

The performance of portable extensometer calibration rigs

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Portable extensometer calibration rigs and their uncertainties

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Abstract

This report looks at the design of the UK's most commonly used portable extensometer calibration rig (ECR). Based on specialist operator experience and a range of new measurements using NPL's laser calibration system, the importance of different aspects of the design are quantified. This information will be useful for the calibration technician trying to optimise the performance of an ECR.

The effect of temperature changes on calibration results for ECRs is also detailed. A series of measurements are described that separate the influences of temperature changes on ECRs from those on the calibration system. The uncertainties of the laser calibration system are also described since they limit the final uncertainty of the measurements made with an ECR.

AQD design ECRs are prone to misalignment during transport so guidance is provided on their packing and handling. Some of the limitations of the AQD design are summarised and the design of a simplified portable ECR is discussed.

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Approved on behalf of the Managing Director, NPL,
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1. Introduction

This report is published as completion of milestone 2.8.3 of the DTI's National Measurement System Programme for Mass "Uncertainties associated with calibration of existing designs of ECRs".

One of the most important properties of a material is its behaviour under load. This performance is characterised by parameters such as tensile strength, impact toughness, hardness and Young's modulus. Young's modulus describes how much a material stretches when pulled¹. The amount of stretch is measured using an extensometer. Some materials do not stretch far before they break so extensometers need to be able to accurately measure small changes in length.

Extensometers are calibrated using extensometer calibration rigs (ECRs). The most commonly used ECRs in the UK are those built to the design developed by AQD in Woolwich. These are purely mechanical instruments that can have a remarkably good performance but do need to be looked after carefully, especially when in transit.

The object of the work described in this report this report was to investigate how the ECRs are likely to perform under less than ideal laboratory conditions and why some ECRs are better than others. The setting up of an ECR for optimum performance is something of a black art but by looking at the influences of all the different adjustments on the ECRs this has been partially de-mystified.

The performance of an ECR is difficult to separate out from the performance of the calibration system. This is because the uncertainty in the measurements made by the ECR may be limited by the performance of the calibration system, and things that affect the ECR (for example temperature) may also affect the calibration system.

2. The design of the AQD ECR

The design of the ECR is illustrated in Appendix 1. A micrometer drum drives a lever arm using a long push rod. The other end of the lever arm raises or lowers the upper test bar holder via a short push rod. The lever arm has a 10:1 reduction thereby increasing the resolution of the micrometer. The travel of the upper test bar holder is constrained by spring strips. The lower test bar holder is fixed.

Test bars are placed in the two holders and the extensometer mounted on the two bars (sometimes referred to as a split test piece). The micrometer drum is then used to move the upper test piece and the reading from the micrometer (reduced by a factor of 10) is compared with that of the extensometer.

¹ **Extensometry terminology** - The pull on a material is called the stress and has units of $\text{N}\cdot\text{m}^{-2}$. The amount that a material stretches is called the strain which is expressed as the relative increase in length. Young's modulus describes how hard it is to stretch a material and is the stress divided by the strain.

When using an extensometer to measure strain, the extensometer is attached to two points on a test piece. The distance between these two points is called the gauge length and the change in this length as the material is stressed is called the extension.

3. The calibration of ECRs in the UK

NPL offers a calibration service for ECRs. This is done using a laser interferometer to measure the travel of the upper test bar. An interferometer block is mounted on the lower test bar and a retro-reflector is mounted on the upper test bar. The laser is automatically compensated for refractive index and is traceable to the UK realisation of the metre. If the performance of the ECR is unsatisfactory, NPL offers a setting-up service during which its performance is optimised.

Most of the ECRs submitted for calibration are of the AQD design. AQD generously made the design available to anyone who wanted it. Companies still contact NPL about the design and are issued with a complete set of engineering drawings. The original calibration service was operated by MOD at Harefield. This moved to MOD Woolwich when MOD Harefield was closed down. When MOD Woolwich was also closed, NPL bought the service so as to maintain a traceable calibration system for the UK.

NPL still uses much of the original measuring equipment but has replaced all the computer hardware and software. The reading of the laser display, classification of the ECRs and production of the certificate is all done on a PC. The service is accredited by UKAS.

There have been several changes to the national and international standards governing the calibration of ECRs. The current standards are ASTM E83-96¹, and BS EN 10002-4 : 1995² which is identical to ISO 9513 : 1999 (E)³.

4. Summary of factors influencing the performance of ECRs

The following factors will affect the performance of an ECR. They are considered in detail in the subsequent sections of this report.

- Micrometer - The repeatability, reproducibility, reversibility and linearity of the ECR is limited by that of the micrometer.
- Push rods - The length of the push rods and the roundness of the ends will both affect the ECR's performance.
- Lever ratio - The indent which accepts the end of the long push rod is mounted in an adjustment plate that can be moved up or down the lever arm thereby altering the lever ratio.
- Lever arm travel - As the micrometer is screwed in and out, the indents in the level arm that accept both the push rods follow arcs. The lever ratio therefore changes with position.
- Eccentric - The small push rod locates in a hole in the upper test bar holder. This hole is drilled off-axis in the end of a piece of steel dowel (the eccentric) secured in the test bar holder with a screw. The eccentricity is used to compensate for the lever arm following an arc (see above). The degree of offset, depth of hole and rotational position of the indent can all be varied.

- Upper test bar holder travel - This is oriented in a vertical plane by the strip hinges but its travel is an arc.
- Alignment of the test bar holders - If the test bars are not aligned, the extensometer may see a different displacement to that applied by the upper test bar holder.
- Temperature - The ECR will be affected by thermal expansion.
- Friction - The lever arm is mounted in a couple of V slots. The end travel is constrained by two screws and the lever arm is prevented from jumping out by brass retainers. These retainers must secure the rod without introducing too much friction.

5. Analysis of previous calibrations

Some ECRs perform well, others never achieve particularly good classifications. The current electronic records of calibrations made at NPL were examined to see if they provided any clue as to what makes a good ECR.

When correctly adjusted, ECRs produce a linear relationship between the displacement set by the micrometer and that measured by the laser. When out of adjustment, the same ECRs can produce a relationship of varying curvature under conditions of good repeatability. If repeatability is poor it can be difficult to discern the correct relationship.

The computer records of calibrations performed at NPL over the last three years were collated and the curvature and offset of each micrometer-displacement curve was quantified. This was done by fitting a quadratic curve to each data plot and using the parameter of the quadratic term to determine the degree of non-linearity. Analysis of this data using a database did not reveal any useful data. This may be because there is no trend there to be found or that there is insufficient data.

6. Effect of ECR characteristics

6.1 Micrometer performance

The drum micrometers used on ECRs are usually of 25 mm travel although at least one has been fitted with a 50 mm version. The drums have a vernier scale fitted and their resolution is typically 2 μm (which after reduction by the lever ratio gives a resolution of 0.2 μm). They are precision devices and are usually reliable and accurate if looked after properly.

