QUALITY IN WARSHIPS

BY

CAPTAIN W. A. HAYNES, O.B.E., R.N.
(*Director of Naval Ship Production, M.O.D.*)

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INTRODUCTION

The twenty years since the Second World War have seen not only vivid technical changes, but equally vivid changes in the international scene and the balance of world power. Both have had, and doubtless will continue to have profound effects on the Royal Navy and on Her Majesty's Ships. Technical advances have resulted in ships that are vastly complicated and 'system integrated'. Their greater cost, within the increasingly tight defence budget that peace always brings, has resulted in there being fewer of them. Yet the Royal Navy's world-wide tasks have, if anything, increased; and many of the over-

seas bases, where previously the Fleet could look for shore support, are no longer available. In consequence, H.M. ships and their crews are being worked far harder than ever before in peace time; the distances steamed are far greater, and speeds and usage are far higher. On the other hand, opportunities for maintenance are much fewer, and the consequences of breakdowns or delays to make good defects are very much more serious. These, and other factors (not appropriate to this Paper) have led to substantial changes in design, and in the balance between and the emphasis upon various basic requirements. For example, reliability and maintainability have become of almost overriding importance.

Many of the technical advances in warship design have been made possible by advances in production and manufacturing techniques. These advances have been paralleled by great advances in management techniques, of which quality control is one. If the Royal Navy is to be properly served, this is a field where full advantage must be taken of modern methods.

Scope and Treatment

One of the first questions the title 'Quality in Warships' poses is—What is Quality? Of the many meanings and overtones with which the word 'quality' is endowed, this paper is primarily concerned with the meaning—'Degree of excellence, relative nature or kind or character . . .' (Oxford English Dictionary). When this meaning is applied to warships, their relative nature is gauged by the extent to which the characteristics which the Navy needs are provided. Accordingly this Paper starts with a short review of these needs condensed into a number of required characteristics. It is the responsibility of the designers and producers of warships and their machinery and equipment to provide these characteristics; of the Ministry of Defence and its Servants to obtain assurance that this is done; and of all good subjects to see that it is done at the least cost to the Crown. This theme has dictated the pattern which follows on from the review of characteristics. We look at the control of quality in warships and suggest the lines along which an organization might run, then at quality assurance, and finally at costs.

It is important to bear in mind throughout this Paper that whereas quality control is a prime concern of any good supplier, quality assurance is what is demanded by any prudent customer. The difficulty in recognizing this distinction is that we are all in our way suppliers at one moment and customers the next. Nevertheless the distinction is real and important because the two call for quite different attitudes and reactions.

Let us look first at the Navy as a customer.

REQUIRED CHARACTERISTICS OF WARSHIPS

To meet its world-wide commitments the Navy needs certain characteristics in its ships, and in their machinery and equipment. The more important of these characteristics are discussed below.

Performance

In the main, required performance is relatively easy to define accurately in terms of speed, horsepower, range, capacity, etc; and it is relatively easy to check, by trials on completion of production, that the specified performance can be met. Of course the Navy often requires exceptionally high levels of performance; and indeed, large sums are spent on research and development of materials, designs, and production techniques with this object in view. Nevertheless there remain important areas where the performance required cannot be precisely defined (such as sea-keeping and handling) and warship design must ever retain the art of compromise.

Reliability

The probability that a machine or system will not fail to meet its specified performance whenever required to do so is the true measure of reliability. The advanced performance required of modern warships demands great complexity and system interdependence. Clearly, the more complex a machine or system becomes, the greater the chance of system failure for a given level of material or component reliability. Only partially can this be offset by duplication and the provision of stand-by units. It follows that the Navy needs an exceptionally high degree of reliability and predictability of useful life.

Robustness

Warships have to withstand not only the ordinary hazards of the sea—a corrosive environment, violent movement, vibration, wide temperature and humidity changes, etc.—but additionally the effects of enemy action. One of the most difficult of these to provide for is the effect of underwater shock. There also used to be a need to make naval equipment 'sailor proof', but the modern naval rating is a 'user/maintainer' and respects the machinery and equipment he looks after. Often the shipyard or dockyard worker has to be equally well trained to show the same respect.

Maintainability and Repairability

Maintenance is a very expensive charge on operational time and scarce manpower; and ideally none should be needed. In practice the aim must be to reduce maintenance requirements to a minimum. Whenever a servicing frequency is involved, it should be designed to fit the pattern of ship usage. Ease of and accessibility for refit or repair are important contributions towards reducing cost and time out of service.

