Macmillan Handbooks in Industrial Management

V. G. Parry

The Control of Quality

Introduction to the Series

The eight books comprising the 'Macmillan Handbooks in Industrial Management' series were from the outset planned as an entity, and together they cover comprehensively yet concisely the varied aspects of knowledge required by those who manage a modern factory or plant. At the same time, care has been taken to ensure that each volume shall be complete in itself, and carry sufficient basic management theory for a proper understanding of its specific subject.

By this means, it has been possible to avoid a common pitfall in the path of many writers on management subjects, namely an attempt to cover all possible ground in one major volume, with varying degrees of success.

By contrast, each author in this series is experienced in the subject of his contribution. A similar pattern has been followed in each book, but each bears the stamp of the personality of its author. Well-established principles and tested techniques are explained, but equally new and up-to-date concepts are explored.

It is expected that many practising works managers and mature students will wish to have the whole set on their shelves, but that others will welcome the opportunity of buying single volumes to meet their particular needs.

Thanks are due to the authors for the enthusiasm with which they have joined the enterprise, and to members of the staff of the Institution of Works Managers for practical support on many occasions.

J. EKINS

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The Control of Quality

V. G. PARRY

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Contents

Foreword

In the world of modern industry, it becomes increasingly necessary for managers to be aware not only of the fundamental principles of good management, but also of the latest techniques necessary for putting those principles into practice.

Works managers in particular, because of the salient position which they hold in the management structure of modern industry and their responsibility for translating policy into execution, must be both educated in sound theory and trained in modern methods.

This series of eight books has been designed to provide the basis of that education and to supplement essential experience.

I welcome the opportunity the Institution of Works Managers has been given to sponsor this venture and commend the books to all present and future managers in industry.

RICHARD MARSH
Chairman, British Rail
President, Institution of Works Managers

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V. G. P.

1 | Introduction

AIMS AND OBJECTIVES

Much has been written on the subject of quality and reliability usually covering specialist procedures, statistical applications and methods of control primarily suited to the larger organisations.

This book is based upon practical 'down to earth' experience, rather than any academic or theoretical approach. The purpose is to give quality product guidance and assistance to the personnel of both large and small companies. (There are approximately 70,000 companies in the U.K. which employ fewer than 100 people, and over 80 per cent of the total number of companies are in this category.) The book may also interest apprentices and students.

The subject-matter is presented in an easily readable format with particular emphasis on the practical aspects and supported by examples, illustrations and reference material, as applicable. Inevitably the contents will be primarily related to engineering, but an effort is made to include other industries where possible.

BACKGROUND

To provide an orderly introduction to the subject, it is desirable to present some historical information. At the start of this century, manufacturing, and engineering particularly, were still very much highly skilled craft activities with quality provided by the skills of individuals, rather than a specially organised overall system. This arrangement worked well under the conditions of that time and high-quality products were produced, giving Britain an enviable quality reputation. (Current quality philosophies again recognise that quality assurance commences with the people who actually produce and is ensured at the time operations are performed.)

Craftsmen often produced complete products, carrying out sequential operations and making parts to suit each other.

INTERCHANGEABILITY

Higher production rates, manufacturing products at separate locations, and developments such as the motor-car, demanded interchangeability and spares which would be freely available and could be used without special fitting or adjustment. Schedules and tables for limits, fits and tolerances became more necessary and consequently so did the need for reference length standards.

Interchangeability was made possible primarily through the brilliant invention by Johansson, the Swedish engineer, of sets of length blocks or 'slip' gauges and a very ingenious and highly accurate method for their manufacture. This subject is an engineering saga in itself about which very little has been written, or is known, even today.

Sets of length standards gradually became available to all engineering companies and are now taken very much for granted.

DEVELOPMENT OF INSPECTION

Ever-increasing production rates and high-speed machine tools, relatively easily controlled, made possible the use of semi-skilled operators, including females. There followed a drift away from operator responsibility for quality, with continuously more inspection of the finished product.

The situation was worsened by the introduction during this period of highly sophisticated and accurate measuring instruments, which were acquired by inspection organisations. Such instrumentation enabled inspection to become increasingly critical of production, and to pass judgements from a jealously protected position of strength.

DECLINE OF 'IN ARREARS' INSPECTION

Progressive managements realised that inspection 'after the event' was largely negative in principle. It usually involved 100 per cent checking and the sorting-out of good from bad. Rejects might possibly be corrected by costly and difficult rework, but scrap rates could also be serious. The procedure wasted time, material, equipment and personnel and also disrupted output owing to the wastage outlined.

DEVELOPMENT OF QUALITY CONTROL

The situation led to the introduction of quality control personnel and concepts. Unfortunately the early quality appointments were often quite distinct from the existing chief inspector hierarchy, and this resulted in friction and slow development.

At the time much emphasis was given to the statistical approach and this activity became almost synonymous with quality control. The professional statisticians became deeply involved and introduced complicated schemes and procedures, some of which serve useful purposes but which in total had the unfortunate effect of connecting quality control almost entirely with statistics.

Gradually, quality control functions merged with inspection organisations in a logical manner, with the development of the quality control manager and then the quality manager, succeeding the chief inspector as the member of the organisation responsible for product quality.

QUALITY PHRASEOLOGY

Reference can now usefully be made to the *Glossary of Terms Used in Quality Control* issued by the European Organisation for Quality Control. This is a comprehensive guide on most of the terminology used in quality control and is published by EOQC, Rotterdam, Netherlands.

Associated with the evolutionary stages outlined above, a jargon of terms has arisen, initially extensively associated with statistical methods and latterly on broader concepts. We have, for instance, had single, double and sequential sampling plans, average quality levels (AQL) merging into zero defects, quality assurance and total quality control. Some of these philosophies embrace very wide spheres of company operations and are by no means universally accepted at this time within the larger organisations, to which they are principally applicable.

As stated earlier, this book is primarily for practical guidance and also for the smaller company, and it is not, therefore, intended to dwell extensively on these philosophies. However, it is useful for the reader to have some knowledge of these concepts and a very brief description may be helpful.

MEANING OF CERTAIN TERMS

AQL, or average quality level, is widely used but should not be confused with AOQ and AOQL.

AOQ stands for **average outgoing quality.** It is normally a value compiled from accepted batches, together with rejected batches, when the latter have been 100 per cent checked and rejects changed for satisfactory items. Some variations are practised regarding replacement of rejects.

AOQL stands for **average outgoing quality limit.** (Some people use the word 'level' instead of 'limit'.) This relates to sampling plan procedures. Such plans can provide various degrees of quality level according to the characteristics of the operating curve of the sampling plan selected. The reader is referred to various books on statistical quality control and sampling plans for full information on this subject.

AQL is the level of quality specified by an inspection sampling plan and normally provides that a small number of defectives can be tolerated. (Also, some tests are destructive and cannot be applied 100 per cent.) Many people experience concern about any system which nominally allows a small permitted number of acceptable defects. They often overlook the fact that 100 per cent inspection is very costly and can also be shown to have limitations of perfection, as compared with inspection of a representative smaller sample quantity.

Nevertheless, activities such as space travel demand total elimination of defects and were primarily responsible for the 'zero defects' outlook. The principle is that if an AQL is allowed, there will always be some defects. In various walks of life, we do not provide for, or expect, errors **in principle.** We expect our salary payments to be coriect and not in error, say, two or three times a year. The same applies for our bills and day-to-day purchases. Errors do occur, of course, but the emphasis of zero defects is that errors should not be allowed in principle.

The corollary of 'zero defects' is 'total quality control', which is still a fairly controversial subject owing to its planned impact over a much wider field. The theory is that quality control should not only apply primarily to manufacturing facets but also to **all** the other company functions. Quality representatives should oversee sales, marketing, engineering, design, purchasing and customer relations or service activities. The reader will appreciate that such 'infringement' on very jealously guarded domains can generate very hostile reactions. In large companies there is normally very good quality **liaison** with all the above departments, but this is quite different from the **total** quality **control** concepts outlined.

QUALITY

Let us now endeavour to amplify, qualify and define quality, and its implications.

The word 'quality' has a fairly clear meaning to people generally, whether they be technically expert or laymen. Furthermore, it is fortunate that the word has an almost literal translation into, and equal importance in, many other languages.

Unfortunately, awareness and recognition of the need for quality is sometimes only realised and appreciated following experience of the effects of poor quality. Most readers will know of recently developing countries which acquired a reputation for shoddy goods but whose governments now actively and stringently enforce good quality by mandate, backed up by legal penalties. As a result, these countries' products now carry a high quality standing.

Quality is satisfactory conformance to specifications and design, such that the product gives customer satisfaction, dependable service and reliability. **Optimum quality** is that which provides these standards at the price the customer is prepared to pay.

QUALITY COSTS

It is the aspect of costs which creates most misunderstandings relative to product quality.

Firstly, the definitions above make it clear that from the customer viewpoint the price he is prepared to pay is a prime factor. For example, if he requires a gold watch he would not be satisfied with a stainless steel one, and would expect to pay for the higher quality, although both watches may provide accurate time.

Similar examples could be quoted for many other products: domestic goods, clothes, furniture, motor-cars, etc. Unsatisfactory quality occurs when a customer pays a price which should provide a corresponding standard, but receives an inferior or faulty product apparent initially, or which breaks down or deteriorates in use.

The producer must therefore ensure that he supplies a conforming product and provides adequate quality assurance cover, as appropriate.

Costs of **properly** organised quality are not just an expenditure which is of doubtful necessity. Good quality cover is a sound investment and assurance. A reputation for poor quality can be much more easily acquired than remedied. A customer who purchases an unsatisfactory product is unlikely to continue a customer of the supplier concerned. Superior quality is a decisive factor in ensuring survival over competition, when other factors such as price, delivery, etc., are similar.

These principles are usually fully appreciated by managing and sales directors. The latter may occasionally seek low prices to give sales advantage, but usually with the firm proviso that poor-quality products should not be a consequence.

Buyers may negotiate a keen commercial price, but they fully realise that a low-priced, unsatisfactory product will react to their detriment. Somewhat similarly, chief engineers and designers expect full product conformance in manufacture and test, with no degradation of design standards.

It is usually at production levels that conflict of outlook arises. The production manager and his personnel have targets to meet and quality personnel can be, and often are, regarded as added expense, or people who simply criticise and hold up production.

Quality control are in a very invidious position at these levels. They are either the people who hold up production unnecessarily, or who are responsible for faulty work having been accepted. The fact that faulty work originates in production and that quality control simply failed to extract rejects is very rarely something for which production personnel are called to account.

The stresses are frequently more difficult when the decisions involved are subjective or, as mentioned earlier, are due to the fact that inspection usually has better facilities for fault-finding. Subjective decisions on features such as appearance, finish, noise, etc., can be very much a matter of opinion. Grounds for friction on subjective aspects can be minimised by agreed physical samples or standards, and word descriptions of method of assessment and permitted blemishes, such as scratches, dents, etc. Good quality liaison is vital to meet these problems.

Production people will quickly appreciate quality control as an asset rather than a hindrance when QC operates the three basic procedures:

OBSERVE

REPORT

ACTION

This implies the **observing** of problems, defects, etc., and the recording of information and data to facilitate the **reporting** of incidence, causes and possible remedies, with a view to effective **action** to improve methods, facilities, procedures and training, as necessary. Such procedures can indicate differences between machine tools, shifts, individual personnel, etc. The action required may also include request for design to review tolerances, heat treatment, protective coatings, etc.

These activities are the basis of effective quality control, which must always have the primary objective of eliminating the causes of rejects so that they are unlikely to occur, rather than the older inspection procedures of ensuring acceptable output quality by sorting good from bad. The negative aspects of 'in arrears' inspection have already been mentioned. To this can be added the fact that successive batches of work can continue to have similar rejects, unless corrective action has been taken.

Once production people realise that quality control can save them producing faulty work, avoid scrap or rework, and highlight personnel, equipment and method limitations, with support for action, they quickly change their outlook. Their production schedules improve and they tend to depend more on quality control as a production aid. The difficulty at this stage is that requests can arise for undue extension of quality coverage to relieve supervision of some of their responsibilities.

We are now able to come back to the heading of this section, which is quality costs. It should be readily apparent that the cost of effective quality control of the kind outlined can easily be offset by the direct savings from reduction of faulty work, saving of time and material and better ensurance of production programmes. These benefits can extend to more trouble-free assembly, test results and ultimately reliable product and customer satisfaction.

It is not easy to place or assess the **savings** as distinct from **expense,** which can arise as a result of such properly organised quality control. The fact that faulty or scrap parts are minimised can be shown by scrap analysis figures over a period, but savings in respect of overall improved efficiency, more reliable production deliveries, and improved field and customer satisfaction, are difficult to quantify. These factors are again referred to along with other associated features covered in Chapter 2.

PHILOSOPHY

It may sound the reverse of quality thinking if we pause to consider that ultimately everything becomes virtually scrap, including ourselves. The whole scheme of Nature and its cycles has a sequence of growth, bloom and decline. The time-span of these cycles varies enormously from a fraction of a second for particles of matter, to thousands and millions of years for the universe and geological features. Similarly some insects live for only a day, and some animals for over a hundred years.

Nature is always busily counteracting the efforts of man. A road built through the jungle will revert with time. Metals corrode and mechanisms wear out.

These facts should not discourage but should stimulate us in our efforts to provide optimum-quality products which will defy 'the tests of time' for an appropriate period. For example, many motor-cars have been produced, but the outstanding quality of Rolls-Royce cars provides a longer life and continuing value for these cars, considerably exceeding other makes. (There is, of course, a significant relative cost differential originally incurred.)

Conversely, some products have an initially inbuilt, precisely defined life-span. Our daily papers suffice for one day only. Similarly, a printed calender, or diary, may cover a period of a year, but a diary which fell to pieces after a few weeks would be of very unsatisfactory quality.

THE ODDS WITH WHICH ENGINEERS CONTEND

Normally there is only one condition whereby a product is correct, or satisfactory, but there are often, cumulatively, many thousands of ways of possible deviations, errors or faults in a complete assembly.

Let us consider a very simple bar (shaft, or spindle) which consists virtually of only a length and a diameter. We have stated that there is only one way in which such a part is correct. Conversely, even though the part has only two basic dimensions, there are a number of ways in which errors can be present. A few of them are:

Wrong material.
One or both ends out of square to the axis.
Ends out of flat/irregular/dished/domed.

Material hardness incorrect/too hard/too soft.
Diameter tapered/domed/convex (longitudinally).
Bar not straight.

The reader will easily be able to think of other possible errors and can usefully test his thoughts with the additional list tabulated in the footnote below.[1]

This is one of the simplest types of piece parts. Immediately one starts to add further diameters, shoulders, grooves, radii, screw threads, undercuts, recesses, etc., we meet with additional dimensions and possible relationship errors, and the odds increase rapidly.

Similarly, acceptable piece parts have to be put together correctly, lubricated, etc., and it will be readily appreciated that it becomes almost impracticable, and would be extremely costly, to inspect for all these possibilities.

The reader will be very much aware that, fortunately, engineers have normally already catered for elimination of most of the possible variations listed (and thereby reduced the odds) by perfecting methods and processes, such as true quality control, that reduce the likelihood of errors. For example, modern precision machine tools readily produce parallel, smooth surfaces, with square flat ends and of correct dimensions, very reliably and consistently (provided sensible controls and practices are followed with quality monitoring).

From the example outlined above, it can be better appreciated why the concept of a permitted number of defects, or specified AQL (average quality level), is often not readily acceptable. One must of course stress that the word 'defect' used in this context means a deviation from specification or tolerance and may not automatically imply a **failure**-type defect (e.g. a reject for unsatisfactory appearance). In complex electrical assemblies, **individual** transistors, capacitors, diodes, resistors, etc., may have a very low AQL figure. When the collective effects of a large number of very low individual failure rates are accumulated, the **overall** failure rate of the complete assembly can be very high and completely unacceptable, particularly as the defect in an electrical piece part can very likely cause malfunction failure. (It is appreciated that the overall failure rate is not a simple arithmetical addition of individual rates. Failures occur over varying periods of time, and mean times between failures

[1] Ovality on diameter; sharp edges on corners; damage marks; finish too rough/too smooth; diameter too large/too small; length oversize/undersize.

become involved, with failures quoted as hours between failure rather than percentages.)

STATUS AND RELATIONSHIPS OF QUALITY PERSONNEL

Large companies can justify, and require, sophisticated quality organisations, whereas smaller companies need such cover on proportionately smaller scales. A very small company of under ten employees may cover its quality requirements under the control of the owner only, and have no staff solely on QC.

As size increases gradually, we may have one person responsible for all quality facets, e.g. 'porter, signalman and stationmaster'. In such circumstances, the required calibre of the individual can be equally important to that of a **departmental** QC manager. The smaller company's QC man cannot justify specialists in every field, or laboratories, etc., and has to be widely knowledgeable, although probably in a somewhat specialised field operated by some small manufacturers.

Whatever the scale, the person responsible for QC needs to have important personal qualities and abilities, apart from technical skills. He must always remember that advice is the easiest thing to offer and the hardest thing to accept.

He must be able to command respect and not resentment.
Prompt and positive decision-making is essential.
A practical down-to-earth approach is vital.
Involvement at all levels must be practised.
The quality manager must enjoy suitable status and receive maximum support from senior management.

In large companies the reporting responsibility is normally considered more satisfactory, if it is not likely to be influenced by production considerations. The quality supervisor controlled by the production manager is not considered desirable but can and does work well, provided the individuals concerned have the right personal approach and qualities of rapport. The more usual arrangement is line responsibility to a director or the managing director. In some companies the senior quality man has director status, such as quality director or director of quality.

The important factor is that quality is an overall concern of every facet or department and of all personnel within an organisation. The quality manager is dependent upon every link in a long chain of responsibilities and understandably the weakest possible links in such a chain are individual people.

Quality is a continuous activity which cannot be relaxed or terminated, even when control has been established. All too often, companies experience problems on product, quality, reject levels, scrap, etc., and then give maximum support to quality procedures to resolve the situation. Once problems are resolved, there can be a reaction, on the impression that future quality has been permanently assured. Efficient quality departments must always be appraising the continued need for various quality coverages. This is quite a different activity from arbitrary cuts and economies imposed by management, on the assumption that few quality problems imply justification for reduced support of quality activities.

Just as the wise QC manager will introduce new quality activities gradually and ensure the support of all concerned, so should senior management liaise with the quality manager in ensuring that easements of quality coverage **are** based on sound assurance, that improved methods, controls, etc., have removed the likelihood of troubles and will thus allow corresponding adjustment of QC activity.

PRESENTATION AND FORMAT

Many companies perform a service to other sections of their industry by undertaking to provide supplies to customers' specifications, as distinct from direct marketing of proprietary products.

In the interest of logical presentation, this book has been written mainly in the sequence of the average factory which produces complete products, and therefore commences with administration, tooling and raw materials, and progresses through manufacturing stages, assembly and test to dispatch. Some chapters on more specialised subjects follow. It is hoped that the various interests will be covered by some or all of these sections. Smaller and direct service companies' personnel will realise that the various remarks and comments cannot always necessarily apply to the smaller firms' scale and scope of operations, but should find much of interest in the various details provided.

There is no automatic scheme for quality activities which can be obtained from charts, tables, textbooks, etc., for application within particular companies, industries or organisations. Each has individual needs, requirements, product factors, scale, market requirements, customer relations, etc., which affect the situation.

Furthermore, schemes need to be constantly reviewed and amended, where necessary, to meet changing circumstances and to keep abreast of technological advance.

QUALITY SCALE

Few companies are able to spell out their quality levels or outlook in precise detail. Normally the terms of reference for the quality manager are broadly that he should ensure customer satisfaction economically, rather than costly over-perfection.

Because there is no linear measurement of quality which can be

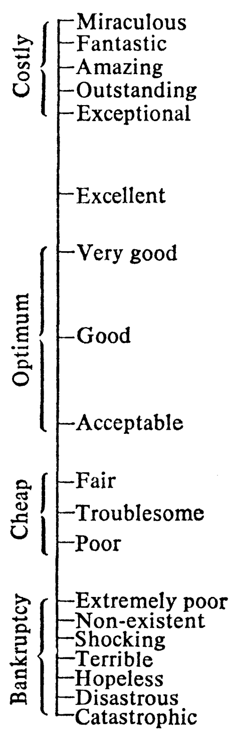


Fig. 1.1. Quality scale

readily evaluated or determined, the quality manager is faced with ensuring that his company operates at the optimum range of a very significant attributes type of quality scale, as shown in Fig. 1.1. Fortunately, the desirable regions of this type of scale occupy a wide span, as shown in the diagram. The suicidal extremes are more logarithmic.

No company would logically set out to occupy either of the extreme positions. The quality manager has a major responsibility in ensuring that a drift in either direction does not take place. Managements normally provide adequate support, where the factors are clear. The quality manager has to provide the information, data, etc., which will engender maximum support. The level of quality is very much dependent upon the individual quality manager. He has to make the guiding decisions, subjective or objective. He has to be seen to be fair, impartial and purposeful.

The situation is very similar to the effects of good management in other walks of life:

1. A bank staff reacts to the example and influence of a good bank manager. The service is prompt, efficient, courteous and considerate.
2. Conversely, a restaurant can provide a cold, badly cooked, limited range of food, with doubtful cleanliness and indifferent service, if the manager is himself indifferent.

In either instance, the actual relative costs are not directly significant.

The competent manager has to ensure that numbers and quality of personnel are appropriate and that personnel are trained, instructed and equipped for the duties involved. They must be provided with satisfactory supplies, materials, etc., and have equitable recompense. Personnel relations must be satisfactory.

Although 'custom-built' quality assurance schemes for particular applications are not available as a package, much has been written on quality practices and procedures which should help those involved in quality activities and management.

A short bibliography of publications on quality subjects is given at the end of this book, for the benefit of readers who seek further information.

2 | Administration

DESIRABLE ATTRIBUTES OF A QUALITY MANAGER

The personal attributes of the administrative head of the quality department are of prime importance. His individual qualities and ability to fit in with other senior personnel rate at least equally with technical competence and experience. He needs to be a stable, assured and not easily excitable person, particularly when under stress. The choice of individual to head a quality department needs very careful consideration and attention, as the overall success of the department is very largely dependent on first-class leadership.

Unfortunately, the personality of an individual is almost impossible to assess at an interview. Ideally there should be some dependence on reliable personal recommendation, or proven qualities previously displayed in a junior position, or in another appointment within the organisation. Let us list some desirable attributes:

1. Ability to communicate at all levels: upwards to senior management, or down to individuals, especially within his own sections; also crosswise, particularly to other departmental managers of equal status, supporting a bond of team spirit with good manners and good humour. Ability to express himself briefly, clearly and with sufficient confidence to inspire respect, but not resentment.
2. Ability to compile accurate and clear reports and information, conduct correspondence associated with the appointment, within the plant and with outside suppliers, customers, representatives, inspection authorities, etc. Good follow-up system.
3. His personnel should have optimum respect, optimism and confidence in him, appreciating disciplines imposed and examples set, while fully able to make contact to report or discuss departmental (or important personal) issues quickly.

Any executive who becomes 'too busy' to maintain adequate close liaison with his personnel will lose touch and control.

4. It is sound policy for the head of the department personally to interview potential 'new starters' (with the sectional head concerned, where the overall size of the QC organisation is appropriate).

   Such interviews should include practical tests, as well as technical questions on QC methods and procedures. The reader may possibly be surprised by the number of people who quite blissfully apply for appointments as QC personnel, but who are unable to use first-principle measuring equipment. In some instances they have been employed in certain industries and become expert in a narrow visual check activity and then assume they have overall quality experience.

5. He must manage his personnel fairly, without bias or favouritism, particularly with respect to salary or wage rates, merit awards, etc. In the larger companies these matters are mainly governed by job description and enrichment, salary and wage grades, performance targets and appraisals, management development and similar procedures. Nevertheless, the departmental head is still able to exercise considerable discretion and must be seen to be fair and impartial, particularly on these issues. It is most unwise to make firm promises of future advancement to personnel, particularly during initial engagement.

6. Closely allied to the above factors, most quality managers become involved in trade union discussions at various levels. Very special care is essential in such duties. Industrial relations is a major subject, which is outside the scope of this book, but is amply covered by various publications and guidance material.

7. The QC manager must keep himself and his personnel up to date with developments and with new equipment and technologies in his field. Most companies run training or instructional courses of various kinds and there is no lack of symposia seminars, courses, etc., on quality control, both nationally and internationally. In fact the main problem is to decide which ones are worthwhile attending. This kind of activity has tended to become 'big business' with substantial course fees required.

8. No individual can be a specialist in all fields. The good quality manager recognises his own limitations and, where required,

enlists the aid of specialists in such fields as electronics, process controls, chemical and metallurgical laboratories, X-rays and non-destructive testing.

9. Chairmanship of various committees and meetings is often required. Again, this is a subject in itself and outside the scope of this book. There must be ability to keep meetings controlled, brief and purposeful, to issue agenda and write minutes, with actions, and to ensure follow-up.
10. The head of the quality department needs to be able constantly and convincingly to 'sell' the philosophy, principles, purposes and mutual benefits of optimum quality control.

This list does not claim to include every desirable attribute, but it is already sufficiently long for readers to begin to feel that 'birds' with all the above qualities must be extremely rare. Let us therefore turn to the administrative aspects of a quality control department.

TYPICAL INDUSTRIAL SEQUENCE

The scale of activities will of course be proportional to the size of the company. However, virtually all companies operate on varying degrees of the following sequence:

1. Market research.
2. Engineering design; testing; specifications.
3. Sales; orders.
4. Planning.
5. Purchasing.
6. Incoming materials; supplies.
7. Manufacturing.
8. Processing.
9. Assembly.
10. Test.
11. Packaging; dispatch.
12. Spares; service.

It is appreciated that many other activities may be significant, such as personnel, accounts, etc., but the main involvement of QC usually occurs in the latter stages, 4–12 inclusive. Smaller companies on purely subcontract work will be even more specialised around the production stages.

REPORTS

Finally, under administration should be mentioned the importance of a regular report by the quality manager to management.

This activity is additional to normal routine reports and returns. These special summary reports can be issued at intervals of not longer than a month. Intermediate urgent matters or events should, of course, be reported separately and immediately.

The quality manager's monthly report summary should preferably not simply record extensive statistics which are available if required from normal routines, e.g. the number of batches of work passed through a department.

The report should be concise, easy to read and should highlight features to which it is desired to draw attention or to provide information.

The exceptions to routine activities are the matters about which management needs to be informed, e.g.:

1. A very significant increase (or decrease) in the number of batches of work handled, especially any much higher defect or rework experience.
2. Serious quality problems with particular suppliers.
3. Adverse field experience.
4. High scrap or reject experience.
5. Personnel problems, etc., wages, salaries, trade union pressures.
6. Serious delays in any areas.
7. Inter-departmental difficulties.

Management will appreciate such communications from the quality manager and will usually liaise, support and follow up, as necessary, on the information provided.

QUALITY CONTROL OF DESIGN

Much has been written about quality control of design, recommendations on practicability of tolerances, machine capability studies and other specialised techniques. While these more sophisticated procedures are practised (mainly in the larger companies), they are not generally widespread. Further comment will be made on them in later chapters.

As a general rule, the QC department's involvement begins with the planning stage. Gauging, facilities, equipment and inspection methods require consideration and action. Large companies enjoy 'gauge planning' and 'inspection methods' personnel. In a small organisation the quality manager plans these activities.

Next comes liaison with purchase and supplier appraisal, followed by receipt of raw materials and bought-out finished supplies. These features will be covered more fully in Chapter 5.

There follows the manufacturing, assembly, test and packaging stages, all of which will also be covered in later chapters. The last stages of spares and service will normally directly affect only those companies marketing their own proprietary products. Nevertheless, these are again important areas which will be covered later in this chapter under the heading of field reports and liaison (see p. 40).

TYPICAL COMPANY ORGANISATION STRUCTURE

Fig. 2.1 illustrates very briefly the relationship of a quality department in a company and the basic departments in an average quality control organisation.

Some companies (mostly small in size) still do not operate a recognisable quality activity.

Depending on a company's size and type of product, this basic structure can be amended as appropriate. It will normally show titles such as quality manager, his deputies or assistants and the respective departmental supervisors, who may be variously called foremen, assistant managers or quality engineers. Except in the very small company, the quality manager's importance should merit his having an efficient personal secretary. Such services provide immense help with administration activities and general organisation.