The usual problem with micrometers is that the spindle is too tight or too loose. NPL receive several ECRs each year that require adjustment. If the spindle is too tight, the drum is hard to turn and the results are not very repeatable. Repeatability is also a problem if the spindle is too loose. In both cases the problem is usually obvious as soon as the ECR is operated and the tightness can be reset by dismantling the micrometer and adjusting the spindle nuts using a purpose-made spanner.

There is no evidence that the performance or choice of micrometer drum affects the overall performance of the ECR.

6.2 Push rods and the eccentric

The push rods locate in indents in the lever arm, upper test rod holder, and the end of the micrometer spindle. Because the travel of the lever arm indents are arcs, the ends of the push rods need to be hemispherical. This is usually achieved by cementing ball-bearings to the ends of the push rods. It is important to use only a thin layer of hard-setting cement or there will be some elasticity. NPL have received a couple of ECRs with balls cemented in with a thick layer of adhesive - these rigs exhibited non-repeatability.

The ends of the push rods should ideally be hemispherical but experience has shown that some of the ECRs with the best performance have push rods with very poorly turned ends. This indicates that it is more important that the push rods are rigid and hard enough to ensure that they do not wear.

The push rods need to be of a length such that the effect of the rotation of the lever is a minimum. This is when the push rods are perpendicular to lines joining their indent and the axis of rotation. Referred to as the neutral position the push rods are made of such a length that the neutral position is at the mid point of the micrometer's travel.

In the neutral position, the relationship between the micrometer reading and the displacement of the upper test bar is a simple 10:1 ratio. Once the lever arm moves away from this position, the relationship changes as the push rods deviate from the perpendicular. This introduces two cosine errors which do not necessarily cancel. For these errors to cancel, there needs to be symmetry at both ends of the lever arm. This requires both push rods to be perpendicular in the neutral position, and the short push rod to be 10 times shorter than the long one.

6.2.1 Effect of eccentric position

The height of the eccentric is dictated by the length of the push rods. It must be set so that at mid-travel of the micrometer, the strip hinges constraining the upper test bar holder are perpendicular to its direction of travel. This can be easily checked with a spirit level on the strip hinges if the ECR is positioned on a horizontal surface.

Measurements were made to demonstrate the effect of rotating an eccentric. A 115 mm long push rod and a 20 mm short push rod were used. Tension and compression calibration runs were performed with the eccentric at different rotations.

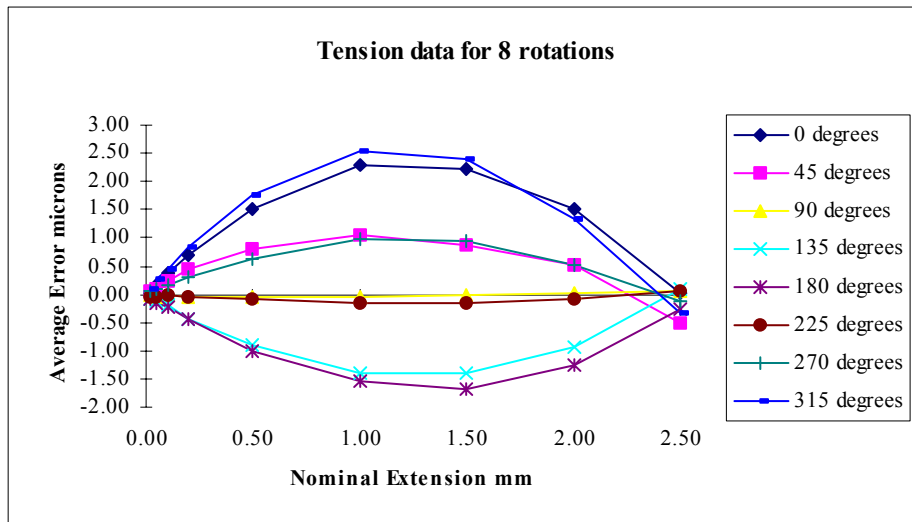


Figure 1 : Tension data for 20 mm and 115 mm push rods in 8 rotational positions

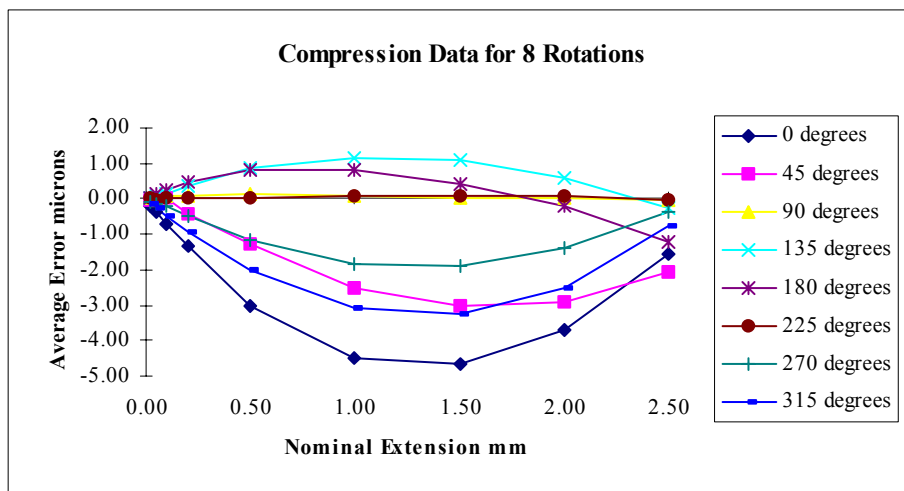


Figure 2 : Compression data for 20 mm and 115 mm push rods in 8 rotational positions

The results clearly demonstrate the effect of rotating the eccentric. In both directions the optimum positions were at 90° and 225°. The fact that these two positions were not 180° apart is probably due to the indent in the top of the lever arm not being exactly underneath the centre of the eccentric. This is an important effect and explains why some ECRs will not give linear results with the ECR in any position. If the push rods are of the correct lengths, one solution may be to manufacture an eccentric with its indent further offset.

The change in the final reading with different rotations of the eccentric demonstrates the relationship between the eccentric's linearisation and the lever ratio. For comparison, the zero repeatability was better than 0.1 µm.

The differences between the tension and compression curves is not understood but the agreement of the best rotational position is as expected.

6.2.2 Effect of push rod lengths

A ECR was installed with a 115 mm long push rod and measurements were made using short push rods of 16 mm and 25 mm (measurements with a 20 mm short push rod being shown above).

