Chapter 5: Accuracy Analysis and Evaluation of Distance Measurement System
Sample Quiz

Multiple Choice Questions
Circle the most appropriate answers to the following questions.

1. Which of the following is not a source of systematic error in EDM measurement?
   a. System constant
   b. Effect of refraction
   c. Long-term variation of modulation frequency
   d. Centering error of EDM instrument

2. Which of the following is equivalent to scale graduations on a surveyor’s tape?
   a. Carrier wave
   b. Modulating signal
   c. Modulated signal
   d. Carrier wave frequency

3. Which of the following is equivalent to a surveyor’s tape?
   a. Carrier wave
   b. Modulating signal
   c. Modulated signal
   d. Carrier wave frequency

4. Which of the following properties of EM wave is not likely to be changed by the atmospheric conditions only?
   a. frequency
   b. wavelength
   c. velocity
   d. amplitude or intensity

5. Which of the following will not contribute any error to the determination of the refractive index of the atmosphere for the EDM measurements?
   a. precision of measuring the atmospheric temperature
   b. precision of measuring the dry-air atmospheric pressure
   c. precision of measuring wet-air atmospheric pressure
   d. precision of the EDM measurement

6. Which of the following is not true about the first velocity correction?
   a. it is the correction for the effect of the difference between the manufacturer determined refractive index and the realistic one
   b. it is the correction for the variation of refractive indices in the propagation path of the wave
   c. it corrects for the changes in speed of the wave in the atmosphere
   d. realistic atmospheric refractive index is used in computing it
7. Which of the following is false about the second velocity correction?
   a. it is the correction for the effect of difference between the manufacturer determined refractive index and the realistic one
   b. it is the correction for the variation of refractive indices in the propagation path of the wave
   c. it corrects for the difference between the curvature of the earth and the actual curvature of the wave path.
   d. It is negligible in most engineering applications

8. The accuracy of an EDM distance $S$ can be given as $\pm a \pm bS$. Which of the following error sources will not contribute to the distance-dependent error ($b$)?
   a. error of the frequency modulation
   b. error of the refractive index determination
   c. error of the velocity of propagation
   d. error of the phase difference determination

9. Which of the following is false about refractivity?
   a. it depends on the atmospheric condition
   b. it is the change in refractive index expressed in parts per million
   c. it is also known as refractive number
   d. it is the refractive index expressed in parts per million

10. If the difference between reference refractivity and the actual refractivity is given as 30 (in the units of refractivity) and the measured distance is 1 km, what is the approximate correction to be applied to this distance?
    a. 0 mm
    b. 1 mm
    c. 3 mm
    d. 30 mm

11. Which of the following types of frequency is directly used by an electro-optical EDM in distance measurement?
    a. the EDM carrier frequency
    b. the EDM group frequency
    c. the EDM modulation frequency
    d. the EDM infrared frequency

12. Which of the following is not an outcome of an EDM calibration on a baseline?
    a. best achievable precision of the EDM measurement
    b. additive constant and cyclic errors of EDM equipment
    c. scale error of EDM
    d. realistic modulated frequency of EDM
13. Which of the following is not a characteristic of a typical EDM calibration base network?
   a. it consists of about 6 to 8 base stations
   b. it consists of forced-centering devices
   c. it can be established by experienced surveyors for their personal use
   d. baseline lengths are precisely known

14. Which of the following will not be needed in EDM calibration on a baseline?
   a. temperature sensor
   b. atmospheric pressure sensor
   c. relative humidity sensor
   d. frequency sensor

15. If an EDM calibration base network consists of 4 calibration stations, what is the minimum number of distances that should be measured amongst the stations?
   a. 7
   b. 6
   c. 5
   d. 4

16. Which of the following is not a main purpose of standards such as ISO17123 and DIN18723?
   a. to discredit the manufacturers’ quoted precisions of their equipment
   b. to help in classifying equipment
   c. to provide means of associating precision (accuracy) to different equipment.
   d. to help investigate if precision quoted for the equipment is appropriate

17. Which of the following is not about the standardization of an EDM instrument?
   a. it is the determination of the scale of the instrument
   b. it is the comparison of the instrument length to a national standard of length
   c. it is the determination of the operating frequencies of the instrument
   d. it is the determination of the instrumental constant

18. Which of the following is not computed and tested in the EDM calibration procedure?
   a. scale factor of distance measurement of the EDM
   b. system constant of the EDM
   c. centering error of the EDM
   d. standard deviation of scale factor of the EDM

19. Which of the following corrections need not be applied to the EDM measurements for the purpose of calibrating the EDM?
   a. first velocity corrections
   b. geometric corrections
   c. effects of the weather condition at the time of measurements
   d. effects of EDM frequency variations
20. Measured distances between a collinear array of points can be used in determining the EDM zero constant. How many points will be needed in uniquely determining the EDM zero constant?
   a. 2
   b. 3
   c. 4
   d. 5

**Discussion and Calculation Questions**

Answer the following questions.