In setting up his organisation, the quality manager must keep uppermost in his mind that the personnel outlined above are primarily administrative and rarely carry out actual inspection or quality control duties. Too much supervisory cover is very unlikely to ensure good quality production. The production or assembly-floor involvement of quality rank-and-file personnel is the essential requirement of efficient quality control. These are the areas where the **support** of quality people has the main company impact and value. In the smaller companies where the total people engaged on quality control are few in number, such problems should not arise.

Where the quality manager has a department of such a size that it merits deputies and foremen, he must ensure that such personnel

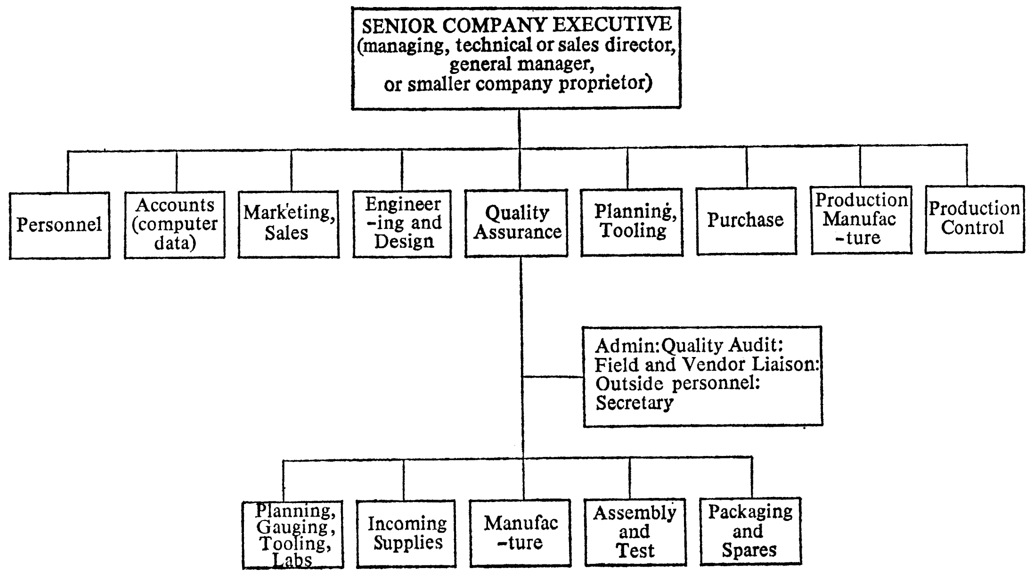


Fig. 2.1. The quality department in a company, and its sections

have the appropriate technical competence and personal qualities, and considerable care must be taken when any such appointments are made.

Similarly, the relative status of such personnel must be clearly defined for a satisfactory and important departmental team spirit to prevail.

PERSONNEL RATIOS

The above comments touch indirectly upon the subject of ratios of numbers of personnel. Inspection or quality control is an activity where it is all too easy to engage too many personnel. All such people will appear to be actively inspecting and most likely over-inspecting by, e.g., repetitive or multiple inspection of the same work in differing locations.

This is a most undesirable situation which can give rise to severe criticism. 'Too much' inspection results in critical standards and high reject levels, with corresponding and justifiable resentment by all concerned, particularly production personnel.

Similarly, inspection activities should be continuously monitored, otherwise some work will continue long after the need has disappeared. The same comments also apply to paperwork systems and records.

Unfortunately there is no simple or reliable way of assessing ideal ratios of numbers of quality personnel. Without significance of importance in the relative order listed, some of the many factors involved are:

Size of company.
Type of product.
Variety of product.
Quantities.
Manufacturing methods.
Condition of equipment (machines, processes).
Tooling and gauging.
Class of labour: skilled/unskilled/male/female; labour turnover/training.
Shift-work problems.
Proportion of in-house manufacture.
Company quality standards; attitude; support.
Design standards; specifications; complexity; tolerances.

In some companies raw material supplies are controlled by chemical or metallurgical laboratories which are headed by the chief engineer. Similarly, final test personnel are also sometimes controlled by the chief engineer. In other companies these people are part of the quality department. These are just two instances, apart from the above list of factors, why ratios will vary markedly between different plants and companies.

Additionally, the method of computing ratios may vary widely. Inspection or quality personnel are most commonly expressed as a ratio of actual numbers on production, i.e. people actually making the products, direct operating personnel. To be realistic, this ratio should exclude the administrative staff in the QC department and count only those actually carrying out physical inspection duties. However, it is normal to include the whole of the QC personnel when assessing ratios; hence the importance of keeping QC administrative personnel closely controlled in numbers, as stressed previously.

The reader will no doubt still expect some guidance on ratios, but this guidance can only be very approximate for the reasons outlined above.

Ratios can vary from one inspector to four producers in an industry such as aero-engines, and conversely, to one inspector to forty producers in industries where the nature of the product is less critical, or the processes are automated and very unlikely to require other than infrequent sample monitoring.

These would normally be considered the extreme ranges. Always the aim should be to place the responsibility for quality with the people actually producing the product. Quality personnel primarily monitor the product and should not relieve the producers from their responsibility for ensuring a satisfactory product.

The reader will obtain some further guidance by noting the concentration of ratios which roughly prevails to one side of the mean of the range as shown in Fig. 2.2.

Normally a general machine shop is an area where the need for most inspection of quality control is necessary. Parts are being originated from raw material and faults can easily mean costly scrap or rework and delay. Conversely, in assembly areas the final function and performance tests can be sufficient to monitor product quality adequately. Failure of product to pass final test can usually be resolved by further adjustment or assembly correction backed up by action to prevent recurrence at the source of the trouble.

It is appreciated that some readers will know of areas where the above general statements are not applicable. For example, some companies use highly skilled machine-shop operators upon whom they are able to depend for quality, without extensive cover by quality control.

Some products, if wrongly assembled, can be extensively damaged

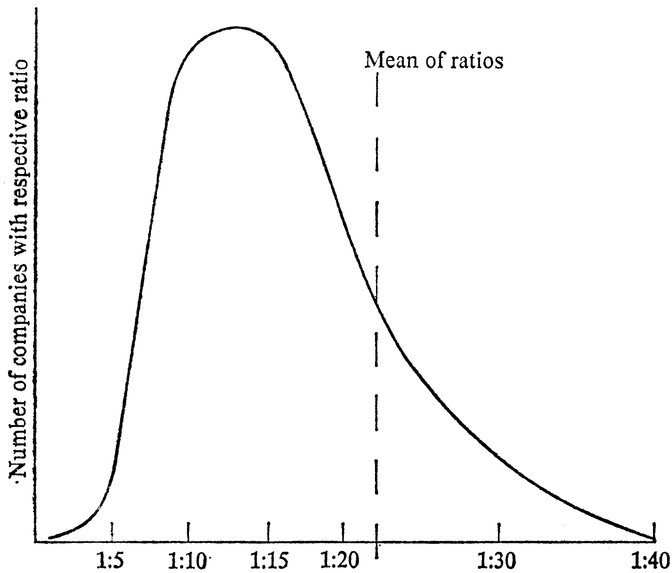


Fig. 2.2. Ratios of quality control personnel to number of producers

during final tests. Hence the need, in such instances, for stringent sub-assembly quality controls.

Clearly, in any industry a great deal depends upon the quality manager, his senior personnel or both, in exercising careful and continuous monitoring of inspection duties. Skill and acumen in this field, closely applied in the day-to-day activities, is the only positive way of ensuring satisfactory ratios. The QC manager must not be an 'empire-builder'.

There are dangers in applying too sophisticated methods, such as incremental times for each step involved in inspection, especially if multiplication is carried out on initial approximations:

10 minutes to obtain drawing and paperwork
90 minutes to inspect
10 minutes to write report
10 minutes for discussion on results

120 minutes = 2 hours

If one then proceeds to multiply such data by, say, 500 batches of work in a week, one obtains a total of 1,000 hours, equivalent to 25 personnel on a forty-hour week. Even this has to be amended foı an average (say) 80 per cent effective time utilisation, resulting in 31¼ inspectors apparently being necessary. This is usually rounded off to 32, and could be repeated for several departments. The result would be gross overstaffing. The reader will readily see the flaws in such a system.

Another fallacy often put forward is that if the rate of production is varied, the inspection or quality personnel should vary directly proportionately. The quality manager who adopts this argument must be prepared for it to operate both ways. If it is contended that because output is doubled, twice the number of inspection personnel are required, then conversely a halving of output should justify a 50 per cent cut.

Obviously, increased output results in better production tooling for larger batches and longer runs, and could mean only marginally more inspection. Alternatively, more machine tools could be involved, or additional shift working. The effect of these latter measures would have a more significant impact on the amount of quality coverage required.

These factors serve to illustrate the difficulties in attempting to specify inspection ratios by arbitrary means, and emphasise the importance of the integrity and expertise required from the quality manager in establishing his personnel requirements relative to his particular company.

In the context of goods inwards and tooling inspection, there are further special factors in connection with personnel ratios which will be dealt with in Chapters 3 and 5.

Finally, the continuing advances in semi-automated processes and equipment have a bearing on this subject, and some examples of new developments on these lines are dealt with in Chapters 5 and 7.

QUALITY COSTS

Staffing ratios are directly connected with quality costs. In this respect, simple personnel unit numbers can sometimes be varied. For example, it may be practicable to utilise higher numbers of semi-skilled personnel and juniors on certain work rather than small numbers of costly, highly skilled personnel.

Much has been written on methods of assessing the value of quality, ranging from the costs of actual appraisal or monitoring through fault prevention, corrective action, costs of scrap, service and warranty claims. Transcending all these in importance is the ultimate target of optimum customer satisfaction.

Unfortunately, unless a company has actually and painfully experienced the effects of poor overall quality, it is usually difficult to allot meaningful criteria and values in these areas. A few examples follow.

A reduction of a very high scrap rate by additional expenditure on QC can look most impressive and could no doubt be fully justified. However, the improvement could also be due to better facilities, prompted by QC effort. Indefinite continuance of the same higher level of incidence of QC cover may not be necessary.

As stated in Chapter 1, an optimum acceptable level of quality is

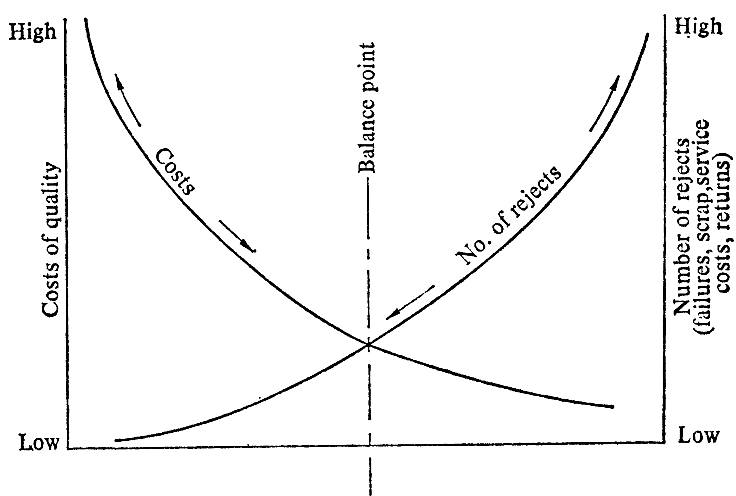


Fig. 2.3. The acceptable balance point between quality costs and incidence of failures

the correct target. The costs of quality accelerate rapidly according to the nearness of a goal of absolute perfection.

Fig. 2.3 illustrates that there can be a point where an acceptable balance occurs between quality costs and the incidence of quality failures (rejects, scrap, returns, etc.).

It must be emphasised that better quality can often be achieved **without** a corresponding increase in costs. Rejects can be reduced by better staff instruction, organisation, or methods and facilities without significant cost penalties. Obviation of piece part faults can minimise assembly problems and ensure satisfactory function on final test.

BUDGETS

Personnel ratios and quality costs lead logically into budgetary controls. Virtually all modern companies operate on a budgeted costs basis. One of the more important duties of the quality manager is to prepare his departmental budget, submit it and obtain approval from management. Usually budgets are on an annual basis, with periodic reviews and future forecasts.

To enable him to prepare his budget, the quality manager must have detailed advice from management of production programmes, activities and anticipated new developments.

The primary sections of a budget are normally personnel, test expenditure, capital plant and equipment, furniture and fittings, travel and training. Then possibly more incidental items such as stationery, printing, etc., which may or may not be covered by individual departments in some companies.

In most instances personnel costs form the bulk of the expenditure of a quality department. Hence the need for the careful control of numbers emphasised earlier. In assessing his personnel costs, the quality manager must allow for wage and salary advances, overtime and night-shift premiums. High incidence of overtime and night-shift working can add substantially to the total. Hence the need for information on production programme plans.

Anticipated increases (or decreases) in personnel strength are usually required to indicate their phasing-in over the period being budgeted. This is logical, as an effective budgetary system will provide for monthly returns from accounts to departmental managers reporting progressive budgetary experience.

In some companies test expenditure can be the next largest figure to personnel. This activity is also closely related to production programmes. However, the quality manager needs carefully to review test procedures periodically and especially at budget times. Test experience may show that some procedures can be modified or improved with possible cost savings.

Another significant area of expenditure can be for capital equipment items. Modern budgetary control usually requires that proposed expenditure on capital equipment be supported by information on probable savings in time or manpower, improved efficiency, etc., and also on whether the new equipment replaces or augments previous equipment and has any disposal value. Details may also be necessary showing that the equipment is the most economical for the purpose, relative to cheaper alternatives.

When budgeting for capital equipment, the quality manager must allow for cost increases which may arise between the time of submission for approval and the actual delivery of the items concerned.

The other areas of budgetary expenditure mentioned earlier are not usually major cost activities. Further comment here is not deemed necessary as their estimating and control are fairly straightforward.

All sections of the quality department should be consulted on respective budget factors. Personnel must be encouraged to anticipate future requirements and advise their needs. Items belatedly found essential, after budgets have been prepared and approved, entail supplementary cover, which can be very difficult.

Furthermore, the involvement of personnel in the budget preparation promotes their active participation in subsequent operating results and any corrective actions required.

QUALITY AUDIT

An efficient quality organisation will operate a systematic quality audit procedure, to ensure that the procedures in operation are being followed consistently and that the outgoing product quality is meeting design and performance requirements. Procedures should audit:

Piece part manufacture (including raw material controls).
Sub-assembly stages.
Final assembly and test.
Packaging and dispatch.

Product should be selected on a random basis for audit, to avoid audit checks being anticipated.

The audit should not simply be a repetition of previous routine procedures, but directed more towards observing the random unforeseen faults which can virtually creep up on a well-organised routine, e.g.:

1. An operator is ill and a new operator creates a fault, or omits a step in a process.
2. Effects of one of the many possibilities of damage.
3. Breakdown of equipment, especially intermittent faults.
4. An unauthorised, albeit well-meant, change is introduced.

In other words the skilled audit observer virtually looks for troubles which have escaped the system.

Audit personnel should have reporting status direct to the quality manager. Graphs of the incidence of audit checks to total production should be compiled to present a readily appreciated picture of results.

Faults found should be detailed individually in reports with action required and people responsible, including any retrospective action and steps required to prevent future recurrence.

The audit function should extend right up to the user or customer satisfaction stage. Too many companies assume that because a product is manufactured successfully it automatically satisfies the customer.

Some companies operate good market research and customer liaison activities, but the emphasis is frequently on pricing factors, publicity, market share, etc., as distinct from satisfaction on design, reliability and quality.

In Chapter 9 some further comment on this theme will be made. However, the engineering industry does produce various products which have limitations to some degree. The motor industry is usually singled out in this respect, possibly to some extent unfairly, but so many features which annoy the customer could be fairly readily improved by better quality audit or market research activities. It is appreciated that this is an industry where price is usually the limiting factor. Improvements are not very readily adopted if higher prices are a consequence. The industry is very skilful in emphasising virtues and excluding limitations. Let us list a few examples which come into the categories outlined:

1. Elimination of certain suspension routine lubrication sometimes culminates in the long term in more costly overall replacement of the 'self'-lubricating assemblies.
2. Sealed beam headlamp units have to be replaced complete if the front glass is broken, or chipped by a stone.
3. Front wheel drive and independent suspension sometimes have heavier tyre wear and universal drive replacement cost penalties.
4. A stainless steel exhaust system would cost little extra initially, but would obviate the usual two-year replacement of the modern very thin-section corrodable type usually fitted.

Readers can no doubt list similar features which are price rather than direct quality of manufacture factors.

Conversely, the overall reliability and performance of the modern motor-car is exceptionally good. Despite the millions of miles covered by motor vehicles generally, it is comparatively rare to see one stopped at the side of the road owing to mechanical failure, or malfunction breakdown – this despite the fact that many owners often neglect this everyday but complex piece of machinery to the extent of failing to add water, oil and even fuel adequately.

The advent of motorways and continuous higher cruising speeds resulted in a short period of slightly higher breakdown incidence. The industry rapidly adjusted and cars regularly and reliably achieve high sustained speeds (on motorways) which were absolute maximum speeds a few years ago.

Let us be fair and proceed to list a few other engineering industry aspects which have limitations as seen by the user:

1. The ordinary domestic reel-type lawn mower is difficult to clean and usually has a limited capacity grass box which is 'fiddly' to fit and remove. The motor types rarely start readily.
2. Most domestic household appliances need frequent service, despite the fact that the hours of usage, compared with industrial equipment, are very small.
3. The instructions for assembly of many items supplied as kits rarely take into account that the users may not be engineers or understand technical terms. Diagrams are unclear.

These examples are intended to indicate the desirability of the quality audit function extending beyond manufacturing stages.

PACKAGING AND TRANSIT AUDIT

The satisfactory packaging of products is a vital link. A beautifully finished and well-engineered product is useless if it reaches the customer corroded or damaged. Packs suitable for various transit methods and distances are usually necessary, as it is rare for one kind of pack to be universally applicable. Even the packs themselves can have problems. Some countries will not accept timber packaging materials which have small areas of residual bark owing to insect or grub dangers.

Protection from moisture, corrosion, sea air and the elements can be necessary.

Supplementary items packed with a main product must be of correct type and quantity and clearly identified. It should not be overlooked that such items can easily be accidentally thrown away with the packaging materials.

Audit procedures should therefore verify satisfactory packaging and transit unless such factors are covered separately within the organisation.

A very important activity associated with packaging is the supply of spares. It is very important that spares should be right, correctly protected and packed, and clearly identified. Few things are more frustrating than a spare in an out-of-the-way place, at a difficult time, which proves to be damaged, of the wrong type or short of essential details.

Some special comments on damage are desirable. Despite normally satisfactory packaging, products can still be damaged owing to special factors, e.g.:

A lorry may be involved in an accident.
An insecure load can fall off, or a stack of products topple over.
Work can fall off a hand truck.
Heavy objects can be placed or dropped on to finished work.
Work can be distorted by too high stacking.

It is clearly impossible to foresee and prevent all such eventualities. The important maxim is to ensure that all personnel handling goods understand their quality involvement. They should be encouraged to report any such problems for action and be sure that they will not be criticised for their involvement in any mishap.

It is appreciated that in the areas outlined the activities of audit can interact with other departments and that total quality control concepts arise. Normally quality audit activities are readily accepted as constructive and helpful and maximum co-operation is received.

FIELD REPORTS AND LIAISON

Quality departments of companies which market their own products (directly or indirectly) should be actively associated with field reporting and service engineers. Quality audit also has interaction in these areas.

Product quality can be constantly monitored and continuously improved by information on field experience. The system of field reporting should provide regular and adequate details and include return of failures for examination and any corrective action required. Similarly, at the plant, field information must be promptly and regularly studied and analysed. Action necessary must be instituted and followed up effectively. The field should be advised of results of analysis and the action taken, and regular field service bulletins issued.

Visits to operating branches and liaison with service engineers and customers are valuable to all concerned. These external people can often comment and advise upon design, reliability and quality facets. Factory personnel can see the field and customer problems and often arrange appropriate action for improvement and support.

TRAVELLING AND OUTSIDE RESIDENT QUALITY PERSONNEL

The organisation of any quality personnel with duties outside the factory rests primarily on the administrative function of a quality department. Companies who purchase large volumes of supplies sometimes find it advantageous to have external QC cover. Depending on the scale and geographical factors, this activity can be covered by travelling or resident personnel, or both.

The travelling inspector visits suppliers and approves batches of supplies for dispatch. He may sign dispatch paperwork or issue a clearance certificate. Such supplies should not warrant further inspection upon receipt other than for possible corrosion or transit damage. This procedure is particularly suitable where special packing is involved or where the supplies are being forwarded direct to 'the field'.

Where the total volume from one supplier is large, or consists of many different types of part, there can be justification for a resident quality representative. Similarly, in large cities or manufacturing areas, a locally resident QC man can cover several companies. It is important that visiting or residential personnel should mainly ensure that the supplier's QC people are operating effectively, rather than relieve them of their responsibilities by doing too much checking. In the same way, the supplier's managing director must appreciate that he is still responsible for any faulty work found after delivery and must accept any rejects, despite the fact that the batch delivery has been nominally accepted by the customer's representative.

The advantage of these procedures is that they largely ensure receipt of satisfactory goods and save transit costs and delay. The latter can arise on normal goods inwards inspected supplies which have to be rejected.

For other than resident personnel, the disadvantages are the costs of travel and accommodation and the calibre of personnel required. Such personnel need wide experience over a range of supplies and must operate reliably with minimum supervision.

Travelling, rather than actual quality work, can occupy a high proportion of total time and frequently results in demand for additional personnel. Visits by normally main-plant-based goods inwards inspection personnel can often operate as a successful compromise arrangement.

CONCESSIONS AND PRODUCTION PERMITS

In most companies the quality manager becomes administratively involved in concessions and production permit procedures.

Concessions are used on occasions when detail parts, or products, **which have already been produced,** are found to have discrepancies, or fail to meet performance or functional specifications. Concessions should not be used if it is possible to correct the part or assembly by appropriate rework.

The quality manager, chief engineer, design engineers, chief metallurgist and other senior people involved must invariably be satisfied that the deviation can be permitted before concession procedure is operated. The document is serial numbered and provides a record of the event and the quantity involved, in addition to authorising the deviation.

It is most important that the reason for the deviation should be recorded and action taken to preclude recurrence. Particular concessions are primarily 'once only' events. For the same reason, repetitive concessions must be discouraged, otherwise today's concession becomes future tolerance of greater latitude. In due course such greater latitude is again exceeded. Similarly, the incidence of concessions should be constantly monitored. Undue numbers of concessions can indicate overall quality degradation.

The quality personnel must never apply the concession procedure unless **they** are satisfied that the deviation does not impair quality. It is wrong to submit a concession application to other signatories in the hope that quality people will have a difficult 'accept or reject' decision made for them. Similar comment applies to companies producing on a subcontract basis, who apply to the customer company for latitude on defective products they have produced.

Production permits are normally used to allow production of a specified quantity of items or product away from specification. Note that this procedure allows a **future** deviation as distinct from a concession.

Usually this activity is because of material supply limitations, new tooling problems, tooling breakdown or process difficulties. The same general cautions apply as for concessions. However, it is not uncommon for production permits to be subsequently ratified by drawing or specification changes adopting the revised situation for all future production. Sometimes the production permit is used to introduce changes in design pending normal modification procedures.

QUALITY PUBLICITY

The appreciation of the purpose, aims and objectives of a quality organisation within a company needs to be constantly publicised by the quality manager to sustain interest and understanding. The extent of such activity will depend on the situation prevailing at any particular time.

A newly appointed quality manager in a company which is commencing quality activities will have a major responsibility for presenting the quality objectives throughout the organisation.

The prudent approach is to introduce any new quality control activities gradually, into one section at a time, and to win acceptance and approval such that other sections become anxious for the 'new system' to be applied in their areas.

People are naturally averse to change. Wholesale application of 'new' quality control methods over a complete plant can be very difficult.

All quality activities are particular to respective industries and plant conditions. There is no universally applicable method. Hence gradual introduction will facilitate amendment to suit local conditions concurrently with the breaking down of initial resistance.

In plants with established quality control activities, the 'publicity' may comprise formal routines:

1. Regular meetings with production, design, planning and quality control personnel on quality trends and on problems, scrap, rejects, rework and actions required, e.g. campaigns to reduce scrap.
2. Periodic reports for each section and overall plant quality levels.

EXTERNAL QUALITY AUTHORITIES

The quality manager and his personnel may have involvement with visiting surveyors, consultants and agents, from official government ministries and public associations. There are many such organisations and regulations to which conformance is required with certain products, particularly those with electrical and other safety aspects.

As a general rule, visiting surveyors like to see evidence of an efficient quality department operating systematic procedures. They will then delegate the detailed verifications and checks required to the company QC personnel. Surveyors will wish to witness certain tests and see satisfactory records of routine checks, equipment calibration, etc. Some organisations require certificates of quality and test results.

The essential requirement is the establishment of the surveyor's confidence in the quality procedures.

In this context, the evidence of effective and comprehensive quality control can often be of considerable influence on prospective customers visiting the plant. Customers impressed by the standard of quality seen during a visit often follow up by placing substantial orders. This is particularly true of overseas visitors.

3 | Tooling and Gauging

GAUGE PLANNING AND PROVISIONING

As mentioned in the previous chapter, the quality department may or may not enjoy the benefit of a gauge and tool planning section.

In the smaller company it is usually the responsibility of the quality manager to assess and provide for gauges and tools. Almost invariably the provision of first principle measuring equipment, such as micrometers, verniers, height gauges and thread gauges, is arranged by the quality manager, whatever the company size.

Companies of a size which operate a production engineering, or planning, department usually arrange for production checking equipment for use by operators. Such gauging is normally of the fixed-limit go/not go type, ranging from plain caliper (gap) gauges to the more sophisticated acceptance or receiver gauges.

At the time that operator checking facilities are planned, it follows logically that inspection equipment is also provisioned simultaneously, by production engineering or gauge planning. However, it must be stressed that a policy of duplicating all gauging, into workshop and inspection allocations, is not recommended. It is costly, time-consuming and inefficient, for reasons which will now be explained.

Comment has previously been made that the primary purpose of quality control is to ensure that the producers have the facilities to check their work as it is produced. If gauging is duplicated, disagreements between workshop and inspection versions often arise, leading to uncertainty and frequent rechecking of gauges. Meanwhile production is held up and suspect parts quarantined. The better arrangement is nominally workshop gauging only, with adequate routine gauge inspection controls to ensure that such workshop gauging is satisfactorily maintained.

Inspection personnel carry out a monitoring procedure commonly referred to as a 'call-off check'. They can either request to see an operator carry out a check on an article just produced, or they actually select a recently produced item and test it using the operator's equipment.

Some companies arrange to include an allowance in the operator's time to cover the checking of his work. This can be a time to check possibly every item, one in three, one in five, or one in twenty, according to the likelihood of the parts varying, or the importance of the operation concerned.

Where gauges involved are of the more complex type utilising dial indicators, or various other kinds of gauging head, it is sound practice to have a setting master available at the point of production. Such masters are used to verify the gauge settings periodically. Where masters are provided, quality personnel invariably cross-reference with them before carrying out monitoring checks.

The above comments apply largely to the production use of gauging, primarily in manufacturing or assembly areas. Mention is made here to avoid repetition in later chapters and to emphasise the principles of sound gauge provisioning.

ROUTINE GAUGE CONTROLS AND SYSTEMS

As mentioned above, a good system of routine gauge control is an essential corollary to the principle of workshop gauging. There are a number of ways of ensuring periodic recheck of gauging, largely depending on company size. Where the total number of gauges is small, routine checks on, say, a weekly basis can sometimes be arranged as one QC individual's responsibility.

With large companies and large numbers of gauges, a problem arises in simply locating and collecting gauges for checking, and also in avoiding production hold-ups while gauges are being checked.

A card index in a gauge store can have a date follow-up system indicating gauges which successively become due for check at varying intervals, according to wear rate and importance of tolerance involved.

One way of overcoming the location and collection problem is to have departmental mobile routine gauge inspector(s) who patrol specified areas systematically. This system minimises production delay and can avoid having to move heavy gauges away for checking.

Another system utilised is to date-mark gauges when they are **next** due for check. Coloured cellulose tapes with rolls for each day of the month are used. There is a roll with all figure 1s marked on it, another with figure 2s and so on up to 31. Another set in a different colour is used for the next month, with usually up to three months' total.