Ease of Operation

All too often, defects put down to mal-operation are really attributable to insufficient attention at the design stage, to the need for simplicity and ease of operation. The importance of this characteristic is stressed by the need for machinery and equipment to be operated correctly even in extreme stress of action.

Silence

Underwater silence is a doubly important requirement, since underwater noise not only makes detection easier for an enemy, but makes a ship's own sonar less effective.

Safety

This characteristic is obviously important in all warships; it is particularly so in submarines, and overridingly so for nuclear propulsion. Equipment and systems must be so designed that there is no tendency for the effects of any failure or damage to spread.

Compactness and Lightness

The limited amount of machinery and equipment needed high up in the ship must be light. Otherwise, in modern warships adequate volume and deck space are at a great premium and compactness is generally more important than lightness.

Habitability and Appearance

Though last on the list, the importance of these two characteristics to morale and peace-keeping should not be underestimated.

The above characteristics could be called qualities but there is a danger of overworking the word. Suffice it to say that the extent to which they are provided is the real measure of quality in a warship. Let us turn to how they can be provided.

Quality Control

Until relatively recently the term 'Quality Control' has been used rather narrowly to mean a method of process control based on the statistical analysis of routine sampling. Now, generally (and certainly in this Paper), quality control is taken to mean what was at one time called 'Total Quality Control'. This is defined as 'the function of direction and management which must be performed in order to make sure that the end product meets the users requirements'. On analysis you will find that this definition embraces a very wide field indeed.

Elements of Control

The achievement of proper quality control calls for:

(*a*) Determined direction and management

(*b*) The required characteristics and quality implicit in the design, drawings, and specifications

(*c*) Production processes that are potentially capable of producing repeatedly articles which conform

(*d*) Process control to realize this potential

(*e*) Inspection and testing to ensure that requirements have been met.

Direction and Management

The first, and probably the most important step towards effective quality control is taken when direction and top management are convinced that it is necessary and economic.

They must accept that quality control needs to be administered in much the same way as the control of money, men, and production.

Quality of Design

It is not enough for the designer to concentrate upon meeting the performance characteristics alone, however advanced these may be and however great the challenge. At the prototype stage his ingenuity and inventiveness should certainly be untrammelled, though even at this stage producibility cannot be entirely forgotten. But by the time development is complete, the design is accepted as serviceable, and production becomes a reality, then all the required characteristics should have been taken into account. Clearly understood drawing-office rules, together with some form of check-off list are needed to ensure this.

Of course most of the design of warships and their machinery and equipment is performed in industry, and it is a misapprehension to suppose that M.O.D.(N) approval of drawings constitutes the complete quality check required. M.O.D.(N) approval is not intended to do more than ensure that the main requirements have been covered. The detail quality check should be done in the firm's design office.

Production Processes

It is not infrequently the case that technical advances must await the solution of the attendant production problems and the design of special processes or

machine tools. The every-day use of stronger materials has had to wait until means of working them have been developed. The rise of precision has been marked by such milestones as the introduction of the micrometer, high speed steel, gauge blocks and the centreless grinder. Yet all too frequently do we find precision work being attempted with worn or ill-maintained tools or by entirely unsuitable methods and being checked with gauges whose accuracy is questionable.

Process Control

Satisfactory processes cannot of themselves produce satisfactory products unless properly controlled. The required degree of control must be carefully thought out and defined so that production supervisors know clearly what is required. Similarly the requirements of the design must be clearly defined and communicated to production so there is no ambiguity or lack of clarity as to what has to be accomplished. Management must make provision for proper material identification, proper choice of processes and tools, adequate manufacturing information, the necessary gauges properly calibrated, and above all properly trained (and re-trained) men.

Inspection and Testing

Inspection is best defined as the business of measuring, examining, and testing material, components, assemblies and equipment, before either passing on to the next stage of manufacture or out into service that which appears (*sic*) to be adequate, or rejecting that which is defective or is judged to be of inadequate quality. Usually, non-destructive measurements and tests can be devised to give reasonable certainty that requirements have been met. But where no method of non-destructive testing can be found to prove vital characteristics, process control becomes of overriding importance; and procedures and operators must be proved and reproved by destructive testing.

