THE TESTING OF MODERN NAVAL ORDNANCE

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Recent experience of developments in gunmounting design and production indicates that a new and more advanced approach to ordnance engineering problems will soon become a general requirement. This article attempts to make clear the reasons, and to point the way ahead to those not intimately acquainted with current trends.

The need for this new approach has sprung almost entirely from the enormous strides made in the aircraft industry since the Second World War. It requires little imagination to appreciate the implications of jet propulsion and supersonic flight in terms of the anti-aircraft defence of surface ships. From the time an attacking aircraft or guided missile comes within range of a ship's A.A. batteries to the time its attack is completed, there will only be a few seconds available for defensive fire, and it is of paramount importance that ships' weapons are capable of making the best possible use of those vital seconds. In addition, airframe structures are now more robust, and the ' lethal sphere ' of a bursting shell of any given calibre is consequently much smaller. These are the facts around which the present-day Staff requirements for A.A. weapons are formulated.

Hitherto, problems arising from the production, testing and maintenance of naval gunmountings have been satisfactorily solved by orthodox methods of mechanical measurement and visual observation. Just as the development of precision engineering outmoded the foot-rule, more advanced methods of scrutiny are now required to keep pace with recent developments in ordnance engineering. A brief examination of the new type of weapon will make clear the reasons for this change.

Firstly, fire will have to be accurate to a degree never before seriously contemplated in A.A. gunnery. On the assumption that the transmissions produced by the stabilization and prediction systems are substantially correct, the accuracy depends for the rest upon accurate following by the weapon itself, and therefore upon the performance of the R.P.C. equipment.

Secondly, shell will have to be delivered to the target area at as rapid a rate as possible to enable allowance to be made in the limited time available :—

(*a*) for those inevitable incidental errors whose combined effect we call ' spread ' and

(*b*) for any wander of the point of aim of the armament.

In brief, the higher the rate of fire, the denser the distribution of shell about the target, and hence the better chances of a ' kill.'

Thirdly, owing to the reduced size of the sphere of lethality of any given shell, it is necessary that the weapon should handle and fire as large a projectile as possible. This requirement is naturally at variance with the need for a high rate of fire but, by suitable compromise the best combination of projectile size and rate of fire must be obtained. However, observing that the calibre selected is likely to be fairly large, and that the weight of the round varies roughly as the cube of the gun-bore, it will probably be impossible to consider manual handling of the ammunition except in the initial stages of stowing and loading. Moreover, owing to the need for high performance in training, the weight (and hence inertia) of the revolving structure must be kept as low as possible. From this, it is evident that ready-use ammunition (of which there will necessarily be a considerable quantity) must be kept off the mounting and conveyed automatically the whole way from the fixed structure to the guns ; in this way, the only ammunition on the mounting will be such rounds as are actually in the ' pipeline.' Considerable complication is therefore unavoidable.

It is clear, therefore, that there is no alternative but to think in terms of medium calibre automatic guns fitted in mountings with high-performance R.P.C. and carrying an elaborate automatic ammunition supply mechanism. The operation and maintenance of such a weapon requires intimate and precise knowledge of all that is taking place at any stage and at any position in the system. Though the engineering principles involved in the operation of these new gunmountings may not be out of the ordinary, the various processes are often so rapid that it is impossible to know how everything is working without recourse to certain specialized methods of scrutiny. The fundamental series of operations which take place in the vicinity of the gun breech serves as an illustration. The events which take place are as follows :—

(*a*) A round is placed in the loading tray.
(*b*) The round is rammed.
(*c*) The breech closes.
(*d*) The gun fires and recoils.
(*e*) The rammer returns to its fully withdrawn position.
(*f*) The breech opens.
(*g*) The gun runs out.
(*h*) The spent cartridge is ejected and disposed of.
(*i*) The entire process is repeated.

Though they may not necessarily occur in the order given, these events are common to all gun weapons. To quote a current medium/low calibre automatic weapon as an example, the whole process from (*a*) to (*h*) takes place in almost exactly half a second, and it is plain that no human eye can keep track of the action as it is going on. Nevertheless, everything must happen precisely at the right moment and under the right conditions, and must be exactly synchronized with other operations which are taking place elsewhere. In the event of a misfire, or some other kind of stoppage, it is impossible to know unaided precisely what stage in the sequence of operations was reached when the stoppage occurred, and it would be even harder to establish the primary cause of failure. Even when there are no obvious indications of trouble, it is still necessary to be able to confirm that everything is functioning according to plan.

