RICS Guidance Note

EDM Calibration

2nd edition

RICS

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Contents

RICS guidance notes

This is a guidance note. It provides advice to RICS members on aspects of their practice. Where procedures are recommended for specific professional tasks, these are intended to embody 'best practice', i.e. procedures which in the opinion of RICS meet a high standard of professional competence.

Members are not required to follow the advice and recommendations contained in the note. They should, however, note the following points.

When an allegation of professional negligence is made against a surveyor, the court is likely to take account of the contents of any relevant guidance notes published by RICS in deciding whether or not the surveyor had acted with reasonable competence.

In the opinion of RICS, a member conforming to the practices recommended in this note should have at least a partial defence to an allegation of negligence by virtue of having followed those practices. However, members have the responsibility of deciding when it is inappropriate to follow the guidance.

On the other hand, it does not follow that members will be adjudged negligent if they have not followed the practices recommended in this note. It is for each surveyor to decide on the appropriate procedure to follow in any professional task. However, where members depart from the practice recommended in this note, they should do so only for a good reason. In the event of litigation, the court may require them to explain why they decided not to adopt the recommended practice. Also, if you have not followed this guidance, and your actions are called into question in a RICS disciplinary case, you will be asked to justify the steps you did take and this may be taken into account.

In addition, guidance notes are relevant to professional competence in that each surveyor should be up-to-date and should have informed him- or herself of guidance notes within a reasonable time of their promulgation.

1 Introduction

This document has been prepared by the RICS with the aim of providing professional surveyors with background information and guidelines as to acceptable procedures for the calibration and testing of electromagnetic distance measurement (EDM) instruments. It has been written with due consideration of quality assurance requirements and of developments within both the International Federation of Surveyors (FIG) and the International Standards Organisation (ISO), and hence should be in accordance with their recommendations.

Inadequate calibration and verification of instruments introduces a significant risk, particularly to engineering and construction projects. These practical guidelines are intended to reduce and control these risks cost-effectively and promote higher standards throughout the surveying industry.

To achieve this, clients are advised to state, as part of contract documentation that involves surveying, that all EDM instruments shall be calibrated or verified according to these guidelines.

Definitions

Verification is the determination of whether or not an instrument conforms to a published (normally the manufacturer's) specification.

Adjustment is achieved by changing the settings on an instrument that has been checked in a laboratory so as to remove systematic biases.

Calibration is the determination of the systematic errors of an instrument such that either an adjustment can be made to improve the uncertainty or a correction formula or table produced.

Summary of best practice

Instruments that are to be used on work demanding a high accuracy should be calibrated on an international or national standard baseline to remove all systematic biases. Only these instruments and their ancillary equipment should be used on high accuracy work and must be regularly verified to show that they are reading within the tolerances required for the type of work. These instruments should be re-calibrated on an annual basis.

All other instruments should be regularly verified on a local baseline which has been measured with an EDM which has been calibrated on an international or national standard baseline. Local baselines should be re-observed annually using a calibrated EDM.

