FIG N^0 9 1994 – A technical Monograph

Recommended Procedures for Routine Checks of Electro-Optical Distance Meters

Procédures Recommandées pour les vérifications de Routine des Appareils Electroniques de Mesure de Distances (AEMD)

Empfehlungen zur routinemäßigen Überprüfung von Elektroooptischen Distanzmessern (EDM)

Edited by Rudolf STAIGER
February 2007

International Federation of Surveyors (FIG)

RECOMMENDED PROCEDURES FOR ROUTINE CHECKS OF ELECTRO-OPTICAL DISTANCE METERS

CONTENTS

1 INTRODUCTION: AIMS AND WORK OF THE WORKING GROUP 5.1

The increased use by surveyors of automated measurement processes means that measurements can be made more rapidly and easily, but the need to carry out checks of the performance of the instruments is still very important. In recognition of this fact, Resolution 5/1-1990 was passed at the XIX FIG Congress in Helsinki. This Resolution was to the effect that the FIG should publish recommended procedures for routine checks of electro-optical EDM instruments by the time of the congress to be held in Melbourne in 1994, and that a draft be presented to the Permanent Committee Meeting in Madrid in 1992

FIG Working Group 5.1 under the Chairmanship of Mr J-M Becker (Sweden) was given the responsibility for carrying out Resolution 5/1-1990. The other members of the Working Group were: Mr B Andersson (Sweden), Professor A H Dodson (UK), Dr R Gottwald (Germany), Professor M Kasser (France), Dr Yang Junzhi (China), Dr M Mayoud (France), Mr D G Pursell (USA), Dr J M Rüeger (Australia), Dr J Santala (Finland), Dr-Ing W Schwarz (Germany), Dr Takao Seto (Japan) and Dr-Ing V Slaboch (Malta). Other professional surveyors with much practical experience in many countries have also contributed to this document.

A draft was sent to national delegates of all FIG member associations for comments. Furthermore, the draft was submitted to all EDM instrument manufacturers who participated in or communicated with the Working Group.

These recommendations are not intended to be a substitute for Manufacturers manuals, or for textbooks. They are intended to provide generally recognised professional procedures which are feasible and should be part of routine practice wherever EDM surveys are carried out. This document complements existing regulations and standards where they exist, it does not replace them. Where such regulations and standards do not exist, these recommendations could be used as the basis for formulating such regulations.

I would like to thank colleagues in FIG Working Group 5.1 for the time and effort they have given to formulating these recommendations, in particular the chairman, Mr. J-M Becker who prepared the final document and Professor M Kasser and Dr R Gottwald who wrote the French and German versions respectively. We are grateful for the comments of all those who responded to invitations to put forward views an the draft document It is our hope that users of EDM Instruments their employers and professional organisations and all other professionals involved in the process of EDM, including manufacturers will follow the recommendations for mutual satisfaction and the good practice which benefits society in general.

(M A R Cooper, City University London. August 1993)

2. DEFINITIONS

It is necessary first to determine the terms "test", "calibration and "check" according to their meanings in these Guidelines

A **test** is an evaluation of the overall performance of an EDM Instrument with respect to specific errors, in particular in relation to the manufacturer’s specifications Tests can include "delivery tests" (with results in a document from the factory) "acceptance tests" and other tests for specific purposes. Tests are made in a laboratory or on a test field

Note: it is recommended that an acceptance test be made immediately after delivery to get information about the instrument's performance over the whole operating range and to check conformance to the manufacturer's specifications. If the results of the first test do not conform to the manufacturer's specifications, and if all operations during the test have been carried out according to the instructions in the manufacturer's manual, the instrument should not be accepted, but returned and exchanged for another

Calibration is the evaluation of relevant and statistically significant terms of the instrument corrections (ICs) for a specific EDM instrument. The results of a calibration (calibration parameters) are presented in the form of a calibration certificate and are applicable to the specific EDM Instrument at the time of the calibration. The values determined for the ICs should be used to correct subsequent EDM measurements. Calibration is normally carried out on calibration baselines.

A **check** of an EDM instrument is a process to establish whether or not an instrument is functioning properly and whether any large changes in the instrument correction terms (ICs) have been detected. Checks are normally made daily, or weekly, are simpler than calibrations, and can be carried out on-site, in the field, or on a local testfield.

3. WHY SHOULD EDM INSTRUMENTS BE CHECKED OR CALIBRATED?

The surveyor as a professional has to work in an optimal way according to the quality of the work (legal accuracy requirements, survey regulations, or tolerances for example), the date for completion of the work, and the optimum cost/benefit of the work.

