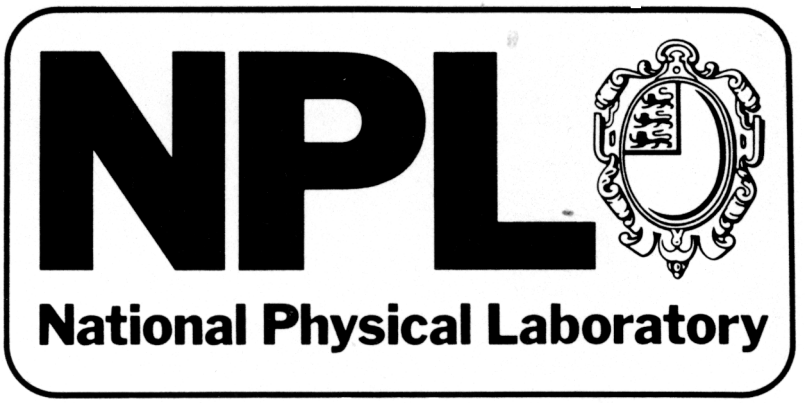

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Recommendations for the design and equipping of Engineering Metrology Laboratories

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N A T I O N A L P H Y S I C A L L A B O R A T O R

RECOMMENDATIONS FOR THE DESIGN AND EQUIPPING OF ENGINEERING METROLOGY LABORATORIES

Abstract

Suggestions are made for size, site, general design features, environmental control, equipment and other factors which affect the satisfactory functioning of an engineering metrology laboratory. A bibliography and a list of some suppliers of equipment is included.

This report was originally published in 1970, having been prepared by T R Oakley; subsequent revisions were issued in 1972 and 1977. The current up-dated version has been produced by T Fletcher.

INTRODUCTION

This report has been prepared to meet the need for a digest of information on environmental and equipment requirements for engineering metrology laboratories. A degree of generalization has been unavoidable as engineering metrology covers such a wide field.

In planning a metrology laboratory a number of factors should be considered in order to meet as many as possible of the technical requirements. It is clear that for the purpose of ensuring repeatable measurements of a desired accuracy, a suitably controlled environment is an important feature of the laboratory. By making a realistic assessment of the required measurement capability at the outset, it can be possible to avoid expensive and unnecessary elaborations.

There is a widespread demand for verification of engineering measurements and a consequential need for traceability of calibrations to national standards. This is a point which should be borne in mind when obtaining the measuring equipment for a laboratory.

In the United Kingdom the majority of national measurement standards are maintained by the National Physical Laboratory and a calibration service is available there for laboratory standards of the highest accuracies. For measurement standards and instruments of less than highest accuracy, traceability will be through a chain of intermediate standards and will generally incorporate the calibration services of laboratories approved by the British Calibration Service. A number of metrology equipment suppliers have their own BCS approved calibration laboratories and can readily provide BCS Certificates of Calibration with their products.

LABORATORY DESIGN

Size

The size of laboratory required is directly dependent on the nature of the product being inspected and on the amount of work handled. In practice, the limiting features are commonly the money and the space available for the project. A room with a height of 2.5 m to 3 m and a floor area of approximately 50 m^2 is sufficient for smaller firms, whilst one of about 70 m^2 will meet most industrial needs. In both cases, if a horizontal optical projection apparatus is included in the equipment, then additional accommodation of about 8 m x 3 m will be needed; it is not essential for this extra accommodation to be within the temperature controlled area.

Space should also be provided, either in the laboratory or in an adjacent, similarly controlled enclosure, to house the workpieces that are to be measured. If these workpieces are large or bulky as, for example, surface plates and machine tool parts, their thermal settling time will be correspondingly long and their effect on the temperature of the laboratory could be significant. Because of this it may be expedient to make provision for the bringing in, at the end of each working day, a sufficient supply of parts for the following day's work which will then be at laboratory temperature when measured.

The size of the laboratory should be adequate without being over-generous, for unnecessary space will not only raise the initial cost, but will result in higher running expenses throughout the life of

the installation. Adequate additional space will be required for the air-conditioning plant and air filtration units, with easy access for servicing.

Access to the laboratory should allow for the passage of large workpieces and measuring instruments. Removable wall sections and adaptable doors can be of advantage to meet infrequent requirements of this type.

Site

The careful choice of location for a metrology laboratory has a direct beneficial effect on its first cost, the running costs and also the standard of performance of the laboratory. An ideal site is usually an impossibility, but it is most desirable that the room has a minimum of surfaces that are directly influenced by climatic temperature conditions, such as external walls and lightweight non-insulated roofs. The site should avoid sources of heat such as boiler rooms and furnaces and also sources of vibration and shock.

Another factor that should be considered is the direction of the prevailing wind, and a site should be avoided that is down-wind of chimneys or ducts that emit fly ash, coal, cement dust, etc.; also, access to the laboratory should not be through a potentially dirty area of the factory.

A basement location or a ground floor position where the laboratory is surrounded by rooms or passages of approximately the same temperature offers considerable advantages.

General Features of Design

The materials and form of construction used for the walls, roof and floor of the laboratory should be selected to provide adequate thermal insulation. In the case of exterior walls, dense masonry is of added benefit in combatting potential vibration problems from external sources. Whilst the walls and roof are usually given proper consideration, the floor is often ignored as a possible source of considerable heat loss. Equipment bolted to a cold floor will acquire temperature gradients that may adversely affect measurements. Even if equipment is supported a few inches above the floor on feet, the cooling effect may still be appreciable and a thermal barrier such as glass fibre sandwiched between aluminium sheet and laid on the floor below the machine will be beneficial.