This avoids a gauge being dated, say, as due for check on 28 January and marked in yellow, being thought to be still O.K. for returning for checking on 28 February. The colour for February could be blue for example. A gauge marked in yellow for 28 January would clearly be out of date on 1 February, when the colour is blue, if the gauge had not been sent for check on 29, 30 or 31 January.

This system works well but requires the co-operation of gauge users and particularly supervision, to be on the lookout for 'outdated' gauges still being used.

The permitted interval allowed between checks on various types of equipment will depend on a number of factors:

1. The frequency and amount of use.
2. The conditions of use; presence of abrasives; material being gauged. (Cast iron wears out gauging quickly.)
3. The tolerances involved. Small tolerances permit very little latitude for wear on gauging.
4. The feature being measured and method of measurement. Holes wear out plain plug gauges more quickly than diameters wear out plain caliper gauges. Similarly, internal screw threads wear out screw plug gauges more rapidly than screw caliper gauges. The wear on screw plug gauges can be a particularly pronounced taper effect. It is worth while enlarging on this aspect: Imagine a 1 in. (25·4 mm) diameter by 16 TPI screw plug gauge checking threaded holes 1 in. deep. The reader will realise that the outer leading end of the thread on the screw plug travels $\pi(P_T)$ times the diameter, for each revolution, or very roughly 3 in. (76·2 mm). In gauging a thread 1 in. deep with sixteen threads per inch, this outer end of the screw plug thread therefore travels approximately 48 in. (1·22 m) in, and the same amount out again – a total of 96 in. (2·44 m) for each threaded hole gauged! Other portions of the screw plug gauge travel proportionately smaller distances and wear correspondingly less, thus giving the tapered result mentioned.

Possibility of damage is also a significant factor in assessing intervals between checks for various gauges, etc. This is an area where maximum co-operation of all users is paramount, in reporting possible damage and arranging recheck. No routine system can really cater for damage aspects, as damage can occur within minutes of the last recheck. Excluding damage factors, it is usual for periods between recheck to vary from two to thirty days, to meet the criteria outlined in 1–4 above. This range is sometimes extended, at either end, to suit special circumstances.

So far we have commented mainly upon the linear measuring type of equipment. Many companies use torque tools, pressure gauges, revolution counters, flowmeters and a host of similar kinds of special-purpose test facilities. Then there is also a whole family of electrical test meters ranging from resistance testers to oscilloscopes.

All such apparatus should, of course, be regularly tested and systematic records kept of calibrations. In some instances reference to official test laboratories is necessary, as basic standards can become involved. It is outside the scope of this book to cover the various special procedures involved.

Some of the larger companies maintain laboratories specialising in individual fields. Electrical component makers have extensive electronic meters and equipment. Material suppliers may have metallurgical and physical test facilities as well as chemical laboratories and heat-treatment equipment. (See p. 50 below on the British Calibration Service.)

METROLOGY LABORATORY; STANDARDS ROOM; JIG AND TOOL INSPECTION

In manufacturing engineering it is fairly common for companies to operate varying degrees of sophistication in the spheres described by the above headings.

Almost all companies provide some of their own tooling. Even those larger companies who make a lot of their own tooling also depend very much on outside toolmakers and the specialist facilities required.

The area in a company where tooling work is controlled can be variously known by one or more of the above three headings. Some companies maintain separate departments with jig and tool inspection possibly controlled by production engineering or toolroom supervision, rather than directly by quality control. Whatever the title of the department or departments, these are the areas where accuracy and suitability of tooling and gauging is assured.

Figs. 3.1, 3.2 and 3.3 show a rather sophisticated metrology department operated by one of the large industrial organisations, and a view of a gauging fixture being checked.

Some readers may become involved in establishing such departments and may welcome comment on the equipment required. Such facilities can be expensive and the level of expenditure is usually

TABLE 3.1

Description of equipment	*Approximate cost* £
Surface table (size range extensive; size required determined by relative work dimensions; granite types have advantage but are more expensive than cast iron, except in the larger sizes)	50–1,000
'Slip' gauges (sometimes known as 'block' or end length gauges), 1 set	100
Slip gauge accessories (these considerably extend the usefulness of slip gauges)	150
End measuring bars, for longer lengths	150
Accessories for end measuring bars	200
Optical projector (large range available)	200–5,000
Surface finish instrument	400–2,000
Vertical comparator	300–1,200
Horizontal measuring machine	1,000–5,000
Circular indexing table	400–4,000
Optical dividing head	1,500–3,000
Universal measuring machine	6,000–12,000
Accurate spirit level	50
Gear measuring instrument/rolling tester	1,000

closely related to the relative size of the company and the nature of products manufactured. For example, castings usually require minimum facilities for high-precision measurement, as compared with aero-engine or machined piece parts.

In Table 3.1 we list some equipment and rough costs, in approximate order of priority, which would be fairly typical in setting up a new department. It is assumed that most companies will already have micrometers, verniers, height gauges, vee blocks, dial indicators, engineer's parallels, sine bars, etc.

There are many other items of equipment which have specialised applications and are therefore not of interest except to a limited field. These include:

Sophisticated equipment for gear measuring such as involute and lead testers, bevel and spiral gear testers, automatic pitch and spacing measuring machines.
Slip gauge measuring and calibration equipment.
Interferometers and flatness testing.
Optical and lens test equipment.
Auto-collimators and alignment telescopes.

Enough has been said for the reader to appreciate that this is a highly technical field of engineering in which the equipment can be very expensive. Furthermore, such equipment has to be used by experts and very carefully maintained.

Metrology and jig and tool inspection personnel need to have extensive craft and practical engineering experience together with good mathematical ability, especially for trigonometric calculations. A methodical, systematic personality is desirable with clear, concise report-writing ability.

Reliable tooling and gauging is an essential requirement to ensure satisfactory quality production. Tooling and gauging is initially verified in these areas and subsequently maintained by the routine controls already described.

Efficient tooling can provide considerable assurance of product quality, and this can often minimise the amount of production inspection, because the likelihood of faults is reduced. Reference is made in this chapter (see p. 51) to press tools, which are very much in this category of satisfactory tooling virtually ensuring good product.

Another group is plastic moulding dies. If these are carefully made and tried out, they will produce many thousands of consistent accurate mouldings, with only a very small percentage of production requiring quality monitoring.

Figs. 3.4 and 3.5 show two fairly ingenious checking gauges which test features not otherwise easily verified by first-principle methods. Figs. 3.6 and 3.7 show a modern facility for high-precision measurement of cams, or similar profiles.

Various companies and organisations operate a scheme known as the British Calibration Service. This is a national service established by the British Government to provide facilities to industry and others for calibration and accurate measurements of virtually all kinds, using the types of scientific equipment listed above and other specialised facilities.

Some companies may have no justification for expensive equipment, likely to be used only occasionally for their own requirements. In such instances and for many other reasons the British Calibration Service is a very useful organisation. Full details are obtainable from:

The British Calibration Service
Stuart House
23–25 Soho Square
London W1V 5FJ

TOOL TRY-OUT

Even in the small company, tooling should always be verified and preferably 'tried out' before release for production. This procedure will ensure that any necessary tooling corrections are made before production commences and will avoid costly delays and idle production machines while belated corrections to tooling are carried out.

Some companies operate comprehensive 'tool try-out' procedures whereby most tooling and gauging (particularly new supplies) is tried out and proven. The actual production facilities (machines, materials and operation methods) should be utilised, duplicated, or simulated as faithfully as possible. Tooling and gauging is modified, amended, adjusted or even redesigned on the basis of these exercises.

Tool try-out is a very important activity upon which the ultimate product quality is highly dependent.

This activity can (and should) be extended to the purchase of new machine tools, particularly special-purpose equipment. Orders should be placed on the proviso that a new machine tool must be proven as capable of satisfactorily performing and consistently producing the part required, **before** the machine is dispatched from the makers. A tool try-out engineer will then visit the machine-tool makers for such proving trials.

This procedure ensures that the machine produces satisfactory product. It avoids many problems at the user's plant in struggling to produce good parts, if there are otherwise unknown machine-tool problems involved. Conversely, if it is known that the machine has been tried out satisfactorily, efforts can continue to overcome problems.

Even so, the machine-tool purchase order should provide that the machine must also be proven at the user's plant. This proviso is to cover possible transit damage or disturbance, which can easily arise with normally heavy machine tools, owing to the fact that some machines are often dismantled for transit and reassembled on arrival at the customer.

PRESS TOOLS

The tool try-out procedure is particularly applicable to press tools. It is very difficult to design a press tool to produce a component precisely. Adjustment on try-out is often necessary owing to various features:

1. Material variations in size and physical properties.
2. Blanking and piercing operations sequence.
3. Flow of material, particularly bends and radii, the need to overbend to allow for 'springback', section variations.
4. Flatness, distortion, surface marking, cracking, creasing, wrinkles, thinning.
5. Adjustment of press settings, overtravel, etc.
6. Size of press available.
7. Coated materials.
8. Single-stage or transfer tooling.
9. Lubricants used during pressing.

It is not the purpose of this book to enter into detailed aspects of the factors associated with press tool techniques. It will be appreciated that this is a very specialised field, still very dependent on individual know-how and experience. Quality personnel involved with press tool inspection and pressed parts can really only learn the finer points by practical and close connection with presswork production. Even then, there are problems of size range: pressed parts can vary from large car bodies to tiny clips, etc. Few people are experienced in all types of pressed part production.

The following illustrations show two smaller examples of some of the press tool features tabulated above. The first is a part produced from material $\frac{1}{8}$ in. (3·2 mm) in thickness. Fig. 3.8 shows the piece as blanked out and pierced.

The wider portion carrying the slots then has to be formed with a double bend and very little straight surface between the bend radii. Fig. 3.9 shows the plan view of the formed part and also five 'gripper'

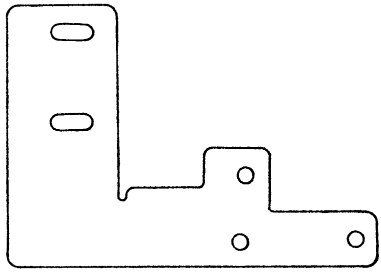


Fig. 3.8

marks on the surface. These are often used in presswork to hold material securely during severe forming operations. Fig. 3.9 also shows an end elevation and the bends produced.

The forming tool was tried out at the toolmakers on a 75-ton press and produced satisfactorily with this power. The manufacturer used a 40-ton press, and the part was then produced with the slotted portion out of parallel with the other surface. The tool was modified

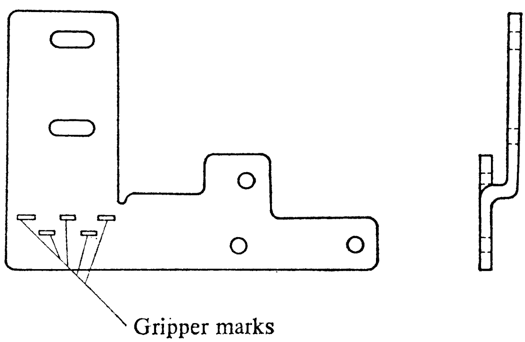


Fig. 3.9

to provide for a 1° 'overbend'. After 'springback' the part was again satisfactory.

This particular example illustrates one of the effects of relatively thick material. A further example is shown in Fig. 3.10, which again is a view of a piece in the blanked-out and pierced stage.

The next stage was initially to part form the bends, particularly as shown by the dotted lines in Fig. 3.11.

The third operation was to set the dotted portion to 90°. This operation proved unsatisfactory, as the thinner gauge material

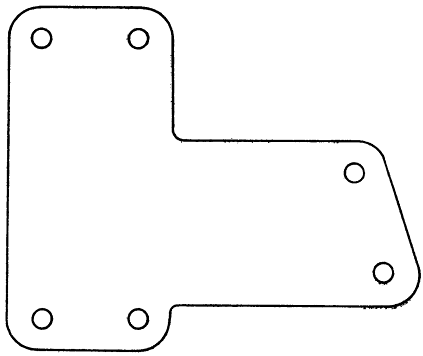


Fig. 3.10

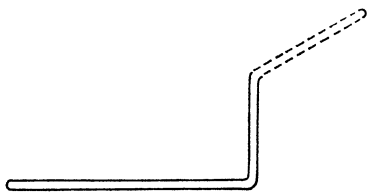


Fig. 3.11

involved in this instance moved on the previously formed completed bend and displaced the adjacent surface from the vertical, as shown in Fig. 3.12.

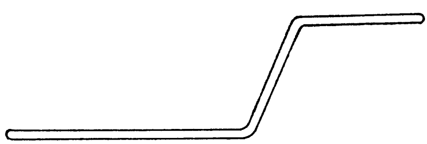


Fig. 3.12

The tool was remade to form the two 90° bends separately and successively, on individual formers, to provide the required finished part as shown in Fig. 3.13.

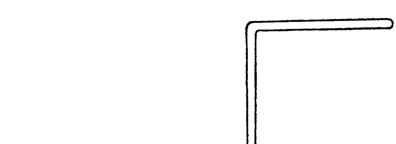


Fig. 3.13

It is appreciated that there would be alternative methods of overcoming this problem, possibly involving more elaborate tooling than the simple open-sided forms used on this part.

Figs. 3.14 and 3.15 are photographs showing typical pressed parts at a very early stage of assembly. The scope of the process is indicated by slots, apertures and large numbers of holes which can be accurately and consistently produced, when quantities justify appropriate tooling expenditure.

PRESS TOOL MAINTENANCE

This fairly lengthy comment on press tools would not be complete without reference to maintenance controls. A fully tried-out and approved tool will in time require refurbishing, after producing large numbers of parts.

It is good practice to operate the following system. At the end of a run on a press tool a sample of the last few parts produced should be attached to the tool. The samples and the tool are forwarded to tool control. The parts are fully checked and any signs of tool deterioration noted. Rework is arranged as necessary. If this is extensive, the tool is again tried out. This procedure ensures that rework can be carried out without production delay; moreover, the next run should be trouble-free and without tool breakdown.

JIG AND TOOL PERSONNEL RATIOS

Ratios of quality personnel engaged on tooling and gauging inspection depend upon:

1. Volume of product tooling provided.
2. Types of tooling.
3. Product precision.
4. Whether tooling made in house or bought out.
5. Sophistication of tool engineering and drawing standards, and whether the toolroom accepts entire tooling responsibility.
6. Whether metrology and routine gauge departments are operated additionally to jig and tool inspection.

The reader will appreciate how these variables make it very difficult to give much guidance. Very roughly, the number of QC personnel engaged on these duties approximate to one-tenth of the total QC in the average plant.

4 | Raw Materials

CRITICAL FACTORS

Adequate quality attention to raw materials is basic and fundamental to satisfactory product. Parts produced from incorrect material can have very serious consequences and failure effects, which can ruin complex machinery and installations. Effort put into producing parts which are made from incorrect material is wasted. Also, costly machining operations may have been expended.

Parts in wrong material are not usually readily apparent and will appear to assemble normally, sometimes into very complex assemblies. The subsequent dismantling time and costs to remove faulty material parts can be immense. Examples are faulty blades in a gas turbine aero-engine or engines for a large ship, or again a defective material in a nuclear power-station reactor.

In this chapter, and where necessary elsewhere in this book, some details are listed of 'causes' of problems. It is a valuable aid to good quality control to be aware of possible likely types of defect which can arise from certain methods and processes.

POSSIBLE SOURCES OF TROUBLE

Some companies accept incoming raw materials very much on trust and with very minimal verification inspection. Such complacency can have serious effects, as outlined above. This does not imply that overwhelming inspection activity on raw materials is recommended, but simply adequate monitoring.

Producers of raw materials normally provide reliable consistency of chemical and physical properties and the customer has a minimum element of risk in these areas. It is nevertheless wise to demand from suppliers, whenever raw material quality is important, certificates of test and conformity to specification. Adequate subsequent identification and segregation controls must be operated.

The danger arises from the fact that producers normally make large quantities, well in advance of the ultimate use by a manufacturer. Material is then handled by various firms – stockholders, etc.– split into smaller batches and held in stock for long periods. Few manufacturers use quantities large enough for them to deal directly with the raw material producer. Furthermore, the manufacturer cannot usually allow for the very long delivery period which would be entailed if his supplies were provided direct from steel mills, etc.

Therefore agents and stockholders are used who vary considerably in size, controls, facilities, etc. Clearly, very high standards of storekeeping, identification and orderly discipline are essential if material mixing or crossover of identification is to be avoided. Raw materials are not easily identifiable visibly, are heavy and difficult to handle and need space allocations for satisfactory segregation.

SAFEGUARDS

There are fairly comprehensive methods of material colour coding and identification marking specified by British Standards and used within industry. These markings are of value to raw material inspection personnel and provide a fairly ready means of control. (Unidentified material can be suspect and should always be verified, or rejected.)

The degree of verification of materials will generally depend on the importance of the intended application of the material, quantities involved, special physical properties or chemical analysis features. Sometimes a simple hardness check may suffice, or conversely full metallurgical and chemical checks may be necessary.

RANGE

These remarks have so far been mainly applicable to ferrous and non-ferrous materials and their basic properties as distinct from material manufacturing defects. Let us proceed to wider aspects.

Mention has already been made of weight and handling problems usually associated with raw materials. It is therefore desirable that the location of inspectional activity should be near raw material receipt, or a suitable initial quarantine area of raw material stores. The more normal forms in which engineering raw materials supplies are received are:

Bar: round, square, hexagonal, etc.
Sheet.
Strip; coils.
Forgings; pressings; stampings.
Castings; mouldings; sintered parts.

These forms may consist of main groups:

Ferrous/non-ferrous.
Stainless and special steels; nimonics.
Paints.
Plastics; synthetics.
Rubbers; rubber-based materials.
Glass; glass fibre compounds.
Chemicals.
Adhesives, etc.

CONTROLS

1. Ferrous and Non-ferrous Raw Materials

Each of these headings has special factors, problem areas and possible defects. Mention can only be made of some of the more common of these facets.

Size deviation and variation. Bar materials are usually consistent and fairly accurate for size. Some care may be necessary where portions of components produced from bar carry areas of the original bar on the finished item.

Portions of 'black' bar can be very irregular and of poor appearance. Ground bar can be slightly undersize and will not therefore produce components with slightly plus tolerance on the portion which is the nominal bar size. There is also very likely to be eccentricity of the unmachined to machined diameters.

Sheet materials can vary within the range of the gauge thickness tolerance and can also have local variations in thickness over the surface of larger sheets. Thickness variation can markedly affect press tool performance and may require special control, primarily on a sampling basis.

There are usually few problems with surface appearance and finish, although varying standards of finish can be purchased, particularly with stainless steels which are available from a matt to a highly polished finish. Flatness problems are not usually troublesome. Damage and scratching can be avoided by appropriate protection, handling and transit disciplines.

Chemical and physical properties. Some comment on these factors has already been made. It is usually possible to obtain material with a certificate detailing the chemical analysis and physical test results. These certificates should be specified as a requirement on the order. Such certification does not normally incur significant charge. Certification is a valuable routine procedure which can save much trouble and normally avoid the need for separate laboratory checks.

Hardness is a very significant criterion for many materials. It can be a valuable guide regarding physical properties. Materials for use with press tools can be supplied with a hardness range relative to a particular specification. These ranges are commonly known as soft, ¼ hard, ½ hard and hard. Once a press tool has been tried out and proven with one of these ranges of hardness, it is clearly important that future batches of material, supplied for use with the tool, should be to the same hardness standard. Otherwise unsatisfactory parts are very likely, or inability to produce from the press tool and possibly damage to it.

Defects in raw materials can occur in numerous forms. Surface markings can be caused by methods of processing – rolling, drawing, folds, etc.

Corrosion and contamination faults can arise for a variety of reasons. Some faults can stem from defects in the original large billet from which smaller sizes of bar and sheet have been produced. These arise longitudinally in bar material owing to successive rolling or drawing down to smaller sizes and thus extending original 'piping' defects in seams and oxide inclusions.

Inclusions can be of various kinds and can affect material physical properties or make machining difficult. Aluminium alloy castings can contain very hard inclusions caused by flaking from ladles carrying the molten metal. Such inclusions can damage the cutting edges of inserted multi-tooth cutters and be very troublesome.

Chilling of cast iron is another problem which makes subsequent machining almost impossible, except by grinding. As the name implies, chilling is due to sudden cooling of the molten metal during casting. Sometimes 'chills' are placed in moulds to produce particularly hard areas purposely. These are located in positions where hard wear resistance of a casting is required in use.

Material may be unstable owing to ageing or working stresses, or faulty heat treatment. Bar materials can also have longitudinal cracks extending over complete lengths. Forgings may have laps, incorrect grain flow and grain size, tears, cracks, etc.

These types of defect have gradually been reduced in recent years through improved techniques and controls in the mills and forging plants. Fortunately such defects are also usually readily apparent visually and therefore tend to some extent to be nuisance factors. For instance, stock of a certain size bar is found unusable because of a longitudinal seam or crack. If such defects are not observed, they can cause major troubles.

Far more serious are the defects which are not open to the surface. Some may become apparent during machining, but others can remain subsurface. Such defects in ferrous materials can be revealed by magnetic crack detection. Non-ferrous materials may entail ultrasonics or X-ray methods. These are relatively costly methods and not ideal for exploring large areas or large quantities.

Another method of crack detection widely used is the dye penetrant system, which can be used on most materials, including non-ferrous. One limitation is that the fault must be open to the surface to allow the dye to penetrate. The method is very versatile, will reveal very fine defects or pinholes, can be applied to portions of large objects, does not require specialised techniques, is readily portable and is not expensive.

The procedure is to brush on or dip into a dye penetrant solution. (Surfaces should first be cleaned or degreased, otherwise penetration of the dye may be impaired.) The parts are then left for about twenty minutes for penetration to occur. Surplus surface penetrant is wiped or washed off and a 'developer' applied. This is a powder solution usually applied from an aerosol spray. (Larger installations use factory compressed air and a spray gun.) After a few minutes the developer dries and larger defects are readily visible as penetrant emanating from cracks, etc., and staining the developer powder in the area involved. Finer cracks may require twenty minutes or so to become evident.

Table 4.1 endeavours to set out material types and defects in a readily understandable format.

2. Paints

Most modern industries use synthetic paints specially developed to facilitate applications by spraying (air, electrostatic, etc.) or dipping,

TABLE 4.1

MATERIAL TYPES AND POSSIBLE FAULTS
(OTHER THAN VARIATIONS IN CHEMICAL AND PHYSICAL PROPERTIES)

	Possible Faults										Forms Normally Used				
Material type	*Porosity*	*Corrosion*	*Contamination and inclusions*	*Instability; ageing stresses*	*Cracks*	*Flaws*	*Faulty heat treatment*	*Chilling*	*Faulty protective treatment*	*Remarks*	*Bar*	*Castings*	*Sheet*	*Forgings*	*Mouldings*
Aluminium alloys	√	√	√	√	√	√	√		√		√	√	√	√	
Magnesium alloys	√	√	√		√	√	√				√	√		√	
Coppers and brasses	√				√	√	√		√		√	√	√	√	
Tins; bearing metal	√					√					√	√	√		
Steels	√	√	√	√	√	√	√		√		√	√	√	√	
Nimonic alloys			√		√	√	√				√	√		√	
Cast iron	√	√		√	√	√	√	√	√	Chilling sometimes intentional		√			
Stainless steels			√		√	√	√				√	√	√	√	
Sintered metals	√	√	√	√	√	√	√		√			Pressing			
Titanium	√	√	√	√	√	√	√				√	√	√	√	
Rubbers			√	√		√	√								√
Plastics	√		√	√	√	√					√		√		√
Laminates					√	√					√		√		
Glass fibre compounds					√	√							√		√
Adhesives			√	√	√	√				Many special factors covered separate					
Paints	√		√	√	√	√									
Glass	√		√	√	√	√	√				√	√	√		√

often followed by stoving. Material surfaces are often specially prepared to give underpaint protection and to provide an adhesion 'key' by etching, phosphate treatments and the like.

These requirements entail special paint formulations and their controls are often delegated to the specialist paint supplier. Some larger companies or high-volume paint users carry out their own laboratory cross-checks.

Checks on painted parts and manufacturing factors will be dealt with in Chapter 6. British Standard 2015 gives a full range of

TABLE 4.2

SOME TYPICAL PAINT TERMS

Alkyd	Synthetic resin-based paints with organic solvents. These divide into melamine and oil-free alkyds.
Driers	Substances added to vary and speed up drying times normally separate from stoving operations.
Sissing	The gassing of solvents if the finish is stoved too soon after spraying. Consists of many volcanic-type pimples in the paint surface.
Polymer	A large-structured molecule produced by linking-up effects on smaller molecules of one type.
Co-polymer	Two or more molecule types in combination as for polymer.
Scaler	A coating which may or may not be transparent and which is used to 'seal' the surface.
Stoving	The baking process used to dry and produce required hardness of certain paints.
Hardness Gloss Shade Adhesion Wear-resistance	All these properties are fairly self-explanatory, and there are standard test instruments, criteria and properties for them all.
Orange-peel effect	Characteristic appearance due to faulty viscosity/spraying technique.
Show through	Undersurface or primer coatings visible through portions of the painted surface.

paint terms. Some common terms used in industry are listed in Table 4.2.

Paints should be stored within a temperature range of 55°–75°F (13°–24°C) and maximum permitted periods of storage of paint stocks are usually clearly defined. Good stock rotation controls are essential.

3. Plastics; Synthetics; Rubbers

Raw material controls in these groups are again largely in the field of the specialists and appropriate laboratory facilities. Satisfactory packaging, handling, identification and storage criteria are usually provided in the relative specifications.

4. Glass and Glass Fibre Compounds
These are usually fairly stable raw materials not subject to contamination and deterioration effects or too readily damaged.

5. Chemicals and Adhesives
Again a very specialised field in which makers' certification is usually reliable. Many special factors of safety, such as handling and storage, are involved.

DESTRUCTIVE AND NON-DESTRUCTIVE TESTING

Some of the raw materials mentioned are only finally proven once they have been used, e.g. paints, chemicals, adhesives. Testing of such items is therefore known as destructive in so far as the situation is committed. Such tests are therefore made on a sampling basis and results will have been virtually assured by adequate process controls during initial manufacture.

Non-destructive test (NDT) methods are widely used in industry and include:

Radiography (X-rays).
Ultrasonic testing.
Crack detection, etc.

These are the more specialised areas widely known as non-destructive. Each industry has its own special kinds of test. Clearly dimensional tests, surface finish tests, visual tests, etc., are normally non-destructive also, but such tests are not usually considered in this category.

X-ray and ultrasonic testing usually requires specialist personnel. Those of us who have been X-rayed in hospital know that exposures are usually necessary in two planes for adequate X-ray results. Analysis of radiographs requires experienced radiologists. Settings and ratings of X-ray equipment are also significant. Ultrasonics requires skilled settings of the equipment, selection of probes, etc.

In the field of crack detection it is usually possible, and desirable, to provide procedural techniques and instructions for specific components which provide adequate guidance on methods and routine. We have already mentioned dye penetrants. Magnetic crack detection requires prescribing of current, method and time of application, to ensure revealing various types of crack and avoidance of burning at the points of current application. AC or DC currents can be used and often both these methods are used sequentially with, finally, satisfactory demagnetisation after examination.

Normally only very small numbers of around 1 to 2 per cent of total QC personnel are engaged full time on raw material inspection. These people are usually controlled by the goods receiving inspection supervisor. They are usually aided by laboratory and metallurgical personnel, as required.

Finally, mention should be made of the Non-Destructive Testing Centre at Harwell, which was set up in 1967 for information, advice and sponsored research in collaboration, but not competition, with industry, offering NDT testing services. This organisation has developed interesting techniques in the field of high-definition and neutron radiography. They are also able to advise on applications and uses of ultrasonic testing and its limitations.

Incidentally, on the subject of ultrasonics, the reader may be involved in quality aspects of ultrasonic cleaning. This process is very good on areas which are fairly open and exposed. Dirt in oilways and passages of valve bodies, etc., will be loosened by ultrasonics, but may not be flushed out of the system. Similarly, ultrasonic cleaning is best applied as a super-cleaning operation. Heavily soiled parts should be separately cleaned first, otherwise the normal relatively small ultrasonic tank can quickly become contaminated.

One other application of ultrasonics being increasingly used in industry is the 'ultrasonic welding' of plastic components which facilitates certain assembly procedures.

5 | Goods Receiving Inspection

This department is also variously known as:

Goods inwards inspection.
Incoming supplies inspection.
Bought-out supplies inspection, etc.

