is not surging due to:
(*a*) a reduced register state,
(*b*) an excessively dirty boiler.

Check (9)—That blower, fuel pump and spill control valves are operating correctly (i.e. no excessive stiction or backlash), and are being supplied with air at the correct pressure.

Check (10)—That the master, supply, spill and air-flow controller settings are correct and that there are no air leaks (test with soapy water).

CONCLUSIONS

It is hoped that this article will help the Engineering Departments of ships to get to grips more decisively with some of the snags which they may encounter in their machinery control systems. Although the D.M.E. specialist sections and civilian manufacturers constantly strive to supply trouble-free control equipment this is by no means an easy task, particularly when one considers the arduous duties imposed on this novel equipment and the accuracy demanded of it at sea. It is therefore a regrettable fact that troubles will be in season for some time to come, and until the day when all troubles have been eliminated the ability of operators and maintainers to trouble-shoot accurately is of paramount importance.

References:

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