If for some reason it is necessary to have a laboratory with outside walls, exterior windows should be kept to a minimum, they should be multiple-glazed and should face north (south in the Southern hemisphere). Windows with an aspect that allows direct sunlight to enter the laboratory must be provided with blinds or shades, for the temperature in a patch of bright sunlight may be several degrees higher than elsewhere in the laboratory and the relative humidity may be lower by more than 10%. External shades are preferable; failing these, slatted blinds, white roller blinds or reflective curtains inside the room may be used. Protection against solar radiation can also be provided by special glazing or by reflective film which may be applied to existing glazing. The spaces between the panes of glass in multiple-glazed windows should be hermetically-sealed and the width of the gaps need not be greater than about 20 mm, otherwise convection currents in the air

spaces may offset the beneficial effect of the double glazing.

Internal walls are commonly of a sandwich type construction incorporating thermal insulation material. The inner faces require a durable, hard, smooth finish which will minimize the generation or harbouring of dust. Metal or plaster facings should be finished in hard, non-gloss paint. Plastic laminate offers an acceptable alternative. Ceilings, too, should be painted; depending upon the material of the ceiling, it can be advantageous to paper it prior to painting. In some situation the installation of a false ceiling will facilitate both temperature and dust control. In all cases a light-coloured, glare-free decor is recommended.

The floor should be covered with linoleum or plastic, preferably welded or laid as one piece. If wood blocks or linoleum or plastic tiles are used the floor should be sealed with a suitable compound in order to reduce dust and facilitate cleaning. For the same reasons the angle betwen the floor and walls should be filled with a suitable coving. Joints between room sections, panels, windows, entries for services, etc., should be sealed adequately and doors should be designed to open outwards into an airlock of adequate size to provide easy access for equipment and personnel.

The design of the laboratory should exclude protruding features that could interfere with the flow of air in the room and, for the same reason, bulky furniture should not be included in the equipment. Bare structural steel-work, hot and cold service pipes, and conduits should be covered with thermal insulation. It is preferable for service pipes, ducts and wiring to be installed outside the laboratory space, with runs inside the room to outlets and terminals kept to a minimum length. Location of outlets for electricity, water, compressed air, drainage and other services therefore requires careful planning and the possibility of a need for these in the inner part of a large room should not be overlooked. Adequate provision of electrical power outlets is of importance. The compressed air supply, if required, should be clean, dry and oil-free and fitted with pressure regulation.

A number of firms specialize in the design and construction of environmentally-controlled rooms. Given space in an existing building these manufacturers can readily erect a metrology-dedicated room from prefabricated modular sections, with double-glazed windows if required, and complete with temperature and humidity control and normal services.

Temperature and Relative Humidity

For metrology laboratories in the UK it is customary to work to the standard reference temperature of 20°C and to a relative humidity of about 55% (sometimes lower). The degree of temperature control that is necessary will depend upon the required accuracy of measurement and is a function of the temperature-related uncertainties introduced by the measuring equipment and the material of the work to be measured. The degree of control required by the British Calibration Service for certain types of dimensional calibration in its approved laboratories will be found stated in BCS Publication No. 0402; General criteria for laboratory approval - Length, angle and form.

In general the measurement of components by comparison with standards of a similar material having a like thermal coefficient of linear expansion will not require close adherence to the standard reference temperature, provided that there are no rapid temperature fluctuations.

The measurement of items by other techniques using, for example, computer controlled co-ordinate measuring machines, can require much tighter temperature control for the same level of accuracy. Measurement of non-ferrous components by comparison with ferrous standards should be examined carefully to ensure that the effects of temperature are understood and that adequate temperature control is provided.

Humidity control is generally provided in metrology laboratories to avoid the onset of corrosion of ferrous material but will also be important if optical methods of measurement are used because the refractive index of air is a function of humidity.

The interdependence of humidity and temperature should be remembered when deciding the conditions required in a metrology laboratory, for the stringency of the humidity requirement will affect the allowable temperature variation. As an example, a normal controlled atmosphere recommended by the International Organization for Standardization (ISO) and suitable for some types of laboratory work specifies an allowable relative humidity range of 60% to 70% with a temperature range of 18°C to 22°C. In order to keep within these limits of ±5% relative humidity, the actual change of temperature of the air as it passes through the room will have to be not more than about 1°C (see BS 4194 Design requirements and testing of controlled-atmosphere laboratories).

One of the main problems in a controlled room is to avoid the effect of local sources of heat and moisture gain or loss. (A person is a source of heat approximating to 100 watts). In order to reduce these effects and the common fault of temperature gradient, that is, a lack of uniformity of temperature at different points in the room at one time, the distribution system must ensure that air reaches all parts of the laboratory in sufficient quantities. Factors that affect uniform distribution of temperature and humidity conditions include, in addition to the presence of work-people, heat from apparatus, lights, direct sunlight and areas of single-glazed windows. As mentioned earlier, structural features and bulky equipment within the laboratory may also cause gradients by impeding the flow of air. A warning should also be given here that continuous heating is required in cold weather, even out of working hours, in order to ensure that the temperature of massive equipment and workpieces remains constant and that rusting will not occur on highly finished metallic surfaces.

Types of air flow in controlled rooms fall into the two broad categories, laminar and non-laminar flow systems. In the latter and more common system the air from an exterior control plant is usually introduced through inlets near the ceiling of the room and extracted through ducts near the floor or, alternatively, the air flow is provided by units around the walls. This system is much cheaper than the laminar flow system, but it does not provide a complete and uniform distribution of air. In the laminar flow type of installation the whole ceiling forms the inlet for the air and extraction takes place through the floor (vertical downflow system); alternatively the whole of one wall and the whole of the opposite wall act as inlet and outlet respectively (horizontal crossflow system). The downflow is the better of the laminar systems as there is a minimum of interference with the air flow to the work stations by equipment and furniture, and a better control of temperature is achieved. Where extraction cannot be through the floor, a compromise arrangement is to have sufficient outlet vents in the side walls near floor level to give the most uniform airflow possible. Inlet

of air through a large-area perforated ceiling, with a corresponding outlet area, will permit the large volume flow rate which is desirable for temperature stabilization at the low linear flow velocity (perhaps 3m/min) which may be desirable for certain types of measurement, particularly some involving optical instrumentation. Distribution of airflow can be modified by suitable placement of mats on the plenum side of the perforated ceiling, thus closing perforations where required. A slightly positive air pressure should be maintained within the laboratory to minimize the ingress of dirt.