PURPOSE

Understandably, this is an area where inspection 'after the event' is still normally practised. Theoretically, receiving inspection should be unnecessary, if vendors operate effective quality control. It is implicit in any purchase order that the vendor undertakes to deliver supplies which fully conform to the customer's drawings, specifications and requirements and which have been adequately checked and tested accordingly.

Unfortunately, this theory does not work out in practice. It is vitally necessary for manufacturers to monitor their incoming supplies, even though normally only 2 to 5 per cent of batches delivered may have to be rejected. If these faulty supplies are not extracted, the manufacturer can expend time and money in using them and end up by having to replace, when the faults become apparent, as well as to correct any consequent effects. Where the faults are found within the manufacturer's procedures and plant, corrective action is usually less troublesome than when faults become apparent only after the final product has been delivered to customers, possibly all over the world. The costs of corrective action can then be very large. Also, the quality image of the final product maker can be seriously impaired. Furthermore, these consequences have to be borne by the final product supplier. He has virtually no redress on the vendor who originated the faults.

However, the extent of monitoring of incoming supplies must be

Fig. 3.1

Fig. 3.2

Fig. 3.3

Figs. 3.1, 3.2, 3.3. Views of the sophisticated Metrology Department in a larger-sized British organisation

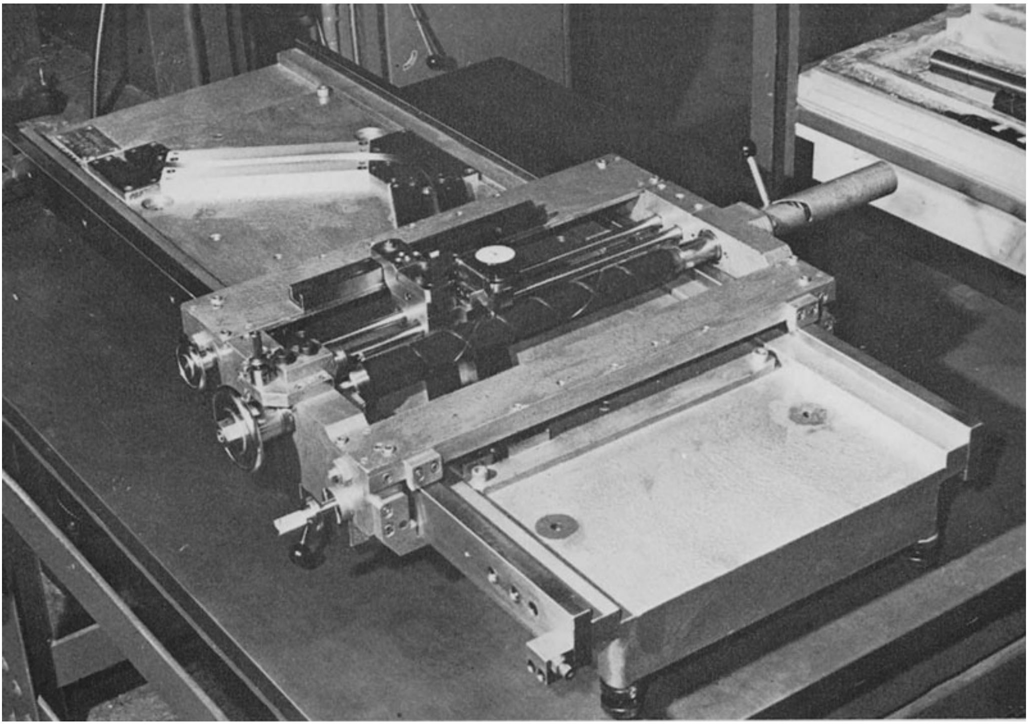
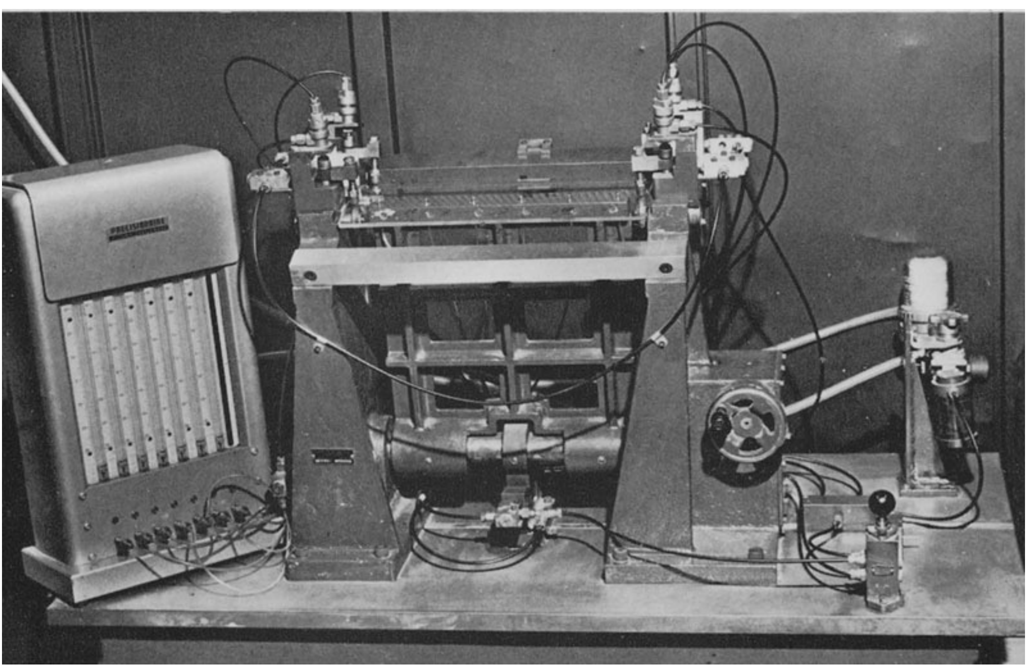


Fig. 3.4. This ingenious device checks the critical helical grooves cut into a shaft, with any helix errors shown as deviations from zero on an indicator gauged by a stylus

Fig. 3.5. A large special checking device for a curved glass platen, with any deviation from the required curvature shown on the air column indicator unit



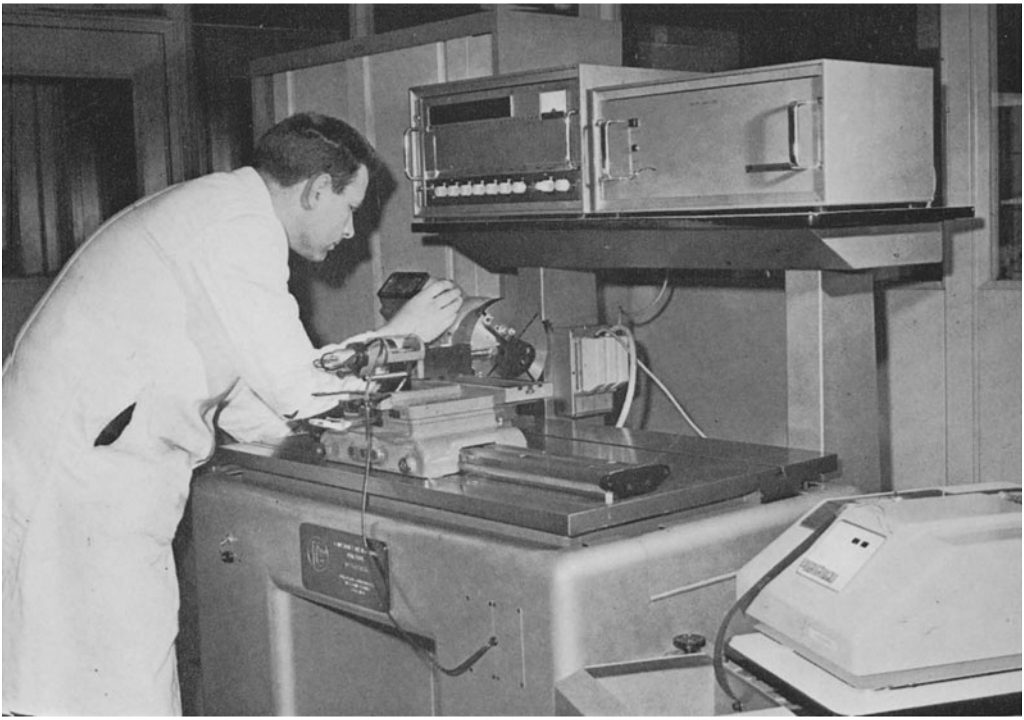
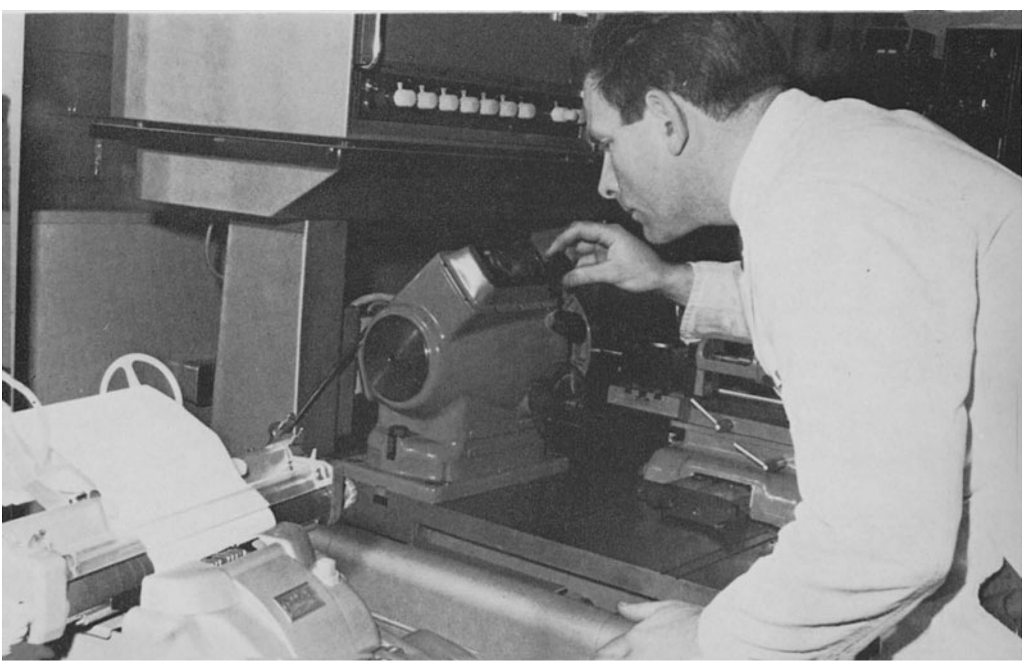


Fig. 3.6. Automatic Cam Profile Test equipment with a punched tape reader (right) controlling the angular dividing head, linear displacements of which are measured and recorded

Fig. 3.7. The recording unit to Fig. 3.6 automatically prints out each ordinate checked, the nominal correct reading, the reading found and the amount of error, if any



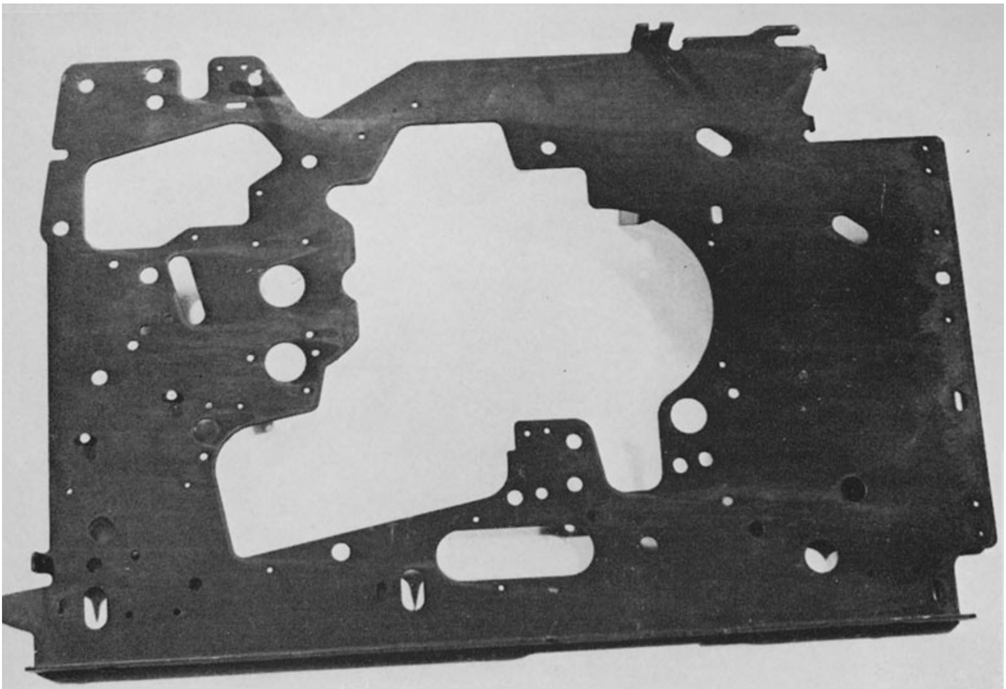


Fig. 3.14. A typical pressed part at an early stage of assembly

Fig. 3.15. Another pressed part at a similar stage, showing apertures and large numbers of holes

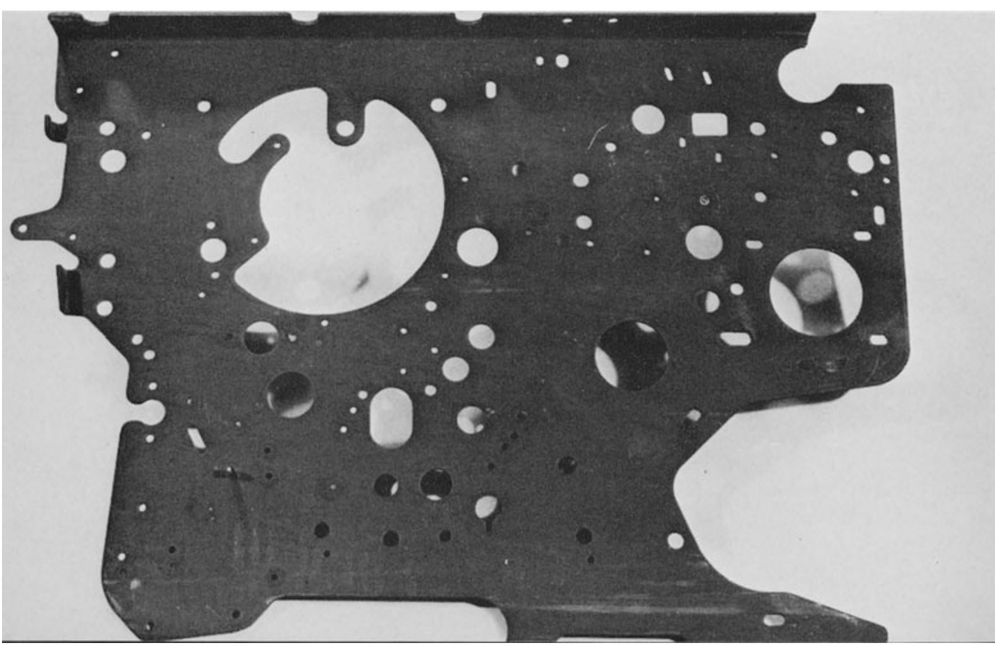
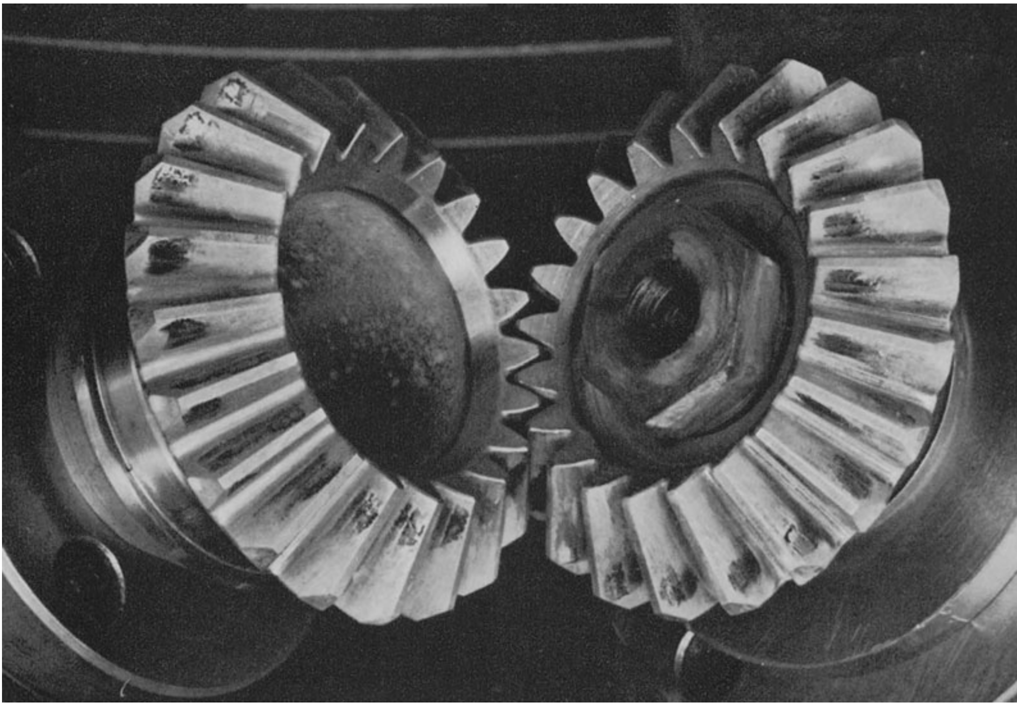


Fig. 5.1. This shows a goods inwards inspection area laid out on the roller-track principle

Fig. 5.2. An electrical test section laid out on the roller-track flow system

Right Fig. 5.4. A modern quality control device using computer technology for testing electric and electronic components



Above Fig. 6.2. Heel/Toe Cross-Bedding, resulting from one gear having teeth cut off centre line

Left Fig. 6.3. Rolling type tester for gears. The recorder produces a chart which shows eccentricity, profile and spacing errors

Fig. 7.2. A wiring jig for electrical sub-assemblies

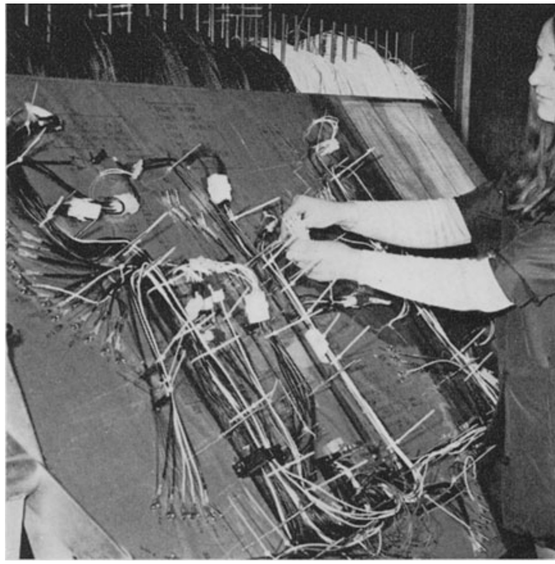


Fig. 7.3. An automatic control system for the electrical sub-assemblies produced on the wiring jig in Fig. 7.2

Fig. 8.2. This is a view of a rig which is testing heater elements (top shelf) and their control units (second shelf): for infant mortality type failure during functional operation

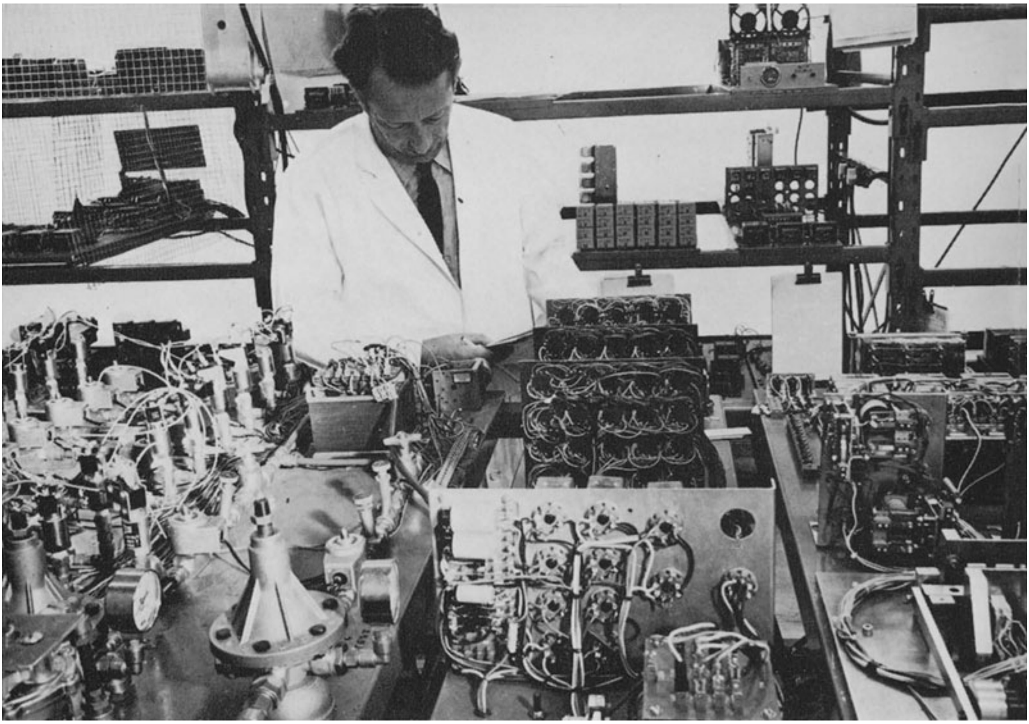
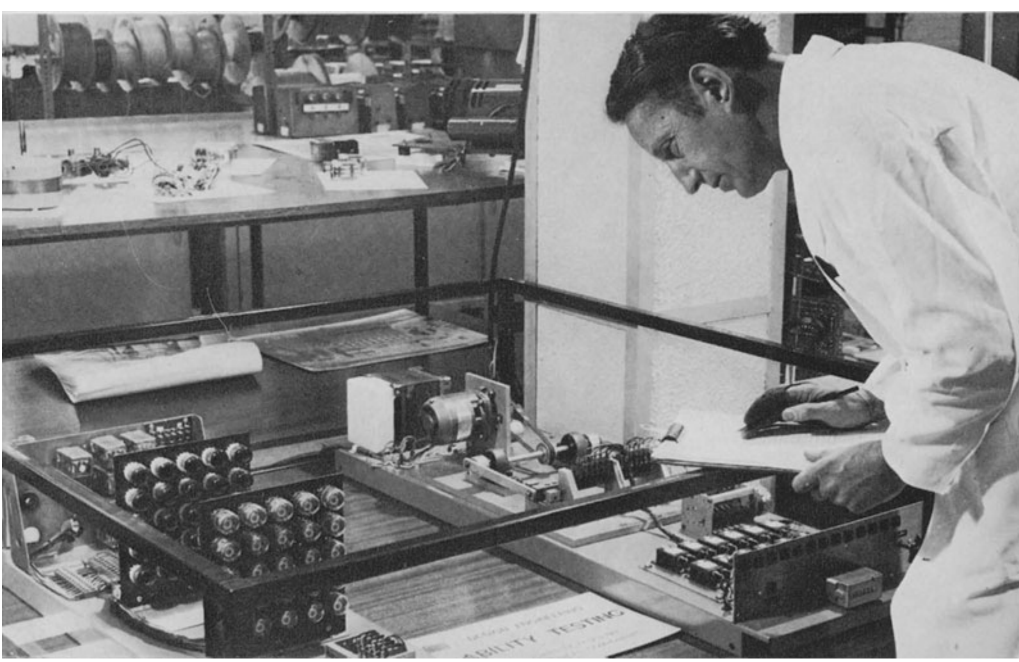


Fig. 8.3. On the left is a rig for reliability testing of pressure switches

Fig. 8.4. On the left is a rig for testing number indicator tubes commonly known as 'Nixies'. In the view, the number 6 is illuminated on the front bank of tubes. On the right the rig is for testing microswitches. A bank of switches under test is visible just below the clip of the test engineer's clipboard



carefully controlled, otherwise the manufacturer can easily take over all the quality control effort which should have been carried out by the vendor.

COSTS

Some companies charge the cost of incoming inspection to the purchase costs of supplies. Other companies have the department as a direct charge to the purchase department. In a few instances, the purchase department administers the activity.

Readers would no doubt welcome some guidance on goods inwards inspection costs. A very rough guide is that these should be in the range of ½ to 1 per cent of the actual value of incoming supplies handled. Any attempt to recommend actual numbers of personnel is very difficult owing to the varied nature of incoming supplies, volumes, delivery frequencies, proportion of branded or proprietary products and many other factors.

LOCATION AND SPACE

A goods inwards inspection section should logically be located as closely as possible to the area where supplies arrive. It is often convenient (and minimises excess handling) if a relatively small amount of inspection which is required on some large-volume supplies is performed externally to a department, e.g. bulk chemicals can be sampled from a container. If cleared, the delivery can then be made direct to a storage point.

Adequate space should always be provided for goods inwards inspection. This factor is frequently neglected and operations are carried out under cramped and unsatisfactory conditions.

However, provision of adequate space should not be abused by allowing goods to accumulate and be held in abeyance. An efficient system must operate on a flow basis such that supplies are handled virtually sequentially, as received.

Operation of several goods inwards and inspection areas at separate points in a large plant is not recommended because:

Goods will frequently be delivered to the wrong location.
Incoming vehicles may be directed and redirected to the frustration of drivers and others.
Duplication of test and inspection equipment arises.

Duplication of paperwork systems and records occurs.
Excess manning, but incomplete utilisation,[1] can result.
More space is utilised in multiple locations than in a centralised area.

Pressure for diverse locations of goods inwards and inspection areas usually arises because various vested interests like to see 'their' supplies given special or preferential treatment. There is no need for such arrangements if a systematic rapid 'flow' system is operated. Comment on this system follows.

'FLOW' SYSTEM

Some large companies operate a computerised system of goods receipt, paperwork and controls, but most companies have less sophisticated systems.

The aim should be to minimise clerical work and system delays. Purchase departments at the time of placing orders can anticipate the ultimate arrival of supplies, by providing purchase order copies and part drawings to goods receiving and inspection areas.

If inspection proceeds as supplies are received, then all deliveries should be covered within a few hours. There is then no need for progress personnel to 'chase' urgent work repeatedly and to operate priorities, etc. Priorities lead to other work being left and ultimately becoming urgent. Such work may be held for several weeks and then found faulty. The supplier has probably produced further faulty batches and may also be complaining to accounts because of non-payment for earlier deliveries.

A department working on a non-flow basis will inevitably become cluttered up with 'abeyance' supplies. These have to be sorted to find wanted supplies and multiple handling arises.

Figs. 5.1 and 5.2 are photographs of a modern goods inwards inspection department handling hundreds of batches of work every day. The department is laid out on a motorised roller-track principle.

[1] Some enlargement on the above comment on incomplete personnel utilisation, due to diverse locations, is worthwhile, as it particularly affects inspection and quality control activities generally. Imagine a company with, say, six goods inwards inspection areas, each manned by two people. If the volume of work rises slightly, 2½ people in each department may be required. We cannot divide individuals and this could mean that 3 people are employed in each section making an overall total of 18. With one central area the increase would only be to a total of 15 (6 × 2½). This is a very simple example, but it does show one of the consequences of diverse locations.

Supplies arrive in the receiving area and are placed on the track, after unpacking and counting. The supplies pass through booking-in and recording areas, then gauge and drawing stores, where these items are placed, with the parts, on the track. Several tracks are used for mechanical, electrical and hardware supplies respectively.

The goods pass to various inspectors, who carry out the checks necessary, compile records, etc., and return the parts to the conveyor, which carries the supplies directly through to the respective stores areas.

ROUTINES AND SUPPLIER LIAISON

1. Appraisal Reports

Close liaison with purchase department is an essential feature in connection with bought-out supplies.

Following the initial proving of new designs and components by reliability testing (covered in Chapter 8), the purchase department will normally advise quality control of their intention to place production orders with a vendor. A QC representative with the buyer concerned will probably carry out a vendor appraisal on any new supplier.

The purpose of this activity is to ensure that the vendor has the necessary experience, expertise, facilities, procedures, methods and quality coverage to make delivery of satisfactory supplies practicable. It also enables contacts with supplier's personnel to be established and quality requirements of the customer to be clearly defined. Tooling and gauging provisions should also be clarified at this stage. It is much more difficult to obtain cost cover for additional or better tooling and gauging, found to be required later, because of troubles. A vendor appraisal does not ensure satisfactory supplies. It merely reduces the risk of faulty supplies. The ultimate performance of a supplier on production deliveries is the only real measure of his quality.

