METROLOGY SYSTEMS WALES

Roll Measurement and Inspection Systems

CADNO 2000

Technical Note 9801

ROLL MEASUREMENT AND INSPECTION SYSTEMS

Calibration of CADNO Calliper

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Introduction

This technical note describes the calibration procedure for the Cadno roll measurement calliper.

It also includes an analysis of the potential sources of error in measuring roll profiles, quantifying the errors from the various sources and evaluating their significance in the context of roll profile measurement.

The tracability of the measurements made by the calibrating instruments is demonstrated.

1. Background

The CADNO electronic roll measuring instrument is based on the long-standing traversing calliper principle. The variation in roll diameter is measured by an electronic distance measuring probe (a linear variable differential transformer, or LVDT) which generates an X-signal. A corresponding Y-signal is provided by a shaft encoder that generates 100 pulses per complete revolution. This is coupled to a precision urethane coated wheel with a circumference of 100 mm in contact with the roll surface. One pulse is therefore generated for each mm of linear travel across the barrel - the cumulative number of pulses comprising the Y-signal

(Although the instrument is capable, if used in conjunction with physical length standards, of giving the absolute diameter of a roll it is ideally suited to relative diameter measurement: e.g. if zeroed at one end of the roll barrel it will thereafter display the deviation from this zero datum.)

2. Calibration of the Instrument

The most comprehensive method of calibrating the instrument is to make use of a *standard roll* of known profile and to produce a trace of the variation in diameter along the barrel length of the roll using the instrument to be calibrated. Obviously, such a standard roll will need to be measured periodically by an independent means.

Clearly, wear in the centre bearing of the carriage or in the carriage wheels and bearings can affect the measurement. The effects of such wear are discussed below and are analysed in Appendix1.This shows that under the normal operating conditions in the average roll shop these effects have minimal impact on the measurement of difference in diameter. Under normal circumstances therefore, and provided care is taken in the pre-configuring operation, then one need only be concerned that the output from the instrument corresponds to the linear movement of the (LVDT) probe tip.

This being so, then one method of calibration is to place feeler gauges of known thickness between the probe tip and the roll when the instrument is in the initial calibration mode, and to compare the change in reading on the instrument display with the known thickness of the feeler gauges. Care needs to be exercised to ensure that the feeler gauges are in contact with the roll surface at the point where the roll tip would make contact and substantially perpendicular to the line of action of the probe.

A special calibration rig is available which obviates the need for a roll during calibration and allows the calibration to be undertaken more conveniently and reliably. The rig uses a stub micrometer mounted in a machined housing that can be attached to the face of the precision measuring unit of the calliper. The face of the micrometer anvil constitutes a reference surface that can be presented to the probe tip to displace it very accurately by known distances.
The detailed procedure for calibrating the calliper using this rig is given below:

1. Release the locking knob on the precision measuring unit of the Cadno calliper and retract the probe using the knurled adjustment knob until the probe housing protrudes by about 5mm in front of the machined face of the unit.
2. Retract the stub micrometer within the calibration rig housing and attach the housing to the calliper precision measuring unit using the two captive screws provided.
3. Position the stub micrometer at a convenient setting, preferably in the middle of its range.
4. Use the knurled adjustment knob of the precision measuring unit to advance the measuring probe until it makes preliminary contact with the face of the micrometer anvil.
5. Switch on the Cadno microcomputer unit. The calibration mode of the unit is entered automatically and in this mode, adjust the position of the LVDT probe using the knurled adjustment knob until the display reads zero.
6. One complete revolution of the micrometer in either direction should produce a reading of plus or minus 0.500mm. This provides an immediate check on the accuracy of the instrument: the reading should be within 0.005mm (1%).
7. Normal calibration involves taking readings at 0.050mm increments over the range +0.300mm to –0.300mm.