The freshness of the air must also be considered for this is a psychological as well as a physiological factor and is governed by the number of people working in the area, the volume of traffic entering and leaving the room and also the temperature differential between the inside and outside atmospheres. It has been found that in a recirculating air system, a continuous fresh air intake of from 15% to 25% is usually adequate for the avoidance of personnel discomfort. The external fresh air intake to the system should be positioned sufficiently high to avoid intake of disturbed dust from the ground or adjacent flat roofs.

Originally air conditioning systems were in the form of a large central plant connected to the controlled rooms by extensive ducting, a system still widely in use, but now being superseded in smaller installations by prefabricated 'package' air-conditioning units, which afford an economic means of controlling either temperature alone, or both temperature and humidity. These packages are best sited outside the room or building to be controlled and are connected to it by ducting, but may be placed within the controlled area in the form of one or several small units. If they are placed within the laboratory it should be remembered that some disturbance and dust trouble may be encountered when the units are serviced; also in some situations the operating noise may be worrying. Package units are obtainable in a range of sizes and often from stock, their size and type depending on the closeness of control required and the size of the laboratory, and detailed advice should be obtained from the many firms who specialize in this field. The provision of stringently controlled temperature and humidity atmospheres can be very costly, particularly if the laboratory is large. When rigid control is necessary it is often advantageous to arrange for relatively small sections under close control to be positioned within the confines of a less-critically controlled main laboratory.

A particular form of atmospheric rusting encountered in metrology work is the corrosion of highly finished steel surfaces after contamination by sweat from the hands of personnel. Whilst palmar sweat glands are activated mainly by physiological and psychological factors, they are also influenced by both temperature and relative humidity. The recommended values given above for temperature and humidity are unlikely to increase an individual's capability to cause sweat corrosion, but precautions should be taken to reduce or eliminate likelihood of the trouble. All steel working surfaces should be wiped carefully after handling and actual finger contact should be avoided whenever possible, for finger-print contamination is more corrosive than sweat from the palm of the hand. There are a number of barrier creams that can be used where circumstances permit, but these are effective only in preventing corrosion by personnel with low palmar sweat rates; in the case of individuals with high palmar sweat rates barrier creams may not reduce the risk of corrosion to an acceptable level.

Dust

The stringent control of dust can be most expensive and when it is specified precautions should be taken to ensure that the efficiency of the filtration system is matched by the cleanliness of the personnel who use the laboratory and of the workpieces that have to be measured.

The almost-clinical air cleanliness required in the computer, guided missile and artificial satellite fields is not necessary for the normal metrology laboratory, particularly as it is customary to wipe measuring anvils and gauging surfaces immediately before they are used. However, experimental work has shown that highly finished steel surfaces are susceptible to a form of corrosive rusting induced by dust in the atmosphere settling on the surfaces, so from this aspect alone, some form of dust control is necessary.

It is the larger-sized particles of over 10 μm in size that tend to settle under gravity and special attention should be paid to these when filtration is being considered. Experience has shown that general metrological work can satisfactorily be carried out in a controlled area where the count of dust particles of 0.5 μm and larger does not exceed about $3 \times 10^7/m^3$. This level of control can be achieved by the use of standard dry or viscous-type filters in the incoming air ducts and further enhanced by recirculating filters placed within the laboratory, which will deal with internally generated dust. The advice given earlier to position fresh air ducts away from sources of dust is repeated here, because good siting reduces the need for frequent replacement of filters. The provision of an airlock with a dust-collecting floor mat at the entrance and a slightly positive air pressure within the laboratory will minimize ingress of dirt.

In special situations more strict dust control may be considered desirable. Where better-than-normal control is needed for only a small proportion of the work within the laboratory, clean air cabinets afford a ready means of providing the necessary environment. The type best suited for metrological work is the open-fronted cabinet that has a pressurized filtered air supply which passes forward from the rear of the cabinet in a laminar flow and leaves through the open front. Such a cabinet operating in a controlled metrology laboratory provides a working space that is as dust free as the atmosphere in a specially built clean room and, at the same time, results in a substantial reduction in the dust levels of the laboratory itself.

The effective control of cleanliness depends very much on the 'good housekeeping' of the metrology staff and those responsible for cleaning. It it worthwhile to make special arrangements for cleaning; for example, the floor should not be waxed or polished as this tends to retain dirt, which accumulates and cannot be removed without solvents. As mentioned earlier, it is better to seal the floor with a plastic sealer and restrict floor cleaning to regular washing and vacuum cleaning. It is desirable to keep a special vacuum cleaner for this purpose or to have a vacuum cleaning system which exhausts outside the room.

Lighting

The lighting of a measuring room should be uniform and adequate for the classes of work undertaken. Recommendations for the design of lighting systems are given in The Chartered Institution of Building Services (CIBS) Code for Interior Lighting. Here the suggested value of illuminance at the work surface in gauge rooms is 1000 lux. This will be

subject to variation depending upon the conditions existing in any particular work situation. In some cases a value of 750 lux will be sufficient. It should be borne in mind that the increased illuminance required for very fine work can be achieved by means of auxiliary localized lighting.

The system of lighting employed must provide an adequate level of illumination without causing glare or dark shadows. The Code recommends appropriate ratios of the illuminance on the main room surfaces to the illuminance on the task. Fluorescent lighting provides a shadowless illumination with a minimum of heat; it also offers a means of controlling colour quality. Miniature fluorescent lighting is particularly important if auxiliary lighting is required, because it avoids the heating effect of filament lamps used in close proximity to the work.