During an appraisal visit some suppliers tend to start with their finished product, of which they are naturally very proud. For a systematic appraisal it is best to follow the format of this book, i.e. incoming supplies, manufacture, assembly, test, etc., and such a sequence should be requested.

It is important during an appraisal visit that any aspects causing concern should be mentioned to the supplier at the time. He may have explanations, reasons or future intentions to cover the situation. It is very unsatisfactory to appraise a supplier, let him think everything is satisfactory and then write a critical report upon return.

Vendor appraisal reports are best compiled on a standard format. This lists:

Vendor's name, address, telephone number, types of product.
Vendor's senior personnel: names and titles.
Quality systems: procedures, facilities, laboratories, status, housekeeping.
Number of QC personnel.
Other information recorded is usually mainly of interest to purchase department, such as capacity, size, future expansion plans, etc.

The use of a form for these details can provide an aide-mémoire during an appraisal visit.

A system of scoring for the excellence of the various criteria provides a better method of such initial appraisal ratings and comparison with other suppliers than a purely subjective individual assessment. The method also provides better comparison of results from different personnel making appraisals.

2. Recording of Performance

A good system in goods inwards inspection is the maintenance of a folder for each item covered. These should be filed in part number order. The folder should contain:

(*a*) The drawing. (It is assumed that a drawing revision and updating system is efficiently operated.)
(*b*) The quality record form. This record should carry virtually all details and history relative to the item concerned:
  (i) Successive delivery dates and quantities.
  (ii) Various columns listing checks to be made and provision for ticks or other indication that such checks have been carried out. This is a systematic procedure and ensures that inspectors do not forget or overlook a feature.
  (iii) Any faults found on a dimension or criterion are recorded in the respective column with additional

remarks, as required, e.g. action taken, rejected, supplier advised, conditionally accepted, etc.

(iv) Inspector's name and number.

(v) Laboratory or external department reports.

(*c*) Inspection instructions. If an inspection or gauge planning section is operational, these instructions give full guidance on method of checks, equipment or gauging to be used, sample sizes and important features.

(*d*) Copies of any concessions or production permits issued.

(*e*) Correspondence with suppliers and record of visits.

(*f*) Details of any rejections made.

Where there is more than one supplier for a particular part, a separate quality record form should be maintained for each supplier, identified by his name and address at the top of the form, but filed under part number order, in the one folder for each part. Such quality records provide a complete history of particular parts. They enable different inspectors to pick up deliveries and be aware of any problems previously experienced, special factors, etc.

The purchase department normally maintains records of various part numbers supplied by any one vendor such that his overall performance can be assessed in the event of several rejects occurring.

An important factor in connection with bought-out supplies is the degree of risk relating to proprietary products. Designs are often established which specify the use of proprietary paints, switches, lamps, adhesives and a host of similar products. The design approval is based on such products as they were known at the design issue stage. Drawings often actually quote the use of brand X type 123 items, for example. No actual finite criteria are usually available, and proprietary item suppliers often jealously guard their specifications.

The dangers are that over the course of time, or even at short intervals, such suppliers may make changes for various reasons:

Claimed improvements.
Use of alternatives.
Process changes.
Changes to suit certain major customer requirements.
Competitive pressures.

Such changes can sometimes seriously affect a particular company's application of such products. Therefore it is most important that understanding should be reached with the proprietary item supplier that proposed changes should be advised. Purchase orders should be annotated accordingly. Repeat orders should carry comment such as 'Identical with supplies made against previous purchase order XYZ'.

Finally, the only sure safeguard is for the customer regularly to monitor proprietary supplies for criteria, which are important in his application and usage.

3. Vendor Statistics and Quality Indices

Some quality departments compile statistics on vendor performance and resort to calculations to provide quality indices and vendor rating values. Such activities have several limitations:

(*a*) They entail work by people who count as quality department personnel but who could be more usefully employed on actual inspection duties in the quality department.

(*b*) The results are normally 'in arrears', and therefore historical.

(*c*) Mathematical computation is usually involved, using an arbitrary formula to provide a quality index numerical value and to compensate for system shortcomings (e.g. a supplier making one ultimately rejected batch delivery in a period would have a nominal zero index).

(*d*) Such quality indices can be misleading unless fully qualified. Usually a quality index figure of 80 is the optimum established. Reference to a figure of 75 can convey to some people that it is 75 out of 100. Three-quarters efficiency is implied and this, below ultimate, is tolerated and 'good enough'.

Lower levels, and the index which is considered 'bad', is again arbitrary and may be fixed at 50. By inference, a rating of 51 is not yet 'bad' even though the 51 figure can be largely due to the 'rounding' effect of a mathematical calculation.

(*e*) Quality indices cannot safely be quoted to suppliers because vendors can become complacent, or possibly use the information to quote to potential new customers on how good they are, by the standards of the quality index advised by company X. This is most undesirable. A good supplier to one company can produce very unsatisfactory **different** items for another company. This latter company can then assume that the high quality rating quoted for company X indicates its own poor quality standard.

(*f*) Such indices should be compiled by part number. A supplier may provide, say, six different items. Five may be trouble-free. The sixth may be difficult and involve frequent rejection. It would be quite wrong to show this supplier as generally unsatisfactory on the basis of rejections on one part number out of six.

(*g*) Quality indices are normally based on batch or quantity reject experience only. They do not usually discriminate between serious or reprehensible faults, as distinct from other factors. Rejects may be for a single fault per item, or multiple faults on each item.

It is usually difficult to convince the proponents of quality index schemes that they are really using systems to tell them something which is already apparent initially.

The better procedure is to ensure that the goods inwards inspection supervisor effectively monitors the reject situation. As mentioned previously, the incidence of rejected batches is usually small, around 2 to 5 per cent. The good supervisor will ensure that:

(*a*) He is aware of all rejects and their seriousness.

(*b*) Rejection is justified, and clearly stated. Comments like 'incorrect to drawing' or 'returned for reinspection' are most unsatisfactory. Similarly, a statement such as '78·87 mm diameter incorrect' is very unsatisfactory. The reject should clarify by how much, or whether the error is ovality, taper, finish, eccentricity, etc. If a delivery is rejected because a fault is found on one of the first features checked, this should be clearly advised. It is futile for a supplier to correct such a fault and then have the supplies again rejected, for further faults on features not checked initially.

(*c*) Prompt contact is made with the supplier to ensure immediate corrective action and avoid production of further similar faults, although the actual rejects may not reach the supplier quickly.

(*d*) He arranges any retrospective action necessary.

(*e*) He arranges possible correction 'on site' if urgency or cost of packaging and transit, or delays in transit, necessitate such procedure. Such 'on site' correction may be carried out by supplier's representatives. Alternatively, the customer arranges correction and the appropriate agreed 'charge back'.

Close involvement of this kind automatically ensures that the supervisor knows which vendors are giving quality troubles. In conjunction with QC records in the department and liaison with purchase department, he arranges for poor quality performance to be made an issue with the senior people at the suppliers.

This procedure follows the recommendation previously made that the best approach is by concentration and action on the important exception situations, rather than extensive statistics on the overall activity, including aspects which are satisfactory.

The supervisor should of course report upon the 'bad' suppliers actioned as above and arrange for special monitoring to ensure that troubles are duly resolved.

4. Sample Castings

The previous chapter on raw materials is directly related to goods receiving inspection. Quite often raw materials are handled in the same area as other incoming supplies and controlled by quality personnel, who also cover bought-out finished parts, etc. This particularly applies to castings and initial sample proof castings, which usually require special facilities and experience to ensure that casting faults are detected. For this reason, comment on sample castings was not extensive in the previous chapter, but will now be dealt with more fully.

Casting foundries have tended to concentrate on the process aspects, with limited capability on measurement facilities, etc. This situation has been gradually changing in recent years, but many foundries still depend largely on outside specialists for:

Pattern-making.
Die and tool manufacture.
Chemical and metallurgical laboratories.
Properties (purity, etc.) of their raw material supplies.
Test facilities: X-ray, porosity and crack detection, pressure test, impregnation.

As a result, casting customers usually need to exercise above-average attention to monitoring castings and especially initial samples. Proof samples should be:

(*a*) Carefully set up and marked out to verify every dimension and to ensure that sufficient (but not too much) machining allowance is left for subsequent machining. This is a very skilled inspection operation, requiring balancing and correct use of datum points and surfaces.

(*b*) Radii should be systematically checked. They can be omitted, malformed or seriously undersize.

(*c*) Wall thicknesses and sections must all be verified with extensive sectioning (cutting-up) of complex castings to expose sections for examination. Some foundries sell castings – particularly the larger castings – by weight. There is therefore a tendency to leave extra metal on surfaces and wall sections, in addition to keeping the latter on the 'safe' side. Weight therefore needs to be monitored, particularly on castings where weight factors are important, such as aero-engines.

(*d*) Surfaces must be examined for finish, faults, irregularities, unsatisfactory flash removal and dressing.

(*e*) Porosity, crack detection, hardness, pressure tests and all such metallurgical aspects must be verified, usually in conjunction with laboratory personnel.

(*f*) It is good practice when proof inspecting sample castings to tick each dimension on the drawing as it is checked. Where deviations are noted, the measured result is annotated next to the dimension concerned. This ensures that no dimensions are missed. The deviations previously pinpointed facilitate discussion with design, production engineering and supplier.

Most of these checks should have been carried out at the casting makers before submission of samples.

The exceptionally competent (but rather rare) foundry will supply whole and sectioned samples fully marked out and with a dimensional report. This is good practice which should be followed more often. The foundry will then have noted and corrected faults, and this should give a better chance of first-time approval of the sample.

Alternatively, the customer proof inspects, reports faults, returns the sample and the foundry makes corrections. A new sample is produced and submitted and may be accepted, or the reject and correct procedure may again occur, with long delays as a consequence.

A supplier should therefore be provided with a sample report form, preferably with the order. This form is required to be completed and submitted with the sample. A typical sample report form is shown in Fig. 5.3. This form can be used for all types of samples.

SAMPLE QUALITY REPORT

Purchase Department Complete This Section

SAMPLE CLASS:	NEW PART	CHANGED PART	NEW SUPPLIER	PART FINISHED	FINISHED	TYPE OF SAMPLE:	
SUPPLIER				ORDER NO.		MODEL NO.	PART NO.
				BUYER		DESCRIPTION	

Supplier Complete This Section		*Q.C. Complete This Section*
• DIMENSION OR SPECIFICATION CHARACTERISTIC	SUPPLIERS INSPECTION CHECK RESULT	QUALITY AUDIT RESULT

SAMPLE MADE ON PRODUCTION SET UP AND TOOLING:	YES	NO
ADDITIONAL HAND OR OTHER WORK PERFORMED	YES	NO
SAMPLES MADE TO DRAWING ISSUE NUMBER:		
DATE INSPECTED:	SAMPLE QUANTITY:	
SUPPLIERS CONTACT	TELEPHONE NO.	

I Hereby Certify that the Inspection and Functional Checks outlined above are believed to be correct and the sample meets the Drawing Specification requirement of Limited, or is submitted as qualified above.

SIGNATURE OF RESPONSIBLE OFFICIAL	
TITLE	DATE

REPORTS REQUIRED				
	Mechanical	Electrical	Laboratory	Reliability
YES:				
NO:				
APPROVED:				
REJECTED:				

SAMPLE APPROVED:		APPROVED: DESIGN TO BE CHANGED	
SAMPLE REJECTED:		Limited Approval: Supplement by Check on First Delivery	
INSPECTED TO DRAWING ISSUE NO.		EVALUATION CARRIED OUT BY	
SIGNATURE		QUALITY CONTROL	
TITLE		DATE	

DISTRIBUTION: (a) 3 Forms to Supplier with Order (White, Pink, Yellow)
(b) Supplier return first 2 with samples (White, Pink).

Fig. 5.3. Sample quality report

It is usually necessary to make clear to casting suppliers that undue straightening or setting operations, after casting, should not occur. Where necessary, such work should be followed by appropriate crack detection and stability checks. Similarly, unauthorised impregnation, soldering, filling or welding 'repairs' should not be practised without prior approval.

Approval of samples (or advice of rejection) should be provided as quickly as possible. The supplier may have production lines held up and delivery delays can result. However, such approval advice must be qualified to the effect that production can proceed upon authorisation by purchase department. The **quality** approval does not authorise production schedules, but suppliers may assume this, unless the quality approval report is qualified, as stated above.

5. *Incoming Paperwork*

Apart from the sample reports just described, it is important that good understanding should be reached with suppliers on paperwork requirements, especially for the smooth running of the flow system described earlier in this chapter.

Suppliers' paperwork should be:

(*a*) Correct and complete with full and accurate details.

(*b*) Advice notes should be qualified or annotated where any aspects of the supplies concerned do not fully conform, e.g. concessions or production permits applicable, features submitted for approval or acceptance. (It is very wrong for suppliers of proprietary products to forward what they consider as alternatives, without comment.)

(*c*) The supplies must be complete to the order. Machining operations, protective treatments and finishes should not be omitted.

(*d*) Certificate and test results required should be provided with the consignment, unless arrangements have been made for them to be supplied separately.

6. *Communications and Liaison*

Suppliers must not assume that they can operate arbitrary latitude on requirements. Specifications, tolerances, etc., must be defined without ambiguity and adhered to consistently.

Verbal deviation agreements with suppliers should be virtually prohibited, except under very special emergency conditions. Any such 'emergency only' verbal agreements must be covered in writing by the quality manager. Verbal agreements are most unsatisfactory. They lead to arguments, misinterpretation and even disclaimers, if

NOTES ON QUALITY CONTROL FOR GUIDANCE OF OUR SUPPLIERS COMPILED BY XYZ COMPANY QUALITY CONTROL DEPARTMENT

Introduction
A high standard of quality and reliability with a reputation for a first-class quality product is an essential public image with our customers.

Each item or component can affect the overall reliability of a complete machine and supplies must therefore consistently conform to drawing and specification in all respects.

These comments are intended to be constructive. We appreciate that some suppliers maintain very high product standards and facilities. Nevertheless, even in the best organisations, human factors, new personnel and other changes can, and sometimes do, lead to trouble. These important notes from our considerable experience are designed to lay emphasis on the basic principles and the need to provide systematic control to preclude incorrect supplies. Vendors are requested to ensure that their internal lines of communication are such that *all* personnel concerned with our supplies are fully aware of these factors and implications.

Quality Concepts
We require adequate inspection and quality control by our suppliers during all stages and processes, from raw materials through manufacture, packaging and transit, to ultimate receipt. This also implies full responsibility by the vendor for the materials he uses, or for work he may partially subcontract. Quality surveillance, assurance and audit activities are all part of a good overall system.

Efficient quality control will detect production of faulty product early enough to prevent large quantities of scrap or rejects. Good quality control is an investment and an indication of modern management. Scrap and rejects cost money in materials, production time, packaging, transit and administration, apart from frequently serious delays.

We require parts correct from the start, and no after-thoughts and excuses to account for defective parts. Guarantee, free replacement or belated corrective action is of little consequence if we become involved in enormous service costs necessary to replace parts which are failing in machines, perhaps distributed near and far throughout the world.

Facilities and Techniques
It is essential, *at the outset,* to ensure that all necessary equipment, gauging, controls, etc., are available *and utilised* for production of satisfactory supplies. Facilities, methods and training should ensure the production of satisfactory product, rather than sorting of good from bad items *after* they are produced.

Some procedures, such as spot welding and painting, require strict adherence to routines, as also do control techniques, test procedures and special test facilities. Lack of adequate attention to such disciplines can result in widespread difficulties and reject product.

Drawings and Modifications
Our drawings are most comprehensive. They give extensive detail and comments, which should be fully studied and actioned as necessary. There is no doubt that adherence to the design tolerances and requirements tabulated is essential for our satisfactory assembly and machine operation. Latitude on tolerance must not occur at any time. If suppliers produce their own drawings for internal use, adequate cross-checking with the original drawing is important and the complete information must be included on suppliers' own drawings.

Official Documents
Our official concession or production permit procedures are the only recognised cover for deviations. Incoming paperwork should be annotated where such

procedures are involved. Verbal agreements between individuals are not recognised officially and are most unsatisfactory. Temporary written authorisation pending the above *official* procedures may sometimes be issued by our purchase department to cover urgent situations.

Instances have arisen where we receive supplies which are incomplete in various ways, such as omission of required markings, heat treatment or protective finish, and yet are still advised as purporting to be specified part numbers, without qualification. If omissions have been agreed for some emergency reason, the advice notes *must* be annotated accordingly. If supplies do not fully conform they should not be forwarded without prior authorisation and the incoming paperwork should be suitably annotated.

Testing
Where proprietary or other individually complete components are involved, such as electric motors, switches, power-supply units, relays, timers, etc., it is important that regular performance and cycling tests are carried out continuously to monitor production quality and reliability. We shall be pleased to advise and demonstrate suitable procedures, if requested. Alternative proprietary items which may be considered as suitable substitutes by the supplier should not be forwarded without authority and qualification.

Samples
Approval submission of samples of new supplies will be welcomed. However, it is essential that suppliers check samples before submission and advise us of their findings. This particularly applies to new type castings which should be fully marked out dimensionally and have been checked for material physical specification and analysis. Also to be covered is porosity, crack detection, surface conditions, satisfactory fettling and freedom from distortion. Where multiple moulds are involved, a sample from each mould is necessary.

Failure to adhere to these basic procedures can result in delay and extra transit or packing costs. Errors found by ourselves may necessitate reports, correction and reinspection, possibly repeated several times, and this is clearly unsatisfactory.

Liaison
Optimum liaison on quality control on a continuous basis will be welcomed.

(signed) QUALITY MANAGER

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trouble arises later. Such agreements are unsatisfactory to all concerned and should be avoided.

It can be helpful to issue guidance notes to suppliers similar to the example shown on pp. 76–7. These can be provided by the purchase department with first orders on new suppliers. However, periodic reissue or verification that suppliers have this advice is necessary. The information is mislaid, filed or forgotten. It may not have reached all personnel concerned at the suppliers, or such personnel may have changed jobs, retired, etc.

Close liaison by visits of suppliers' representatives can be most valuable on day-to-day problems. Many technical and other problem factors can be resolved by discussion 'on the job' and study of assembly or use conditions. Where large numbers of suppliers are involved, such liaison needs to be controlled and kept as brief as possible, otherwise the supervisor and his personnel can find that their time is unduly committed to discussions with suppliers.

However, close liaison should avoid the frustrating experience of futile remarks from suppliers when trouble is experienced, such as:

(*a*) We didn't realise 'that' was important.
(*b*) We did not think 50 per cent or so beyond tolerance would matter.
(*c*) We really need a gauge to check 'this feature'.
(*d*) They have always been like that. (Two wrongs do not make a 'right'.)
(*e*) We cannot make these correct at the price we have quoted.
(*f*) We cannot hold this tolerance on our machine.
(*g*) We 'thought' you were going to paint, protective treat, harden, crack detect, heat treat, etc.
(*h*) Now we see the problem we ought to have made it in a different manner.
(*j*) None of our other customers complains. We have never had this trouble before. (Such comment usually relates to proprietary items despite the fact that the supplier agrees the supplies are wrong.)

This type of comment, coupled with reasons and excuses, such as 'The operator forgot to do something, or made a mistake, and we have made changes', are of little consolation to the customer. He may have utilised faulty supplies and be faced with immense rectification and warranty costs.

PURCHASE DEPARTMENT INTERACTIONS

There is clearly extensive involvement of quality control with purchasing, regarding bought-out supplies. This aspect has been touched upon previously in this chapter, but further comment is now desirable. Optimum understanding and liaison is essential for satisfactory bought-out supplies. QC must fully appreciate purchasing principles, objects and philosophy and in turn purchasing must freely recognise quality requirements. Each must have mutual confidence and trust in the other.

Some purchasing departments insist that all contact with suppliers be via their department, rather than direct. This is not a good procedure and is largely protective in purpose. Quality personnel should have freedom of direct contact with suppliers **on quality matters,** but must keep purchase fully informed.

If purchase reserve all contact with suppliers, there can be delay and insufficient or wrong information conveyed. The lines of communication become:

Customer QC to buyer.
Customer buyer to supplier sales manager.
Supplier sales manager to supplier QC manager.

Other intermediate people within these departments, or additional departments, such as production control, can become involved. The whole tedious procedure also applies in reverse to the three steps listed above. Good relations, communications and co-operation can obviate these problems and excellent team attitudes can be established.

Regular meetings of senior purchase and quality personnel on bought-out supplies are most valuable. Incidence of rejects, problem supplies, new suppliers and current suppliers giving trouble can all be usefully discussed and actions agreed. Quality control can advise purchase of any field problems reported and of any function, manufacturing or assembly difficulties experienced with bought-out supplies.

GOODS INWARDS INSPECTION PROCEDURES: METHODS AND EQUIPMENT

1. Sampling Procedures

As stated earlier in this chapter, goods inwards inspection is an 'in arrears' quality monitoring activity. Therefore it logically uses sampling procedures. There are various methods of sampling and considerable information is available on this subject, including normal and skew distributions, standard deviations and all the other statistical features which can become involved. There are schemes relying on a single sample, which can be fairly large, to provide assurance of being representative of a particular batch.

To offset this sample size aspect, double sampling schemes were developed. These provide for an initially smaller sample which is followed by a second (double) sample if the results of the first sample are not decisive.

Finally, sequential sampling allows for successive small quantities (down to unit samples) to be inspected until a go/no go decision is obtained on numbers of rejects found. There is a sequential analyser marketed which computes the trend and can indicate the go/no go at a fairly early stage. This equipment is good, but it can be initially costly to purchase sufficient units for a large inspection department.

One shortcoming of the system is that each piece part has to be checked for all criteria sequentially and then the next piece part similarly. This means that each gauge or instrument has to be picked up, used on one part, and put down again. Normally it is better to gauge several parts, say for outside diameter, then for overall length and for the other features, in this sort of order.

The reader will realise that one of the problems which arises, particularly in sampling inspection, is the definition of what comprises one defect. A part may be defective because of one discrepancy, or it may have errors on a number of features. Most quality activities define **an item** as one defect, even though it may have several errors. However it is important that multiple errors are emphasised by qualifying comment, as necessary. Some organisations select critical features on an item and only class it as defective if there is a fault on a critical feature.

The principles, procedures and characteristics of sampling methods are extensively covered in the book *Sampling Inspection Tables,* by H. F. Dodge and H. G. Romig (Wiley, 1959). These tables give operating characteristics of various plans, for various degrees of average outgoing quality limit assurance and lot tolerance percentage defective protection. They give figures of sample sizes relative to a wide range of batch quantities and degrees of risk.

So much has already been written on this subject that it is better to recommend the reader who requires greater detail to refer to such publications, rather than attempt to cover the subject in this book. In addition to the Dodge and Romig tables mentioned above, the subject is comprehensively covered in the book on *Total Quality Control* by A. V. Feigenbaum, published by McGraw-Hill (1970).

Enough has been said about sampling methods. It remains to be stressed that, like many other activities, they should be used as an aid, rather than a rigid discipline. For example, it would be illogical to inspect a sample quantity of 115 plastic mouldings out of a batch of 1,000 supplied because the sampling tables specified this size of sample for a given assurance. Plastic mouldings are normally very consistent and a much smaller sample would suffice. (Where multiple moulds are involved they should be identified by corresponding marks on the parts, and samples from each mould inspected.)

Similarly, nuts, bolts, washers, etc., are produced fairly consistently by mainly automatic methods and in very large quantities. Relative sample sizes specified by sampling tables would be much too large and involve undue inspection.

True random sample selection is most important. The sample quantity must be truly representative of the batch rather than a biased portion of the total quantity.

2. Methods

The importance and value of quality records for each part number has been stressed together with inspection instructions. Sample work on castings has also been fully covered.

Samples of many other items besides castings are a regular feature of goods inwards inspection. This work, and a high proportion of the work handled, entails considerable first-principle checking in a goods receiving inspection department. Personnel skills and experience need to be commensurate. This applies particularly to electrical components such as motors, relays, timers, power supplies, transformers, solenoids, switches, etc.

Methods of applying electrical test equipment and the tests carried out must verify functional, safety and reliability factors. It is good practice regularly to select a sample electrical component, dismantle it and study internal workmanship, freedom from foreign matter, insulation standards, etc. Such tests can be most revealing and minimise failures in service. Where necessary, dismantled units should be returned to the supplier for reassembly and test, under an established procedure.

Apart from these activities, it is also good practice to submit sample components for reliability testing, to verify quality of production manufacture as distinct from proving of initial designs.

3. Equipment

As a consequence of the first-principle testing mentioned above, a goods inwards inspection department requires first-principle equipment suitable for the supplies involved.

On the mechanical side a comprehensive range of first-principle instruments such as micrometers, verniers, height gauges, dial indicators, etc., are usually supplied and also spring testers, pressure testing equipment and small tensometers. A very useful item of apparatus is a co-ordinate measuring machine. This enables hole spacing, positions and linear measurements to be taken much more quickly and accurately than by surface table set-ups.

Electrical equipment can include:

'Avo' meters.
Wattmeter.
Thermocouples.
High potential testers for electrical breakdown tests ('Flash' testers).
Oscilloscopes.
'Variacs' for applying selected steady voltages.
Digital voltmeters.
Electronic timers.
Cambridge AC test set.
Universal bridge set.
Electrostatic voltmeters for high voltages (*circa* 10,000).

Fig. 5.4 shows a modern development which uses computer technology for quality control of items such as relays, timers, printed circuit board assemblies, etc. The equipment has memory stores and can be programmed to carry out a variety of electrical test sequences, at three separate test points on differing components simultaneously, if required.

A component, such as a relay, can be connected up and a test sequence selected. Part number criteria, etc., to be checked are shown on the display monitor. Up to thirty relays located on a jig can be tested sequentially. The test button is pressed and the results can be a simple accept or reject decision, a display on the monitor or a print-out recording the test made, the drawing specification figures, the actual reading and deviations.

Test speeds can vary from two seconds (to allow for the switching time of some large relays) to as high as 50,000 tests per second. The logic of a printed circuit board assembly can therefore be tested in approximately 20 seconds. This compares with a full day, using standard first-principle test equipment and exploring out all circuits, etc.

One section of the three stations is specially arranged for soak-type tests and measurement of coil temperature rise, with pass or fail print-out, if required.

This equipment is highly sophisticated and relatively expensive. Few companies would have the need or justification for such expenditure. However, the reader needs to be aware of rapidly advancing technology, particularly in the electronics field. Modern miniaturised electronic parts and assemblies need ever-increasing refinements in equipment to monitor and control their successful application.

ELECTRONIC COMPONENT PROBLEMS

Many examples could be listed of problems experienced with electrical components. Some typical examples are:

1. **Soldered joint faults.** Such faults are almost entirely due to unsatisfactory techniques, equipment, training and controls. Attention to these factors will virtually ensure trouble-free soldering. Female personnel usually carry out such work and can be remarkably adept, diligent and reliable given the right technical supports mentioned. (See also heat transfer effects mentioned below under glass-sealed parts.)
2. **Fuse faults.** Most electrical equipment is protected by fuse(s). Too often the rating is set much too close to operating values. There is no margin for 'spikes' and current 'surges'. Fuses themselves may 'blow' at slightly below their rated value, and these rated values tend to diminish during prolonged operation. As a result 'spurious' fuse failure occurs fairly often and can be very troublesome.

   Fuse locations are often inaccessible, very tight in grip and yet poor contact arises. This again leads to trouble-shooting investigations, only to find the fault is in the fuse area, and current is not reaching the device involved.
3. **Wiring faults.** These can be of many types:

   Faults in leads themselves. Poor crimping and tag contact.
   Poor connections.
   Routeing faults. Leads touching earthed areas.
   Insulation breakdown.
   Wiring too tight, leading to mechanical or temperature fracture.
   Pressure on wiring, leading to breakdown.

4. **Contact faults.**
   Insecure.
   Out of square; misaligned.
   Unsatisfactory 'wiping' effect, leading to arcing.
   Arcing and burning due to opening or closing speeds.
   Unsatisfactory material for current switched.

5. **Glass-encapsulated parts.**
   Leads to such parts can easily be fractured at the glass entry point.
   The glass vacuum seal can be disturbed by movement of the leads or during soldering of connections to it. Also undue heat transference during the soldering operation can damage internal structure. This problem also applies to soldering connections to other electrical components.

