CIV2202.7: ELECTRONIC DISTANCE MEASUREMENT

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PREVIEW

Introduction

Most engineering organisations now use combined theodolite and EDMs for fast and accurate surveying work, usually combined with electronic data gathering so that the results can be fed straight into a design package on a computer.

In Distance measurement so far we've looked at:

1. Chaining/taping (accurate, slow)
2. Tacheometry (inaccurate, fast)

Now we'll consider EDM which is both accurate and fast.

Objectives

After completing this topic you should be able to understand how an EDM works and what factors limit its accuracy. You should already understand the process of transforming the slope lengths (as measured by the EDM) into horizontal distances as required for drawing plans, using the vertical angle measured by the theodolite.

Readings

Read Muskett, Sections 4.3, 4.4, 4.5

REQUIRED

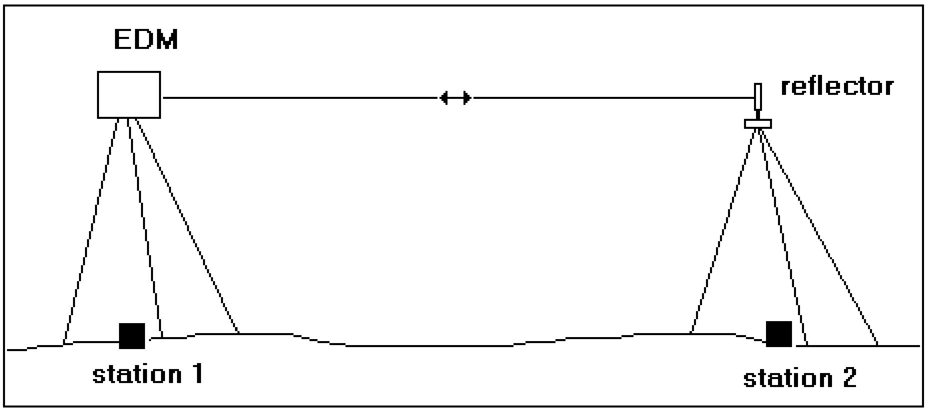
HISTORICAL BACKGROUND

Michelson (1926) established the velocity of light at 299796 km/s ± 14 km/s using a rotating 8 sided drum, and an accurately measured line. He could have done the opposite to measure distances, but this didn't happen, due to problems with his mechanical device.

Non-mechanical interruption devices were later developed with a high rate of oscillation. The current value of the speed of light, c = 299,792.5 km/s ± 0.2 km/s. However, early EDMs did not work on the speed of light. They used the **phase shift** between the outgoing and incoming signals. Some new instruments measure the time for a pulse of ligh to travel to the end of a line and return.

Others developments have included the use of Gallium Arsenide diodes to produce infrared light for short range instruments and the use of Microprocessors.

Principle of EDM



1. transmitter of modulated electromagnetic radiation.
2. reflector

The length is determined by measuring the **phase difference** between the outgoing and incoming signals for a couple of different frequencies. (more about this later)

TYPES OF INSTRUMENTS

EDM Applications

2 Categories of EDM applications

(i) long lines (base lines, triangulation nets).
(ii) shorter lines. (Engineering and general surveying.)

Which Frequency should be used for each application?

10^5 Hz(radio waves - lower limit)
10^{15} Hz (visible light - upper limit)

Long wavelength instruments

There are 3 Categories of EDM Instruments:

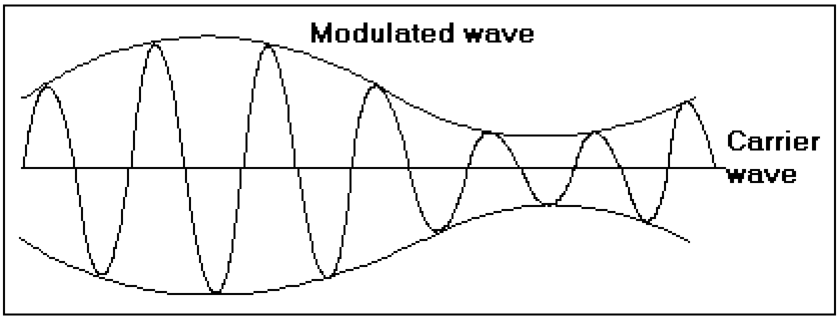
(i) low frequency radio systems (10^5-10^6 Hz)
(ii) microwave radio " (10^{10} Hz)
(iii) visible light systems (10^{15} Hz).

Lower frequency instruments have better range, but require larger (and heavier) transmitters. They are also more affected by the atmosphere, and hence are less accurate. They are suitable for marine and air navigation (position - fixing systems). Wave lengths used are of the order of 10^2 to 10^3 m and phase differences are measured in terms of the basic wave.