The decoration of the laboratory and the colour and material used for the working surfaces are significant in the effectiveness of the illumination, in the reduction of glare and reflections and also in the psychological effect on the well-being of the personnel.

Vibration

It is considered that a tolerable level of vibration in an area used for engineering metrology would not exceed 0.25 μm displacement (peak-to-peak) or 0.002 g_n acceleration at frequencies up to 200 Hz. This is the frequency range in which many laboratory vibrations are found to occur. Higher frequencies can of course be encountered and some measurement techniques are affected by these.

As mentioned earlier, the best insurance against vibration is by judicious siting of the laboratory. If sources of vibration cannot be avoided, instruments which are vibration-sensitive should be isolated by using standard antivibration pads or mats, which are usually adequate for most metrological measurements. Another method of damping that is sometimes used is to place instruments on a relatively heavy platform, such as a steel plate which, in turn, is supported on inflated rubber sacs resting on the workbench. Also available are proprietary vibration-isolated tables comprising honeycomb-structured tops on cylindrical air mounts. If it is found that commercially-made damping devices are unsatisfactory it may be necessary to design mounts oneself, ensuring that they have an appropriate natural frequency. In many cases this may well be of the order of 2 Hz or less.

Wall-mounted measuring instruments, such as flatness interferometers or level comparators, are likely to be affected by the opening or closing of doors, not only of the metrology laboratory itself, but also those of adjoining rooms. Instruments of this type are sometimes affected by transmitted vibration from the temperature-control plant or from power driven equipment outside the laboratory and whenever possible, bench-type rather than wall-type versions of these instruments should be used so that satisfactory forms of damping can easily be employed.

Voltage Regulation

With the widespread increase in the use of metrology measuring equipment that employs electronic circuitry a constant-voltage electrical supply can be important. Many instruments have built-in

regulators, and variations in the electrical mains supplies in the UK are unlikely to affect the majority of metrology measuring instruments; however, the laboratory may share a common supply with a machine shop where electrical reversal or other heavy loading affects the supply. Some instruments, such as the photo-electric autocollimator, are particularly susceptible to changes in voltage and where such sensitive instruments are used, or where it is known that there are significant voltage fluctuations, it may be necessary to install regulators in the supply leads to the individual instruments.

Furniture

Stout wooden tables or benches are needed to support measuring apparatus and also to serve as worktables. They should be about 760 mm high, with knee room to enable the inspector to sit and with adequate work-top space for instrumentation, workpieces and inspection sheets. The tables should be covered with linoleum or laminated plastic. The latter provides a cleaner surface, but where delicate apparatus is handled cork linoleum is preferable. The effectiveness of the table surfacing material in reducing glare and reflections should also be considered in making a choice.

Cupboards and cabinets of drawers are desirable to house apparatus not in constant use, but care should be taken in siting tall or bulky items of furniture so that they do not adversely affect the flow of air in the laboratory.

Health and Safety

All relevant health and safety regulations should be observed. In the UK attention is drawn particularly to the Health and Safety at Work etc. Act, 1974.

MEASURING EQUIPMENT

General

The amount and type of measuring equipment for a metrology laboratory depend directly on the nature of the product being inspected and therefore it is possible only to give general guidance on the choice and range of instruments required.

Most equipment in a new laboratory should be in metric measure but many organizations will also need some items reading in inch units and a few may be faced with the need to duplicate equipment in both units for some years to come. Some instruments are obtainable with both metric and inch scales, e.g. vertical comparators, but care should be taken in choosing dual-reading instruments as in some applications errors are likely to be introduced by misreading.

Detailed information on the apparatus mentioned in the following list is obtainable from the makers, the appropriate British Standard, the NPL Notes on Applied Science Nos. 1 and 5, and other publications listed in the bibliography. The instruments have been grouped in an attempt to associate them with particular types of measurement, but it should be realised that some instruments are used in a number of measuring applications.

Basic Standards

Sir Joseph Whitworth's maxim that precision measurement is based on a flat datum plane is as valid today as when he expounded it, and accurate reference planes in the form of surface plates, toolmakers' flats and optical flats are essential items in a metrology laboratory.

Small and medium size Grade 0 scraped surface plates are necessary for normal precision measurements and a larger, Grade 3 plate for less accurate work. These plates are obtainable in cast iron or granite (BS 817). When very high precision work is involved or when it is desired to wring gauge blocks to the plate, then steel toolmakers' flats (BS 869) hardened, and lapped to a high degree of flatness, should be used. A glass optical flat, approximately 75 mm diameter is desirable for checking the flatness of lapped surfaces, such as the working surfaces of gauge blocks. There is another type of optical flat, about 25 mm in diameter, with its faces optically flat AND parallel, that is used for checking the flatness and parallelism of micrometer and measuring machine faces. This type is sold as a set of flats of different thicknesses.

Engineers' standards of length are normally in the form of rectangular-section gauge blocks (also known as slip gauges) for sizes up to 100 mm and as circular-section length bars for longer lengths. Both of these types of end gauge are made in various grades of accuracy; for general metrology work gauge block sets of Grades 0 and I (BS 4311) and length bar sets of Grades 1 and 2 (BS 5317) are adequate. Sets of precision steel balls and rollers, whilst usually associated with the measurement of tapers, also serve as useful secondary standards of size.

If the work of the laboratory includes the measurement of external cylindrical components then the equipment should include a set of cylindrical setting standards on which micrometers, diameter measuring machines and comparators can be standardized. Similarly, if internal cylindrical work is involved, a set of plain setting rings (BS 4064) will be required for standardizing the measuring instruments that are used.

Whilst not essential, the provision of a temperature recorder and where applicable, a humidity recorder, will be found most useful for showing variations in atmospheric conditions. There are advantages in having a portable rather than a wall-mounted instrument, so that local conditions in any part of the laboratory can readily be measured.