Inspection is a safeguard against defective equipment getting into service but it is axiomatic that quality cannot be inspected into a product. How many continue to labour under this delusion? 'Inspection' is just one element in 'quality control' yet there are many who think them synonymous. Inspection merely accepts or rejects, but quality control recognizes that quality is everyone's business.

Feed Back

An essential step in the control of quality (particularly in respect of reliability and predictability of useful life) is a feed back of information about experience in service. This is more difficult to achieve than would appear at first sight. The mass of data available needs to be codified and analysed before conclusions useful to designers and producers can be distilled out. The Navy have established a central Ship Maintenance Authority charged (among many other tasks) with the analysis of defects and unreliability. It is hoped that, in due course, it will be possible to provide the feed back required. 'Pareto' charts of defect frequency, classified by cause, already clearly show that over 50 per cent of all defects resulting in unavailability of modern warships are attributable either to dirt or to manufacturing errors.

ORGANIZATION FOR QUALITY CONTROL

Clearly, quality control must be the responsibility of the primary producer since to provide it is a function of direction and management. Where production is to a precisely specified scaled design, then it is the quality of conformity that needs to be controlled. This situation is relatively rare in shipbuilding and its

supporting industries. The firms concerned are either the designers or are intimately concerned with the design and its development, so they must take responsibility for control over the whole field of quality.

Form of Organization

It is difficult to be definitive about organization for quality control, and about how it should fit into the general organization of a firm. Much depends on the nature of the existing organization, the division of responsibilities, and the firm's objectives, traditions and skills.

In a shipyard or manufacturing firm of any size one might expect to find a Quality Manager of senior status responsible to a Director, and having under him the Chief Inspector, the Quality Engineer, and the Test Engineer (or in a shipyard the Chief of the Dockside Test Organization) together with their departments.

In Britain it is not easy to find suitably qualified men, and we need a nationally concerted effort to improve this position. A valuable start has been made by the National Council for Quality and Reliability. Across the Atlantic, the American Society for Quality Control has been established professionally for nearly 20 years.

Inspectorate

The responsibilities of the Chief Inspector and his department are familiar; they normally cover such areas as receipt inspection, material identification, dimensional and assembly inspection, non-destructive testing, and the maintenance of standards.

In the past great importance has sometimes been attached to making inspection entirely independent of production, so avoiding the temptation to solve production difficulties, by forcing the acceptance of defects. This arrangement may well be necessary where output incentive bonus schemes operate. But the contrary view expressed as 'every man his own inspector' is beginning to gain ground, and certainly a good production manager must take the view that quality is very much his business.

Quality Engineer

One would expect the Quality Engineer to exercise a staff or advisory function rather than a strictly executive function. His department should be small and streamlined for effective action. Its responsibilities might cover such areas as examination of specifications to determine required quality, procedures to ensure requirements are met within the firm and understood by sub-contractors, value engineering, inspection and test schedules, documentation, defect analysis and correction, and audit of the effectiveness of quality control measures. A close link with the planning organization must be established.

Testing

A special department for running tests and trials of machinery and equipment is well established in many firms. Such test departments make a substantial contribution to removing defects and establishing correct performance. But all too often test requirements and procedures are not sufficiently carefully thought out, the recording of results is inadequate, and the test instrumentation is unreliable. With the possible exception of resistance to shock, it is very rare that testing is designed to establish any of the required characteristics other than performance.

Putting the Test Department under a Quality Manager should help to point the true objective of their activities.

Shipyard Test Organization

Already for nuclear submarines and in future for the more complex surface warships the M.O.D. specify requirements for a proper Shipyard (or Dockside) Test Organization designed to ensure the effective, efficient, safe and timely inspection, testing setting-to-work and trials of equipment, machinery and systems. Three essential elements are required in the organization, viz:

(*a*) A manager with adequate authority

(*b*) A number of test groups

(*c*) The necessary support in terms of the right to call-up services and facilities.

Each test group is, in effect, a small committee of nominated people required to act unanimously, each member having defined powers of veto. Each test group must include, at least, nominees of the Shipbuilder, the Inspecting Authority, and the Senior Officer appointed to stand-by the ship. The number of test groups required is related to the type of ship concerned, for example, for a destroyer, the following Test Groups might be appropriate:-

Ship

Propulsion

Weapon systems

Air facilities.

The organization is required to draw up schedules covering the setting-to-work and trials phases, to compile check-off lists so that nothing is overlooked, and to prepare proper operating and emergency instructions.