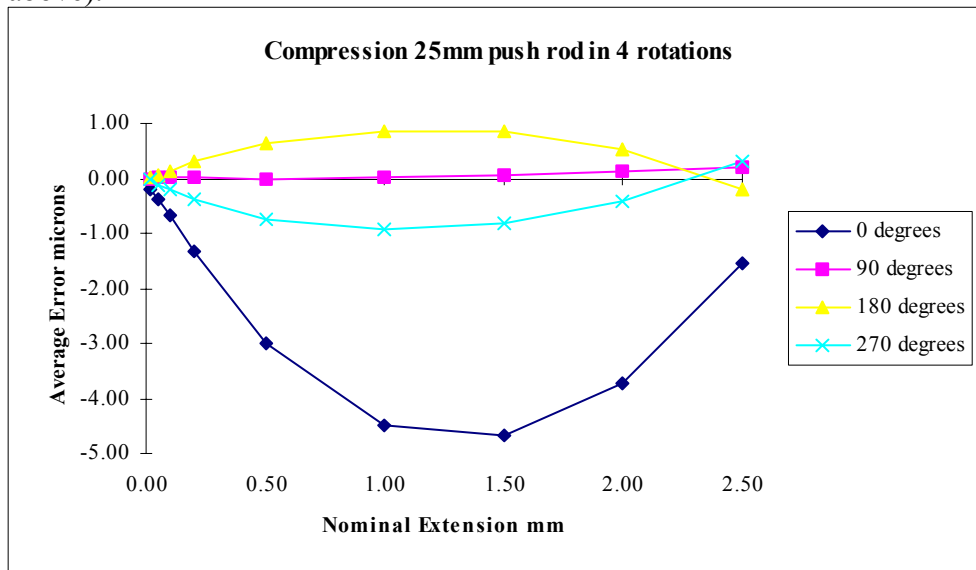


Figure 3 : Tension data for 25 mm and 115 mm pushrods

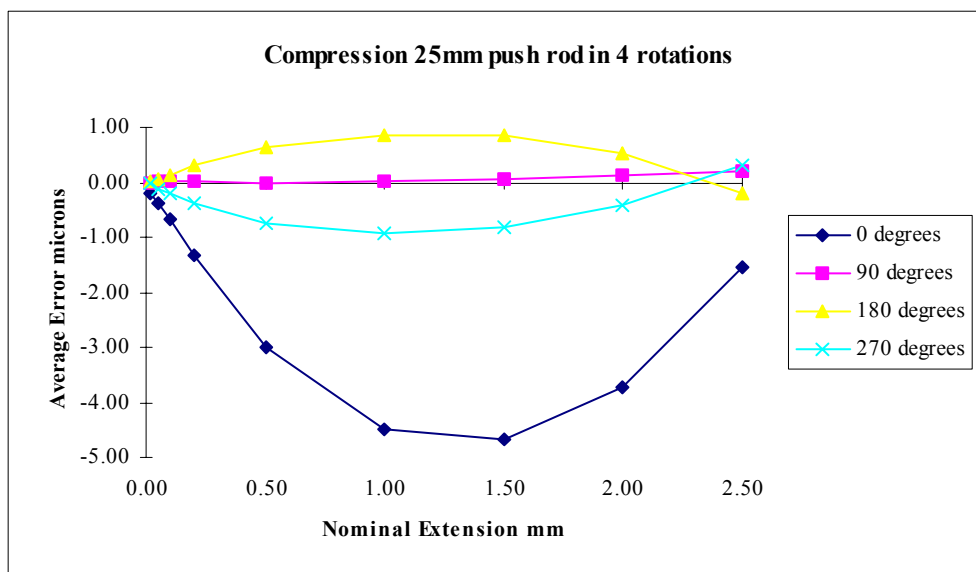


Figure 4 : Compression data for 25 mm and 115 mm pushrods

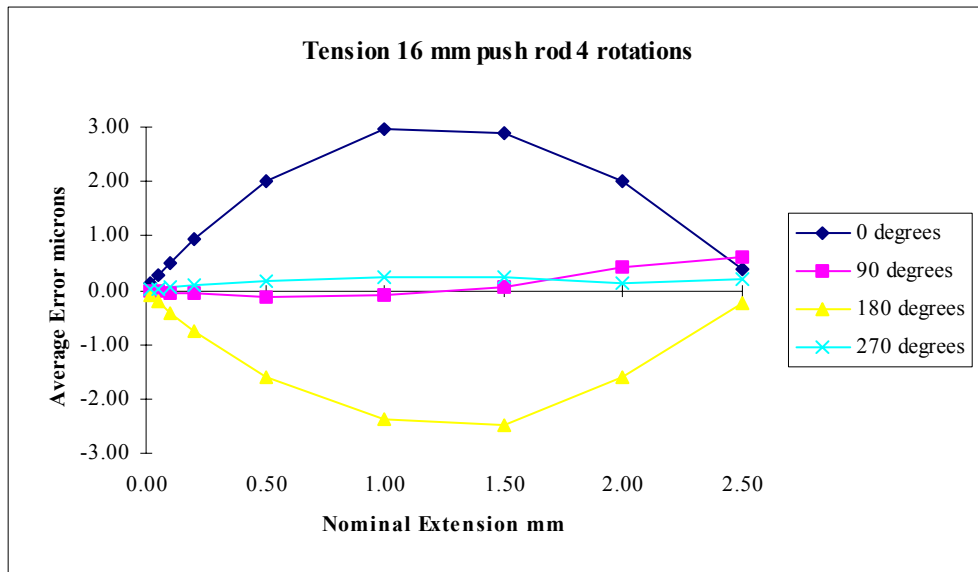


Figure 5 : Tension data for 16 mm and 115 mm push rods

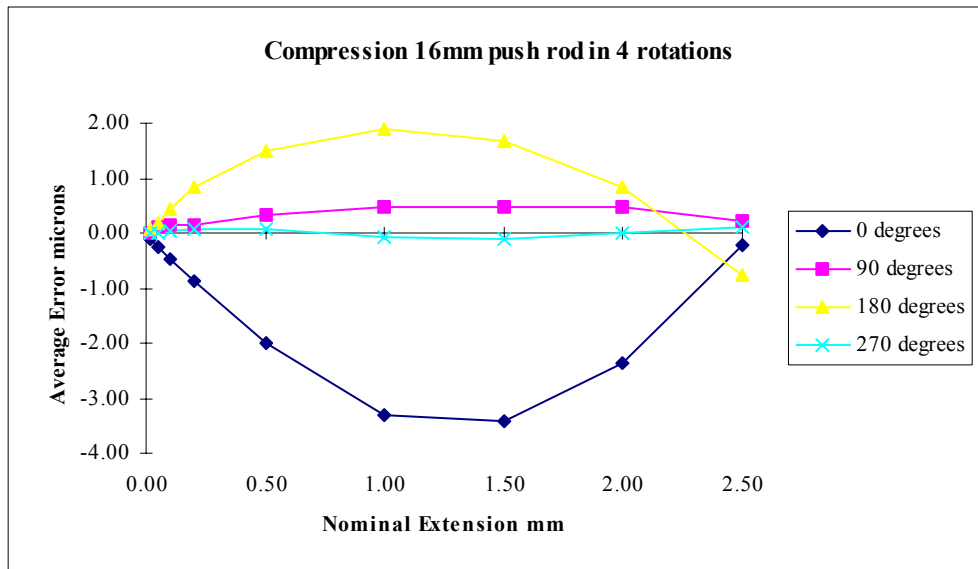


Figure 6 : Compression data for 16 mm and 115 mm push rods

Figures 1 to 6 show that all three push rods introduced similar amounts of eccentricity. All three push rods were longer than the ideal 10:1 length ratio with the 115 mm long push rod. A further series of measurements were made in which the 20 mm short push rod was used with 105 mm and 125 mm long push rods.