6. **Safety trip devices.** These are usually of two possible types:
   Thermal operation.
   Current-operated.

British and other standards for electrical safety require that various electrical components such as motors, lamp ballasts, etc., shall have overload or fault trip devices built into each unit.

As the name implies, thermal devices operate on undue temperature rise and cut off the current supply. Unfortunately, the temperature spread of thermal cut-out operation between open and closed conditions is usually fairly wide and designers tend to choose one which has an ample margin of safety at the top end. As a result the lower end of the range is often fairly close to the component operating levels. Slightly adverse ambient conditions and surge or switching effects, plus inaccuracy of actual temperature operation, frequently result in spurious operation, i.e. false high temperature cut-out. As resetting is normally such that a reset button has to be pressed, a service call can be necessary.

The current-operated device is arranged to operate if the current flow rises above a predetermined level. These devices will operate over closer ranges than thermal cut-outs and with closer reliability to the specified figures. Spurious operation still occurs because the designer does not allow for transient surge or spike effects in current supplies with or without electrical interference effects from other parts of the machine, or nearby electrical apparatus. (In the jargon of the electronics engineer, electrical interference effects are often referred to as 'noise'.)

ELECTRICAL BREAKDOWN TESTS

Tests for this fault are sometimes referred to as **hypot** (high potential) or **flash** testing.

Various electrical standards specify safety features requiring minimum clearances between points, connections, casings, etc., and wiring, components, etc., carrying mains or higher voltages. Various proprietary instruments are available for flash testing and these may indicate electrical breakdown or 'flash-over' by a neon-tube indicator or fall-back of a meter reading.

The test is normally carried out at roughly six times the standard mains voltage, i.e. 1,500 volts in the U.K., and for a duration of one minute. This is a severe test and care must be taken that the 1500 volts is not applied to low-voltage rated components, which may be excluded from the regulations.

Similarly, the 1,500 volts must be built up gradually and not applied as the full voltage instantaneously. Repetitive flash testing can rupture an assembly which was initially satisfactory. Flash test trouble-shooting can therefore be an extremely tedious and frustrating exercise.

Here again the basic principles apply of effective quality control of the methods, procedures, training and facilities. The likelihood of flash test breakdown must be obviated rather than repeatedly searching for the fault in a complex assembly.

Each and every component which is itself built into a machine or complex assembly must be individually flash tested and rigid disciplines enforced to this effect on internal manufacture and bought-out supplies. The test is relatively quick and the cost negligible as compared with the high cost and trouble of finding where a complete assembly is breaking down on final flash test.

SOME CASE EXPERIENCES OF ELECTRICAL COMPONENT PROBLEMS

Case 1

Electric motors were found to be seizing up after a short period of operation.

The cause was found to be metal cuttings left in rotor grooves, following an assembly operation of drilling holes in the rotor for balancing purposes. The metal cuttings became displaced and jammed between the rotor and stator.

Case 2

Relays were 'drifting' from set operating characteristics. This was a random fault which existed over a long period without a cause being determined. In fact the customer was even accused by the vendor of tampering with the settings of relays supplied. A quality man was visiting the supplier concerned and in the manufacturing area, when the lunch-time break siren sounded. He noticed that a girl had just finished applying a locking adhesive to the adjustment screw on a tray full of relays. The **next** station on the assembly line was the setting of the adjustment screw to the relay criteria required, using adequate test apparatus.

Inquiry revealed that the locking adhesive hardened within an hour after application. Normally the setting operation took place well within this time and the adjustment was locked satisfactorily.

The cause of the intermittent problem was then clear. Some of the relays to which adhesive had been applied before a break had the locking effect broken, by setting adjustment after the adhesive had hardened.

The solution was simply to apply adhesive **after** adjustment and take care that the setting was not subsequently disturbed before the adhesive had hardened.

Case 3

An AC current solenoid was reported as noisy. The supplier suggested copper plating of the plunger and submitted samples.

These were tested with an exactly equal on/off pulse and appeared satisfactory. Quantity production was authorised. In the actual application these solenoids were in operation for seven seconds and off for three seconds. After roughly 200 cycles the plunger became strongly magnetised, owing to the copper coating, and stuck at one end of its travel, resulting in functional failure.

Large quantities had to be reworked to correct the fault.

Case 4

A printed circuit board assembly included some power transistor devices secured to the board by small nuts and bolts. The wiring supply to the transistors was taken through the securing bolts from the printed circuit on one side to the transistor devices.

The heat from normal operation of the power transistors expanded the bolts. Repetitive expansion and contraction in use resulted in breakdown of connections and failure. The action was to arrange a metal plate 'heat sink' on which the power transistors were mounted and for the current supply to be independent of the mounting bolts.

(Through connections to the opposite sides of printed circuit boards are a notorious known failure cause, and 'through-plated' holes have to be used under carefully controlled procedures.)

6 | Piece Part Manufacture

GENERAL PRINCIPLES

Effective quality control in piece part manufacture can minimise lost production, wastage, scrap, etc. Subsequent satisfactory assembly, test and reliable function in service are very dependent on satisfactory individual piece parts.

Items are largely originated during piece part manufacture and it is rarely easy to start again if not 'right first time'. Whereas an assembly can often be rebuilt, a portion of metal in the form of a piece part cannot be put back on to a metal bar or a casting easily recast. Similarly, an oversize hole or a stripped screw thread is often cause for scrap. (It is appreciated that engineers have various ingenious ways of meeting such problems by bushes, threaded inserts, etc., but these remedies are best obviated, especially when large quantities can be involved from modern high-speed machine tools.)

MACHINE CAPABILITY

Earlier emphasis has been laid on the need to ensure that machines used are **able** to produce requirements. This activity is generally known as machine capability study. Some companies operate extensive cover of this philosophy. The principle is logical but sometimes applied at the wrong stage, i.e. on equipment which is already established and which cannot readily be changed. New machines should always be proven at the machine-tool makers **before** delivery and again verified immediately upon delivery.

Functional performance is more significant to the machine customer than integral machine dimensions, such as bed flatness, straightness, spindle run-out, etc. These features are normally checked by the machine-tool maker, but any errors show up in functional tests, which are the ultimate verification.

Difficulty usually arises because established machine tools can be required to produce differing products from that for which the machines were originally provided.

Adequate, efficient, regular and systematic maintenance of machine tools is an essential requirement which is all too often neglected.

Where a company enjoys the benefit of a planning or production engineering department, machine capabilities are rarely a main problem, if the machines are well maintained. The planning department fully realises that parts with fine tolerances cannot normally be produced by ordinary turning or drilling methods. Grinding, fine boring, reaming, honing or lapping procedures may be specified and arranged.

These comments lead to the contention that actual effective quality cover in piece part manufacture is the better way of monitoring and actioning the factors involved, rather than involved and sophisticated machine capability activities.

FIRST-OFF INSPECTION AND INSPECTORS

Such control commences with 'first-off inspection'. This is virtually the most important quality control, particularly in piece part manufacture.

The machine operator, or setter, produces and checks samples until he is sure, to the best of his ability, that he has a 'first-off' which can be submitted for inspection approval. It is very wrong for 'first-offs' to be presented which have not been checked by the producer. The inspection department should keep records of numbers of first-offs submitted. If multiple first-offs are commonplace, before individual samples are finally approved, then production supervision must be required to take action as necessary.

Once a 'first-off' is approved, production can commence – always with the proviso that quality **originates** with the producer and is only monitored by inspection.

Machine-shop inspectors should be encouraged to mark the approved sample, in addition to shop paperwork. The marked sample can be referred to in the event of large numbers of faulty parts subsequently arising, owing to operators failing to carry out the production checks specified and for which time is normally allowed.

On machines producing large quantities, or on long production runs, it is usual to operate a patrol inspection system, whereby further sample piece parts are inspected at regular intervals. The two-box system is a very good arrangement which is widely practised.

Piece parts produced are held in an abeyance box until the patrol inspector has carried out a further sample check since his last visit. If the check is satisfactory, the parts in this abeyance box are transferred to a second box of accepted items. If, as a result of the sample check during a patrol visit, the part is found wrong, then the parts in the abeyance box are subjected to a 100 per cent inspection to extract faulty parts. This 100 per cent check may be carried out by production personnel under inspection supervision, or by inspection personnel, according to established company procedures.

Returning to machine capability, it will be clear that any machine limitations, due to suitability or maintenance faults, will be highlighted by the above procedures and appropriate action necessitated. Such experience can still arise, despite previous capability studies, in so far as various unforeseen factors occur, e.g. tooling or other equipment aspects upset the capability anticipated.

The first-off inspector is a very important link in this system and needs to be widely experienced in the manufacturing processes concerned. Knowledge of the type and nature of faults which may be likely to arise is essential. He must be able to maintain good understanding with production people. Typical factors are:

(*a*) Not autocratic, dictatorial or excitable.
(*b*) Not fussy or unreasonable.
(*c*) Not derogatory or prone to exaggeration.

1. Helpful.
2. Clear.
3. Confident.
4. Rapid.
5. Methodical.
6. Impartial.
7. Decisive.

In this (and most quality activities) it is wise to avoid confrontation arguments on borderline situations or subjective opinion features, e.g. finish, sharp edges, burrs. Choose the definite issues if argument occurs with 'difficult' operators. It is easier to prove that a part is several thousandths of an inch in error than only one ten thousandth beyond tolerance. Usually inspectors maintain the excellent understanding mentioned earlier and are probably more often helpful than difficult.

The first-off inspector should not normally have to carry out extensive calculations to enable him to inspect piece parts. He is usually operating under pressure and noisy conditions and should therefore have all information required provided on the drawing, or in manufacturing instructions.

The number of machines a first-off inspector can cover will vary widely owing to:

Class and accuracy of work produced.
Gauging, jigs, fixtures provided.
Machine-tool quality, type and maintenance efficiency.
Variety of work.
Length of runs (size of batch).
Quality of operators or setters.

Managements must always bear in mind that machine tools standing idle, awaiting first-offs, etc., cost far more than labour. Inspection cover should therefore be adequate, rather than minimal.

TYPICAL MACHINE PROBLEMS

1. Lathes

As stated earlier in this book, modern machine tools are generaly fairly reliable and can produce appropriate good-quality parts. They must be tooled, set and operated correctly and adequately maintained.

The most frequent problem on lathes is the standard of finish produced. Materials machined have a marked influence on the finish obtainable. Light alloys usually machine much more readily than high-tensile tough steels. However, turning is normally a form of thread cutting and the coarseness of the feed (longitudinal traverse of the tool) can result in a ribbed-type finish. Similarly, the depth of cut and number of cuts taken also have an effect on surface finish. To some extent these factors are a compromise with speed of production. There is always a tendency to sacrifice finish for high rate of output.

Modern piece part drawings normally specify surface finish criteria for each feature of a part which requires control of the surface finish and with a general overall figure to cover other features not separately specified. This partially removes the old source of argument where the drawing either specified no surface finish data or vague details such as good, smooth, ground, polished finish.

However, measurement of surface finish is a complex procedure requiring fairly sophisticated and expensive instruments. (The subject of surface finish assessment is covered by British Standard 1134.) Such expensive equipment will not often be available in the small company. In larger companies, the equipment is usually located in the metrology or other centralised inspection area. Small portable instruments are marketed, but are still too expensive to become freely available to all inspectors in a machine shop on an individual basis. It is therefore usual for the inspector to have to borrow the portable equipment or refer sample piece parts for surface finish check.

Physical sample surface finish standards at the point of inspection are thus still of considerable assistance to individual inspectors. These may consist of sample piece parts which have been calibrated, or there are several makers of physical surface finish samples. These may be small rectangular flat plates or cylindrical specimens. They range from smooth to coarse finish samples over the geometric progression of surface finish numerical values recommended in the British Standard.

Such comparison samples provide valuable assistance in the day-to-day assessment of surface finish. Inspectors develop good visual ability to assess finishes fairly accurately. However, visual assessments can be misleading and should not be relied upon extensively.

The machine-shop inspector will know that shoulder faces and the sides of grooves (particularly narrow ones) can be much rougher than diameters and also that important radii must be free from ridges and correctly blended. Specified radii must not be omitted from the inner corner stress points of grooves and undercuts.

Relationship or geometric faults are the next most likely trouble regions with turned parts.

Whenever a part is relocated for a second operation, it is very likely to have eccentricity or squareness relationship errors, relative to previously produced features. Checks for such possible errors are essential.

The relationship faults mentioned are, of course, basically geometric but are mainly associated with relocation effects. Other geometric features are roundness, parallelism, flatness and straightness.

Holding methods and pressures, in machine tools, can often cause ovality or distortion on the finished part, particularly with tubular or thin-section parts.

Finally, on lathes, the aspect of screw threads should be mentioned. Special machines often used for threaded work are very versatile and effective. However, considerable threaded work is produced on lathes, and modern taps and dies make this operation fairly reliable. Faults to watch for are: internal threads tapered oversize at the outer end ('bell-mouthed') and eccentricity. It is difficult to produce threads fully at the bottom of a hole or close up to a shoulder owing to the 'lead' on the cutting tools involved. The length of effective thread required must be verified, otherwise screwed plug parts will not enter far enough into threaded holes. Alternatively, shouldered parts, like bolts, cannot be screwed in up to the shoulder.

Sometimes undercuts are provided adjacent to shoulder faces to enable 'full' threads to be produced. It is important that verification should be made that threads are 'clear' into such undercuts, otherwise assembly will still not be possible.

Any undue flat area on the major diameter of an external thread or the minor diameter of an internal thread probably indicates inadequate thread depth and a weak thread. The 'plain' diameters involved can be readily checked and verified.

There are many lathe types and an immense size range. Apart from 'cut' threads on lathes they can be produced by rolling, forming, grinding and moulding (plastics). They are therefore a subject in themselves and further comment is outside the scope of this book.

2. Grinding Machines

Again there is a wide range of machine tools which come into the general group of grinding machines: external and internal cylindrical, surface, centreless, thread, cutter, jig grinders.

The remarks on surface finish relative to lathes are also broadly applicable to grinding operations. Finish on shoulders, etc., produced with the side face of a grinding wheel are likely to have a rough 'cross-hatched' lined finish. Such shoulder faces are also very likely to be out of flat or 'domed'. The finish on a surface ground part will have a pronounced 'lay' effect. The finish in the direction of longitudinal travel of the grinding wheel will be much smoother than across the part, i.e. at 90° to the longitudinal travel.

A kind of fault commonly experienced with grinding operations is known as 'chatter marks'. These are small flats on the surface which can arise from several causes. Some of these are:

Grinding wheel out of balance.
Grinding wheel loaded (clogged with material particles causing 'bouncing').
Unsuitable type of wheel for material being ground.
Material insecurely held during the grinding operation (loose on centres).
Material unstable owing to thin sections, spring, etc.
Grinding machine spindle loose in bearings, or work-table instability.

Chatter marks can be very pronounced and are usually detrimental. Furthermore, they are normally avoidable by attention to factors such as those listed above.

Chatter marks can be partially obscured with slightly rougher ground surfaces. Parts may need to be viewed from different angles to reveal 'chatter' which may otherwise be unobserved. The fault may or may not exist over the whole area of a ground surface.

A 'chattered' finish on a surface ground part can also result in overall flatness errors. The hammering effect associated with the chatter marks can produce distortion and the out of flatness mentioned.

For purposes of oil retention, or to provide a 'bedding-in' capability to accommodate small geometric irregularities, parts may be required to be produced with a specified degree of 'roughness', i.e. a particular surface finish rather than the best finish possible. It is usual to produce such parts by controlled grinding operations, or a variation of grinding known as honing which uses a controlled type of abrasive for the desired results.

The same relationship or geometric faults mentioned under lathes are also possible with grinding operations, particularly eccentricity errors.

A fault particularly associated with grinding is 'burning', i.e. particularly hard or hardened parts. The fault is due to intense heat generated at the surface during grinding operations. Clearly, many factors influence this problem:

Volume and type of coolant.
Grit and grade of grinding wheel.
Correct dressing of the grinding wheel.
Type of part and heat dissipation ability.
Feeds and speeds.

Burning sometimes produces individual cracks but more frequently a crazy-paving type surface, criss-crossed with cracks, which may or may not be visible immediately after grinding. Such cracks tend to become more pronounced subsequently, over hours, days or even weeks. Burnt parts are almost always scrap. This is therefore a serious fault which requires careful attention and the aid of metallurgical tests, where such faults may arise. (It must be emphasised that cracks of any kind are rarely permissible because a crack frequently extends or propagates until failure occurs, particularly in parts which operate under stress conditions.)

Centreless grinding machines can produce parts with an error known as 'lobing'. The fault arises mainly by incorrect setting of the work rest relative to the centre lines of the grinding and control wheels. A gyratory motion of the piece part occurs during the grinding operation. The part is then not truly cylindrical, but consists of an odd number of lobes, most commonly three. There may be five, seven or occasionally a much larger number of lobes. With larger numbers of lobes the deviation from a true circle is less pronounced.

Any two-point measurements of the part with a micrometer or similar instrument will appear to indicate a normal round part. However, a 'lobed' part will not enter a corresponding size hole. The amount of error can easily amount to several thousandths of an inch.

The lobing is based on a true geometrical shape with large and small radii produced from apex points, as shown exaggerated in a three-lobed example in Fig. 6.1.

The basic figure in this instance is the equilateral triangle shown by the broken line. The small radius is shown as r from one apex point and similarly (for clarity purposes) the large radius R, from another apex point. **Both** radii occur from **each** apex point. The apparent two-point measured diameter is the sum of the two radii (dimension A). This will appear constant from a succession of two-point 'diametral' measurements.

The lobed part will, however, only enter a hole which is larger than the apparent two-point measured diameter by an amount X, as shown in the diagram by the larger broken-line circle.

This kind of fault can be revealed by rotating the part in a vee block with a dial indicator registering on the circumference. Checks should preferably be made in 90° and 60° vee blocks, to reveal differing basic polygons, which may be involved with any lobing effects.

It will be appreciated that one effect of lobing is to prevent parts being assembled. A more serious effect is where the fault exists on rollers in a roller bearing or similar rotating application.

Thread grinding machines are not very frequently found in production machine shops. The modern high-speed special-purpose

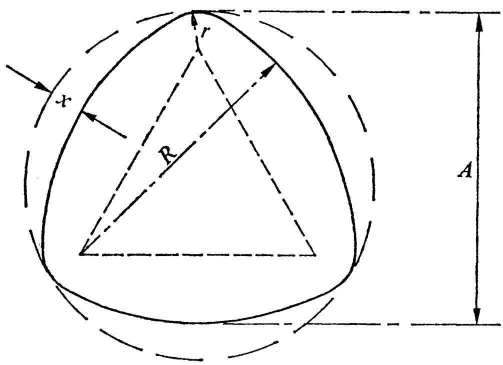


Fig. 6.1. Exaggerated drawing of a three-lobed grinding fault

reciprocating 'Cridan'-type machine offers a wide range and size of screw thread production as an alternative.

Thread grinding is therefore more usually confined to specialist applications and tougher materials. Production of screw thread gauges, cutting tools, taps, etc., necessitates thread grinding machines in toolrooms.

Thread grinding is a very accurate method of thread production and virtually ensures a high standard of finish, without the roughness, tears, etc., of lathe-type methods. Size can also be closely controlled. The most common fault is wear of the outer diameter of the formed grinding wheel, leading to profile and taper faults. External threads can be oversize in the root of thread (minor diameter) or tapered relative to the wear on the leading edge of the grinding wheel.

Cutter and jig grinding machines are most commonly found in toolrooms and have the special-purpose applications which their names imply. Satisfactory tool and cutter grinding is essential to good machine-shop operations. The effect of incorrect cutter-ground tools is usually readily apparent in their performance, or is revealed by normal piece part quality control.

3. Milling Machines

This group of machine tools covers horizontal, vertical, surface, routing and thread milling machines.

Surface finish from milling operations is usually fairly coarse compared with other machining methods, but again factors such as those outlined for lathes influence the finish obtainable.

Milled surfaces are also very prone to the 'chatter' fault described under grinding operations. Causes can be due to factors such as:

Loose spindles and machine vibration generally.
Worn cutting edges.
Incorrectly ground cutters.
Speeds, feeds, depth of cut.
Interrupted cut.
Too few teeth in cutter relative to speed, feeds, etc.
Work insecure, unstable, 'springy'.

The very nature of the milling operation is conducive to 'chatter' effects and it is therefore often more difficult to obviate this fault entirely than it is with grinding. However, the degree can usually be minimised to acceptable levels, commensurate with the average level of finish associated with milled surfaces.

Thread milling machines can develop extensive wear on the helix cam, which during production of threads repetitively progresses the cutter head through one thread pitch on successive piece parts. The resultant error in helix of a milled threaded item is very difficult to find, as it will not be revealed by normal gauging methods. Adequate machine maintenance is important to obviate this fault.

Additionally, the milling operation requires that the work piece be held very securely during machining. Distortion effects upon release from the work clamps can be very pronounced. Milling jigs and fixtures frequently utilise air or hydraulically operated clamps to ensure secure and consistent work holding. This minimises possible variable distortion after release, which otherwise might occur if tightening of clamps is dependent upon operator variables.

Milling is often a process where the amount of material removal is extensive, resulting in a profusion of metal chips and cuttings. Such debris can easily be left on location surfaces, unless operator care and attention is exercised. The machine-shop inspector needs to be on his guard against faults from such causes.

4. Gear Cutting Machines

This is a special machine group which may be much more predominant in some plants than in others. The machines include hobbing, shaping, grinding, milling and gear generators (bevel gears).

Spacing and eccentricity faults are the most troublesome in gear manufacture. Spacing faults are usually connected with machine or cutter factors. Eccentricity faults are most frequently due to lack of care in mounting of the work piece.

Control of gear manufacture can extend to very sophisticated profile projectors, involute testers, lead and spacing tests. The important requirement is a means of rolling test against a known standard. This rolling test can be very effective in revealing various spacing faults, profile and eccentricity errors.

Rolling gear testers can vary from a simple sliding carriage unit with a dial indicator showing carriage movement during the rolling test, to pen recorder read-out instruments.

Marking of the areas of teeth contact by use of the well-tried 'engineers' marking blue' medium during the rolling test can reveal unsatisfactory contact faults. Fig. 6.2 shows unsatisfactory mating tooth contact due to 'heel and toe' cross-bedding on bevel gear teeth.

Fig. 6.3 shows a rolling test instrument for gears, which is very versatile.

Enough has been said to emphasise that gear manufacture is an activity which must be supported by adequate verification equipment and instrumentation. It is most unwise to produce gears relying solely on the gear cutting machines involved.

5. Drills

Drilling machine tools range from small single-spindle types to multi-spindle, high-speed and large radial arm machines.

Drilling is another operation where the standard of finish can be rather poor. A torn ragged finish is very likely, especially on tough materials. Such poor finish is readily apparent on through holes, when held up to the light. This test is not possible with large parts, small diameter or 'blind' holes, but rough finish in such holes can usually be discerned by judicious use of lights or the more sophisticated internal bore viewing instruments.

Incorrectly ground drills can produce poor finish. Also, lack of suitable cutting or cooling fluid markedly affects the finish obtainable. The most common effect of incorrect grinding of drills is tapered ('bell-mouthed') and oversize holes. Badly ground drills will produce holes much larger in diameter than the nominal size of the drill. Large burrs around the outer edges of drilled holes indicate a blunt drill or undue drilling pressures.

Drilled holes can 'run' out of line, or out of straight, and the drilling first-off inspector must always watch for such faults. Because of the problems outlined, drilled holes are often finished by reaming to obviate the geometric errors, provide size accuracy and a good finish. A common fault here is that the drilled finish is not entirely removed during the reaming operation and a rough (not 'cleaned-up') area remains.

Some drilled holes are finally tapped with a screw thread. The drilled finish in such instances is not usually critical for the thread minor diameter concerned. However, this should not be badly oversize, otherwise a shallow, badly truncated thread is produced. There are, of course, special-purpose tapping machines, but it is not deemed necessary to comment on them as a particular group.

6. Automatics

The predominant types of automatic machine are those which produce components from bar material. There are other types known as 'chucking' automatics and multi-station machines usually designated by the number of spindles.

The essential requirement with automatic machine-produced parts is maximum care in approving first-off samples, as large numbers of parts may be produced similarly. Automatic machine setters normally cover several machines and much reliance is usually placed on first-off and patrol inspection on automatic production lines, to authorise production to commence and proceed.

Automatic machine production is an area to which control charts and statistical sampling methods have been most successfully applied.

7. Numerically Controlled Machine Tools

These machines are a modern step forward from the previous group and can perform complex sequential machining operations such as turning, boring, drilling, milling, tapping, etc. They are also distinct from the transfer production lines often used in the motor industry, for various types of sequential machining operations and stations, to produce complete components, such as cylinder blocks and cylinder heads.

NC machines are operated by punched paper or magnetic tapes and can be programmed for various machining steps. Initially this development was thought to be most suitable for the longer type of production run. However, the obviation of special-purpose jigs, fixtures and tooling makes NC machines valuable for short production runs, where expensive tooling is unjustified, or for urgent work before production tooling is available. The same applies to prototype and experimental work.

The next step forward being forecast is the application of minicomputers to machine-tool control. Programmes could be more easily changed than with numerical tape control. Again, the first-off approval is critical, as any errors in programming or tape production must be observed.

Numerical control is also being increasingly applied to the adaptation of existing machines of various types to 'automate' certain operations.

8. Other Machine-Tool Groups

Mention has not been made of broaching, plano-milling, boring and various other more specialised machines which do not readily fit into the main groups already listed. These machines are not universally predominant to the extent that requires their grouping into distinct categories. Careful first-off attention is a good maxim for quality control of production from these machines just as with other groups.

GAUGING; TOOLING; INSTRUMENTATION; INSTRUCTIONS

Manufacturing areas particularly need adequate cover for the items listed in the heading to this section. Piece parts are **originated** in manufacture, normally by processes which cannot be reversed.

Metal removed from a surface cannot be put back. Piece parts cut off from bar material may require special holding provisions if rework is later found necessary. Maximum attention to obviation of faults during manufacture can therefore be well worthwhile.

Gauging provision to enable the **operator** to check his work, as it is produced, is a primary quality factor. Gauging is generally preferable to first-principle measuring equipment, as it is more rapid and positive in operation. However, fixed gauging is often special to particular piece parts and may not be justified for short-run or small-quantity production.

An alternative is the adjustable gauge which can be preset in the gauge room and then functions as a fixed gauge for the run of the part concerned. The gauge can later be reset for another tolerance, when required.

A variation of the adjustable type are the indicating instruments. These are again set for a particular nominal size but the tolerance is read off by a pointer over a short scale. Limits of tolerance may be indicated by slidable pointers which are also set at the same time as the nominal dimension. Such indicating gauges should preferably have a cross-check standard supplied, for occasional setting verification, at the point of use. This facility ensures that the setting has not been disturbed.

Indicating gauges are initially expensive compared with the solid and adjustable types. The investment can be worthwhile, depending on the variety of type of piece parts produced.

The above gauging remarks relate primarily to diameters, bores, lengths and screw threads. Gauges for angled surfaces, tapers and relationship checks are usually more special purpose. They may or may not include dial indicators. Again, the need for checking standards is important.

Certain gauging can be virtually provided by the piece part tooling arrangements. For example, a comprehensive drill jig will virtually ensure consistent hole positions, if once verified and the tooling properly maintained. An elaborate and costly receiver-type gauge is rarely justified. Deviations due to faulty piece part location, drill run-off, etc., are possible error causes.

Tool designers are normally very good at ensuring that errors from tooling are minimised. Good, positive locations, adequate and well-positioned clampings, etc., are ensured. A particularly sophisticated arrangement was seen by the writer on a jig for a part which contained a large number of threaded holes of various sizes. Periodically the operator missed producing the thread in one or more holes. The fault was not found until the part had been assembled into a large machine. It was then very difficult to produce a missing thread.

The tool designer's solution was to provide electrical contact switches under each of the threaded hole positions. Unless the various thread tools (taps) were passed through every hole involved, the part could not be released from the clamps. The operator would then know he had missed a thread from a hole and make the necessary correction. No further trouble was experienced. The investment was fully justified in the saving from assembly delays.

This is an example of the control of quality by removing the likelihood of faults. An alternative would have been to put an inspector to check every thread, but this would be a sorting of good from bad exercise and a continuous added expense.