The schedules are required to include such information as names of people responsible, tests to be completed before setting to work, auxiliary services and test equipment required, test instructions and details of records to be taken. The check-off lists must cover all essential preliminaries and safety precautions.

Co-ordination

Since virtually everyone in a firm has some responsibility for quality the need for proper co-ordination, across professional and departmental boundaries, is particularly important. Not only must this need be taken into account in setting up a quality control organization, but it should be implicit in written procedures and control documentation. Specially constituted committees are sometimes set up to improve co-ordination.

Training and Indoctrination

The effective introduction of quality control requires a well thought out (not necessarily expensive) campaign of training and indoctrination. Although American methods of propaganda are not always entirely to our taste in this country, we have a lot to learn from them in this respect.

QUALITY ASSURANCE

While the supplier is responsible for quality control, the customer needs assurance that the end product has the required characteristics and quality. Quality control and quality assurance are complementary, and supplier and customer must work together. The U.S. Navy Bureau of Ships define Quality Assurance as 'a planned and systematic pattern of all actions necessary to provide adequate confidence that the product will perform satisfactorily'. The Bureau's quality assurance slogan is 'One ship's worth of confidence with each ship!'

Obtaining Assurance

Customer assurance must be obtained without weakening the producers' control of quality, or in any way diminishing his responsibility or vigilance. This is not easy because the customer or his agent must often be intimately concerned right through the process of manufacture in order to obtain a required degree of assurance. Only in the case of materials and relatively simple articles can such assurance be obtained by mere examination and test after delivery. Certainly the Ministry of Defence could not obtain assurance of the required qualities in a warship by nothing more than inspection and trials, however searching, immediately prior to acceptance; and this is equally true of much of the machinery and equipment the M.O.D. supplies to the shipbuilder. By the same token, the shipbuilder needs assurance of quality from his suppliers and they from theirs.

There are three elements in obtaining a reasonable assurance of quality, viz:

(*a*) Proper definition of requirements

(*b*) Auditing the producers quality control

(*c*) Conducting, or witnessing the producers conduct of tests and trials.

Definition of Requirements

The basis of quality assurance is clear definition of what is required. For anything as complex as a warship clear definition is extremely difficult to achieve. It is made doubly so by the need to make changes in the course of design and construction. But these changes are necessary to take full advantage of technological advances in meeting an ever changing task. In defining their requirements for a warship, the comprehensive collection of documents issued or called up by the Ministry of Defence include: guidance drawings; hull, machinery and electrical specifications both general and those particular to the class; weapons specification; British Standard Specifications; Defence and Departmental Specifications; Guides and Lists; Books of Reference; etc. etc.—a formidable array!

It is important in assuring quality that the many documents are kept up-to-date and cross-checked; that their provisions are passed on to sub-contractors, correctly; and that any inconsistencies are immediately questioned and clarified.

Auditing Quality Control

The soundest way to obtain quality assurance is to audit, or verify the effectiveness of the producer's own quality control measures. This is sometimes known as quality surveillance. It is probably achieved most effectively by keeping the following criteria under continuous and critical review:—

(*a*) The effectiveness of the organization and the attitude of the people in it

(*b*) Systematic, comprehensive and integrated planning and control to plan

(*c*) Process suitability and the effectiveness of process control

(*d*) The development of proper quality control techniques and their disciplined implementation and documentation

(*e*) Effective communication down to all levels and laterally, particularly across departmental boundaries

(*f*) The extent of study in value engineering and the control of cost effectiveness.

Obviously such verification demands a very high standard from our Overseeing Service. Overseers require experience and understanding of professional and technical problems, naval user requirements, and people and their management.

Overseers must walk the tightrope of never relaxing their critical awareness or allowing poor quality to get past, while joining in a team effort to make sure the Navy is properly served.

Programming and Planning

The timely completion of warships is very important in meeting operational requirements and keeping down costs. But timeliness is liable to be at the expense of quality unless a proper programme is prepared at the outset of building; and unless thorough planning and scheduling of production, construction and inspections, tests and trials is undertaken, accepted, and implemented.

For warships, the M.O.D. now require a cardinal date programme to be prepared and agreed at the outset of building; and require network analysis to be used to establish that the programme is feasible, to provide a basis for systematic review of progress, and to identify the critical paths so that control can be concentrated upon them.