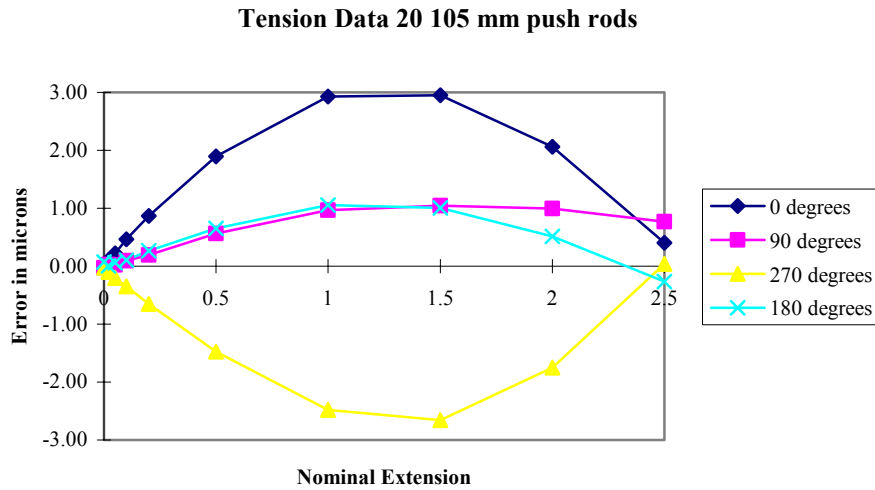


Figure 7 : Tension data for 20 mm and 105 mm push rods

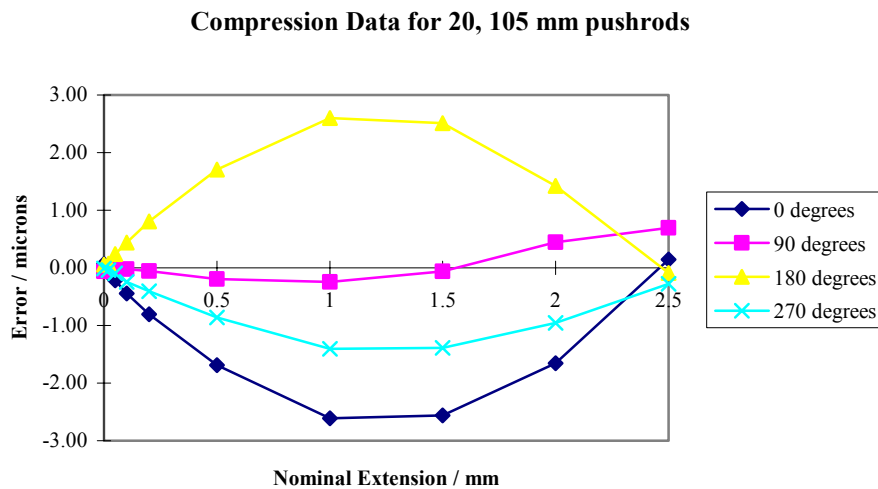


Figure 8 : Compression data for 20 mm and 105 mm push rods

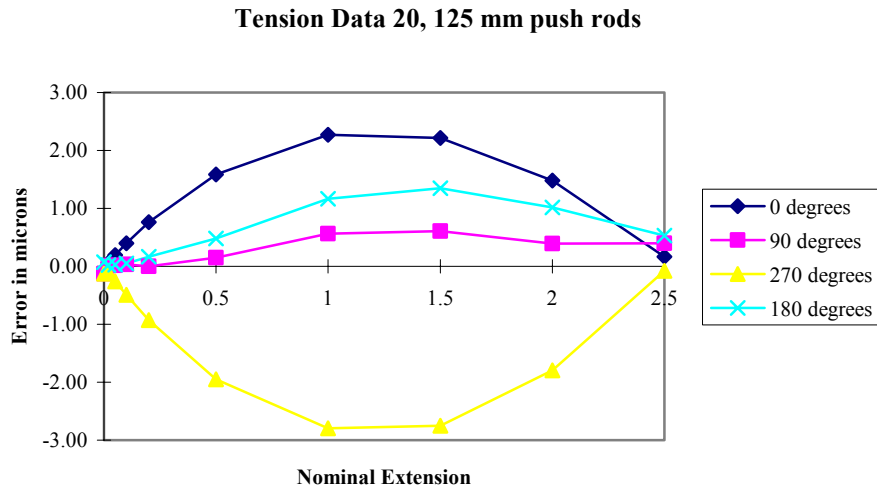


Figure 9 : Tension data for 20 mm and 125 mm push rods

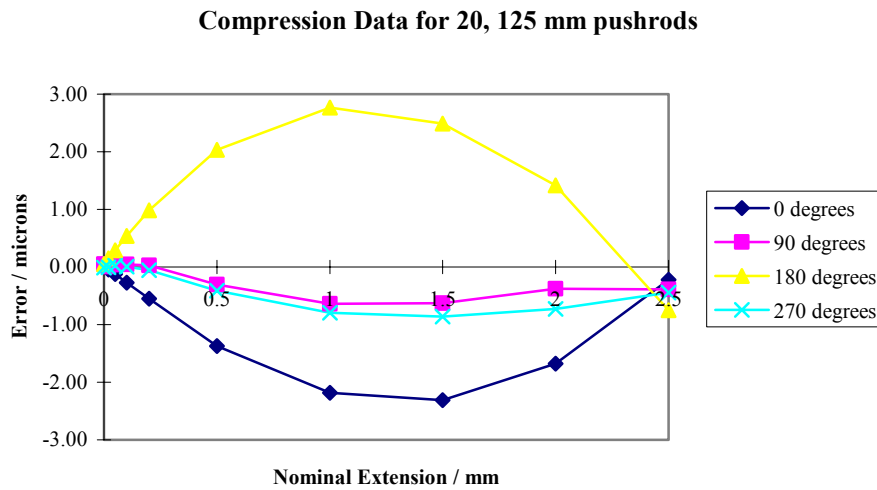


Figure 10 : Compression data for 20 mm and 125 mm push rods

Finally, measurements were made using a 12 mm and 125 mm push rod combination. This arrangement approaches the ideal 10:1 length ratio.