The realisation of these goals demands not only knowledge and use of adequate measurements and calculation methods, but also the use of appropriate equipment for each specific project.

All instruments are "individuals" with specific characteristics (ICs) which can change in time for different reasons (internal or external factors) and which must be well known to guarantee acceptable results from measurements.

The surveyor should realise that the accuracies specified by the manufacturer can be achieved only with calibrated instruments operated in a proper way according to the manufacturer's instructions in the manuals.

Today's "push-button" and "black-box" technology in combination with integrated software packages produce very "user-friendly" systems which apparently take care of all problems (self-calibration and automatic control). Therefore a surveyor can easily have the illusion that everything is under control and forget his or her responsibility. But in reality the manufacturers have only partly devised an error-free System, so a surveyor must take full responsibility.

A long list of the damage caused by ignorance or underestimation of the effects of results from poorly checked and uncorrected equipment can be made. The following practical examples from survey projects illustrate these effects and some of the consequences.

Example 1. **The use of an unchecked, leased EDM instrument**.

Measurement of a traverse network of 180 new points by 1km traverses of 100m legs with a leased tacheometer (total Station) which was not checked before use. The results showed an unexplained systematic error of 26ppm which could not be eliminated by checking calculations or by remeasurements. A subsequent instrument check brought to light a hitherto unrecognised addition constant of 3mm, corresponding to about 30ppm. Application of this IC term eliminated the systematic error in the network.

Example 2. **Badly adjusted and checked accessories.**

EDM measurements were corrected for meteorological factors as recommended, but unfortunately the barometer used to record atmospheric pressure had a zero-point error of more than 30mbar which introduced a systematic error of the order of 10ppm. The zero-point error was introduced by an optical instrumentation engineer setting the height scale of the barometer to read zero at mean sea level, instead of setting the pressure scale according to a calibrated barometer.

Example 3. **Insufficient check of the long-term stability of the EDM instrument.**

Dam deformations were monitored using in-situ instrumentation and long term EDM. The EDM instruments used were poorly calibrated and their stability was not adequately checked during the period of observation. Errors caused through ageing of the electronic and mechanical components (especially frequency drift of the oscillator) contaminated the results. Conclusions about the stability of the dam were wrong. If this error had not been detected in time, the results could have been catastrophic.

Example 4. **Unchecked Instrument after repair.**

Work similar to example 1. One of the instruments had to be repaired during the measurement campaign and was not checked on return. The results of the computation indicated a significant systematic error of about 25ppm concentrated in the part of the network measured after repair. The EDM instrument was suspected. Through calibration an addition constant of 2.8mm was detected which eliminated the systematic error.

These examples make it evident that well-adjusted, calibrated and checked instruments are a basic requirement for accuracy, saving time and money both during the field Operations and during the following office work.

For all of these reasons, the surveyor has to make periodical routine checks to monitor the state of his or her equipment.

4. SOURCES OF ERROR AND THEIR EFFECTS

4.1 SOURCES OF ERROR

Errors in EDM arise from different sources, internal and external, such as: the Operator; the equipment; and the atmosphere.

The EDM equipment comprises not only the EDM Instrument, but also a number of accessories such as: tripod; theodolite; support; reflector; optical plummet; meteorological sensors. Each of these components of the EDM equipment can have specific defects (mechanical, optical, electronic) and/or malfunctions (maladjustment, drift, ageing) which contribute to the final "error budget" and contaminate the quality of the EDM results. Every EDM instrument has an error model which can be described as follows:

$$\text{error budget} = \Sigma(\text{systematic errors}) + \Sigma(\text{random errors}) + \text{noise}$$

The Operator can introduce errors at every step of the measuring process which affect the results through ignorance, neglect or accident.

The ambient atmospheric parameters (temperature, pressure, humidity and their gradients) also have a significant influence on the final value of the measured distance through their impact on the refractive index (or refractivity) and it’s gradient. A simplified over-all error budget can be expressed as:

$$\Sigma = F(\text{equipment, operator, atmosphere})$$

4.2 EFFECTS OF ERRORS

The **index error** (zero error, constant error) comes from the difference between the physical (mechanical) and the electro-optical zero points of the instrument (EDM instrument + reflector). The value of this error is normally constant and unique for each EDM instrument and reflector; both contribute to this error.