The microcomputer unit contains a scaling factor to convert the voltage reading into actual displacement. This factor takes account of the small differences between individual probes and once set should not normally require changing. If, in exceptional circumstances, the factor should require changing, the complete calliper or at least the precision measuring unit together with the microcomputer unit must be returned to MSW. This also applies if the LVDT probe has been changed.
(The exact procedure undertaken by MSW is detailed in Appendix 2)

3. Sources of Error in Reading the Variation in Diameter

Errors are considered in some detail in Appendix1, but the specific sources of error relevant to the measurement of the variation in roll diameter are as follows:

1. The microcomputer unit contains a scaling factor to convert the voltage output of the LVDT to displacement units. If this factor is incorrect the change in the output of the instrument will not correlate with the physical distance moved by the plunger of the LVDT probe. Details of calculating and setting this scaling factor are given in Appendix2.
2. Non-linearity of the instrument reading over the measurement range of the probe. The linearity is checked when the instrument is calibrated as described above. However, the probe used is guaranteed to be linear to 0.3% of the full stroke of the probe (2mm).
3. The instrument being incorrectly set up so that it does not calliper a true diameter.
4. The plane of the calliper not remaining perpendicular to the roll axis during a traverse of the roll.

These potential sources of error are also dealt with in Appendix1.

4. Tracability of the Instruments used for Calibration

The stub micrometers used in the calibration rigs are themselves periodically calibrated against a range of slip gauges of known thickness. These, in turn, are measured using a CADAR electronic micrometer. This micrometer incorporates two optical gratings ruled on a machine calibrated to national sub-standards. The number of moiré fringes produced as the two gratings move with respect to each other is directly proportional to the relative movement of the two gratings. The advantage of this approach is that the accuracy depends on the *average* distance apart of the ruled lines in the gratings and not on the positional accuracy of the individual ruled lines.

Thus the devices used to make measurements during calibration are traceable to recognised national standards and to the units of measurement realised at the National Physical Laboratory or to other recognised national standards laboratories.

Appendix 1

Error Analysis

Errors in measurements can be categorised in two ways:

a) Random errors.
b) Systematic errors.

A1.1 Random Errors

Errors in this category are those that cannot be predicted and therefore cannot be entirely eliminated. In the context of roll profile measurement, they may be due to human error or to environmental factors.

Human errors can include inaccurate reading of the scales on the calliper arms or mistakes in the pre-configuring of the calliper prior to measurement. The nominal diameter of the roll is required in pre-configuring the calliper, so errors made in measuring this diameter by other means can ultimately affect the measurement of camber made by the calliper. These errors are considered below and in sections A1.3 and A1.4.

Environmental factors can include gradual wear in the centre bearing of the calliper or in the wheels and bearings of the carriage. The effect of this on measurements is discussed below and analysed in sections A1.3 and A1.4 of Appendix 1. Environmental factors can also include sustained vibration from localised machinery. In the metal rolling industries, roll grinding shops are often situated adjacent to the rolling mills, where large machinery might present a source of vibration. However, roll mounted measurement instruments tend not to be unduly affected by this, due to the large mass of the roll serving to minimise the amplitude of the vibration. Also, most roll measurement is performed whilst the roll is still in the grinding machines, and these have machine beds designed to minimize vibration during their operation. The design of these beds serves to isolate the roll from any external sources of vibration.