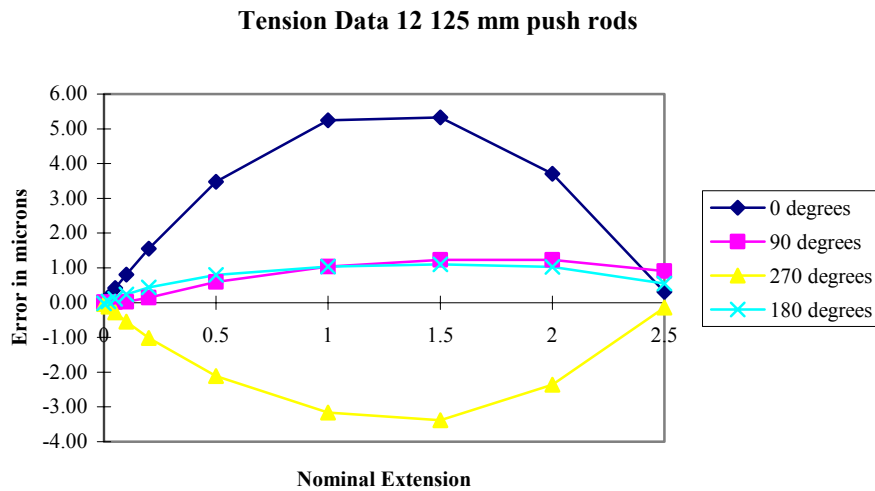


Figure 11 : Tension data for 12 mm and 125 mm push rods

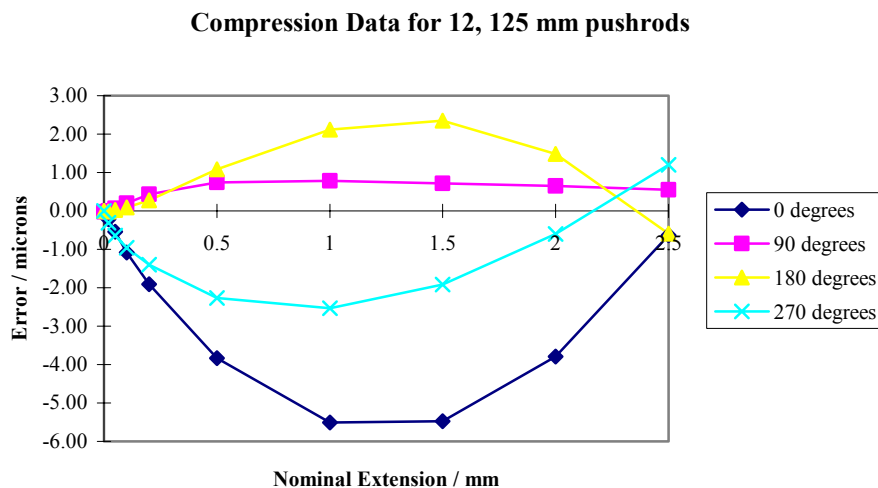


Figure 12 : Compression data for 12 mm and 125 mm push rods

6.2.3 Conclusions

These graphs show little change in curve profile with change in pushrod length. The smallest short push rod produced the greatest range of linearisation. The geometry of the ECR meant that it was not possible to make measurements with even shorter push rods.

As the length of the short push rod decreases, so the non-symmetry in the calibration curves increases which would be expected if the non-symmetry is due to misalignment between the indent in the top of the lever arm and the eccentric.

The actual lengths of the push rods is not critical in producing an ECR with a linear characteristic. It is more important to align the components and ensure that there is sufficient adjustment.

6.3 Upper test bar holder travel and test bar alignment

The upper test bar holder is supported by four strip hinges. As it is moved up and down by the small push rod, the holder is held in a vertical position by the strip hinges. This keeps the test bars parallel although the holder will follow an arc. The effect of this is minimised if the strip hinges are horizontal at the mid travel of the micrometer. For an ECR with a 2.5 mm travel, the maximum horizontal displacement is 5.2 μm . This is quite small compared to how well the test bars can usually be aligned. The horizontal movement would not be detected by the laser since the path length in a cube corner is always the same and the light would still be entering the detector with the wavefront unperturbed.

The usual method of alignment is to insert a single close fitting steel rod into both test bar holders simultaneously. This rod needs to be straight and relatively hard (NPL use silver steel rods). The rod is secured in the bottom holder and the 8 screws securing the strip hinges to the upper test bar holder and frame are released. The upper test bar holder is then secured on the rod and the strip hinge screws retightened.

The alignment of the test bar holders is measured at NPL as part of the calibration process. Two close fitting silver steel rods are secured in the test bar holders. A dial gauge is mounted in a purpose made mount that fits on the lower rod. The dial gauge probe contacts the upper rod. The dial gauge holder is rotated round the lower rod and the changes in dial gauge reading observed. If the rods are misaligned by more than 0.12 mm the test bar holders are realigned as described above.

The effect that the misalignment will have on a calibration of an extensometer will depend on the design, set up, and gauge length of the extensometer

6.4 Temperature

6.4.1 Introduction to the effects of temperature

Temperature can have a significant effect on the performance of an ECR. The magnification (and to some extent the linearity) of the ECR will alter with temperature. More importantly, individual runs will be affected by changes in temperature during the run. The main difficulty in measuring these effects is the effect that temperature will have on the laser calibration equipment. Although the laser automatically compensates for changes in refractive index of the air, the optics are sensitive to air draughts and even the presence of the operator.

The ECRs are made from a combination of steel and aluminium. Most of the moving parts are made from steel because it is hard wearing. The side panels and sometimes the base of the ECRs are made from aluminium because it is lighter than steel (even so a portable ECR will weigh about 20 kg). Aluminium has the disadvantage that it has a thermal expansion coefficient that is about twice that of steel but it reaches thermal equilibrium quickly having a lower thermal mass and superior thermal conductivity. Some ECRs have insulation on the side panels to reduce the effect of draughts and the presence of the operator.

6.4.2 The effect of ambient temperature on the ECR calibration

At NPL, ECRs are always calibrated at temperatures between 18.0 °C and 22.0 °C. In an industrial environment, ECRs are often used at temperatures outside this range. A series of

measurements were made to determine how sensitive the ECR's calibration was to temperature.

An ECR was placed on a table in a sheltered area of a loading bay. By using heaters or opening the doors of the loading bay, it was possible to carry out simplified calibrations at different temperatures. The results showed that a temperature change of approximately 7 °C only increased the extension by about 0.1 μm . An exact figure could not be found because the changes are approaching the uncertainties of measurement. Because the environment was not as stable as that achieved in the calibration laboratory, the measurements were prone to drift.

6.4.3 The effect of temperature on a fixed extension

During the above experiment, the ECR reading was zeroed before each series of extensions were applied. Once an extension had been applied, the ECR is prone to drift as it changes temperature. This indicates that they are more sensitive to temperature changes during a measurement, than to their absolute temperature.

To measure the apparent thermal expansion of an ECR, one was placed in an environmental chamber with the calibration laser and optics. A series of measurements were made at different temperatures as shown in Table 1 below.

Table 1 : The effect of temperature on a fixed extension

Time	Temp °C	Temp Difference °C	Laser Reading μm	Reading Change μm	Expansion Coefficient $\mu\text{m}/^\circ\text{C}$
15:45	30.0	0.0	-0.10	0.00	
16:25	25.0	-5.0	-13.90	-13.80	2.76
08:40	25.0	-5.0	-13.80	-13.80	2.76
10:15	30.0	0.0	0.00	0.00	
13:40	18.3	-11.7	-31.54	-30.99	2.65
15:00	22.0	-8.0	-22.48	-21.93	2.74
15:20	25.2	-4.8	-13.99	-13.44	2.80
15:44	27.3	-2.7	-7.93	-7.38	2.73
16:26	30.0	0.0	-0.55	0.00	
TOTAL		-37.2		-101.34	2.72

The above measurements show that the apparent thermal expansion coefficient is about 2.7 $\mu\text{m}/^\circ\text{C}$. During a calibration in the open (i.e. without thermal shielding) a change in zero reading over a 7 minute run is typically 0.15 μm which represents a temperature change of only 0.05 °C. Such a small change could be caused by the body heat of the operator.