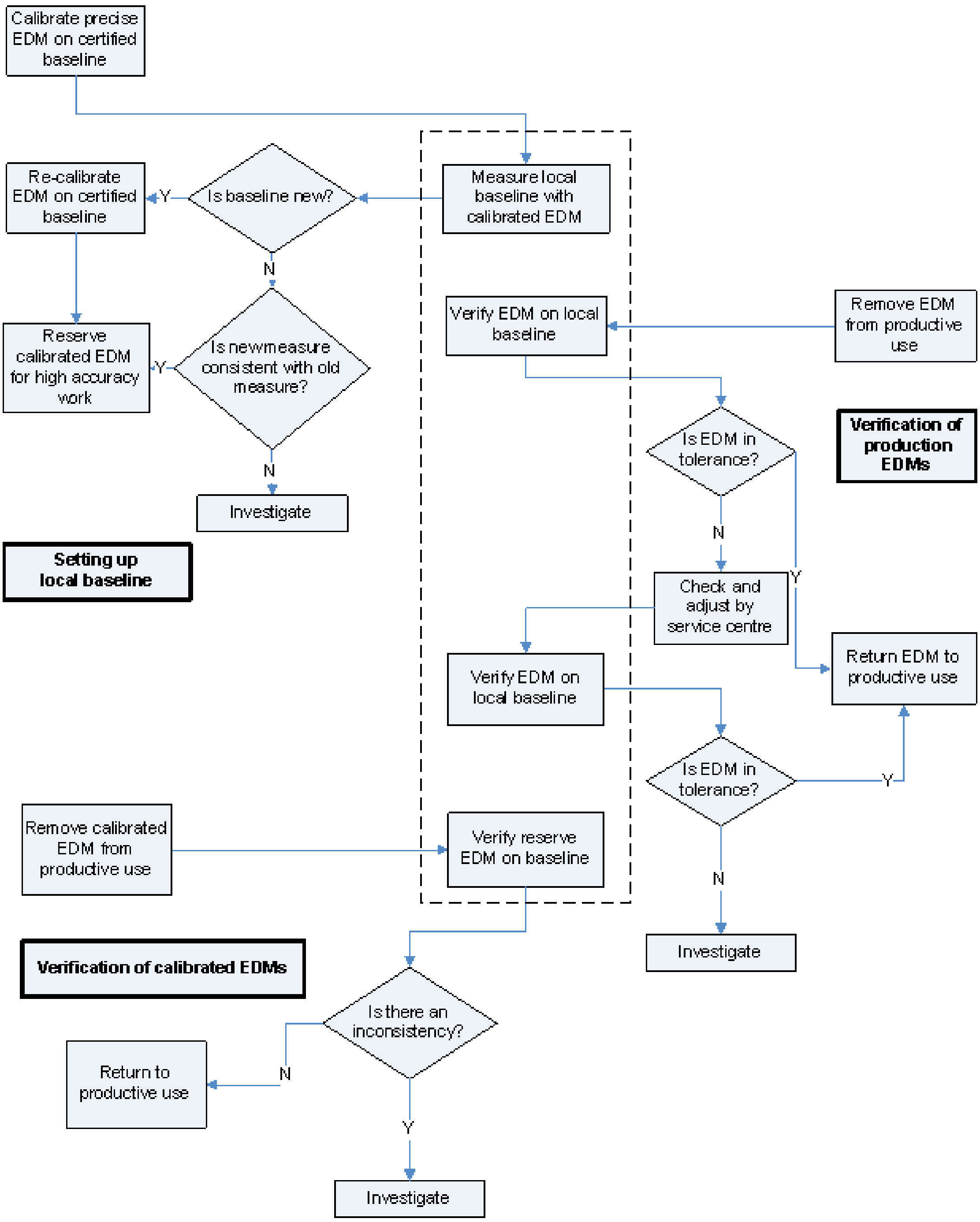
It is recommended that the maximum period between verifications should be one year although verification may be required more frequently depending upon instrument usage and accuracy requirements.

Where verification indicates that an instrument is performing outside its specification it should be sent to a reputable service centre for servicing, checking and adjustment.

Ancillary equipment, in particular barometers and thermometers, should be checked against calibrated standards at least as frequently as the EDM instrument is tested.

The results of calibration on a baseline, laboratory checking and adjustment and verification on a local baseline should all be recorded on certificates. These should show numerical results – not simply a statement of compliance (or similar). In the case of a baseline calibration or laboratory check and adjust procedure which involved changing the settings on the instrument, the values before and after adjustment should be shown. These records should be retained for the lifetime of the instrument (even when it is sold/purchased second-hand). These records should include details of any ancillary equipment used and details of traceability to standard.

Suggested procedure for setting up and use of local baseline



Principles of operation

Most EDM instruments operate on the principle of measuring the number of whole wavelengths of the generated signal, and any fractional part of the wavelength, in the distance between the instrument and the target. (It is thus implied that to obtain the measured distance the wavelength must be known). In electro-optical EDM the measurement is achieved by reflecting the signal back to the instrument where, in most cases, a phase difference measurement is carried out. In some instruments alternatives to phase measurement are employed; frequency variation or a variable path length to obtain a zero phase, or timed-pulse systems being used.

Sources of error

Instruments will have an inherent random error resulting from the basic measurement process, be it phase measurement (as in most instruments), frequency or time measurement. This error will usually determine the internal precision of the instrument.

Much more serious, however, are the sources of systematic error which may be present. These may be classified as scale (or proportional) error, index (or constant) error and cyclic error. These are described as follows:

(a) The scale error is usually due to a variation of the measuring frequency of the instrument from its standard value. This variation may be due to ageing or drift of the frequency oscillator used or to temperature effects on the oscillator.