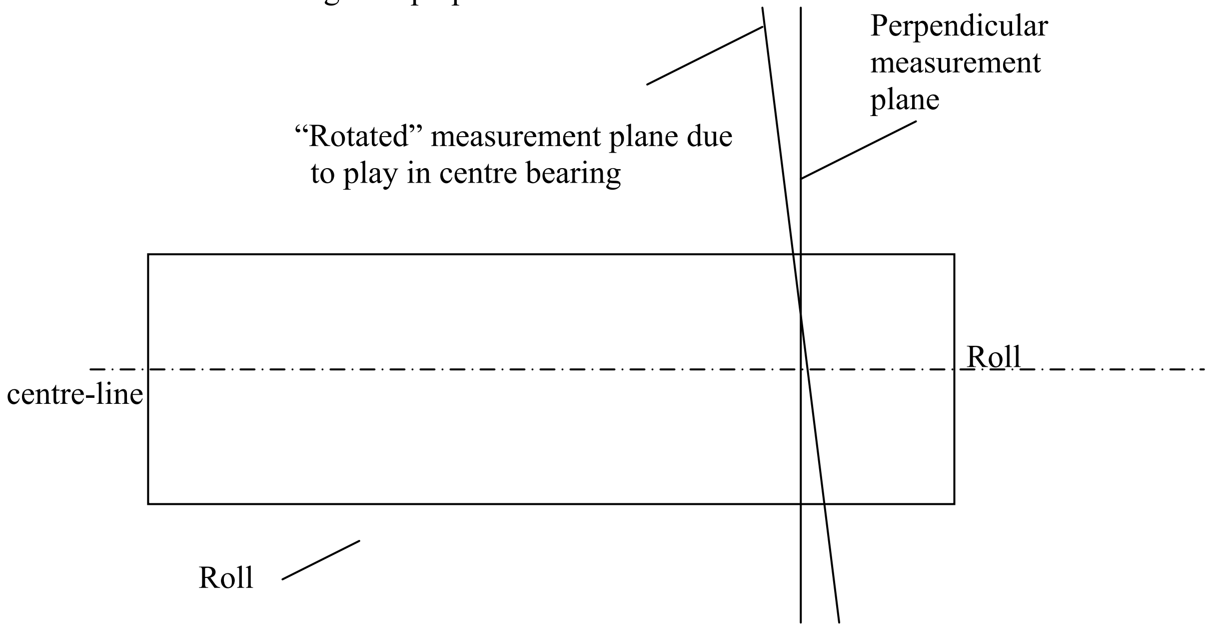
A1.2. Systematic Errors.

Systematic errors are those which are controllable or measurable, and are associated with the capability of the instrument and with the environment. An example of an environmental systematic error is that due to thermal expansion. This causes an error that can be considered negligible when considering roll profile measurement. The reason for this is that the instrument is used only as a comparator between the diameter at the end of a roll and at other positions along the roll. Therefore, as the instrument is able to traverse a roll in a few seconds, there is insufficient time for any significant thermal expansion to occur.

Another possible source of error is that due to elastic distortion in the calliper. However, this too is negligible because the instrument is being used as a comparator rather than being used to make an absolute measurement. Once the calliper has been pre-configured, then only *changes* in the loading of the calliper frame will produce an error. Such changes in loading as the calliper traverses the roll are negligible. Scaling errors in the calibration of the probe can occur but these are minimised by the careful application of the calibration procedure described in section2, above.

Screw threads are employed for linear adjustment of the precision measuring unit and the counterweight follower unit. Obviously, backlash, wear, and settling in these threads can introduce errors in the measurement. To eliminate these, locking nuts are provided and *it is essential that these are locked firmly into position once the calliper has been configured.*

A potential source of error is the central bearing that supports the calliper within the carriage. Any slack in this bearing will result in the calliper being able to rotate slightly about a vertical axis through the roll centre line so that the plane of measurement will no longer be perpendicular to the roll axis. This is shown below:



This will cause a slight depression of the LVDT probe tip, and so introduce an error to the measurement. For this reason, the centre bearing is adjustable and it *is essential that this is checked and adjusted at quarterly intervals when the calibration takes place*.

Obviously, when measuring to an accuracy of a few micron, it is not possible to eliminate this totally. The effect of any small remaining error is compensated for by a sophisticated algorithm in the microcomputer unit. The calliper is configured to the roll diameter, initialised at one end of the roll, and the measurement process begins as the calliper is traversed along the roll. The microcomputer unit monitors the sensors continuously and during the first few millimetres of movement it senses any “jump” in reading caused by the take up of play in the centre bearing. It then re-adjusts the zero reading of the instrument and takes all subsequent readings with reference to this new zero value.

Clearly, it is possible for manufacturing errors to occur, such as the calliper arms being fixed at an incorrect angle, or the erroneous spacing of graduations on the scaled arms. Whilst these possible errors would be detected by inspection during manufacture, it is important to quantify their potential effect on measurement should they go undetected. The net effect of each of these errors is to **offset** the horizontal measurement plane from the horizontal plane through the roll centre-line (as shown in figure A1.3, below). In other words, the calliper is not measuring across a true diameter. The errors introduced into the measurement of roll camber as a result of such offsets is quantified in Section A1.4.