A combination of operator experience and these experimental results has shown that the ECRs reach thermal equilibrium with their surroundings within thirty minutes, perhaps even as quickly as ten minutes.

6.4.4 The effect of temperature on the ECR and the laser system

Measurements were made to try and separate the effects of temperature on the ECR from the effects on the laser system. Two sets of optics comprising an interferometer block and a retro-reflector were set up in the environmental chamber. One set was mounted on an ECR in the

normal way. The second, control optics, were mounted on a steel block and the retro-reflector was separated from the interferometer block by gauge blocks. Both sets of optics were mounted at the same height and had the same separation. Two identical laser systems were set up outside the environmental chamber and were aligned with the optical systems.

The lasers were given an hour to warm up and the alignment re-checked. The laser beams were then covered at source and the environmental chamber closed. The environmental chamber was switched on and set to a temperature of 28°C. The temperature of the ECR was measured using a thermocouple.

After 45 minutes the environmental chamber was switched off, the laser beams uncovered and the laser displays reset. As the ECR and optical systems cooled down, the temperature and laser readings were recorded. The results are shown in the graph below.

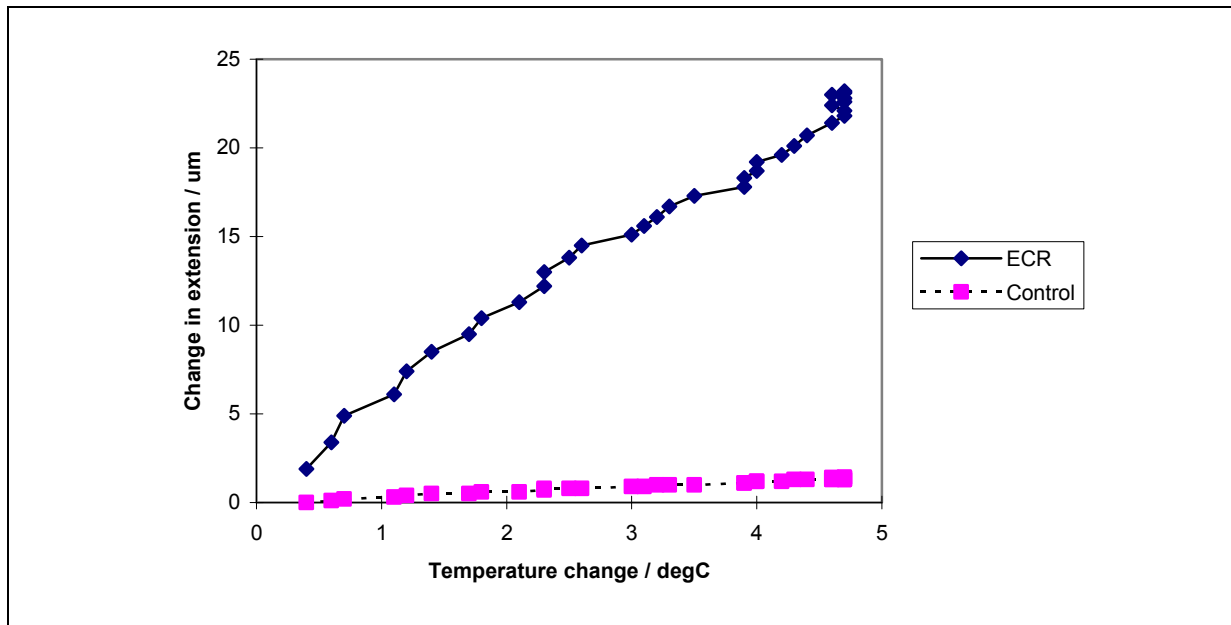


Figure 13 : Graph of temperature v deflection of AQD ECR and control

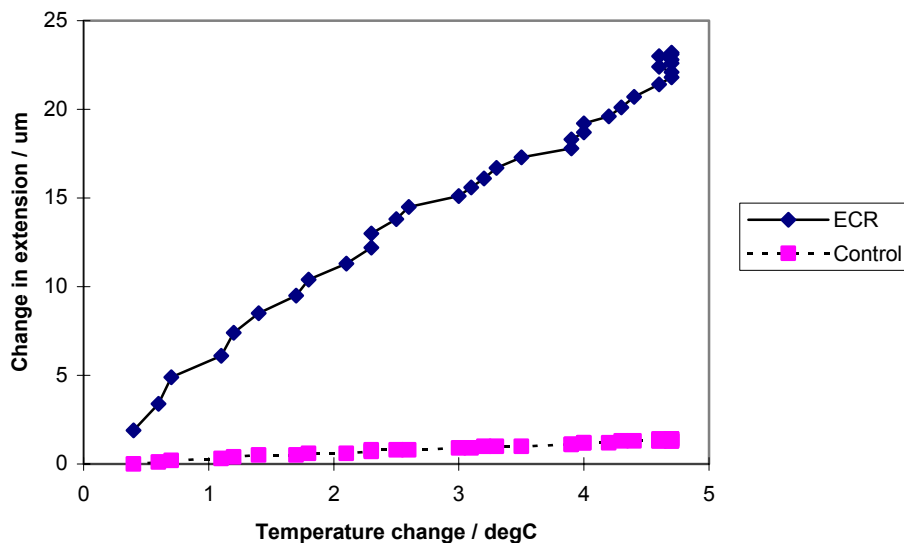


Figure 13 shows that the control optics were far less sensitive to temperature change than the system mounted on the ECR. The thermal expansion of the gauge blocks separating the optics in the control system only accounts for 60% of the observed deflection ($0.54\text{ }\mu\text{m}$ of the $0.9\text{ }\mu\text{m}$). After removing the expansion of the gauge blocks, the deflection of the control is $0.36\text{ }\mu\text{m}$ compared to $12.3\text{ }\mu\text{m}$ for the ECR.

These measurements have shown that the thermal expansion of the optics is only about 3% of that of the ECR. Interestingly, these measurements give a thermal expansion coefficient of $4.8\text{ }\mu\text{m}/^{\circ}\text{C}$ which differs from the value of $2.7\text{ }\mu\text{m}/^{\circ}\text{C}$ measured above. This may be the result of having used different test bars or a different rig and shows how the measurements made in this report are only a guide and cannot be applied to all AQD designed ECRs.

6.4.5 The effect of air movements around the ECR

When the calibration system has been set up on an ECR, the laser reading can be seen to drift. Usually, the measured length increases with time and it was suspected that this was due to body heat from the operator. Measurements were made to try and reproduce this effect using a table lamp as a localised heat source but the results were inconclusive.

To see if the drift was due to thermal effects on the ECR and not the optics, the laser system was set up on an ECR in an air-conditioned laboratory. A computer was used to make measurements of drift without the operator being near the ECR. The drift was very clear, particularly overnight when the air conditioning control is not as tight. In an effort to isolate the effect of the optics from the ECR, the retro-reflector was removed from the upper test bar and mounted directly on top of the interferometer block. This did not greatly affect the measured drift, clearly showing that it was the optics that were affected by some variation in the local conditions.