1. List 3 ways in which the EM waves are affected by the atmosphere when used in EDM
2. List 4 important properties and one practical use of modulating signal
3. List 2 important properties and one practical use of carrier wave:
4. An EDM with two modulation frequencies 30 MHz and 100 kHz are to be used to measure a distance of 325.456 m. Assume the velocity of light is 300 000 000 m/s.
   a. Determine the number of integer wavelengths and the fractional wavelength in the path lengths traveled by each of the modulated signals.
   b. If the phase resolver in the instrument is only capable of measuring the phase delays of signals to four decimal places, determine the accuracy of estimating the distance with each of the signals given above.
   c. Explain how the EDM will use the two frequencies to determine the distance.
5. An EDM instrument having a carrier wave of 0.91 μm was standardized by the manufacturer at 20°C and 1013.25 mb, and the standardization results were programmed into the EDM. The EDM was later used to measure a distance of 1885.864 m at a mean atmospheric pressure of 1030 mb, temperature t = 30°C and the water vapor pressure e = 28.25 mb. (Take the velocity of light in a vacuum as 299 792 458 m/s.)
   a. Using the refractivity approach expressed by Equation (5.40) and assuming that the water vapor pressure at the times of EDM standardization and field measurement is the same, calculate the first velocity correction to the distance measurement.
   b. Compute the difference (in mm) between the wavelength of the light waves under the standard conditions and the wavelength of the light waves under the field measurement conditions, assuming the carrier is modulated with a frequency of 14.985400 MHz.
6. The formula given in a manufacturer’s instruction manual for computing the refractive index ($n_a$) of an electro-optical EDM instrument is

   \[
   n_a = 1 + \frac{(0.000294335)P}{(1 + 0.003660867)(1013)} 
   \]

   Where
   \[
   t = \text{ambient atmospheric temperature (°C)}
   \]
   \[
   P = \text{ambient atmospheric pressure (mb)}
   \]

   The modulated wavelength of the instrument ($\lambda_s$) is 20.000000 m corresponding to a frequency of 14.985400 MHz at specified meteorological reference data of $t =$12°C and
$P = 1013$ mb and carrier wavelength ($\lambda$) of 0.860 $\mu$m. A survey line forming part of a precise test network was measured with instrument and a mean value of 2,999.097 m recorded. The mean ambient temperature $t$ and pressure $P$ were 13.4°C and 978.00 mb respectively.

a. Compute the atmospheric correction to the measured distance using Equation (5.35).

b. What is the corresponding systematic error to the atmospheric correction to the measured distance in (a) if it was later discovered that the field barometer was in error by +20 mb? [Use the systematic error propagation method.]

c. What is the corresponding random error in the correction to the measured distance in (a) expressed in (ppm) if it was later discovered that the calculated refractive index is in error of ±2 ppm? [Use the random error propagation method.]

7. Two survey crews (A and B) measured a baseline (using different instruments) at different atmospheric conditions. The corrected distance determined by crew A is 1800.0302 m; the corrected distance by crew B is 1800.0426 m. The accuracy specification (according to ISO 17123-4) of the EODMI used by crew A is ± 3 mm ± 2 ppm, and that used by crew B is ± 2 mm ± 2 ppm. Assume that crew A measured the overall distance at once while crew B measured about 600 m at a time. Determine if there is a significant difference (at 99% confidence level) between the two corrected distances.

8. The formula for computing corrected EDM slope distance (D) [i.e. corrected for meteorological effects] can be given as

$$D = s + (N_0 - N_a) \times 10^{-6} s$$

where $N_0 = 281.95$ is a constant refractivity value set in the EDM and $N_a = 270.88$ is the refractivity based on the field condition. If the precision of measuring the slope distance ($s = 2,999.097$ m) is $\sigma_s = \pm 2$ ppm and that of $N_a$ is $\sigma_{N_a} = \pm 2$ ppm, determine the expected precision of the corrected distance (D).

9. According to ISO Standard 17123-4, an array of 7 collinear points [21 one-way distances being observable] with spacing following one unit length of the EODMI and on the overall length of the array, which is usually at least as long as any intended use of the EODMI. In this approach, the least squares estimation is possible. Explain each of the following:

a. What information is known prior to the EODMI measurements.

b. What setting out must be done in preparation for measurements by the EODMI.

c. What quantities are “observed” [values recorded in the field];

d. What corrections are applied as “pre-processing” [before the estimation] and why:

e. What quantities are estimated and a typical observation equation [relating observables to quantities that are to be estimated] with an explanation of the variables:

f. The algorithm, in matrix notation with dimensioning, for the estimation, with an explanation of the elements in a typical row of the design matrix:

g. What statistical testing can be done a posteriori (null and alternative hypotheses, statistic, test):

h. How the results are used in subsequent employment of the EODMI.

10. Distomat Leica D1600 EDM equipment was calibrated over the government EDM baseline. The reduced mark-to-mark distances corrected for metrological conditions and the published corresponding distances are given in Table S5.1. Use the DefalsePro software to determine the scale error and the system constant and their corresponding standard deviations.
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