Measurement in some fields may require specialized instruments, as for example, in gear measurement, or where large numbers of identical features have to be checked.

The high cost of some of the items listed may be prohibitive, but alternative means are often available; for instance, a surface finish measuring instrument may not be justified, but a set of surface finish comparison standards could well suffice in many cases.

Flatness, Straightness and Squareness

Autocollimator
Beam comparator
Dial gauges (BS 907) and test indicators (BS 2795)
Flatness interferometer
Levels, engineers' precision (BS 958)
Optical flat

Squares, engineers' try (BS 939)
Squares, engineers' cylindrical and block
Straight edges, rectangular section (BS 5204)
Straight edges, toolmakers' knife-edge (BS 852)
Surface plates (BS 817) and toolmakers' flats (BS 869)

Diameter and Length

Bench micrometer
Cylindrical setting standards
Comparator, external vertical (BS 1054)
Comparator, horizontal and measuring machines
Comparator, internal (cylinder gauges, air gauging equipment)
Micrometers, external (BS 870)
Micrometers, internal and 'stick' (BS 959)
Micrometers, depth
Plain plug, ring and calliper gauges (BS 969)
Setting rings (BS 4064)
Taper parallels
Vernier callipers (BS 887)
Vernier height gauges (BS 1643)
Vernier depth gauges

Screw Threads

External diameter measuring machines
Internal diameter measuring machines
Drunkenness tester
Optical projector (horizontal, vertical or cabinet type)
Projection graticule (for setting the projector)
Screw thread measuring cylinders (BS 3777) and prisms
Screw pitch measuring machine
Shadow protractor
Screwed plug and ring gauges and calliper gauges (BS 919)
Equipment for making casts of internal threads.

Angle

Angle gauges
Autocollimator
Bevel protractor (BS 1685)
Dividing head
Precision polygon
Rotary table
Sine bars and sine tables (BS 3064)
Taper diameter measuring machine
Toolmakers' microscope
Universal measuring block.

Miscellaneous

Bench centres
Dust-free cloths
Electronic linear displacement transducers
Feeler gauges (BS 957)
Force measuring gauges
Gear tooth vernier
Gear testing instrument (meshing type)
Hardness tester
Level, electronic
Light boxes, simple and monochromatic types

Measuring rules (BS 4372)
Parallels, steel (BS 906)
Radius gauges
Roundness measuring instrument (BS 3730)
Surface finish measuring instrument (BS 1134)
Surface finish comparison standards (BS 2634)
Dust-collecting floor covering
Thermograph
Thermometers (BS 1041 Section 2.1)
Toolmakers' clamps
Vee blocks (BS 3731)

CALIBRATION

The requirements in measuring equipment and environment having been satisfied it is advisable for the metrologist to obtain assurance as to the accuracy of his laboratory standards. There are two main sources of officially authenticated calibrations in the UK.

1. The National Physical Laboratory.

This is the national reference laboratory for precise measurements in most fields and it provides calibrations of laboratory standards where accuracy of the highest order is required. Details of the calibration facilities available are given in a series of Measurement Services publications which includes the following titles:-

Engineering Dimensional Metrology
Acoustics
Certified reference materials
Colorimetry, Spectrophotometry, Photometry and Radiometry
Direct Current and Low Frequency Electrical Measurements
Force
Hardness
Mass and Density
Optical Metrology
Pressure and Vacuum
Radiation Science
Temperature
Viscosity

These publications may be obtained free of charge by application to:-

National Physical Laboratory
Teddington
Middlesex TW11 OLW

Telephone: 01-977 3222
Telex: 262344

2. The British Calibration Service.

This national service, managed by the National Physical Laboratory, provides calibration of measuring equipment at approved laboratories covering a wide range of locations in the UK. The service gives traceability to the national standards of measurement and caters for instruments having accuracy requirements less stringent than instruments which would be submitted directed to NPL.

Further information can be obtained from:-

British Calibration Service
National Physical Laboratory
Teddington
Middlesex TW11 OLW [redacted]

Telephone: 01-977 3222
Telex: 262344.

APPENDIX I

Bibliography

The following list of publications is not considered to be exhaustive. Some items may be out of date in certain respects but they have been included for the value of the basic information provided. It is also appreciated that a number of the publications are out of print; in some cases it can be possible to obtain loan copies through library services and some may be available as photocopies.

NPL NOTES ON APPLIED SCIENCE — Her Majesty's Stationery Office

No.	1	Gauging and measuring screwthreads	1969
	4	Measurement of humidity	1970
	5	Gauge making and measuring	1967
	26	Measurement of angle in engineering	1964
	27	Inspection of gauging dimensions involving linear and angular measurements	1962

BRITISH STANDARDS

No. 817 Surface plates
852 Toolmakers' straightedges
869 Toolmakers' flats and high precision surface plates
870 External micrometers
887 Precision vernier callipers
888 Slip (or block) gauges and their accessories (inch)
906 Engineers' parallels
907 Dial gauges for linear measurement
919 Screw gauge limits and tolerances
939 Engineers' squares (including cylindrical and block squares)
957 Feeler gauges
958 Spirit levels for use in precision engineering
959 Internal micrometers (including stick micrometers)
969 Plain limit gauges, limits and tolerances
1041 Code for temperature measurement
1054 Engineers' comparators for external measurement
1134 Method for the assessment of surface texture
1643 Precision vernier height gauges
1685 Bevel protractors (mechanical and optical)
1734 Micrometer heads
1790 Length bars and their accessories (metric and inch, obsolescent)
1916 Limits and fits for engineering (inch)
2634 Roughness comparison specimens
2795 Dial test indicators (lever type) for linear measurement
2856 Precise conversion of inch and metric sizes on engineering drawings
3064 Metric sinebars and sinetables (excluding compound tables)
3643 ISO metric screw threads
3730 Assessment of departures from roundness
3731 Metric vee blocks
3777 Screw thread measuring cylinders (inch)
4064 Plain setting rings for use with internal diameter measuring machine. Metric units.