Short wavelength instruments

For engineering and land surveying, higher frequencies are more suitable. (Infrared wavelength is approx 14 µm)

* instruments are **small** and **portable**
* **propagation** in the atmosphere is **more stable**.
* however, it is **more difficult to measure phase differences** for very high frequencies
* it is thus impractical to use the **carrier wave** for measurement.
* instead the high frequency carrier wave is **modulated** with a lower frequency, and this is used for measurement.
* the **frequency** of the modulation signal must be accurately controlled by **amplitude** modulation (ie. the light flashes on and off).



frequency modulation: (pitch)

OPERATING PRINCIPLE

Basic equation

The EDM measures the **phase difference** between the outgoing and incoming signals. However, we don't know the whole number of wave lengths between the transmitter, reflector and receiver. The Basic equation is:

$$d = n.\lambda + \frac{\phi.\lambda}{2.\pi} + a$$

where,

d = double distance
λ = modulation wavelength = V_o / m.f
n = number of complete wavelengths
ϕ = phase difference (measured) between the outgoing and incoming signals.
a = additive constant to take account of geometrical and electrical eccentricities in the instrument and reflector,
V_o = velocity of light in a vacuum
m = refractive index of the atmosphere
f = frequency of the modulated wave (not the carrier frequency)

n is unknown for any one frequency, but "d" can be found by repeating the measurements at different frequencies, as we will soon see.

Practical Application

Consider, $\lambda_A = 40$ m (with frequency f_A)
$\lambda_E = 50$ m (with frequency f_E)

There are 5 A wavelengths in 200 m.

There are 4 E wavelengths in 200 m.

If phase differences are ϕ_A and ϕ_E, then it can be shown that for a frequency of (f_A - f_E), the phase difference is (ϕ_A - ϕ_E).

In this case, $f_A - f_E = f_A - 0.8 \text{ x } f_A = 0.2 f_A = f$

or $\lambda = 5 \text{ x } \lambda_A = 200$ m.

This would let us measure distances up to 200 m, with n = 0. If we change λ_E to 45 m, we could measure up to 400 m.

So, if we can accurately generate 2 frequencies close together, we can simulate a much lower frequency which is more suitable for measuring.

As an example, if $\phi_A = 1.70\ \pi$, $\phi_E = 0.16\ \pi$

$$\phi = \phi_A - \phi_E = 1.54\ \pi$$

$$d = (1.54\pi / 2\pi)\ \ x\ \ 200 = 154\ m.$$

That means there must have been $n_A = 3$, since

$$3 * 40 + (1.70\pi / 2\pi\ \ x\ 40) = 154\ m$$

Practical Considerations

If λ_A is accurately generated, the only error is in the part wavelength at the end. In practice, to improve accuracy, λ_A is short (10 m is common).

It also depends on accuracy of measuring the phase difference ϕ - some instruments work to 1%, others to 0.1%.

USING THE INSTRUMENTS

Microwave Systems

- Pioneered by Wadley in South Africa.
- Measure distances from 50 m to 50 km.
- Reasonably compact, mounted on standard tripods.
- Use both a Master and Remote device.
- The signal is retransmitted from Remote, phase measurements at Master.

Electro-Optical

These are the EDMs most likely to be used by engineers. They measure from a few metres to several km.

Basic components

- light source
- light modulator
- optical elements for transmitting and receiving light
- photomultiplier and phase meter.
- readout.
- passive reflector/s at the remote station.

Instruments with long range (up to 60 km) use laser.

Most short range instruments use a gallium arsenide diode which produces an infra-red carrier beam which can be amplitude modulated. (The intensity is proportional to the diode current).

Most are small enough to sit on the theodolite telescope, so angles and distances are measured together.

They are significantly affected by **mist/rain** - range reduced. Requires measurement of temperature and pressure.

You should always use the same type of reflector with particular EDM, since the "a" constant from earlier is a function of both EDM and reflector.

Infrared light instruments are more accurate than microwave instruments by a factor of 10.

See text for descriptions of particular instruments.

Electronic Tacheometers

EDM mounted on a theodolite is convenient for tacheometry. The distance, elevation + bearing can be obtained in one operation.

The reflector is mounted on a pole a fixed height (eg. 1.5 m) from the ground.

The horizontal and vertical circles are read electronically, and recorded into solid state memory. A small keyboard for adding identification data to reading is required.

The data is fed directly into a computer (with appropriate software) to produce a Digital Terrain Model (DTM) which is used in the design process (for designing roads, excavations, etc).