The gauge equipment should be supported by procedural instructions. These are sometimes divided into operator and inspection instructions. Tooling and gauging is listed, method of use and significant aspects emphasised. Such information can be updated with information on any trouble previously experienced and thus minimise errors recurring on subsequent batches. Some companies use operational stage drawings showing only the information relative to one particular operation. It is vital that such individual operation drawings specify the requirements for later operations, e.g. that a diameter may have a small allowance for a subsequent grinding operation. The finish on the diameter must not therefore be too rough at the turning stage.

Quality personnel should definitely refer to piece part drawings, in addition to operational drawings. Such reference is probably made at a final inspection stage. The design requirements are for parts to be correct to drawing and it is a quality function to verify conformance. Operational drawings are an aid to manufacture and do not supersede design drawings.

Drawings often contain various notes regarding geometric and relationship aspects, finish, heat treatment, etc. Such notes need to be carefully studied and understood. Drawings often carry a slogan such as 'If in doubt – ask'. This is good advice. Misunderstanding of drawing requirements can easily arise and lead to faulty production. Never put up with an indistinct, dirty, oily or damaged drawing, which can easily be misread.

DOCUMENTATION

Normally the customary work progress (route cards, etc.) paperwork provides comprehensive records for first-off piece part clearance, scrap experience, etc. However, scrap and rework experience is a valuable measure of manufacturing area efficiency. Such data should therefore be processed and analysed regularly for trends and remedial action, as necessary. As a rule, accounts departments should process this information, rather than the QC department.

The quality manager or his manufacturing supervisor ensures follow-up action and meetings with production management, as necessary. However, it is prevention rather than investigation of scrap and rework which is most important. As stated previously, operators must be given all necessary facilities and training and time to verify their work as it is produced. They should be encouraged to feel an involvement in product quality and understand the responsibility they carry for the production of good usable parts. Many schemes exist whereby operators are not paid, or are penalised, for faulty work. These schemes are not generally practicable, successful or desirable. Responsibility is usually difficult to establish clearly, is often historical and causes argument and friction.

PROCESS OPERATIONS

Piece part production frequently involves various treatment operations and finishing processes:

1. Heat Treatment

At various stages of manufacture metals are often subjected to heat treatment. (In a few instances low temperature is also used and provides increased hardness to certain tool steels.) When metal is subjected to working pressures, particularly in forging, pressing and drawing operations, stresses or work hardening effects can be set up. Unless such effects are removed, further work on the material is difficult, the parts are unstable, or both. Such parts are given a heat treatment operation (normalising, annealing) to restore original properties and remove stresses.

Parts which have to withstand heavy wear in service are subjected to hardening treatment. Some parts are through hardened and are then fairly brittle. Others are surface hardened to various depths.

There are other forms of heat treatment, such as the sintering of powdered metal-formed parts, but these operations are mainly confined to specialist companies.

Many firms subcontract their treatment operations, as the volume of work of this kind does not justify having the expensive 'in-house' equipment necessary.

In most instances, metal treatment operations are controlled by chemical or metallurgical laboratory personnel who monitor all the technical features involved.

The manufacturing inspector is generally involved to the extent that he ensures that:

Parts are sent for treatment at the right stage.
Treatment process controls are operated and monitored.
Treatment verification has been made.
Checks for distortion and cracks which can arise are made.

2. Painting

This is more usually an end manufacturing operation, when finished piece parts are given such protective or decorative treatment.

There are many kinds of paints used in modern industry and various types of application. Formulation, mixes, etc., are designed accordingly. Paints may be brushed, sprayed, dipped, electrostatically applied with a special spray gun or by the version of electroplating with parts immersed in the paint solution.

Most modern paints are synthetically based and may be air- or stove-dried.

All too often the subject of painting is approached by some companies on the basis that no special effort is required. Paint is simply applied by brush or spray and will be all right. This attitude is of course very wrong. Satisfactory painted products require careful attention, controls, skilled personnel and facilities.

The surface of parts to be painted must be clean, dry and of suitable surface finish. Paint will accentuate rather than cover scratches and other surface defects. Parts cleaned for painting should not be allowed to corrode before painting occurs.

It is usually better to control surfaces before painting than to indulge in extensive filling and rubbing-down operations.

The first stage, adequate mixing of the solid constituents in a supply of paint, is frequently neglected. Five-gallon (22·7 l) capacity drums of paint (often used in industry) require at least two hours oscillatory shaking before use. Machines are available for this purpose. Paint is difficult to stir by hand, with a stick or similar implement, especially in a five-gallon drum, which often has a relatively small hole at the top.

Quite frequently successive liquid portions are decanted off, leaving substantial amounts of the 'solids' at the bottom of the drum. Careful viscosity checks should give some indication, but these checks cannot substitute for inadequate mixing. It is good practice for paint-shop QC people periodically to have an empty paint tin cut open for examination of solids left at the bottom.

It is, of course, equally important for mixing to continue in the paint shop while the paint is in use. Modern paint facilities usually provide for this requirement, with paddle-type agitators in the paint tanks.

Viscosity markedly affects the spray capability of paints and requires adequate control.

The nozzle spray pattern is important for successful painted surfaces. Too small a cone is usually undesirable, leading to lines, irregularities and patchiness. Painted surfaces which are subjected to final baking or stoving require short periods of air drying. Certain solvents have to evaporate, otherwise they 'boil' during stoving and spoil the paint surface.

Stoving ovens should be verified for correct criteria, especially the open-end flow-through types. Temperature gradients can exist. Painted parts can fail to reach the required temperature, or remain long enough at this temperature for satisfactory drying, hardness, shade, etc.

The air flow through the paint shop must be filtered and oil-free. A slight pressure excess differential is desirable to ensure outflow if paint-shop doors are opened, rather than the reverse. The volume of air flow in the paint shop must not adversely affect oven temperatures by causing undue cooling at the open ends of through-flow ovens.

Where paint thickness is closely specified within a tolerance, the process should be mechanised, e.g. the part is oscillated in front of the spray gun for a prescribed number of passes, or vice versa. Cylindrical parts particularly lend themselves to such controls. They are rotated a number of times, while the spray gun is traversed longitudinally backwards and forwards (or up and down). Alternatively, parts are traversed past a stationary spray gun.

These arrangements provide close thickness control. It is virtually impossible for an operator to control thickness with a hand-held spray gun and guessing the paint thickness applied.

Tests for painted surfaces. Testing of painted surfaces is also usually carried out by laboratory personnel using various items of laboratory equipment. Normal requirements are satisfactory:

Shade.
Hardness or scratch resistance.
Wear or abrasion resistance.
Surface appearance (freedom from inclusions, orange-peel effects, runs, streaks, etc.).
Thickness.
Adhesion.
Gloss.

Yet again, adequate attention to correct procedures and controls will virtually ensure satisfactory production, rather than tests on finished painted parts. Some of the above tests are destructive and can therefore only be on a sampling basis.

Correction of unsatisfactory painted surfaces is usually a costly procedure and 'right first time' a much better policy. Modern, very hard polyurethane paints are naturally very difficult to remove.

3. Electroplating; Anodising; Rustproofing

These surface treatments are mainly protective in purpose but also have pronounced decorative uses. Many materials are used in electroplating, such as gold, silver, nickel, chromium, copper, zinc, cadmium. Once again, adequate process controls will virtually ensure satisfactory results.

Plating bath solutions should be checked daily and corrected as necessary. Similarly, temperatures must be taken and corrected.

Time in the bath and current density affect plating thickness significantly.
Parts must be clean and free from grease or rust.
Holding or wiring points need forethought except in the barrel plating of smaller parts.

Plated materials, particularly nickel, tend to build up on sharp corners. Shafts, etc., should therefore be checked to ascertain undue build-up at the ends. A ring gauge is a simple, quick and effective method for this check. 'Robber' electrodes are sometimes used in the plating operation to minimise this effect.

Conversely, thickness of plating diminishes towards the minor diameters of screw threads and in blind or small-diameter holes. This difficulty is known as the 'throwing power' of the plant and again special compensatory arrangements can be made to counter this limitation.

Thickness of the precious metals (largely used for electronic components and applications) is usually minimal and even coatings are therefore essential.

Nickel and chromium are occasionally applied to a much greater thickness, particularly for hydraulic plungers, etc., usually on an initial thin copper layer. Cadmium and zinc are used extensively for rust prevention.

Electroplating faults can also be costly to correct, as etching or other difficult procedures may be involved in removal of faulty coatings.

Tests for electroplated parts are largely similar to painted parts:

Adhesion.
Thickness.
Hardness.
Surface appearance: Finish, gloss.

Anodising is mainly used on light alloy parts. It has virtually no effect on their size as it is largely a kind of oxidisation of the surface layers. Dyes are frequently used to colour the surface in a very attractive range. One remarkable effect is to make the surface non-electrically conductive to lower voltages. A good test for anodic cover is an ordinary flash-lamp battery and bulb connected by probes. When the probes are applied to an anodised surface the bulb will not light and vice versa.

Rustproofing treatments are usually applied to steels. They consist of various forms of oxide treatment of the surface known under several trade names such as Parkerising, Granodising, etc. These oxide treatments are not fully rust-preventive and are usually sealed with dry film coatings of various kinds, or simply oiled. These treatments and phosphating are frequently used to form a satisfactory base and key for subsequent painting.

SCREENING: 100 PER CENT INSPECTION

Opinions still differ widely regarding the uses and benefits of screening and 100 per cent inspection operations. In piece part manufacture the need for 100 per cent sorting can frequently arise, owing to factors such as tool wear, setting movements or a host of other reasons causing changes or limitations in a production process. Use of the two-box method described earlier in this chapter can minimise the amount of 100 per cent inspection, so can the assurance of optimum operator checking during production.

Adequate planned machine routine preventive maintenance is another important discipline to minimise machine-tool faults and breakdown.

First-off procedure must also automatically recur following:

(*a*) Resets; tool regrinding and sharpening.
(*b*) Machine breakdown.
(*c*) Change of operator; commencement of new shift.

Economic batch quantities are a good concept in minimising frequent changes of set-up for short runs and the consequent higher risk of quality variation.

However, it should be fully appreciated that the extent of 100 per cent screening inspection practised is a measure of the lack of control of quality being achieved. It is far too easy to allow the amount of 100 per cent inspection to grow in order to ensure satisfactory outgoing quality. Such activities can become very firmly established. Production managements are only too willing to accept this situation as their safeguard and an essential practice rather than apply effort to improving methods, facilities, procedures, etc., to reduce or obviate the likelihood of defects.

7 | Assembly and Test

CONCEPTS

Companies who manufacture proprietary products, or who make component assemblies for other manufacturers, will have assembly and test departments.

Depending on the nature and volume of products, assembly and test sections will vary from relatively small activities to large-scale assembly plants, such as those in the motor industry.

Most assembly plants operate on the progressive line system, whereby piece parts or minor sub-assemblies are added sequentially to build up a final product. This system, largely initiated by Henry Ford many years ago, exists now in very widespread and sophisticated forms.

However, developments in modern society and reduced inclination by individuals to be repetitive automata carrying out the same simple task, have resulted in recent reversal trends known as job enrichment.

In Sweden, for example, a company making automobile engines has divided its engine assemblers into groups of five. Each group builds engines, but it is left to a group whether each individual builds an engine complete or only certain portions. In the latter case, the duties are rotated periodically. This is still largely an experiment in job enrichment. The only proviso made by the company is that the total output of engines must not be below the level attained on the conveyor track principle.

As distinct from a machine shop, most assembly operations are reversible, i.e. faults can often be corrected by dismantling and correct reassembly. Not all assemblies can be reversed. For example, spot welded or continuous seam welded assemblies are permanent. Similarly, parts drilled and dowelled in position are difficult to relocate and fix securely.

Even if it is possible to dismantle and reassemble, such activities should be actively discouraged and corrective action taken by quality control, through all concerned, to obviate causes, etc. Reworked assemblies are frequently less satisfactory in overall quality than 'right first time' builds. Apart from this factor, reworking is costly, frustrating and time-wasting. Decisions to rework often become issues of major conflict between QC and production management. This is an added incentive for effective previous controls to obviate such confrontation situations. Production management can strongly argue that QC are very much responsible if rework becomes necessary.

Once again, therefore, the accent is upon effective controls at the operating stages involved.

WELDED ASSEMBLIES AND SPOT WELDING

With welded assemblies (mentioned a few paragraphs previously), the essence is adequate and comprehensive process controls. Welding, like painting, is all too often practised on a 'hope everything will be all right' basis. Bad and unsatisfactory welds are, however, not always visibly apparent. Furthermore, effective testing of a weld is nearly always destructive.

Welding techniques should be specified for each welding operation. Factors involved in spot welding are:

Type of material.
Thicknesses, especially when thin material is being welded to relatively thick sections.
Current.
Time.
Electrode pressure.
Electrode shape.
Positioning of spots.
Adequate support during welding.
Cleanliness of parts to be welded.

Let us enlarge slightly on the last four features.

1. Electrode Shape

Spot welding electrodes frequently terminate in a simple cylindrically shaped end about 0·1 to 0·15 in. (2·54 to 3·81 mm) in diameter and with a very undesirable sharp outer corner edge. Such electrodes produce a well-defined spot, but there is difficulty in ensuring that it is parallel with the main surfaces being welded. The result is as shown in Fig. 7.1.

This defect will normally exist to varying degrees. It can be minimised by adequate support and location during the spot welding operation.

Defective welds can be reduced by using electrodes with a minimum 0·02 in. (5·08 mm) radius on the corners, or alternatively, hemispherical dome-shaped electrode ends.

Either of the spots, but more particularly the one-sided deep

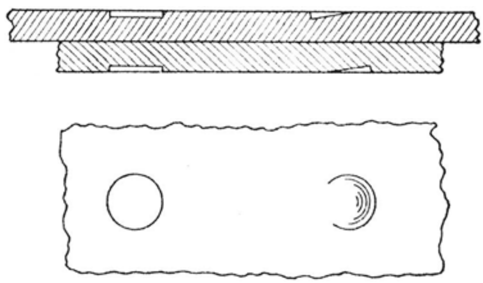


Fig. 7.1. (*Left*) Satisfactory spot. (*Right*) Unsatisfactory spot due to lack of perpendicularity of the electrode to the surface, resulting in deep spot on one side, running out on opposite side of the spot

spot shown on the right of Fig. 7.1 above, can give extensive trouble when welded parts have to be subsequently painted. The spots show up badly on exterior surfaces and can cause troublesome filling and rubbing down.

One answer is to use a relatively large diameter electrode of the range 0·3 to 0·7 in. (7·62 to 17·78 mm) diameter on the surface side which has to be painted. The end face may be very slightly hemispherical, or flat with a corner radius. The weld is not quite so positive because most of the 'spot' is slightly one-sided. However, such spot welds can still be adequately secure. The advantage is that the surface which has to be painted is virtually free of weld spot marks. Other types of welding, of course, need similar adequate process controls, but such techniques specified for each weld operation will virtually ensure satisfactory welded sections.

In addition to the above comment on painted surfaces, it is important that large areas such as panels should be examined in the plane in which they are used on the final product. Panels that lie horizontal should be viewed horizontally and, similarly, vertical located panels should be viewed vertically. Otherwise inspection of panels can become over-critical and rejects be made for imperfections which would not normally be noticed. Personnel regularly inspecting flat surfaces develop marked acuity for observation of defects. If panels are tilted about at various planes, small blemishes inherent in any process become apparent. Even viewing parallel and subsequently at right angles to roof north lights can make a difference. One direction should be selected and adhered to rigidly.

2. Positioning of Spots

Quite frequently the positioning of spots is left to the skill of the spot welder, but it is better to have various aids. Some companies practise the placing of marks in pressed parts to indicate subsequent spot weld positions. Alternatively, spots may be located by back or side stops on the spot weld machine.

Successive spots can be more regularly spaced (than by free hand methods) if ratchet indexing facilities are used. There are several simple ways of providing successive incremental work movements between spot welds.

3. Adequate Support during Welding

Long or awkward-shaped parts are difficult to hold and locate squarely by hand methods. Outrigger brackets in front of, at the side, or behind the spot welding electrodes help. Such supports considerably minimise out-of-parallel 'spots' as mentioned and depicted earlier.

4. Cleanliness of Parts to be Welded

Parts should be particularly free from foreign particles or corrosion.

Contrary to popular belief, lightly oiled parts can be quite successfully spot welded. The heat from the electrodes drives the oil away from the spot and allows a good weld to be produced. Lightly oiled parts can therefore be advantageous, as corrosion of parts awaiting welding is prevented. Dirt must not be allowed to accumulate on the oiled surfaces.

SEQUENTIAL ASSEMBLY AND IN-LINE TESTING

Assembly techniques are still largely based on the logical and sequential build-up of a product using people to carry out the successive operations. Certain mainly smaller assembly activities have been automated, but such machine assembly techniques are not yet widespread.

Using the normal step-by-step sequential build methods, the essential requirement for satisfactory quality is adequate verification of each step. Such control is even more important when stages of an assembly become hidden, or inaccessible, as a result of later stages of assembly.

Tightness and security of fixings must be verified by provision of torque tools, spanners, screwdrivers, etc. Various load requirements can be verified by tension and force gauges.

Torque tools and force gauges themselves should be regularly cross-checked. Setting masters should be located adjacent to where the tools are in use. Operators must be encouraged regularly to check such equipment on the test masters, and QC should periodically monitor this activity.

Similar remarks, of course, apply to any special tests which may be applicable to certain types of assembly, e.g. end float, backlash of gears, etc.

Adhesives are frequently used in modern assemblies. Stringent adherence to methods of mixing, permissible period of storage, two-part adhesives, etc., in addition to standard cleanliness requirements, is essential.

Sub-assemblies should preferably be checked out fully, as units, before release for attachment to the main product. Such practice ensures that deviations are found early, at the point of origin, and corrective action arranged before troubles are transferred to the main product.

These step-by-step verifications are particularly applicable to electrical and safety tests. Faults in such areas can be difficult to isolate later, or may cause serious damage, or dangers, during functional testing. Furthermore, there are usually various official regulations which have to be met in respect of these features.

Adherence to all these aspects is mainly common sense, but it often requires QC reporting and action to achieve acceptance of these principles and the establishment of the procedures outlined. For example, QC may regularly report a right- and left-hand fitment which are interchanged, or two right-hand (left-hand) fitments assembled instead of one of each, where the visible difference is small and either item possible. One reaction would be to fault the operator; another is to put a QC check on the operation. Clearly the much better way is to divide the assembly operation. One operator assembles left-hand fitments only, another operator right-hand fitments only.

FUNCTIONAL AND FINAL TESTS

Most products are required to meet a designed performance specification and product quality standards. Functional and final tests are therefore the logical end of assembly line procedures.

Such tests are **not** proving original designs and are therefore product performance verification checks on such factors as output, cycle time, load, current consumption, noise, speed, consumables usage, cleanliness, absence of leaks, etc. The tests must be adequate to ensure satisfactory manufacture, assembly and proving of all manufacturing procedures.

Additionally, samples should be selected regularly and subjected to longer-term testing exactly simulating customer usage. Most people will have seen the test panels at a paint manufacturer's which are left exposed to the elements for long periods to test paints for durability and colour stability. Similarly, car manufacturers test vehicles on special proving tracks and over thousands of miles of various roads and conditions.

Consumables used during testing may or may not have been provisioned by QC. However, QC must ensure that such consumables are correct and do not invalidate product tests.

Similarly all instruments, test charts, etc., must be properly maintained and regularly calibrated. Product tests should never become suspect because of instrument uncertainty or faults. Certain inspection authorities demand regular and systematic test and calibration of equipment, with comprehensive records.

CLEANING

Following functional tests, most products require cleaning of test consumables, etc. This operation is equally important to other earlier manufacturing stages.

Facilities for cleaning must be effective. If not, small amounts of oil left in a product, for instance, can reach undesirable areas during transit and ruin a previously good unit.

During cleaning, stains, fingermarks, blemishes, etc., should be removed, or corrected, to ensure a high-standard product reaching the customer. This effort costs very little but can make a very marked difference to customers' first impressions.

SALVAGE

In virtually all assembly areas, certain parts will 'fall out' owing to:

Inability to assemble.
Modification changes.
Damage during assembly.
Rejected from test.

It is important that QC ensures that there is an efficient system for dealing with such fall-out supplies. Some parts may be relatively easily salvageable on the assembly floor. Other parts may require return to source of origin. QC must have full control and follow-up to obviate recurrence and ensure effective action.

PACKAGING AND DISPATCH

At this stage, serial numbers are allocated (if not applied previously). Method of serial number allocation should be controlled, to avoid duplication or gaps. Numbers are usually marked on serial number plates. Markings should be applied by a simple hand press with consecutive indexing, rather than by hand. The method is much more reliable, quicker and neater.

Items which can be displaced, or move undesirably during transit, are secured. Methods used should be clearly evident and standardised, to ensure removal before use, when the equipment is installed.

Some companies can justify packaging experts to design packs, etc. Others rely, sometimes unduly, on dispatch personnel. Such personnel may not always realise the fragile aspects and may need instructions and assistance periodically.

Frequent causes of damage in transit are:

Too many parts in a pack.
Too much weight in a pack.
Parts, e.g. panels, located horizontally so that all the weight is on the bottom item. If packed vertically, individual weights only are involved.
Packs not marked with upright signs.

Packs inadequately secured. Steel or plastic banding helps (but not so tightly as to distort contents).
Packs not weatherproof.
Items not interlayered, where necessary, with protective material.
Sharp edges not protected, etc.

Even normally adequate packing cannot protect from severe mishandling. Heavy weights, or multiple stacking, can cause crush damage. Packs are even sometimes dropped from heights of several feet, such as pushing off the back of a vehicle on to the ground.

Packaging areas are not only involved with completed products but may also cover:

Returns to suppliers.
Spare-part supplies.
Supply kits.
Modification kits.

These activities entail verification of markings and identity with paperwork requirements.

Spare parts are particularly important in this respect. A service engineer or customer in a far-off (or near) location takes a very poor view if he unpacks a spare part and finds it different from the part number required, and likewise if the part is short of fixing details, has a simple nut or washer shortage, too many of one type of bolt and too few of another, or alternatively two right- or two left-hand details, instead of one of each. All these rather obvious types of error do occur much too frequently. QC should ensure that procedures are as far as possible foolproofed rather than rely on individuals.

Packs containing a number of items should each have a tick-off check list. Parts should be clearly segregated (prior to packing) into the different items. They should be selected in an orderly way, i.e. right to left.

Another good plan is to issue controlled amounts of each item. Upon completion of, say, 100 packs, no shortages or surpluses should remain. If such evidence does remain, then the whole of the 100 packs should be rechecked until the fault(s) is found.

ASSEMBLY PAPERWORK: MODIFICATION CONTROLS

We have so far dealt with the physical aspects of assembly. Almost equally important are the paperwork controls and systems.

Assembly QC paperwork should list the mandatory checks to be made and provide for recording the number of times faults were found. Such data make possible the primary QC activities of observe, report, action, for continuous preventive attention to be ensured. Trends can be observed, action meetings arranged, etc. Similarly, special factors, features, possible errors, previous troubles, are all highlighted respective to each operation.

Almost all products are subject to modification changes which effect design improvements, update products, rectify failure causes or facilitate production.

There is a further group which may result from value analysis (engineering) activities. These are usually aimed at cheapening production by use of alternative materials, methods and redesign. It is important that ideas from such sources should be fully tried out and verified with maximum QC involvement before being adopted for production.

Modification control is an activity which usually depends greatly on QC monitoring and records. QC personnel normally keep invaluable records of dates for cut-in of changes, serial numbers involved, etc. Such data must be accurate and made available to engineering, sales, service and various other departments. Service bulletins, handbooks, service manuals, etc., all depend on correct modification details.

QC usually also verifies that modification plates or other modification information accompanying products is continuously up to date.

ELECTRICAL WIRING AND CONNECTIONS

Modern products tend to become more electrical in content and may use motors, switches, relays, lamps, solenoids, transformers, printed circuit boards, transistors, integrated circuits, etc.

The latter items in the above list reduce some of the electrical leads which would otherwise be required. However, many connecting wires are still usually necessary. Individual wires are often sub-assembled into what are known as wiring looms, or harnesses, before installation into the main product.

End connections are now commonly made using special tags, which fit on to spade-shaped terminals on components, etc., but round-shaped tags are also available for pin connections. Certain firms, such as AMP, specialise in this activity. These mechanical types of connections are very good and positive. Furthermore, they can, if required, be readily disconnected. Soldered joints do not have this advantage and are more difficult to control to ensure good continuity and strength. Even so, soldered joints still have many applications and are successfully produced in vast quantities, most usually by female operatives who become highly skilled and adept in soldering work.

Wires with tag-type connectors can be produced at a very fast rate on modern wire- or lead-making machinery. These machines cut to length, strip a short length of insulation at the ends, apply the tags and can mark a wire number at each end adjacent to the tag.

In view of the high speed of production, first-off inspection control is vital to ensure:

Correct length.

Correct amount of insulation removed for the tag. The insulation must be removed cleanly and wire strands must not be cut. The insulation must not 'spring' to reduce or increase the length of bare wire.

Wire numbers marked on must be correct and legible.

Tags must actually grip the wire and the insulation at the respective points. A tag attached entirely to bare wire will be a physically weak connection. Conversely, a tag attached mainly to the insulation will cause a poor, intermittent or open circuit. Strands of wire must not protrude outside the tag.

Individual wires are normally sub-assembled into looms or harnesses on a wiring jig, as shown in Fig. 7.2. These jigs carry wire numbers, colours and provision for end fittings and terminal boards.

As part of the production operation, and following good quality control concepts, it is desirable to verify such loom sub-assemblies as they are produced.

My thanks are due to a colleague, Mr W. R. Davidson, for permission to describe a control system which he has developed and which works very successfully.

The wiring jigs are specially produced with connecting wires on the rear of the board, coupling up the various circuits and connecting to multi-sockets located at the bottom right-hand side of the jig shown in Fig. 7.2.

A button is pressed and the test set (Fig. 7.3) sequentially tests every wire in the loom. If there is lack of continuity or a wrong 'open circuit' connection, the test set illuminates an indicator accordingly. The test stops at the fault and the test set shows the wire number involved in the small rectangular display at the top left-hand corner.

The operator corrects the fault and again presses the test button. If the loom is O.K., the set rapidly goes through the total number of wires in the loom and stops at the end figure, e.g. 130. (Any fault on the final wire would also show on the 'open circuit' or 'continuity' fault indicators.) A satisfactory loom is tested in approximately two seconds.

There is provision for a special sequence to test the test set itself, should this be doubted, owing to inability to find an indicated fault in a particular loom.

SEMI-AUTOMATED ASSEMBLY CHECKING

We have mentioned automated assembly previously in this chapter. In Chapter 5 we referred to automated electrical component inspection.

Semi-automated control of assembly checking operations is a further modern development which may interest the reader. A possible application of such techniques proposed by a colleague, Mr R. J. Teague (Gauge Engineering Manager), will now be described.

System Description

1. A schematic line diagram appears in Fig. 7.4. This shows the configuration split into three packages, viz.:

(*a*) the fixture;
(*b*) the setting package;
(*c*) the inspection package;

plus necessary interfacing.

2. One setting fixture will be required for each setting activity group. The measuring media will be linear transducers, one of which will be required for each dimension to be set. The fixture itself will be conventional with the exception of possible foolproofing devices.