It can be seen that comprehensive instrumentation of the feed and loading systems is essential. In addition, it may be necessary to keep a record of conditions in the recoil cylinders and recuperator. Observing that rapid automatic firing is bound to be accompanied by a great deal of heat, water cooling for the guns is imperative, and we must have knowledge of the relevant temperatures. The following table gives examples of the various kinds of information which may be required, together with the types of instruments and recording gear which have become necessary to obtain them.

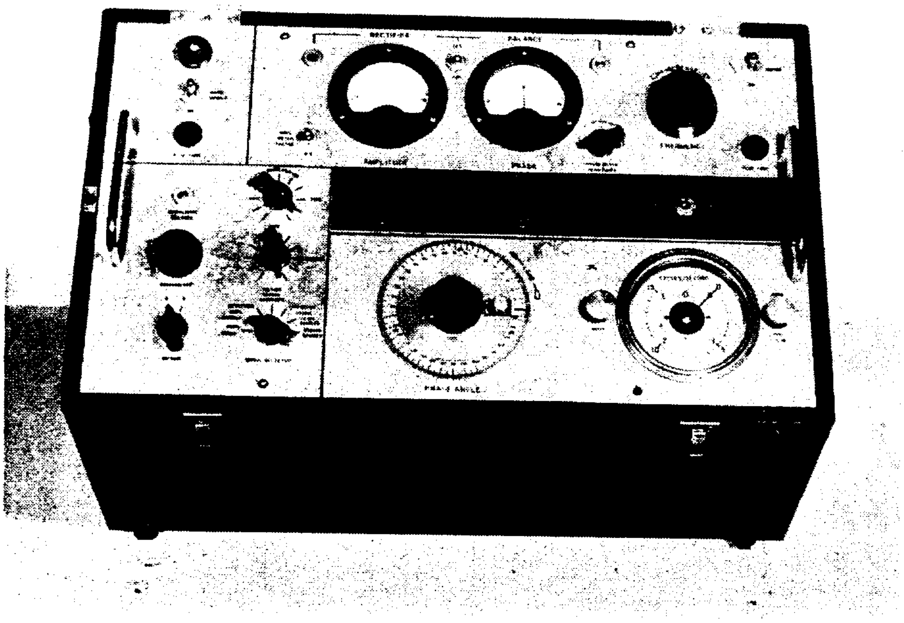
It will be seen that the instruments quoted throw heavy emphasis on electrical and electronic techniques. These techniques have a very high speed of response and thereby lend themselves admirably to the measurement of transient effects.

INSTRUMENTATION TABLE

Quantity	Part of Mounting Involved	Recording Instrument	Pick-up Arrangement
Timing and sequence of events.	Transfer, loading and breech mechanism.	Event recorder (6 or 12 channel as required).	Micro-switches attached to appropriate parts of mechanism and operated by events under observation. Closing of micro-switch operates relay and energizes a pen which makes a ‘ pip ’ on a scroll of teledeltus paper. A timing pulse is marked on side of trace.
Velocity	Rammer, recoil, etc.	Cathode ray tube or oscillograph.	Electromagnetic induction—two steel rods carrying coils are swept by magnets carried by the motion under observation. E.m.f. induced is a measure of velocity.
Displacement	Rammer, recoil ..	Oscillograph	A rod composed of alternate pieces of brass and insulation, each 0·6 in long, is swept by a pair of sliding contacts carried by the motion under observation. Circuit is alternately closed and opened by movement of contacts and a ‘ castellated ’ line is produced on a moving trace. The distance from one crest to the next represents 0·1 ft and the spacing of crests is a measure of the time taken at any stage for the motion to traverse 0·1 ft. This scheme can be used in aid of calibration of velocity instrument.
Pressure (transient conditions, etc.).	Recoil cylinder, recuperator, gun chamber, etc.	Oscillograph	Carbon pressure head—a small carbon conductor whose resistance varies inversely with pressure applied to it. Variations in voltage drop across conductor can be transmitted to oscillograph and calibrated in terms of pressure.
Temperature	Recuperator, gun cooling water.	Oscillograph	(1) Thermocouple. (2) Thermistor—this operates on the principle of the variation of resistance of a conductor with temperature, and the readings are recorded as for the carbon pressure pick-up. It is more sensitive than the thermocouple and more suitable for use with remote recording gear, but it is less accurate.
Torque	Feed and conveyor drives, training drives, etc.	Oscillograph	Torsionmeter—this is most simply constructed by attaching an electrical resistance strain gauge to the outside of the shaft under observation, at 45° to the axis. Readings are recorded in a manner similar to those from the carbon pressure pick-up. The principle can also be applied to measure direct forces.