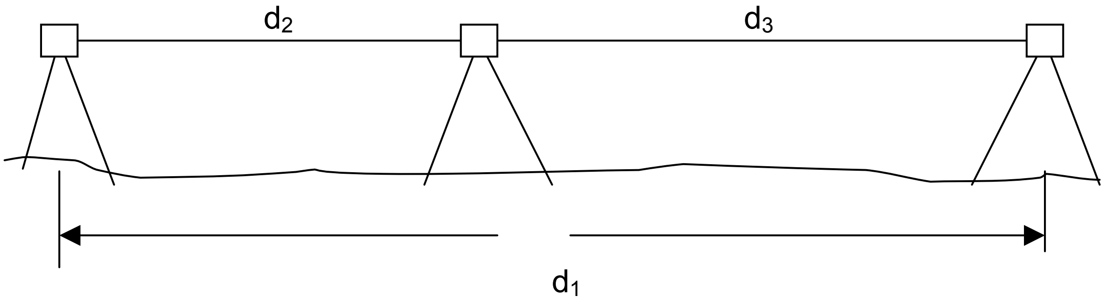
Typical accuracy is **± 5 mm ± 5 mm/km**.

SOURCES OF ERROR

Zero Error
Instrumental and Reflector Constant

- the electronic centre (where signal is generated) may not be the same as geometric centre (vertical axis).

- also discrepancy between optical and geometric centres of reflectors.
- both constants combine to give 'a', which is why a particular instrument and reflector go together.
- calibration over short known distance to get 'a' is important, or, can use a set of collinear points (as follows).



To carry out this test, three tripods are set up with tribrachs in a straight level line. Distances d_2 and d_3 should be integer multiples of 10 within say 0.05 m to eliminate any cyclic error affect, *qv*. Scale error will not affect this test. The prism and the EDM are both fitted with forced centring bases to fit into the tribrachs, and can be interchanged on the tripod/tribrachs with no centring error. Thus any discrepancy in the measurements is purely zero error of the system.

since the true distance, d = d' + a where d' is the actual measurement,

$$d_1 = d_1' + a \qquad d_2 = d_2' + a \qquad d_3 = d_3' + a$$

but, since $\quad d_1 = d_2 + d_3$

$$d_1' + a = d_2' + a + d_3' + a$$

or, $\quad a = d_1' - d_2' - d_3'$

Repeat several times and use the average value.

Scale Error
Frequency and Atmosphere

K depends on frequency and refractive index. Some frequency drift may occur with time.

The design refractive index, eg. 1.000274 at 1013.25 mb, 20°C (also depends on humidity).

* corrections applied for other conditions, eg.
  add 10 ppm for each 400 m increase in elevation
  add 10 ppm for each 16°C temp increase

There is usually a chart provided by the manufacturer for making these corrections.

Scale error is usually determined by check measurements over known distances. If the instrument does not give the correct distance to within the makers specification, the best course of action is to have the makers or their agents adjust the frequencies in an electronics laboratory.

Cyclic or Periodic Error

The electronic circuitry which reads the phase shift by delaying the internal signal until coincidence is attained may not be perfect. This may give rise to a pattern of errors which would be repeated every 10 metres.

For example distances ending in 0.00 metres and 5.00 metres may be read correctly, whilst distances ending about 2.5 metres may be read too long and distances ending 7.5 metres may be read too short.

The manufacturer should have balanced any error, and it should be less than ±e mm referred to in the "Accuracy" section. Cyclic error tends to increase with the age of the EDM.

Cyclic error is checked by measuring a pattern of known distances covering various parts of the wavelength (eg. 20m, 21.25m, 22.50m, …… 28.75m, 30m)

Field Calibration of EDM

There is a number of measured baselines in Victoria for checking the calibration of EDM. Concrete pillars with protected bolts have been established, and the distances between them are measured regularly using a high precision, calibrated EDM.

There are seven or eight pillars arranged to give a range of distances within the ten metre pattern and variation in length from 40 m to 800 m. The data from the test measurements is analysed according to a mathematical model and will give values for zero error, scale error and cyclic error.

Where the calibration measurements are carried out by a Licensed Surveyor and submitted to the Surveyor General for analysis, the results of the calibration are traceable to the National Standard of Length.

Accuracy of EDM

Typically : ±e mm ± p mm/km.

Overall standard error:

$$S^2 = e^2 + [\ D.p.10^{-6}\ ]^2$$

where D is the distance measured in km.

e is dominant for short distances.
e depends on the accuracy of the phase resolver.

p is dominant for long distances.
p depends on accuracy of modulation frequency, and refractive index of the atmosphere.