Errors due to an incorrect nominal roll diameter, or to incorrect pre-setting of the roll diameter on the calliper graduated arms will also produce such offsets. Gradual wear in the carriage wheels and bearings gives rise to the same kind of offset. The analysis given in Section A1.4 can be used to quantify the resulting errors in profile.

The following sections provide an analysis of the effects of incorrect measurement of roll diameter and of the offsets described above.

A1.3. Error in the measured diameter of a roll due to the misalignment of the micrometer (used to measure absolute diameter).

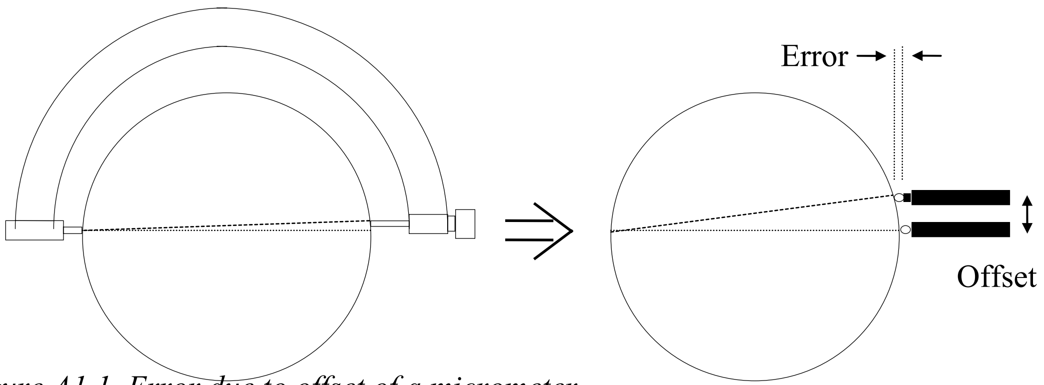
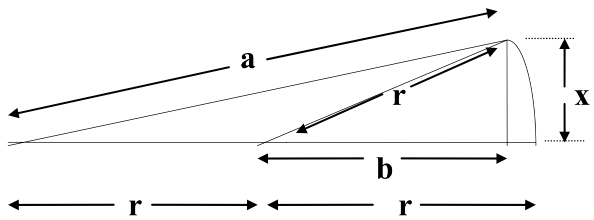


Figure A1.1. Error due to offset of a micrometer.

The error due to an offset from the true diameter increases with an increase in that offset. However as the diameter of the roll increases, the error for a given offset is reduced.
The following serves to show how the error is calculated:



Where **r** = radius, **x** = offset and error = **2r** - **a**. For example,for a roll of diameter 450mm and offset 5mm, the error is calculated as;
$\mathbf{b}^2 = \mathbf{r}^2 - \mathbf{x}^2 = 225^2 - 5^2 = 50600 \quad \therefore \mathbf{b} = 224.944$
$\mathbf{a}^2 = (\mathbf{r} + \mathbf{b})^2 + \mathbf{x}^2 = (225 + 224.94)^2 + 5^2 = 202474.997 \quad \therefore \mathbf{a} = 449.972$

Error = 2**r** - **a** = 450 - 449.972 = 0.028 mm**.**

Figure A1.2 shows the error between the true diameter and the diameter measured, for rolls of different diameters.