Qualitative information regarding the behaviour of mechanisms or structures under conditions of a transient nature can be obtained by photographic methods ; the Eastman-Kodak high speed cine-camera is a well-known instrument in common use.

6-CHANNEL OSCILLOGRAPH
(*Vickers-Armstrongs, Ltd.*)



HARMONIC RESPONSE RESOLVER
(*Vickers-Armstrongs, Ltd.*)

Instrumentation as elaborate as this is not likely to be required for mountings actually in service, but careful thought will have to be given to drawing up the instrumentation requirements for the following purposes :—

(*a*) Shop trials of prototype and production mountings.

(*b*) Installation and firing trials of prototype and production mountings.

(*c*) Pre- and post-refit trials of mountings in service.

(*d*) ' Trouble-shooting ' in mountings in service.

(*e*) Operation and routine checking of mountings in service (this may possibly be simplified to the extent of providing indicator lamps only to show when certain vital processes are completed, etc.).

So far, little has been said about R.P.C., or ' auto-aiming ' as it is called. After radar, this factor probably makes the largest single contribution to the effectiveness of A.A. gunnery, because it allows for continuous compensation for ship movements and also gives an immediate response to any alteration in the transmitted signal. It is therefore obvious that it, too, deserves very careful treatment. The technique of testing and tuning with the aid of the misalignment meter and pen recorder is already familiar to ordnance engineers. The object is to observe the variations in the error signal during a series of tests in which the mounting is made to follow a series of different types of input, e.g. creep, constant speed, simple harmonic motion and run-in, and to arrive at the combination of settings (both electrical and mechanical) which gives the best overall performance.

With the demand for improved accuracy, however, this method does not tell the whole story. Generally speaking, improved accuracy means reduced misalignments, and that means that the system as a whole must be ' stiff ' (in the servo-mechanism sense), which, in its turn, means that there may be a tendency to self-oscillation and instability. Instability in a gunmounting auto system is liable to lead not only to a new source of inaccuracy, but also to greatly increased wear of mechanical components, and possibly considerable distress to the mounting's crew. It is therefore necessary to examine the behaviour of an R.P.C. system so as to establish the relationship between its stiffness and stability for comparison with some desired standard. This is done by examining the response of the system to harmonic inputs of various frequencies ; this method has the virtue of subjecting the equipment under test to its full range of speeds and accelerations. This form of test, which is called ' harmonic response analysis,' can be carried out by plotting amplitude and phase of output against a known simple harmonic input for a series of different frequencies. This is a laborious way of doing it, but fortunately there is a tool, recently developed, which simulates a unit harmonic input signal. This signal, injected into whatever part of the equipment it is desired to test, provides a means of reading-off the amplitude and phase (lag or lead) of the output. The results are finally plotted on the familiar Nyquist diagram, so that the performance of a system can quickly be analysed for comparison with an ideal standard ; the nature of any shortcomings in the behaviour of the equipment can also be observed. This applies not only to the whole system, but also to its components, so that in the event of trouble there is a ready-made dynamic test capable of detecting the offending piece of equipment. This ' harmonic response resolver,' as it is called, is actually in production, and will be available for use in all major dockyards before long.

So far, this discussion has been confined to consideration of the factors affecting gunmountings only, but it must be remembered that the gunmounting is only one of a large team in which each member must play its part correctly and in harmony with all the others. No matter how good the gunmounting R.P.C. is, fire cannot be expected to be effective unless all the following are also up to the mark :—

(*a*) Stabilization.

(*b*) Target following by director or radar.

(*c*) Prediction (computation of target's future position in terms of range, line, elevation and projectile time of flight).