Cardinal date planning and progress review is also required from suppliers of major items of machinery and equipment. It must be recognized that a last minute rush in an attempt to meet completion requirements is one of the greatest causes of inadequate quality.

Cleanliness and Protection

Experience shows that many of the defects occurring early in the service life of warships are due to the ingress of dirt or to damage or lack of care during the building period. This is not an easy problem to solve since much machinery and equipment must be installed at a time when there is a high risk of damage or contamination by shipyard arisings, welding splutter, grit blasting, corrosion products or lagging material. Nevertheless it is essential to establish practices and conditions that provide adequate protection.

Operation and Maintenance

Before a warship is commissioned for service at the end of her building period, quite substantial hours' running or usage of her machinery and equipment are inevitable. To avoid unfair wear and tear, with the consequent depression of quality and reliability at acceptance into service, it is essential to make provision for proper operation and maintenance during the building period.

THE COST OF QUALITY

To say that 'quality is expensive' is not really very meaningful since the statement 'quality is cheap' may be equally true. Evidently there is a need to be much more precise.

It is convenient, when considering cost, to consider separately quality of design and quality of conformance. This is because first cost tends to rise with a rise in the former, and to fall with a rise in the latter.

Cost of Quality of Design

The term 'high quality' usually implies some sought-after combination of rare or specially selected materials, particular care or skill in manufacture, a high degree of precision and finish, and possibly additional complication which is desirable though not essential. Such high quality is expensive in first cost but not necessarily so in the long run. Conversely low quality is cheaper in first cost but may be catastrophically expensive in the long run.

Thus for any given purpose there must be an economic level of quality; it is the least expensive in first cost that will give the required performance and have the required characteristics and continue to do so for the required time—in modern parlance, the most cost-effective. It is this level of quality that the designer must seek to express in the drawings and specifications. It is difficult, if not impossible, to measure this level of quality precisely, to strike the correct compromise is part of the judgement and artistry in design. The tendency will always be to err on the safe side and to provide higher (and hence more expensive) quality than the minimum judged strictly necessary.

Better control of the quality of design should therefore enable the economic minimum of quality to be more closely approached with confidence, and this will make a significant contribution to the reduction of first cost. It is, of course, essential that the designer and the drawing office should work in close harmony with the production departments. All too often can one trace excessive costliness to difficult and quite unnecessary problems in production, and this is usually due to lack of contact between the drawing board and the yard or shop floor.

Cost of the Quality of Conformity

In this area there is plenty of what Juran* calls 'Gold in the Mine'. Improvements in the control of the quality of conformity with the drawings and specifications can show very substantial reductions in cost. These arise from:

(*a*) Better understanding at the 'coal-face' of what is required and of the least expensive materials and methods that will meet design requirements.

(*b*) Reduction in the cost of scrap and re-work. Quality control has discovered instances where this cost is as high as 40 per cent of total production costs. Certainly 20 per cent is not an uncommon figure.

(*c*) The discovery of mistakes, misinterpretation, and defects when they first occur and are relatively cheap to correct, rather than later when the expensive process of diagnosis, stripping-down, correction, and re-erection may involve very substantial costs and delays.

(*d*) Better control of manpower.

(*e*) Reduced risk of accident. This is particularly important in shipbuilding. As fitting out proceeds, the vessel and her machinery and equipment begin to represent very large capital sums. The inherent risks, from such sources as a fire, mal-operation of machinery, and poor protection from dirt and damage, are necessarily very high.

Savings in Cost

Without doubt improved quality control can save its overhead cost many times. This conclusion in logic is reinforced by practical proof in shipbuilding in other countries, and in other industries in this country. The saving should accrue not only to the customer, but to the shipbuilder and his supporting producers. Quality control should go far to ensure the timely delivery and freedom from trouble in service that brings satisfied customers who come back for more.

CONCLUSION

The British shipbuilding and marine engineering industries, and their supporting machinery and equipment producers, have served the Royal Navy magnificently. They have taken the lead in many sweeping advances from wood

*Editor-in-Chief, 'Quality Control Handbook', McGraw-Hill.

and sail through iron and steel, coal and oil, steam and Diesel. They have helped to lay the foundations of victory in two world wars. But the challenge posed by the rapid changes of modern times call for a continuing response in the development of improved methods of management and of production.

Nowhere is this better illustrated than by the need for continually improving the control of quality in naval ship production.