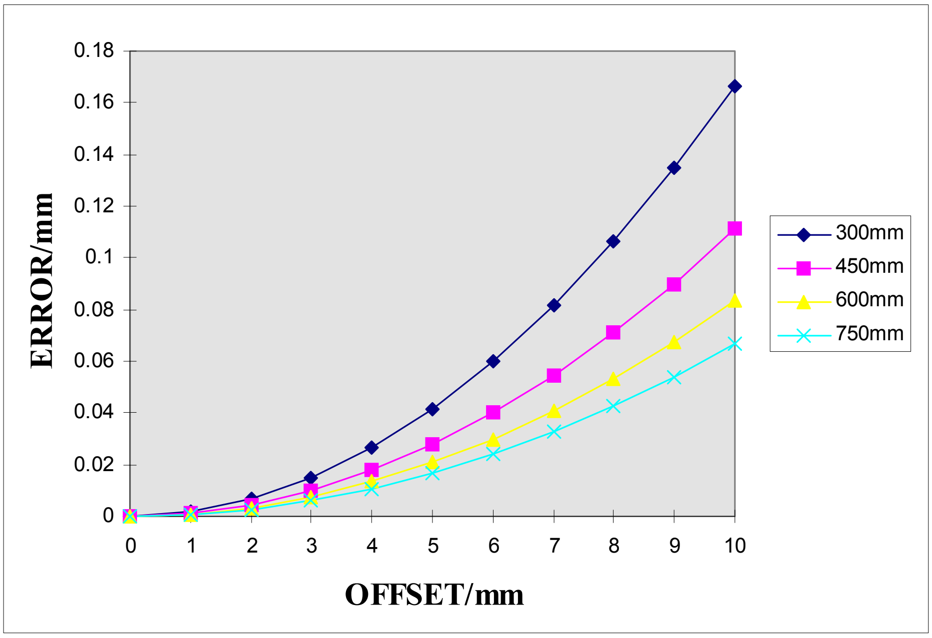


Figure A1.2. Error due to offset for various diameter rolls.

The error in the measurement of roll diameter results in a scanning micrometer calliper being incorrectly configured. This leads to the offset described below and therefore to an error between the actual camber and the measured camber of a roll.

A1.4. Error Due To an Offset from the True Diameter of a Roll.

If the LVDT sensor probe and the counter weighted follower are not configured to the true diameter (Figure. A1.3), the error produced is a function of the amount of offset, the true camber, and the diameter of the roll.

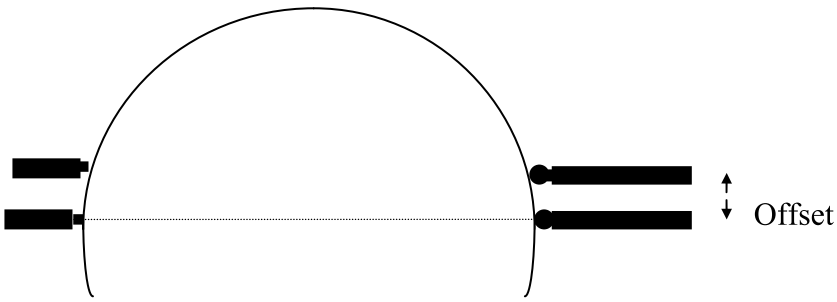


Figure A1.3. Error due to offset of LVDT and follower.

Figure A1.4 shows how the magnitude of this error varies with the offset position for a roll with a camber of 150micron. It is apparent that an offset of as much as 20 mm results in an error of only 1.35micron on a roll of 300mm diameter, and less for larger diameter roll. If a roll has a smaller camber, the magnitude of the error is reduced.

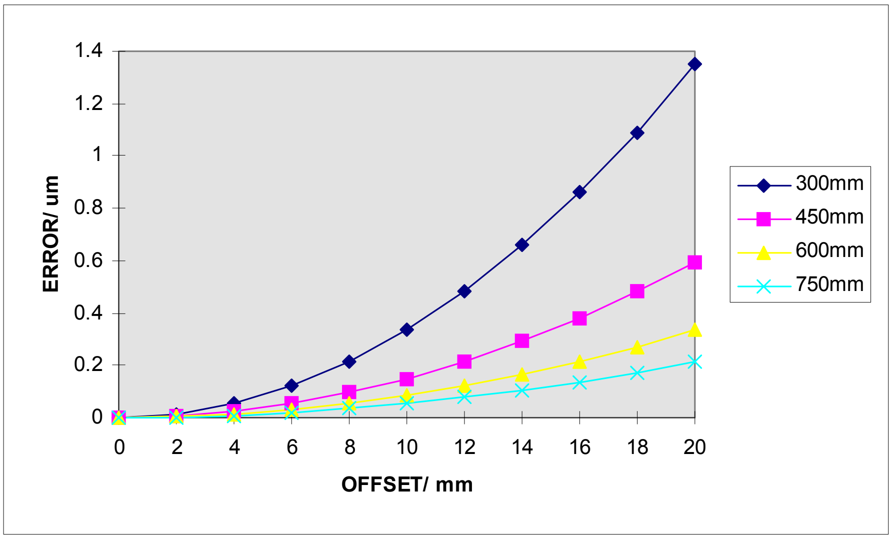


Figure A1.4. Error between measured and true camber of 150 micron, due to offset from true diameter.