3. One setting package will be required for each fixture. The setting package will consist of a continuous display of all dimensions to be set and a key reader. The purpose of the key reader is twofold. It

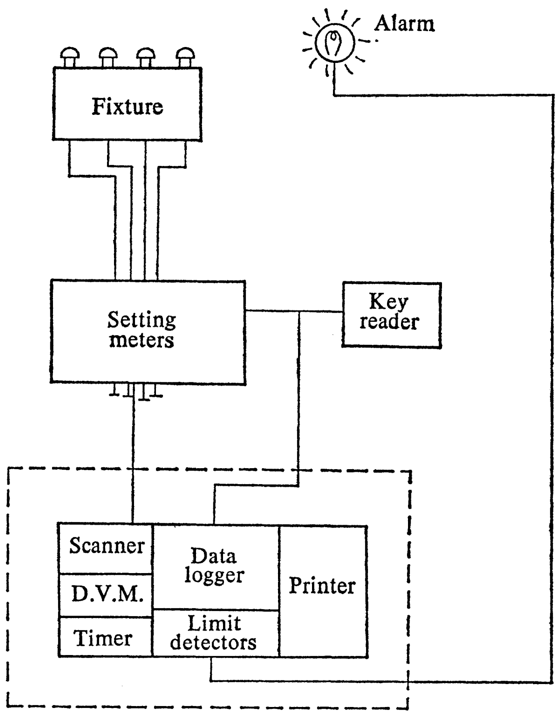


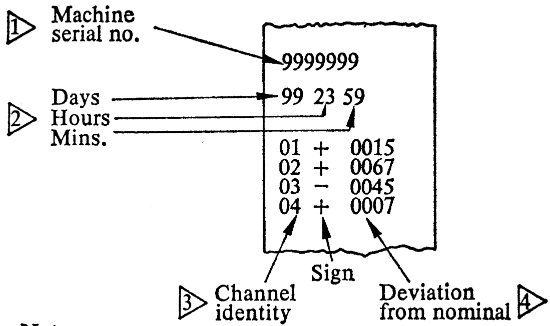
Fig. 7.4. Schematic line diagram of semi-automated control for assembly checking operations

will relay by means of unique keys (one per machine to be built) the assembly serial number to the data logger and it will initiate the data logging cycle.

4. The outputs from the setting packages will be fed into the inspection package. The setting package will be housed in one cabinet and will consist of:

(*a*) Data logger;
(*b*) DVM;
(*c*) scanner;
(*d*) printer;
(*e*) digital clock;
(*f*) limit detecting system.

The setting package will be housed in the central inspection area.



Notes:

1. Machine serial no. (from key reader) 7 digits.

2. Days 99 max.

3. Channels 99 max. (capable of expansion)
Stations will be identified by channel number.

4. Deviation to 4 decimal places.

Fig. 7.5. Print-out from the semi-automated control for assembly checking operations shown diagrammatically in Fig. 7.4

5. Signals will be fed back from the inspection package to indicate that print-out has occurred and include a suitable warning system when dimensions are outside tolerance.

6. The inspection package will receive data from any reasonable number of setting packages. It will initially be provisioned with 100 data channels, but the ultimate capability is 1,000 data channels.

7. An indication of the print-out is shown in Fig. 7.5. The printer speed will be two lines per second. One roll of paper will permit approximately 11,000 lines of data.

8. The cables from the setting package to the inspection package will run, probably in trunking, in such a manner that maximum flexibility in the siting of the setting stations will be achieved.

9. The method of holding signals during possible queueing is not yet finalised, nor the details of the alarm system.

10. The complete system, which is modular in construction, will be fully capable of expansion and possible future interfacing with a computer.

11. The work content in an inspection station will include all the mandatory checks which accessibility will permit, plus any random checks necessary. Any remaining inspection will be performed either on a patrol, a 'call-off' basis or by audit.

12. In order to restrict as far as possible cable lengths between setting packages and the inspection package, careful thought must be given to the floor layout. Ideally, the inspection office will be centrally situated.

13. The advantages of the proposed system are fairly obvious but can be quickly summarised as:

(*a*) Better control with permanent records.
(*b*) A saving in manpower.
(*c*) A saving in space.
(*d*) Minimal tool reinspection cycles.
(*e*) Elimination of equipment duplication.
(*f*) Computer interface possible.
(*g*) Minimal tool or gauge modification costs.

PERSONNEL RATIOS

The number of quality personnel directly engaged on assembly-shop activities will vary widely owing to:

Type of product.
Complexity of assembly.
Amount of testing: nominal, extensive, functional.
Degree of mechanisation: tooling, gauging.
Skill and experience of assembly personnel.

As stated earlier, in some companies the final testing is the functional control of a section other than quality department – most commonly engineering.

The effect of the above variables is that quality personnel ratios on assembly may vary over the major portion of the range shown in Fig. 2.2 (p. 32 above), i.e. from a high concentration of one inspector for five assemblers to a low concentration of one for twenty-five.

8 Reliability Testing

DESIGN RELIABILITY AND QUALITY RELIABILITY

Quality and reliability factors are commonly coupled together. However, reliability itself divides quite positively into design reliability and quality reliability.

The former reliability tests verify a satisfactory standard originated by design. The latter is the fidelity of batch production and manufacture such that the product quality consistently attains the design specification and conformance requirements. The standard is not originated by quality control, but verified by quality activities.

The reliability of manufacturing quality is assured by the quality activities outlined in previous chapters. Theoretically, if all the controls listed are effectively operated, the product quality and reliability should be attained. However, from time to time, and owing to human limitations, events escape the system arranged. Complete quality coverage should therefore include regular reliability test monitoring. Such tests are not proving original designs and therefore not testing for life of the product, or for long-term failure.

INFANT MORTALITY FAILURES

Rather the tests should be aimed at location of what is known as the infant mortality type of failure. This kind of failure is a very high percentage of total failure experience. It is well established by statistics and experience that faults in reliability of manufacture usually show up very early in the life of a product. This situation is usually depicted by what is known as the 'bath-tub' curve shown in Fig. 8.1.

The reader will readily see how the name arises. The graph shows a product which has a designed life of five years. Infant mortality failures mostly occur after a very short period of use. Subsequent

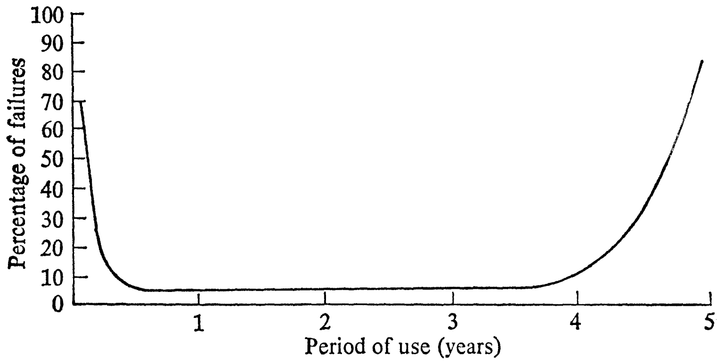


Fig. 8.1. Bath-tub curve for a product designed for a five-year life

failures occur at much larger intervals until the product settles down to an almost minimal failure rate for most of its designed life.

Assuming an accurately estimated design life, failures due to wearing out, lack of maintenance, etc., start to increase towards the end of the expected life period and can mount rapidly again, as shown in Fig. 8.1.

Usually designs have a useful margin and the onset of wear-out failures can be much later than design nominal life. Products often attain twice or three times the planned life figure.

Fig. 8.1 is, of course, very arbitrary, for the following reasons.

A poor design will not settle down as shown.
Faults may develop on a large scale after a period owing to some special factors: poor manufacture, material fatigue, lack of good maintenance, etc.
Type of use may change.
Grade of user may deteriorate.
Consumables used with the product may introduce trouble.

INFANT MORTALITY: QUALITY MONITORING TESTS

However, let us return to the infant mortality aspect. As stated, infant mortality faults can usually be revealed with relatively limited amounts of cycling testing. Such testing may be termed product quality reliability monitoring tests or simple quality tests. Infant mortality faults will usually show up as early as 200 cycles of a component which is required to complete 5 million in normal use.

Failures will occur later than 200 cycles but at rapidly diminishing frequency. For virtually all practical purposes, quality reliability monitoring tests are adequate if performed for 1,000 cycles. Experience could easily show that a lesser figure, of say 500 cycles, would be sufficient for particular products.

The very essential aspects of such tests are as follows:

They should simulate exactly the component application intended.

The attitude of the component during test must be exactly as its attitude in normal use, e.g. horizontal, vertical, inclined.

The test should include vibratory effects. Electrically energised 'limpet' type vibrators are marketed which are very convenient for vibration tests.

The component should be loaded with the torque, resistance or electrical load normally carried.

Such load should be switched on and off for the number of cycles specified, and again simulating normal application but emphatically not using an exactly equal on/off pulse. The latter is most easy to arrange on a test rig, but equal pulses rarely occur normally.

Equal pulses are far less likely to reveal faults than unequal pulses, e.g. components build up temperature, magnetic effects, etc., from longer on than off pulses.

The rig should have self-indicating fault displays and should not need to be constantly watched.

Multiple station rigs are worthwhile in enabling coverage of several components simultaneously.

Soak-type tests whereby components are left under constant load for long periods are frequently used in the electrical component industry. Much shorter-period cycling tests are far more preferable.

Tests should, where required, be applied at other than ambient temperature and humidity conditions.

EXAMINATION FOLLOWING QUALITY CYCLING TESTS

Quality reliability monitoring tests should usually be followed by strip and examination of the components concerned, for two reasons:

1. The quality and cleanliness of the otherwise normally unseen internal areas and parts can be verified.

2. Signs of undue stress, heat, wear, etc., liable to cause subsequent failure, may be observed.

Because the infant mortality tests described are carried out over a relatively small number of cycles, the components concerned are still perfectly satisfactory for normal use. They are by no means worn out. Therefore, concern which can often be expressed about the costs of such testing cannot include the value of items tested.

Emphasis has been made of infant mortality failures, because their effects can be almost catastrophic and yet the precautions which will largely obviate these effects are very easily established, as outlined. The point about infant mortality failures is that, once determined, they usually have readily assignable causes. Such assignable causes can be quickly and effectively put right.

The overriding importance is that infant mortality failures shall be ascertained before products are distributed. The cost of remedial action once products reach customers and then quickly fail can be enormous. Also, customer loyalty and public image can be seriously impaired.

Because design reliability and life tests will often have been carried out on similar rigs to those which are required for quality reliability tests, it is logical that close liaison and co-operation should exist between the departments for the economic use of test rigs and facilities. Such co-ordination is usually welcomed by design engineering as it provides the desired assurance of continued product adherence to design specifications.

It is better to arrange that quality monitoring reliability checks should be carried out successively on samples from each week of a continuous production run, or even daily, if practicable. Such procedure will provide early warning of faults having developed in a production process. Early corrective action is possible on relatively few suspect components. Furthermore, production of further similar faulty product is avoided.

TESTS BY VENDORS

It is a logical step from these principles to ensure that supplies obtained from bought-out sources should have such quality assurance reliability monitoring tests carried out by the vendor concerned and certified with delivery paperwork. Such requirements must, of course, be clearly spelled out at the commencement of the contract for such supplies. Verification of such procedures and their continuance should be part of vendor appraisal and quality liaison visits.

Both design and quality reliability tests have the effect of continuously improving designs, including proprietary products used on particular applications.

RELIABILITY TEST ECONOMICS

Apart from the minimising of continued faulty production, most reliability testing can be shown to have significant economic benefits:

Product design improvement.
Performance improvements.
Infant mortality failure reduction.
Customer appreciation, fidelity, public image.
Reduction in service costs and travelling time.
Minimising of warranty and guarantee claims.
Fewer spares requirements and holdings.
Less product 'down-time' at the customer.
Sales and marketing advantages.

It is clearly difficult to put values on all these facets. However, it is usually possible to show that the savings in service costs alone are usually far greater than amounts spent on reliability testing. The procedures are therefore an investment and assurance rather than simple expenditure.

PERSONNEL RATIOS

As stated earlier in this chapter, it is logical to ensure that bought-out supplies are adequately quality assurance tested before delivery. This factor, and optimum liaison with design and engineering in connection with their reliability testing activities, should mean that normally only 1 to 2 per cent of quality personnel are engaged full time on quality assurance reliability monitoring test activities.

Figs. 8.2, 8.3 and 8.4 show some typical modern sophisticated reliability test rigs utilised for tests as described in the captions to the photographs.

9 | Industries Other than Engineering

SCOPE

It was mentioned in Chapter 1 that some coverage of quality control in industries other than engineering would be included in this manual. Clearly it is impracticable to cover every industry in detail, but some comments on a few specific industries will be made in this chapter.

The broad quality principles outlined in earlier chapters can largely be applied to other industries. In almost every case there will be:

Control of incoming supplies.
Tooling/equipment/processing plant.
Manufacture/processing/treatment.
Finishing/assembly/test.
Packaging.
Transit.
Field experience: customer liaison and satisfaction.

Each of these stages, where applicable, should have controlled systems, methods, procedures and quality monitoring with suitable audit procedures.

Let us proceed with a few industries.

PAPER MANUFACTURE

The paper industry is highly specialised and mostly dominated by large organisations. The raw material is wood pulp, used in vast quantities, such that huge forest areas are utilised in Scotland, Canada and Scandinavia. The trees are felled, debarked and the wood reduced to a pulp condition by mechanical abrading or chemical action, in basic plants located near the forest areas. The pulp bales are the raw materials which arrive at the paper mills.

Contrary to popular belief, waste paper is not particularly attractive to the paper makers. Waste paper contains such undesirable items as carbon paper, pins, staples and paper clips. This foreign matter has to be removed by filtering, magnetic collectors and other devices. Even then the printed matter on most waste paper has to be removed, mainly by bleaching. The net result is that the final product is still usually less clean than paper made from 'new' wood pulp. Paper made from waste, therefore, usually has to be used for second-quality purposes, despite the relatively high cost of reclamation. (It is clearly impracticable to sort waste paper manually, as such action would make reuse virtually uneconomical.)

The quality control man at a paper mill using large quantities of waste paper has a difficult job, in so far as he has continually to decide acceptable levels of dark spots, lines and other markings which will arise on the finished product. The usual method is to provide comparison samples showing acceptable and reject amounts of dark spots, lines and other inclusions. Another method is to apply a squared transparent overlay and to specify that not more than so many spots, etc., shall lie in any one square, with not more than an agreed percentage of the total number of squares to have such defects. Most paper users take for granted that sheets of white paper will have very few surface blemishes in the form of dark spots, etc.

Apart from waste paper, even 'new' wood pulp may give inclusion-type problems owing to unsatisfactory removal of all the bark from the tree and various other factors.

A constant concern in paper manufacture is the amount and evenness of moisture which remains in the finished paper. It is almost impossible to remove all moisture from paper, because very dry paper will automatically and readily take up water from the atmosphere. Accurate determination of moisture content is quite a complex procedure, as it involves heating sealed capsules, containing paper samples, until the weight ceases to reduce further. The moisture content is obtained by the difference in weight before and after drying. This is the laboratory method. There are easier applied methods for day-to-day checks in the paper mill, but they are usually less accurate. However, an analyser has recently been developed by Analysis Automation of Oxford which gives direct process checks of moisture in paper, cement, sand, tobacco, chemicals, foodstuffs, etc.

The method depends on reflection and absorption of infra-red radiation using a rotating filter system for selection of measurement and reference wavelengths via a range of narrow band filters. Reflected radiations are compared using an infra-red detector. The difference in energy levels gives a measure of moisture content. The instrument can give outputs for linear control, recorder or set point controls.

Paper is produced from the wood-pulp fibres suspended in vast quantities of water. This water has to be removed by heated rollers.

Undue moisture left in paper dries out unevenly over a period and the paper curls. Very dry paper may absorb moisture, causing curling. Too wet or too dry paper gives rise to various troubles in normal commercial use, particularly when used in equipment which utilises paper sheet feed mechanisms, resulting in misfeeds, double sheet feeding and jams.

Developments in paper manufacture in recent years have been directed to improved methods of removing water from the 'stock' and to radical changes involving 'dry' paper manufacture, rather than a high water content pulp.

Cutting

Paper is produced on the paper mill in widths as large as 200 in. (5·08 m). The reels therefore have to be slit into various widths for normal paper sizes and the sheets then cut to length. Final cutting was often carried out using a shear or guillotine-type process, cutting as many as 400 sheets simultaneously.

Provided the guillotine blade was sharpened regularly, the system worked fairly well. Inevitably there was a tendency for the edges of sheets to be 'burred' and to be spread over adjacent sheets.

The size and squareness of the cut edges were not usually maintainable closer than within 1/32 in. (0·79 mm) of nominal size. This meant that two sheets could have as much as 1/16 in. (1·59 mm) total variation. These factors and the moisture factor mentioned earlier had pronounced problem effects regarding satisfactory feeding of paper in various types of machines.

Again, true quality control precepts were followed such that rotary-type cutting methods were developed. These avoid burring of edges and cut to within 1/64 in. (0·40 mm) of nominal size, giving a maximum variation of 1/32 in. (0·79 mm) – a very marked improvement.

Kraft Papers
Kraft is the name for the brown papers used in many commercial applications, i.e. the ordinary brown sheets or rolls used for wrapping, etc.; the 'liners' or facing sheets used on corrugated cases; paper sack applications, etc.

Paper Sacks
This is a paper industry activity wherein control of the process ensures consistency of a very low-priced product, which is made in fantastic quantities of around one million per day. Although costing only a few pence, virtually every sack must be so reliable that it opens correctly for filling and does not leak or burst.

The paper is preprinted as reels, with the maker's name, product type, etc. Included at the edge are markings which are scanned electronically during sack manufacture, as described below.

Sacks may be single, double or multi-ply in the number of thicknesses (sheets) of paper used.

The sacks are formed into a continuous long tube on machines called tubing machines, and at very high speed, the fold joints being glued automatically.

The markings in the print, referred to above, are scanned electronically and the tube cut off points, to produce individual sacks, continuously adjusted, to ensure that the print pattern lies equally spaced between the top and bottom ends of each sack. Sacks with half the print design on one sack and the other half of the design on the next sack would be reject. The bottom of the sack is subsequently glued or sewn on.

Paperboard Cartons
Board is the name given to paper pulp-type material produced in thicknesses used in various cartons for an immensely wide variety of products ranging from detergents to breakfast foods. Again, millions are made daily.

As many as forty-eight ultimate cartons for items like suet or gravy mixture are printed on a single sheet of carton board, frequently with elaborate designs, instructions, recipes, etc., and often with colour variations. The QC man has a tedious task in checking each of forty-eight print layouts on the 'proof' sheets submitted from the high-speed printing machine. Few customers probably read or study the print details on such mundane domestic cartons, or appreciate the controls operated, as outlined, which ensures that the print, etc., on each carton is correct.

The printed sheets have to be cut and creased to produce single carton blanks which then have the side joint glued, again at very high speed. The carton user expects every carton to open correctly in the filling machines and not to leak or break when filled.

FURNITURE MANUFACTURE

Modern furniture is generally very attractive and pleasingly designed. It is also reasonably durable and well made. Considerable use is made to good effect of man-made materials such as nylon and laminated plastics.

The customer is always wise to buy furniture specially designed for a purpose. Dual-purpose equipment is always a compromise. A put-you-up bed-settee is not as good as a settee, or as a bed, if compared to the one-purpose designed equivalents.

There appears to be minimum contact by furniture makers with the ultimate customers. Most buyers see and know furniture solely from the furniture store contacts. Possibly as a result, the customer can purchase, say, a heavy settee which for no apparent reason may be easy or very difficult to move on the castors. Castors vary widely in their freedom of movement.

Wardrobes rarely have levelling provision, resulting in doors being difficult to open or close. Sometimes they are not quite deep enough for the average garment on a coathanger. Clothes therefore have to be angled and the capacity reduced accordingly.

By far the main problem with furniture is the minimal or nil protection against transit and handling damage. There is a very high possibility that furniture bought by a customer will have various scratches, small tears, damage marks, etc., by the time it is installed in the home.

HOUSE BUILDING

This is a well-known activity where the concepts of quality control have operated on a rather limited scale. Much dependence is placed on building operatives to carry on satisfactorily with very little supervisory or verification controls.

Many builders are relatively small companies who cannot readily justify sophisticated quality coverage. Partly as a consequence, the National House Builders Registration Council was formed. This organisation carries out inspections and issues a certificate which confirms that a property conforms to the regulations for quality.

This is a very commendable arrangement, in so far as the certificate is backed up by guarantee of satisfaction and corrective action where required, normally for as long as ten years.

Fortunately, in house building, scrappage of the product is very rare, in so far as most defects are of the correctable type. Nevertheless, the arrangements are very suited to the special nature of building activities and provide a very worthwhile quality standard for the final customer, which is rather unique, particularly regarding the long-term assurance period involved.

TEXTILES

This industry is long established and produces generally very good products. Factors such as colour fastness, wear resistance, shrink resistance, are virtually assured, and largely taken for granted by most textile users.

For many years the industry used natural fibres – cotton, wool, etc. – very consistently and reliably. More recently, man-made fibres have been increasingly used and some have been shown to have limitations. This can lead to combinations with natural fibres to obtain the advantages of the latter. For example, Terylene has remarkable crease and pleat-retaining capability but goes very shiny unless adequately combined with wool.

Nylon is remarkably strong and hard-wearing. Men's socks rarely develop holes which need darning. However, nylon is relatively cold compared with wool and cotton garments. White nylon tends to yellow, although this problem has been minimised by various technological improvements.

The ladies' stocking and tights industries were virtually completely changed by the advent of man-made fibres.

Nylon has a tremendous range of applications, from immensely strong cords and ropes to moulded piece parts, etc.

Synthetic fibre manufacturers have to operate quality controls which ensure accuracy and consistency of fibre sizes, strength, etc. They need to check that when fibres are colour-dyed by their fabric- or garment-maker customers, the dye absorption is constant, otherwise finished material may have light or dark streaks. As considerable work will have been expended in making individual fibres up into material or garments usually prior to dyeing, colour inconsistency can be a serious fault.

RUBBER

This is another industry where the influence of synthetic materials has profoundly affected the applications of the original natural rubbers.

Synthetic rubbers in various applications have better properties than natural rubber, e.g. oil- and temperature-resistant seals, or the obviation of degradation and deterioration effects over relatively short periods of time.

In certain fields, it becomes debatable whether the product is still a rubber in the normally accepted sense. One case is the synthetic materials used for certain types of footwear, which compete with earlier leather applications.

There is an immense range of 'hardness' available on rubber and synthetic rubber parts. Control of constituents, mixing and heat treatment is essential to give the required hardness.

Rubber products manufacture is another process which is normally irreversible. Raw materials wrongly mixed or combined, or unsatisfactorily processed, will mostly end in scrap parts, which cannot be reclaimed. This is therefore an industry where meticulous control of ingredients, quantities and methods is the only satisfactory method of ensuring good product and avoiding expensive waste. This is an industry where the customer has to depend almost entirely on the controls operated by the manufacturer to provide the required quality.

Many adhesives have a rubber base. Again, their successful use depends on careful adherence to cleanliness, application and methods.

ELECTRONICS

We have briefly touched on this industry earlier in this book. However, it is an industry where technology advances extremely rapidly and which becomes more and more specialised.

In Chapter 5, reference was made to automated test equipment for items such as printed circuit boards.

Developments in printed circuit board techniques have made their use more and more widespread. They occupy much less space than the larger valves, relays, and semi-mechanical switches which they replace. Furthermore, transistors, reed relays, integrated circuits, silicon chip and similar devices are all available at competitive prices, commensurate with the high production methods developed.

Quite frequently printed circuit boards may comprise well over a hundred miniature components of the kinds listed above, plus resistors, diodes, capacitors, etc. The positioning of a hundred or more resistors, diodes, etc., in their correct location on a printed circuit assembly is not easy. They may be 'simply' the wrong way round, or differing values of ratings may be fitted, or interchanged in position. The coloured banding symbols are not easy to differentiate over large quantities without eyestrain and tedium developing.

A comparison-type instrument is available for comparing a correct board with boards from production. Images of the master and sample are seen repeatedly in the field of view and discrepancies are readily apparent.

However, this is largely 'after the event' control. Preferably production should be fully engineered:

1. Assemblers should have mask-type guides which are positively located relative to a datum surface. These masks have apertures of varying sizes and shapes cut into them which correspond to the electrical components to be inserted.
2. Stages are arranged such that where almost identical parts could be fitted or interchanged, then such parts are only fitted at clearly separated assembly stages.
3. The component wiring ends are bent over after all the items at a stage have been fitted. This operation is easily arranged by a sliding plate which is operated for this purpose, before the board is sent to the next stage.
4. Finally, complete assemblies are semi-automatically 'flow soldered' under carefully controlled conditions.

Items such as diodes, which can be reversed, remain a problem which may require special separate function testing for complete assurance.

The overall reliability of these complex assemblies still leaves much to be desired. Apart from the actual mechanical aspects of manufacture and assembly, the cumulative reliability of the combination of large numbers of miniaturised items results in an undue infant mortality experience.

As a result, complete circuit board assemblies are subjected to extensive 100 per cent testing to extract infant mortality failures. There are initial burn-in or soak tests on individual components, complete boards or both.

Such tests consist of vibration tests over a range of amplitudes and frequencies. Temperature cycling tests consist of rapid transfer from around +80°C (176°F) to −40°C (−40°F) for one to three cycles and long periods of around thirty-six hours at 55°C (131°F). These tests are followed by automated test equipment functional tests to provide the overall assurance of quality required from completed boards.

The stringency of such tests will be readily appreciated and will inevitably lead to continuous improvements. The reader will realise that rejected boards have to be fault diagnosed and repaired. This is a tedious and difficult procedure. Even when a faulty component is located, it has to be carefully unsoldered from a board before a replacement can be fitted. It is very easy to spoil printed circuit wiring during such repairs, normally carried out by hand, rather than by the mechanised 'flow' or other high-speed soldering methods used during production.

CHEMICALS

The chemical industry is one in which disciplines and controls are paramount to obviate disaster situations, which can so easily occur if rules and regulations are broken.

Powerful chemical products are supplied for various domestic uses, with sometimes insufficient warnings of consequences of careless use and the dangers of personal injury. Bleaches, insecticides, weedkillers, etc., should all be used with caution and with careful adherence to the instructions on the pack. There is scope for such instructions to be printed larger, or even also on a separate sheet supplied with small pack products. These instructions should start with cautionary advice which should be comprehensive.

The chemical industry itself practises comprehensive controls and the products can be relied upon to comprise the constituents and quantities usually specified.

Strict procedures are followed to ensure that identification and labelling is accurate and that accidental mixing is avoided.

FOODS, FRESH AND PROCESSED

Fresh foods generally provide readily noted evidence of their quality. Modern methods and controls ensure that produce reaches the public quickly and stocks used quickly or disposed of as fertilisers, etc. The reader may not have realised, for example, that a bad egg has been virtually eliminated. This means reliable quality by control of methods, procedures, etc., rather than sorting good from bad.

Fresh foods are increasingly cleaned and attractively packed in a ready for use condition. Such convenience food packaging has resulted in the stage being taken one step further, and today foods are cooked in the factory and only need to be warmed prior to serving, e.g. mashed potatoes, meats, vegetables.

Processed foodstuffs come in many forms and varieties and can generally be relied upon to conform to very high standards of quality and reliability.

The packaging industry has developed rapidly in these fields, providing attractive and functional packs. Such packs keep contents under suitable conditions which ensure their remaining crisp, fresh, etc., as appropriate. Two examples are breakfast cereals and wrapped bread.

SUMMARY

These comments, on industries other than engineering, are intended to illustrate that quality factors are equally applicable and that controls are extensively operated. This is very largely taken for granted by the average member of the public regarding most of the products involved. The controls operated by the manufacturers have been built up and developed over the years to provide a high level of quality assurance in the fields covered, as well as in many other industries specific mention of which may not have been made in this chapter.

As stated in the section on electronics, technologies now advance so rapidly that dangers arise of extensive investment in capital equipment becoming obsolete by technological development or fashion changes:

1. We now have quartz crystal wrist-watches available which provide extremely accurate timekeeping. Currently these are expensive, but they contain few moving parts and reduced numbers of precise tiny gears, etc., used in the previous spring-operated type. A steady reduction in price of quartz crystal watches could make obsolete certain highly specialised watch industry small machine tools.
2. Somewhat similarly, ladies stretch tights have widely superseded the fully fashioned stockings of a few years ago, and largely made surplus the very sophisticated knitting machines developed for the earlier product.

Sometimes developments do not completely replace the earlier methods or system:

(*a*) A few decades ago, the introduction of fluorescent strip lights appeared likely to eliminate ordinary bulbs. The latter have also been equally developed in various ways and now happily share an overall market, large enough for both.

(*b*) Tape recorders competed with the older gramophone record. Again, both have been continuously developed and neatly fill differing needs.

The quality manager in consumer industries, such as those mentioned, therefore has to keep fully up to date with changing technologies, trends, etc. It would be unreal to expect him to be always able to anticipate developments such as those outlined. He can best minimise the risks by ensuring that his capital equipment is not too rigidly designed for a single purpose, but as versatile as possible.

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In addition to the specific items listed, the following organisations have a number of publications on quality subjects. Details may be obtained from these organisations:

British Standards Yearbook (British Standards Institution)
Her Majesty's Stationery Office
British Institute of Management
National Council for Quality and Reliability
National Physical Laboratory
Various professional institutions.

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