The atmosphere through which an EDM observation is made produces two sources of systematic error in the measurement. The first is due to the bending of the measuring beam and produces a small, usually negligible effect. The second, and much more significant error source, is the variability of the refractive index (due to changes in temperature, pressure, humidity and gaseous composition). This effect, which is a scale (i.e. proportional) error, can be very large (e.g. 1°C change in temperature or 3.4mbar change in pressure leads to approximately 1ppm change in distance). Although local and short-term variations can often be neglected, other than for high precision (or long range) work, it is important for virtually all EDM measurements that at least a correction for average conditions is applied if significant scale errors are not to arise. For high accuracy applications, considerable difficulty can be encountered in trying to estimate or determine the atmospheric error present in the measurement. Note that values of refractive index (or temperature and pressure) are usually assumed within instruments. Refractive index is unlikely to be set to 1.00000.

(b) The index error is usually considered as being due to the optical/electrical 'centres' of the instrument and reflector combination not being coincident with their physical centres. It is important to realise that the instrument index error cannot easily be separated from any reflector error, although difference between reflector constants can be determined. Some researchers maintain that index errors are not constant, in that the electrical measurement centre of any instrument can vary, particularly with the distance being measured (and the signal strength obtained) as well as with time. Such considerations may only be of importance with the highest precision instruments.

(c) The cyclic error can be considered as an error which repeats over a measuring cycle (half wavelength) of the instrument. If present, it is usually due to phase measurement errors caused by internal cross-talk. It can be identified as that residual left after meteorological corrections, index error and scale error have been applied to the measurement. Modern instruments which are functioning properly do not usually display significant cyclic errors but, particularly with ageing of components, malfunctions can occur which can lead to significant errors from this source. Manufacturers of certain very high precision instruments which do not employ direct phase measurement systems maintain that the specific measurement processes of these instruments preclude the possibility of cyclic error.

Some of the errors arising from these sources will be negligible for many applications, but not all of them. The process of verification demonstrates that the instrument (and associated equipment) is operating within defined tolerances. It should therefore be an essential component of the surveyor's quality management system and he should apply it to every instrument he uses.

Calibration takes verification a step further. This procedure results in measurement of the index, scale and cyclic errors in the system, enabling the surveyor to remove systematic biases from his observations even if they are within specification.

2 Calibration and verification

There are two possible approaches to calibration and verification.

1 Create a model of the method of operation of the instrument and determine the characteristics of each element of the model – for instance modulation frequency, cyclic error and instrument/prism constant. In practice, checking and adjustment in a laboratory follows this approach. The results are likely to be optimistic because it will only address error sources that are in the model.

2 Treat the system as a black box and simply evaluate the overall performance under operational conditions. This approach requires no knowledge of the internal workings of the instrument and is likely to give a more realistic assessment of the performance of the EDM (and ancillary equipment) as a complete system, under field operating conditions.

These guidelines recognise the importance of checking and adjustment procedures carried out by EDM service centres in the laboratory but consider that the final assessment of EDM equipment is made by calibration or verification using field baselines traceable to international or national standards.

3 Calibration procedures

Calibration is the process of establishing the accuracy of EDM instruments using approved methods and making a recognised statement applicable to a particular instrument about its performance at the time of calibration. It is possible, of course, that the newly calibrated EDM may suffer damage when taken to site. The calibration values may change as a result. An investigation on a traceable verification baseline is essential if the surveyor suspects significant damage. This may lead to a decision to have a calibrated, dedicated EDM act as a traceable source for testing purposes. Values determined from the assessment of performance may be used to correct subsequent EDM measurements if the test demands it.

A full calibration should give an accuracy statement about the scale, index and cyclic errors present in the system.

An assessment of these three components enables us to make accuracy statements about our instruments, i.e. how confident we are as surveyors that our measurements are near to the truth. In the case of calibration, the truth is comparing EDM measurements to a better system of measurement, i.e. measurements made with a higher accuracy instrument.

These guidelines recommend that calibration is always carried out by direct comparison of the instrument to be calibrated with an international/national standard on a United Kingdom Accreditation Service (UKAS) or equivalent certified baseline.

Calibration is only necessary for EDM instruments which will be used for work where very high accuracy is required and for setting up local baselines which will be used to verify other EDM instruments.

We have established that the calibration process will provide us with values of the three main errors which we can apply as corrections to the measurement, if required, as well as indicating stability and reliability.

It is important to have a higher standard of base measurement than that sought for the instrument under test to negate any noise levels introduced by the calibration process. These can manifest themselves as centring errors, mistakes in the instrument's built-in algorithms, mistakes in the meteorological observations and corrections, and misalignment and misuse of the EDM itself.

To avoid centring errors, calibration baselines should comprise stable concrete pillars, the stability of which must be monitored.