4065 Plain setting rings for use with internal diameter measuring machines. Inch units.
4194 Design requirements and testing of controlled-atmosphere laboratories.
4311 Metric gauge blocks
4358 Glossary of terms used in air gauging with notes on the technique
4372 Engineers' steel measuring rules
4500 ISO limits and fits
4778 Glossary of terms used in quality assurance
5204 Straightedges
5233 Glossary of terms used in metrology
5295 Environmental cleanliness in enclosed spaces
5317 Metric length bars and their accessories
5535 Right angle and box angle plates
5590 Screw thread metric series measuring cylinders
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APPENDIX II

Suppliers of Equipment

The trade association for manufacturers of metrology equipment is the Gauge and Tool Makers Association of Great Britain, 24 White Hart Street, High Wycombe, Bucks HP11 2HL (Telephone: High Wycombe 444645). The Metrology Section of this Association publishes a comprehensive directory of products and services offered by its members.

The companies listed in this Appendix are those which have become known to the Laboratory as suppliers of the equipment stated but are not necessarily the only sources of supply. Inclusion does not imply in any way that these suppliers have received official approval. Names of firms are shown opposite the alphabetically arranged list of equipment; their addresses are listed separately in a later part of the Appendix.

Air conditioning units	F H Biddle Ltd Carlyle Air Conditioning Co. Ltd Matthews and Yates Ltd. Qualitair (Air Conditioning) Ltd South London Electrical Equipment Co. Ltd Temperature Ltd
Air filters	Doulton Industrial Products Ltd Envair (UK) Ltd MDH Ltd Millipore (UK) Ltd Vokes Air Filters Ltd
Air gauging	Thomas Mercer Ltd Sigma Ltd Solex Equipment Ltd
Angle gauges	Rank Taylor Hobson TI Robertson Coventry Gauge Ltd
Autocollimators	Rank Taylor Hobson
Balls, precision	Insley Industrial Ltd Trimos Sylvac Metrology Ltd TI Robertson Coventry Gauge Ltd Verdict Gauge (Sales) Ltd Yorkshire Precision Gauges Ltd
Bench centres	Jones & Shipman plc J E Nanson Gauges (Coventry) Ltd Sigma Ltd Trimos Sylvac Metrology Ltd Verdict Gauge (Sales) Ltd
Bench micrometers	J E Nanson Gauges (Coventry) Ltd Sigma Ltd
Casting material for internal screw thread forms	Amalgamated Dental Chemicals Ltd Claudius Ash Sons & Co. Ltd

Clean air cabinets and rooms	John Bass Ltd Envair (UK) Ltd Hepaire Manufacturing Ltd MDH Ltd South London Electrical Equipment Co Ltd
Comparators, mechanical and electronic	J E Baty & Co Ltd British Indicators Ltd Federal Ayreid Matchless Machines Ltd Thomas Mercer Ltd Sigma Ltd Tesa Metrology Ltd
Constant-temperature rooms	John Bass Ltd Envair (UK) Ltd South London Electrical Equipment Co Ltd
Co-ordinate measuring machines	Crown Windley Ltd Eley & Warren Precision Engineers Ltd Ferranti Ltd Hahn and Kolb (GB) Ltd C E Johansson Ltd Keeling Metrology Co. Ltd E. Leitz (Instruments) Ltd L K Tool Co Ltd Rank Taylor Hobson
Depth gauges	Moore & Wright Ltd L S Starrett Co Ltd
Dial and indicator gauges	J E Baty & Co Ltd British Indicators Ltd Thomas Mercer Ltd Verdict Gauge (Sales) Ltd
Dividing heads, optical	J E Nanson Gauges (Coventry) Ltd Precision Grinding Ltd
Dust-collecting cloths	Gramos Chemicals International Ltd
Dust-collecting floor mats	Dycem Ltd Gramos Chemicals International Ltd Micronetic Services Ltd
Electronic linear displacement transducers	Ferranti Ltd Matchless Machines Ltd Thomas Mercer Ltd Rank Taylor Hobson TI Robertson Coventry Gauge Ltd
Feeler gauges	Buck and Hickman Ltd Moore and Wright Ltd Rabone Chesterman Ltd Yorkshire Precision Gauges Ltd

Force measuring gauges	Mecmesin Ltd Verdict Gauge (Sales) Ltd
Gauge blocks	Broomfield Carbide Gauges Ltd C E Johansson Ltd Select Gauges Ltd TI Robertson Coventry Gauge Ltd Yorkshire Precision Gauges Ltd
Gauges, plain and screwed limit	Horstmann Gauge & Metrology Ltd TI Robertson Coventry Gauge Ltd Yorkshire Precision Gauges Ltd
Gauges, radius	Buck and Hickman Ltd Moore and Wright Ltd Rabone Chesterman Ltd
Gauges, roller	Trimos Sylvac Metrology Ltd Verdict Gauge (Sales) Ltd Yorkshire Precision Gauges Ltd
Gear testing machines	British Indicators Ltd Goulder Mikron Ltd J Parkinson & Son (Shipley) Ltd
Gear tooth verniers	Benson Verniers Ltd
Graticules, projection	Graticules Ltd Heidenhain (GB) Ltd
Interferometers, flatness	Analytical Accessories Ltd Ealing Beck Ltd OMT (Optics) Ltd
Interferometers, length	Hahn & Kolb (GB) Ltd Hewlett-Packard Ltd Linear Instruments Ltd
Length bars	TI Robertson Coventry Gauge Ltd
Levels, electronic	Matchless Machines Ltd Rank Taylor Hobson Verdict Gauge (Sales) Ltd
Levels, engineers' precision	Moore & Wright Ltd Rabone Chesterman Ltd Rank Taylor Hobson Verdict Gauge (Sales) Ltd
Light box, monochromatic	TI Robertson Coventry Gauge Ltd
Micrometer heads	Moore & Wright Ltd TI Robertson Coventry Gauge Ltd
Micrometers, external, internal, depth and stick	Moore & Wright Ltd L S Starrett Co Ltd