The drift without the thermal cover is shown below.

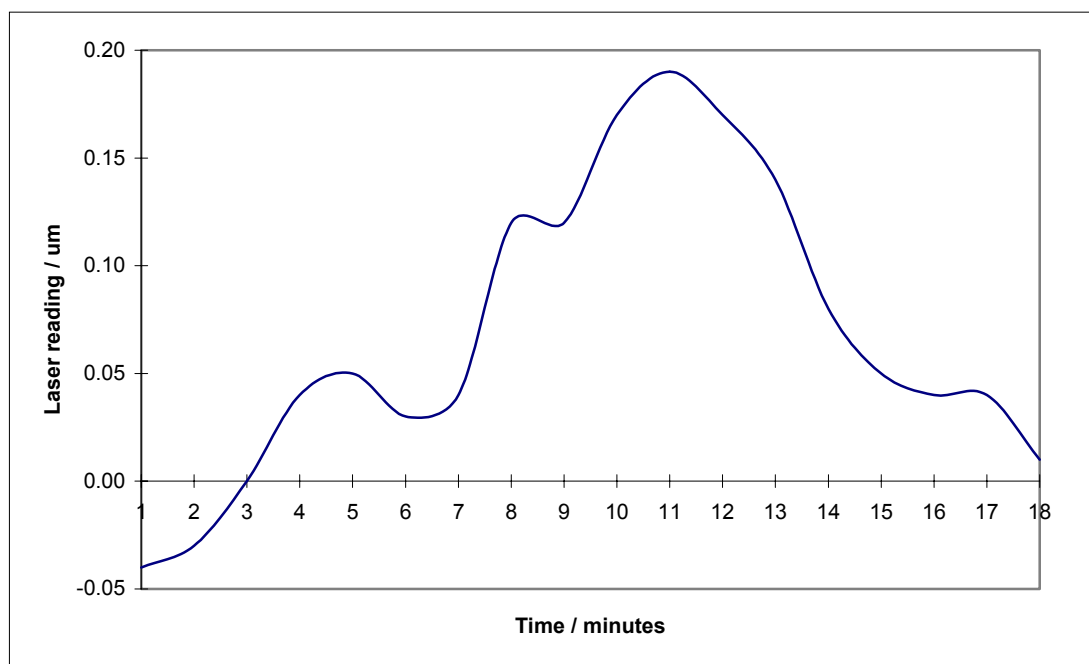


Figure 14 : Graph of laser reading drift without a cover

The laser reading will be sensitive to the thermal expansion of the interferometer block and retro-reflector, and the change in refractive index of the glass.

As the drift had a fairly short period, the air conditioning was suspected. A thermal cover was made that fitted over the ECR. A hole was cut through which the micrometer drum protruded. A smaller hole was cut through which the laser beam could pass. After leaving the ECR for an hour to thermally equilibrate, the drift was re-measured and was undetectable. This result was exceptional and some slow drift is usually seen with ECRs, even with the thermal barrier in place.

6.5 Friction

The lever arm pivot is a horizontal steel rod that sits in two brass V blocks. To prevent the lever arm becoming detached when the ECR is in transit, a mechanism is used to retain it. This is usually in the form of two brass plates, secured to the V blocks with one screw each. These plates press down lightly on the top of the pivot rod. If they press down too hard, excessive friction will be introduced and the ECR will exhibit a poor zero return.

To prevent the sideways movement of the pivot rod, two screws (sometimes with ball bearings on the end), make contact with the ends. These screws must be tight enough to prevent movement (introducing non-repeatability) but not tight enough to introduce significant friction. The screws are mounted in threaded holes in the side walls of the ECR. The best design of screw is a grubscrew secured with a locking nut. Conventional screws without a locking nut are unreliable and NPL always replaces them.

7. Other calibration uncertainties

There are other uncertainties in the calibration of ECRs that are associated with the calibration system and not the design of ECR. These are summarised below.

7.1 The resolution of the laser

The resolution of the laser is the last digit of the laser display. This is 0.01 μm .

7.2 The uncertainty of the laser measurements

The laser, display and sensors are all calibrated traceable to National Standards at the NPL. The certificate 08A011/9404 gave a total systematic error of $+5.4 \pm 3.9 \times 10^{-7}$ as a relative length uncertainty with a coverage factor (k) of 3. Allowing for its use in non-ideal conditions and the possible drift with time, the uncertainty is estimated to be ± 1 nm per millimetre with $k = 2$.

7.3 The squareness of the optics

This is discussed in the manufacturer's literature (Hewlett Packard Laser Measurement System Application Note 156-1). They estimate it to be less than ± 0.01 mm per metre. If we assume that this is only for $k = 1$, then the uncertainty is ± 0.02 μm per millimetre at $k = 2$.

7.4 The alignment of the interferometer block with the laser

This is achieved by wringing a gauge block onto the metal face of the interferometer block and ensuring that the laser beam goes back in the same direction. This is adjusted to better than 1 mm, which, with the laser head positioned at least 600 mm from the interferometer block, corresponds to 0.1 degrees.

A 0.1 degree misalignment gives a laser measurement of $1 / \cos (0.1)$ giving an error of 1.5 nm per millimetre.

7.5 The alignment of the spindles with the direction of travel

The lower spindle mounting is fixed and is taken as the reference direction in which the moving block must travel. The following conditions must also apply.

- The lower spindle must be straight. NPL has no control over this. NPL's spindles are made from silver steel, are straight to within 0.004 mm, and are of the same diameter.
- The upper spindle must be straight and the mounting hole in the moving block must be parallel to the block. Misalignments could be caused by poor manufacture but are more likely to arise from damage to or dirt in the hole.
- The moving block must be parallel to the fixed block. The parallelism of the block fore and aft can be checked with a spirit level placed on the front. The side to side parallelism can be checked by placing a spirit level across the top.

7.6 The alignment of the interferometer block with the direction of travel

A cube corner returns a laser beam parallel to the incoming beam but with an offset. With the interferometer block square to the laser source, movement of the laser up and down and side to side with the beam kept parallel, allows the return beam to be aligned with the centre of the detector on the laser head. A good alignment does not mean that the interferometer block is square to the upper spindle.

Two methods of alignment are described below.

- Ensure that the interferometer block is square to the upper spindle using a spirit level. Setting the interferometer block to within 5 arc minutes in both axes orthogonal to the incoming laser beam gives a total angular error of 7 arc minutes and an uncertainty of + 2 nm/mm.
- Align the spindles and then ensure that the interferometer block is perpendicular to the lower spindle by having an accurately made mounting.

7.7 Mains voltage

The laser system was shown to be insensitive to variations in mains voltage of $\pm 10\%$ from the nominal 240 V.

8. Summary of conclusions about AQD ECRs

The main conclusions from the above sections are summarised below.