If these conditions are fulfilled then the success of the engagement will, as has been said before, depend for the rest upon the correct response of the gunmounting, whose duty it is to interpret transmissions of the above quantities in terms of gun training, gun elevation and fuze. Finally, if the projectiles, propellants and guns themselves are behaving in accordance with their designers' expectations, success is assured.

At variance with the fulfilment of these conditions, there is the need to make all the gear as simple as possible. In calculating instruments, this involves 'fudges' or deliberate approximations to avoid extra calculating elements. Variations in components within manufacturing tolerances also lead to departures from the exact fire control solution, so that the greatest care must be taken at all points in the system to ensure that variations from the 'ideal,' whether due to deliberate 'fudges' or involuntary errors, are kept within the strictest limits. To keep a check upon these factors is therefore a very important requirement. Unfortunately, no rate-measuring instruments can realistically be tested under static conditions. It is envisaged that the next development will be the production of an instrument whereby a set of synthetic values of target position and movement, ship movements, etc., can be fed into the system so that the answers produced at the guns can be observed. This theme is beyond the scope of this article, but the existence of the requirement deserves mention.

Increased instrumentation is not enough. Most testing and tuning of R.P.C. equipment at the present time is being carried out by specialist teams. While it is felt that such an arrangement may be desirable for the early trials of prototype and production mountings, it is necessary that the ordnance engineering staff of every ship and establishment should be trained in this work, prepared at any time to carry out whatever tests and adjustments are necessary, and capable of finding the cause of any trouble without outside help. A knowledge of servo-mechanism theory is vital for this purpose, and everyone associated with modern gunmountings must have a sound working understanding of it; although it is possible to work to the book, diagnosing troubles by trial-and-error methods, the process can be lengthy, laborious and wasteful of effort. With servo-mechanisms, as with other branches of engineering, understanding of the fundamentals is the only true basis for tackling the problems involved.

Finally, it is necessary to say something about weapons of a less advanced character. In addition to major war vessels, there are the fleet auxiliaries, minesweepers, coastal craft and other vessels such as defensively equipped merchant ships (D.E.M.S.) to be armed. Here, the requirement is for much simpler weapons, easily worked by crews having only sketchy training and maintained by staffs of comparatively low standard and numbers. These weapons will doubtless have to be used against the same kind of attack as the more advanced ones already discussed but, owing to the limitations imposed upon their design by the need for simplicity and weight restriction, a lesser destructive power will have to be accepted. The weapon which emerges is a non-elaborate hand-loaded mounting with high elevation, employing ammunition small enough to be worked at a reasonably good rate by inexperienced crews (yet large enough for the projectile to have a biggish lethal sphere), fitted with the simplest form of R.P.C. and provided with a reliable and uncomplicated control system. A further important requirement is that this equipment must be capable of manufacture by mass—or at least batch—production methods. The reasons for this are threefold :—

(*a*) To permit sudden and rapid commencement of manufacture in very large numbers, possibly by firms inexperienced in armament work.

(*b*) To enable manufacture to be carried on at low cost at a time when the country's industrial potential is working at maximum output.

(*c*) To provide readily available stocks of fully interchangeable spare parts, ' catalogue ' items being used wherever possible. Interchangeability with the Americans and/or N.A.T.O. powers may also be necessary.

Summary

To summarize, the following requirements are apparent :—

(*a*) A thorough understanding of modern instrumental methods will soon be required of all maintainers and producers of ordnance equipment.

(*b*) Much instrumentation, some of it built-in, will shortly be necessary to enable modern mountings to be tuned, tested and checked.

(*c*) R.P.C. (or ' auto ') testing and tuning will have to be as well understood and practised by the rank-and-file of ordnance engineering staffs as by the present specialist teams.

(*d*) All designs, in particular those of simple mountings for ships other than major war vessels, will have to be geared to modern production methods. Economy, producibility, standardization and ease of maintenance are the prime requirements, and, as these are virtually interdependent, they call for most careful attention at all stages of policy-making, planning and design.

The author hastens to remark that the ' experience ' he quotes is not his own. The material of this article is based upon a study of the combined experience of others, made whilst he was co-operating with the Research Department of Messrs. Vickers-Armstrongs, Ltd., Elswick Works, to which firm all acknowledgements are due.