Optical flats	Lapmaster International Ltd OMT (Optics) Ltd Optical Surfaces Ltd Optical Works Ltd Rank Taylor Hobson TI Robertson Coventry Gauge Ltd
Optical projectors	J E Baty & Co Ltd Headland Gauges Ltd Keeling Metrology Co Ltd E Leitz (Instruments) Ltd Pexit Precision Ltd Precision Grinding Ltd Rank Taylor Hobson Sigma Ltd
Parallels, engineers'	Crown Windley Ltd TI Robertson Coventry Gauge Ltd Verdict Gauge (Sales) Ltd
Particle size and counters	Delcita Ltd Gelman Sciences Ltd Malvern Instruments Ltd
Pitch measuring machines	J E Nanson Gauges (Coventry) Ltd Sigma Ltd
Polygons, precision	Rank Taylor Hobson TI Robertson Coventry Gauge Ltd
Protractors, bevel	Moore & Wright Ltd L S Starrett Co Ltd Trimos Sylvac Metrology Ltd
Rotary tables	Horstmann Gauge & Metrology Ltd OMT (Optics) Ltd
Roundness measuring instruments	Rank Taylor Hobson
Rules, engineers' measuring	Buck & Hickman Ltd Moore & Wright Ltd Rabone Chesterman Ltd
Screw thread diameter measuring machines	J E Nanson Gauges (Coventry) Ltd
Screw thread measuring cylinders	Horstmann Gauge & Metrology Ltd TI Robertson Coventry Gauge Ltd
Screw thread measuring vees	TI Robertson Coventry Gauge Ltd
Sine bars and sine tables	Crown Windley Ltd Grey Rushton (Precision Tools) Ltd J E Nanson Gauges (Coventry) Ltd Trimos Sylvac Metrology Ltd Verdict Gauge (Sales) Ltd
Squares, engineers'	Moore & Wright Ltd Rabone Chesterman Ltd

	Trimos Sylvac Metrology Ltd
Straight edges, rectangular	Moore & Wright Ltd Rabone Chesterman Ltd Trimos Sylvac Metrology Ltd
Straight edges, knife-edge	Moore & Wright Ltd Trimos Sylvac Metrology Ltd
Surface plates	Buck & Hickman Ltd Crown Windley Ltd L K Tool Co Ltd W B J Engineering Ltd
Surface finish measuring instruments	Rank Taylor Hobson
Surface finish comparison standards	Rubert & Co Ltd
Taper diameter measuring machines	J E Nanson Gauges (Coventry) Ltd
Taper parallels	Trimos Sylvac Metrology Ltd Verdict Gauge (Sales) Ltd
Thermographs	Cassella London Ltd
Thermometers	H Stout & Co Ltd G H Zeal Ltd
Toolmakers' clamps	Buck & Hickman Ltd Moore & Wright Ltd L S Starrett Co Ltd
Toolmakers' flats	TI Robertson Coventry Gauge Ltd
Toolmakers' microscopes	Precision Grinding Ltd Sigma Ltd Trimos Sylvac Metrology Ltd
Vee blocks	Crown Windley Ltd Moore & Wright Ltd J E Nanson Gauges (Coventry) Ltd Rubert & Co. Ltd L S Starrett Co Ltd Verdict Gauge (Sales) Ltd
Vernier callipers, height gauges, depth gauges	Benson Verniers Ltd Grey Rushton (Precision Tools) Ltd Rabone Chesterman Ltd L S Starrett Co. Ltd
Vibration-isolated tables	Cementation (Muffelite) Ltd Ealing Beck Ltd Wentworth Laboratories Ltd
Voltage regulators	Lyons (Claude) Ltd Zenith Electric Co. Ltd

Amalgamated Dental Chemicals Ltd	Hamm Moore Lane, Addlestone, Surrey
Analytical Accessories Ltd	Unit 3, Lagoon Road, St Mary Cray, Orpington, Kent BR5 3QX
Claudius Ash Sons & Co Ltd	Amalco House, 26/40 Broadwick Street London, W1A 2AD
John Bass Ltd	Bassaire Building, Duncan Road, Swanwick, Southampton SO3 7ZS
J E Baty & Co Ltd	Victoria Road, Burgess Hill West Sussex, RH15 9LB
Benson Verniers Ltd	Carlton Works, Carlton Street, Bradford, Yorks BD7 1DA
F H Biddle Ltd	Newtown Road, Nuneaton CV11 4HP
British Indicators Ltd	Acrewood Way, St Albans Herts AL4 0JX
Broomfield Carbide Gauges Ltd	P O Box B23, Huddersfield HD1 3DA
Buck & Hickman Ltd	Bank House, 100 Queen Street Sheffield S1 2DW
Carlyle Air Conditioning Co Ltd	Knightsbridge House, 197 Knightsbridge, London SW7 1RD
Cassella London Ltd	Regent House, Britannia Walk London N1 7ND
Cementation (Muffelite) Ltd	Hersham, Walton-on-Thames Surrey KT12 3PQ
Crown Windley Ltd	Beach's Drive, Chelmsford Essex CM1 2NW
Delcita Ltd	Ver House, London Road Markyate, Herts AL3 8JT
Doulton Industrial Products Ltd	Stone, Staffs ST15 0PU
Dycem Ltd	Ashley Hill Trading Estate, Bristol BS2 9XS
Ealing Beck Ltd	Greycaine Road, Watford Herts WD2 4PW
Eley & Warren Precision Engineers Ltd	Unit 3, Beaufort Court Industrial Estate, Mansfield Road, Derby DE2 4FS
Envair (UK) Ltd	York Avenue, Haslingden, Rossendale, Lancs BB4 4HX
Federal Ayreid	Brick Knoll Park, Ashley Road St Albans, Herts AL1 5PL