- The micrometer drum spindle must have the correct tightness. Although this is difficult to describe, any experienced operator will know if it is satisfactory. If the tightness is incorrect, the ECR will exhibit non-repeatability.
- If cementing ball bearings into the ends of push rods, it is important to use only a thin layer of hard-setting cement or there will be some elasticity.
- The ends of the push rods should ideally be hemispherical but experience has shown that some of the ECRs with the best performance have push rods with very poorly turned ends. This indicates that it is more important that the push rods are rigid and hard enough to ensure that they do not wear.
- The push rods should be of such a length that the neutral position is achieved at the mid point of the micrometer's travel.
- The height of the eccentric must be set so that at mid-travel of the micrometer, the strip hinges constraining the upper test bar holder are perpendicular to its direction of travel
- The actual lengths of the push rods are not critical in producing an ECR with a linear characteristic. It is more important to align the components and ensure that there is sufficient adjustment.
- The two test bar holders must be on the same axis. The effect of any misalignment on the calibration of an extensometer will depend on the design, set up, and gauge length of the extensometer.
- AQD ECRs are not particularly sensitive to the absolute temperature in which they are used. They are much more sensitive to changes of temperature during calibrations.
- ECRs appear to reach thermal equilibrium with their surroundings within thirty minutes, perhaps even as quickly as ten minutes.

- The thermal expansion coefficient of ECRS is several micrometres per kelvin.
- The lever arm pivot rod must be constrained sufficiently to prevent it sliding from side to side but without undue friction. Excessive friction will produce a poor zero return.
- The measurements made in this report are only a guide and the figures cannot be applied to all AQD designed ECRs.

9. Guide to the transportation of AQD ECRs

AQD designed ECRs are precision instruments and need to be treated with due care. They contain a number of heavy moving parts which are not very securely constrained and are liable to come loose or cause damage if the ECR is mishandled. Many of the ECRs that NPL receives for calibration require adjustment. The most common problem is that the upper test bar holder has become out of line with the lower one. ECRs that are transported by carrier are usually inadequately looked after; not only do they require setting-up on arrival, but their calibration is probably lost once it is returned to the customer. NPL has received a few ECRs that have just been packed in a box with bubble wrap and given to a carrier. These usually require the replacement of broken parts and a complete realignment.

AQD ECRs are intended to be portable and many UK companies take them on the road for a year and they do not require adjustment when they come for re-calibration. These rigs are well packed and carefully transported.

The following measures should ensure that ECRs are not damaged by transportation.

- The ECR should be packed in a tight fitting, internally padded, hard case.
- The counterweight should be removed from the upper test bar holder.
- A transit rod should be secured between the two test bar holders.
- Rigid foam packing should be placed between the bottom of the lever arm and the lower test bar support bracket. The micrometer drum should then be gently wound in until the lever arm is held against the foam packing.
- ECRs should be transported in an upright position.

Almost any adjustment or change to an ECR will alter its characteristics. Any of the following adjustments will invalidate the calibration.

- Realignment of the upper test bar holder
- Repositioning the micrometer
- Adjusting the eccentric
- Altering the lever length
- Altering the end float of the lever pivot

10. Possible alternative designs for portable ECRs

The AQD designed ECR has proved its worth over the years. Its limitations are that it is delicate, heavy, a little difficult to use, has a limited travel, and cannot easily be interfaced to a

computer. An alternative design of rig would need to overcome at least some of these problems and yet still be competitive.

In principle, what is needed is a moving test bar mounted in a linear slideway. On the upper end of the test bar holder is a displacement transducer with a digital display and computer interface. A mechanism needs to be provided to precisely position the test bar. The travel of this design can be longer than the 2.5 mm of an AQD ECR. In addition, because there is only one moving part it is easy to secure for transportation. All of these criteria can be met but it is difficult to achieve the required uncertainty at an acceptable price.

NPL have received several designs for calibration but so far none of them have achieved the same performance as an ECR of AQD design.

11. Acknowledgements

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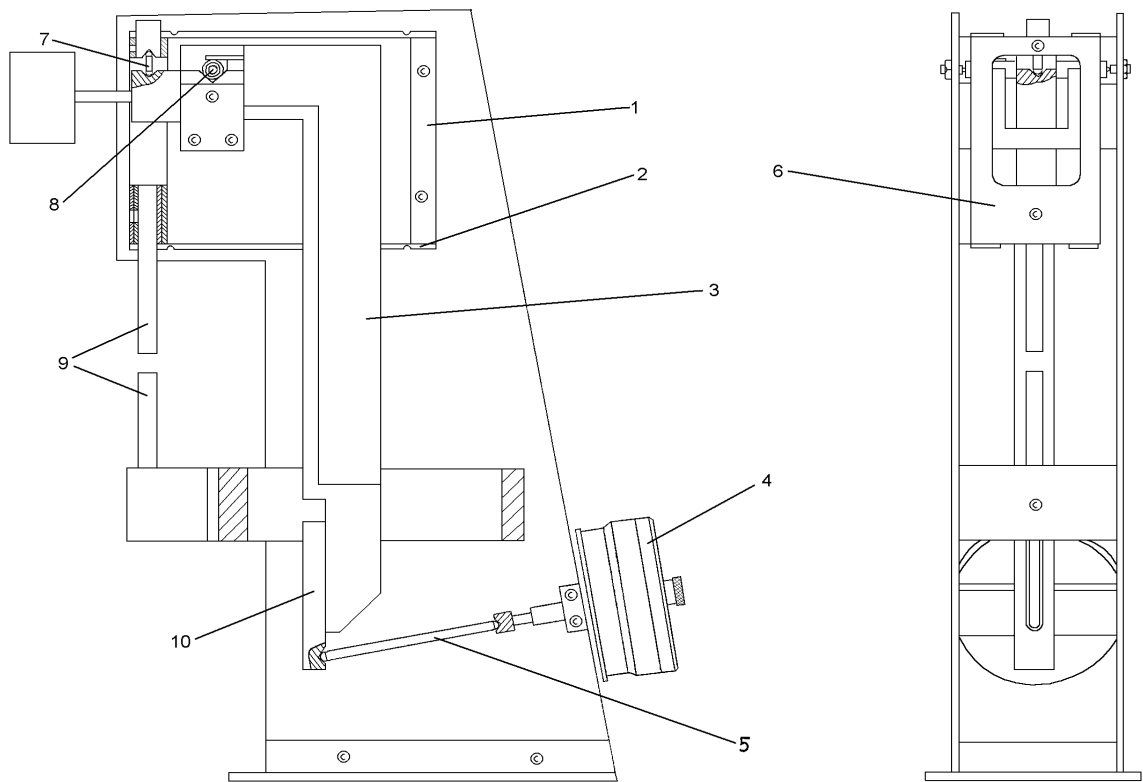
12. References

¹ASTM E83-98^e, Standard practice for Validation and classification of extensometers

²BS EN 10002-4 : 1995, Tensile testing of materials - Part 4. Verification of extensometers used in uniaxial testing.

³ISO 9513:1999(E), Metallic materials - Calibration of extensometers used in uniaxial testing

13. Appendix 1 - Drawing of the AQD designed ECR



1. Ligament system back bracket
2. Ligament strip
3. Lever arm
4. Micrometer drum
5. Long push rod
6. Ligament system front bracket
7. Short push rod
8. Lever pivot
9. Test bars
10. Lever adjusting bracket