Conclusions

Roll diameter measurement
Figure A1.2 shows that even for comparatively large misalignments of a micrometer during the measurement of a roll, the resulting error in absolute diameter is a small fraction of a millimetre. When this is translated onto the scale setting of the Cadno graduated arms the resulting offset (in terms of Section A1.4) will be very small indeed (a few millimetres at most). Figure A1.4 illustrates that the resulting error in the measurement of camber will usually be less than a micron.

Setting of Roll Diameter on Graduated Arms
Figure A1.4 shows that on a 450mm diameter roll, the error in measured camber resulting from a 20mm offset is approximately 0.6 micron. Based on the included angle between the graduated arms, the error in setting of diameter would be approximately 28mm. Obviously it is possible for an operator to make this kind of mistake in setting up the diameter. However, even if the offset is substantially more than this, the error is still small – approximately 1.3 micron for a 40mm offset.

Manufacturing Errors and Errors Due to Wear in Wheels and Bearings
As discussed earlier, errors in this category give rise to the kind of offsets considered in Section A1.4. Wear in the centre bearing will be checked and compensated for at regular intervals as stated above. Experience has shown that wear in the wheels and bearings is minimal but even in the worst cases it is likely to produce offsets of the order of fractions of a millimetre. Figure A1.4 confirms that the resulting error in the measurement of roll camber will be negligible (of the order of 1/100 of a micron). Cadno callipers are produced in small batches for a specialised market and are therefore subjected to rigorous inspection during manufacture. As a result, the likelihood of a calliper being produced with gross errors such as incorrect arm angles or incorrect scaling of the graduated arms is small. Furthermore, such errors would result in the offset considered in Section A1.4, where the analysis shows that even with substantial offsets the error in measured camber would be unlikely to exceed 1 to 1.5 micron.

<u>Appendix 2</u>

Updating the Constant in the Microcomputer Module

If an LVDT unit has been changed the multiplying constant in the microcomputer unit must be recalculated and changed to its new value in the EPROM in the Microcomputer unit.

The constant is held in memory locations in the EPROM with memory addresses 01B6 and 01B7 (hexadecimal). The constant is stored in reverse order, i.e. with the low byte of the constant in the first address (01B6).

The procedure for re-calibrating the constant is as follows:

1. Fit the new LVDT to the Cadno unit and attach the calibration rig as described in "*Calibration of Instrument*", above

2. With the microcomputer unit in the CALIBRATION mode, adjust the LVDT to give a reading of 0.000mm.

3. Rotate the barrel of the calibration micrometer one complete revolution in the *clockwise* direction. Ideally, the reading on the Cadno display should be 0.500mm.

   If this is the case, the multiplying constant will not require changing

   If this is not the case, note the Cadno reading and denote it as **X**mm

4. Remove the EPROM chip from the Cadno microcomputer unit. Note that, in order to do this, the upper analogue printed circuit board will need to be removed to gain access to the EPROM. Read the contents of the EPROM using an EPROM programmer and note the contents of addresses 01B6 and 01B7.

5. Convert the hexadecimal numbers at these addresses into a decimal number, remembering that the least significant byte is contained in the address 01B6. (As a guide, the typical contents of these addresses will be **83**(01B6) and **04**(01B7). This translates to a decimal number 1155. Denote this decimal value as **D**).

6. Calculate the new multiplying constant (**Y**) from:
   Y = 500*D/X

7. Convert Y into hexadecimal format and re-program the contents of addresses 01B6 and 01B7 (least significant byte first) into the EPROM programmer.

8. Burn a new 27C64 EPROM with the new program.

9. Reinsert the new EPROM into the Cadno microcomputer unit and check its calibration

10. If the error exceeds plus or minus 0.003 mm, repeat the procedure.