It is advisable that EDM built-in algorithms dealing with the diverse options open to today's surveyor, such as meteorological corrections, reductions to the horizontal, etc. are checked and set to zero. Distances should be measured in 'slope mode'; indeed, it is preferable for the calibration baseline to be horizontal within say one minute of arc. By negating these algorithms, the EDM appears in its 'crude state' as a simple measuring instrument. Algorithms used to compute reductions within the instrument should be independently checked.

The sampling of the atmosphere through which the measurement signal passes has always been the subject of much debate. However, certain procedures can be taken to ensure that a confident sample has been made to keep the meteorological noise level to within 1ppm. It is best to make observations under uniform meteorological conditions (e.g. overcast skies) rather than under scattered clouds which might result in significantly varying temperatures. We also need good quality, preferably aspirated, thermometers and barometers which have been checked throughout their range against laboratory standards. Readings should be taken at the EDM and its reflector at the time of measurement.

A source of error, perhaps not often realised, is the misalignment of the measuring signal to the line of sight. We recommend that observational care is taken to maximise the return signal strength, as a weak signal will give a false measurement. Insufficient voltage may also give a weak signal and therefore a false reading.

A field calibration baseline should be of the Schwendener (1972) type:

Zero order or primary standard baseline

Schwendener method – 7 pillars, bay distances well known

1		2		3		4		5		6		7
	- – – -		- – – -		- – – -		- – – -		- – – -		- – – -	
	19.5m		39.0m		68.0m		127.5m		256.0m		511.5m	

Note

The distances given in the example above are those given in the reference quoted. The principle of measurement can be applied with different pillar positions, over different ranges. The reader is referred to the references for the principles which determine appropriate pillar positions.

Detailed records should be kept of the measurements made, including identification of ancillary equipment used (e.g. meteorological sensors, reflectors, tribrachs).

The Schwendener base utilises 21 combinations of measurements from the seven pillars, bay lengths are known, integer part wavelengths are represented within the combination of known bay lengths. The EDM under calibration measures all available bay lengths (21 in all) and the least squares computation solves for zero error, scale error and possibly cyclic error.

The three errors can be found by satisfying the mathematical model:

$$S = (1 + k)\ S + E + a \sin (x - x_o)\ 2\pi/\lambda_{eff}$$

Where:

S = distance (meteorologically corrected)

$(1 + k)$ = scale factor

E = zero error

$x = S - (0.5\lambda_{eff})\ \mathrm{int}\ (S/0.5\lambda_{eff})$ = part wavelength

x_o = initial phase length

λ_{eff} = unit wavelength

a = amplitude of cyclic error

We can now examine how each of these three errors may be determined.

Scale error

This can be derived from measurements made on a field calibration base provided the inter-pillar distances are well known, and of sufficient length, the pillars are stable and accurate meteorological observations and corrections are made. Scale error will be more precisely determined over the longer baseline bays.

Index error

The index error can be the most unreliable constant to apply in a practical sense, because EDM can be used with a variety of reflectors and instrument mounts, each combination of which will probably yield a different value.

When ascertaining the index error of an instrument/reflector combination on a calibration base of the type mentioned, the index error becomes the most reliable evaluation because it can be determined independently from each measure. Therefore, there is a high degree of redundancy and the index error can be well determined using a least squares method.

Cyclic error

This can be found from field calibration by comparing EDM measurement to the known bay lengths, which represent the different part wavelength values. Instrument defects can cause errors which will be cyclic in nature. Faults in the phase measuring system will cause errors having a period of ¼ wavelength; while contamination of the receiver channel will cause errors with a period of ½ wavelength. There could well be yet another two more periods to consider. These four periods may affect the EDM significantly if it is to be used on particularly accurate tasks. The important thing to know is whether they are being affected to an unacceptable degree. If an EDM is exhibiting cyclic error, the measurements can be corrected. The correction, once the coefficients have been derived, satisfies the mathematical model given above.

If the least squares analysis does not model a cyclic error then one can only determine the presence of a large amplitude cyclic error from the residuals. For a small amplitude cyclic error the analysis treats the error as random and distributes it evenly through all the measurements. It is unwise to assume that the residuals of a least squares computation can be plotted as the cyclic error, as this may lead to significant errors in the simultaneously derived scale and index error. A single sine wave modelled in the analysis will remove some of any cyclic error present; however, cyclic error is rarely of a simple sinusoidal nature and usually consists of many higher order harmonics. However, modelling to a higher order harmonic will cause a loss of redundancy and, therefore, the ideal is to achieve the optimum condition of accurately determining cyclic error for the lowest order of modelled harmonic.

Cyclic error is usually negligible in modern instruments. If field baseline calibration of cyclic error is not possible (due to insufficient redundancy, or spread of measurements across the wavelength) or the baseline calibration reveals a possibly significant cyclic error, we advise that the instrument is calibrated for cyclic error in a laboratory.