Ferranti plc	Thornybank, Dalkeith Midlothian EH22 2NG
Gelman Sciences Ltd	10 Harrowden Road Brackmills Northampton NN4 0EZ
Goulder Mikron Ltd	Albany Works, Kirkheaton Huddersfield HD5 0QR
Graticules Ltd	Morley Road, Tonbridge Kent TN9 1RN
Gramos Chemicals International Ltd	Hayes Lane, Lye, Stourbridge West Midlands DY9 8PJ
Grey Rushton (Precision Tools) Ltd	Clinton Street, Church Terrace Leamington Spa CV31 1EW
Hahn & Kolb (GB) Ltd	6 Forum Drive, Leicester Road Rugby, Warwicks CV21 1NY
Headland Gauges Ltd	Kingston Road Leatherhead, Surrey KT22 7PT
Heidenhain (GB) Ltd	200 London Road, Burgess Hill, Sussex RH15 9RD
Hepaire Manufacturing Ltd	48-50 Fowler Road, Hainault Ilford, Essex IG6 3XA
Hewlett-Packard Ltd	King Street Lane, Winnersh, Wokingham RG11 5AR
Horstmann Gauge & Metrology Ltd	Brassmill Works, Bath Avon BA1 3JH
Insley Industrial Ltd	P O Box 12, Eastern Road Bracknell, Berks RG12 1LT
C E Johansson Ltd	66 High Street, Houghton Regis Dunstable, Beds LU5 5BJ
Jones & Shipman plc	Narborough Road South Leicester LE3 2LF
Keeling Metrology Co Ltd	Pontefract Street Ascot Drive Industrial Estate Derby DE2 8JD
Lapmaster International Ltd	Lee Mill Industrial Estate Ivybridge, Devon PL21 9EN
E. Leitz (Instruments) Ltd	48 Park Street Luton LU1 3HP
Linear Instruments Ltd	Coltsfield, High Lane Stansted Mountfitchet, Essex CM24 8LQ

L K Tool Co Ltd	East Midlands Airport, Castle Donnington, Derby DE7 2SA
Lyons (CLaude) Ltd	Valley Works, Ware Road Hoddesdon, Herts EN11 9DX
Malvern Instruments Ltd	Spring Lane South Malvern Worcestershire WR14 1AQ
Matchless Machines Ltd	Redkiln Way, Horsham Sussex RH13 5QJ
Matthews & Yates Ltd	Cyclone Works, Swinton, Manchester M27 2AP
MDH Ltd	Walworth Road, Andover Hants SP10 5AA
Mecmesin Ltd	Newton House, Cross Road, Tadworth, Surrey KT20 5SR
Thomas Mercer Ltd	Eywood Road, St Albans Herts AL1 2ND
Micronetic Services Ltd	Micra House, 138 Lower Mortlake Road Richmond, Surrey TW9 2JZ
Millipore (UK) Ltd	Millipore House, 11/15 Peterborough Road, Harrow HA1 2YH
Moore & Wright Ltd	Handsworth Road, Sheffield S13 9BR
J E Nanson Gauges (Coventry) Ltd	Baynton Road, Exhall Coventry CV7 9EL
OMT (Optics) Ltd	Industrial Estate, Fakenham Norfolk NR21 8NJ
Optical Surfaces Ltd	Godstone Road, Kenley Surrey CR2 5AA
Optical Works Ltd	32A, The Mall, London W5 3TJ
J Parkinson & Son (Shipley) Ltd	P O Box 28, Shipley W. Yorks BD17 7EQ
Pexit Precision Ltd	Unit 1 Marshbrook Close Aldermans Green Industrial Estate Coventry West Midlands CV2 2NW
Precision Grinding Ltd	Mill Green Road, Mitcham Junction Surrey CR4 4TX
Qualitair (Air Conditioning) Ltd	Castle Road, Eurolink, Sittingbourne Kent ME10 3RH
Rabone Chesterman Ltd	Pomona Street, Sheffield

Rank Taylor Hobson	P O Box 36, New Star Road Thurmaston Lane, Leicester LE4 7JQ
Rubert & Co Ltd	Acru Works, Demmings Road Cheadle, Cheshire SK8 2PG
Select Gauges Ltd	Select Works, Torpoint Cornwall PL11 2PT
Sigma Ltd	Spring Road, Letchworth Herts SG6 4AJ
South London Electrical Equipment Co Ltd	Lanier Works, Hither Green Lane London SE13 6QD
Solex Equipment Ltd	London Road, Dunstable Beds LU6 3UR
The L S Starrett Co Ltd	Oxnam Road, Jedburgh Scotland TD8 6LR
H Stout & Co Ltd	Holmethorpe, Redhill Surrey RH1 2NL
Temperature Ltd	Newport Road, Sandown Isle of Wight PO36 9PH
Tesa Metrology Ltd	P O Box 418, Halesfield 8, Telford, Shropshire TF7 4QN
TI Robertson Coventry Gauge Ltd	Bradgate St., Leicester LE4 0AW
Trimos.Sylvac Metrology Ltd	South Bank Business Centre 140 Battersea Park Road London SW11 4NB
Verdict Gauge (Sales) Ltd	Thames Road, Darford, Kent DA1 4QZ
Vokes Air Filters Ltd	Barden Lane, Burnley BB12 0DU
WBJ Engineering Ltd	Gorton Industrial Estate Froxmer Street Manchester M18 8EF
Wentworth Laboratories Ltd	Sunderland Road, Sandy, Beds SG19 1RB
Yorkshire Precision Gauges Ltd	Hatfield, Nr Doncaster DN7 6QF
G H Zeal Ltd	Lombard Road, Merton London SW19 3UU
The Zenith Electric Co Ltd	Cranfield Road, Wavendon Milton Keynes MK17 8AT