4 Verification procedures

Most EDM instruments are required only to operate within the manufacturer's accuracy specification. Assurance that they are working within specification can usually be achieved by verification on a local baseline which is traceable to national or international standards.

It is important to determine regularly how an EDM is performing, but to a less rigorous standard than given by calibration. Here the question to ask is: 'is the instrument performing within the manufacturer's specification?' This question may arise if, for example, the EDM has been damaged, some time has elapsed since the last test, or perhaps the next task involves particularly tight specifications approaching the limit of the instrument's performance. At the very least it is advisable that instruments are verified on an annual basis.

In particular, the following questions may need to be addressed in order to properly test an EDM instrument's performance.

1 Is the index error correction equal to zero or of a value consistent with the type of prism used for the test?

2 Is the observational standard error smaller, equal to or greater than the value stated in the manufacturer's specification?

3 Do two standard errors σ_1 and σ_2 determined from two different samples of measurements belong to the same population, assuming both samples have the same degrees of freedom? Where the standard errors σ_1 and σ_2 might be obtained from either two series of measurements with the same instrument at different times or a series of measurements with two instruments of the same type.

There is a need to test regularly but we do not want the procedure to be unnecessarily scientifically exhaustive, time consuming and thereby expensive. The verification base itself, which we may choose to set out or we may have access to, must have been measured using an EDM calibrated on an international or national standard calibration base so that the whole process is traceable to international or national standards.

With modern, high specification instruments, great care is needed to avoid centring errors, so as to minimise noise which might otherwise swamp the instrument errors. We recommend, therefore, that the verification baseline comprise concrete pillars which are observed and monitored with a calibrated instrument at regular intervals. If the baseline comprises tripods set up over ground marks (using rotating optical plummets) it should be measured with a calibrated instrument on the same day using the same tripod set-ups, before and after observations have been made with the instruments that are to be verified.

The end point of the base (point E in the following example) should be located approximately at the maximum range over which the EDM will be used. The verification base is designed to allow the surveyor a simple procedure to examine the instrumental accuracy. A test base such as is shown in the following example will satisfy the criteria of testing.

Measured distances are compared against known/accepted distances along the baseline. The errors are used to compute a root mean square (RMS) value for measured distances. If the calculated RMS error is too large compared with the manufacturer's specification then the instrument may need further examination.

An example of this method now follows with suggested bookings of the observations, together with the simple calculations necessary to determine whether the instrument is performing within the manufacturer's specification.

Example of verification base

A	B	C	D	E
O – – – –	O – – – –	O – – – –	O – – – – – – – – – – – –	O
0m	30.5m	86.5m	158m	max working range of instrument

Procedure

1 EDM at A; set built-in algorithms to zero.

2 Measure A–B, A–C, A–D, A–E; each three times. The mean of each set of bay readings is accepted. Take meteorological readings at each EDM set up.

3 Move EDM to D and proceed in a similar manner such that D–E, D–C, D–B, D–A are measured.

4 The eight sets of measurements, corrected for meteorological conditions, are recorded in a similar way to that shown in the example below.

5 Calculate the error ϵ for each distance.

6 Calculate the squares of the errors, i.e. ϵ^2.

7 Calculate the RMS error by $\sqrt{((\Sigma\epsilon^2)/n)}$.

Where n = number of measured distances.

Worked example of computation

For bays A to D

Distance	Accepted value	Measured value (mean)	Error ϵ (mm)	ϵ^2
A–B	30.466	30.482	+16	256
A–C	86.496	86.503	+7	49
A–D	158.014	158.024	+10	100
D–A	158.014	158.026	+12	144
D–B	127.548	127.552	+4	16
D–C	71.518	71.527	+9	81
				$\Sigma\epsilon^2 = 646$
				$\sigma = \sqrt{(646/6)}$
				$\sigma = 10.4$mm

Over 158m, for an instrument with a manufacturer's specification of 5mm + 5ppm the standard error should be less than 5.79mm. The instrument therefore fails the verification. All errors are positive indicating systematic errors.

For bays A–E and D–E

Distance	Accepted value	Measured value (mean)	Error ϵ (mm)
A–E	562.121	562.135	+14
D–E	404.107	404.118	+11

Over 562m, the standard error should be less than 7.8mm. The error on line A–E is 1.8 times the manufacturer's standard error.

Due to the high redundancy and because the observation is not dependent upon baseline distances being 'known', local baselines can be used to calibrate the index error/prism constant.

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