This constant value can be changed by mixing different reflectors (make and/or type) or through repair involving exchange of components. The major change arises from the use of different reflectors (make and/or type), especially when using cheap plastic reflectors. The corresponding **index correction** or **additive constant** (a) has to be added to the displayed value in order to obtain the corrected distance between the physical zero-points of the EDM instrument and reflector (ISO definition).

An incorrect value will affect all measurements by the same amount (constant size and sign). This is the most important error source, especially for short-range measurements.

Note: for many EDM instruments, the value of the additive constant changes significantly for very short distances ($\leq$ 10m).

Scale errors are linearly proportional to the measured distance and can arise from both internal and external sources. They arise from variations of the EDM modulation frequency from the nominal value. Internal sources are ageing, drift and temperature effects (e.g. insufficient warm-up time) of the oscillator (diode effects).

External sources are variations from the standard value of the refractive index of the air caused by changes of the ambient atmosphere (mostly temperature, pressure and sometimes humidity changes) along the measured distance.
These changes introduce significant scale errors. Incorrect atmospheric data can be introduced in many ways; uncalibrated instruments (thermometers, barometers); incorrect atmospheric measurement procedures (instrument not in shade, at one end of the line only); and often by incorrect entry of the atmospheric correction term at the EDM instrument keyboard or setting knob.

It is useful to remember that an error of 1ppm in the value of the measured distance will be introduced by an error of 1 °C in the atmospheric temperature, or by an error of 3mbar (3hPa) in the atmospheric pressure. (Microwave EDM is more sensitive to small variations in temperature; an error of 0.15° in the wet bulb temperature, or an error of 0.7°C in the dry, will give an error of 1ppm in the value of the measured distance).

The **cyclic error** (short periodic error) is characterised by a periodic function of the wavelength and the phase difference between measurement and reference signals. It usually introduces a phase measurement error. The sign and size of the error depend on where the measurements are made within the unit length of the instrument. In modern EDM instruments, cyclic errors are small, most of negligible size, but can become significant as some components age (this does not apply to instruments which use a pulsed diode).

Pointing error can be caused by phase delays, due to imperfections of the emitting and/or receiver diode combined with careless pointing of the EDM instrument to the reflector and misalignment (not parallel) of the directions of the EDM beam and the theodolite. These errors are frequent when using separate EDM instruments mounted often on different theodolites. They also come from diodes of poor quality or the use of cheap plastic reflectors. These errors can be minimised by ensuring a maximum return signal through adjusting the EDM beam to be parallel to the theodolite telescope axis and by careful pointing to the reflector.

As described above, errors in a measured distance can be random or systematic, constant, proportional, periodic and functions of time and distance. Some errors will be negligible for most applications (short ranges) as described, or can be reduced directly by adequate adjustments and appropriate measurement procedures. but the remaining part can only be minimised by application of corrections for the systematic instrumental errors as follows:

Instrument correction (IC) = additive constant + scale correction + cyclic correction

or IC = F(time, distance, temperature, pressure)

It is therefore important for the user/operator to have a good knowledge and understanding of the error model, so that errors can be identified and quantified to prevent, eliminate or minimize their effects by checks and calibrations.

5. CHECKS

In this section, different types of checks are defined, what each is intended to find out is described, and proposals for the frequency, place and procedure for each check are made.

5.1 TYPES OF CHECK

All possible sources and types of error arising from the equipment and from the procedures must be checked as follows:

- Check 1 - functioning check in two parts:

  visual checks of the equipment and accessories, general maintenance, cleaning of optical surfaces, charging batteries, drying, optical plummet; and operating checks according to the instructions in the manufacturer's manual concerning warm-up time, measuring signal strength, pointing to the reflector, centring, measuring and using meteorological data for example. Site procedures and recommendations must be followed as well.

- Check 2 - performance checks for detection of changes:

  stable performance over time, repeatability, correct adjustments (including pointing), and detection of changes from previous results and/or calibrated values for the Instrument correction (IC).

- Check 3 - using calibration for:

  detection of the error sources, determination of the actual values of the IC parameters (additive constant, cyclic and scale corrections) and meteorological sensors.

5.2 HOW OFTEN, WHEN AND WHERE TO CARRY OUT THE CHECKS

The interval between the checks is directly related to the stability of the error sources and the accuracy requirements of the work.

- Daily - check 1.
  Equipment functioning checks (before leaving the office or starting fieldwork) and field operating checks at every set-up.
- Weekly - check 2.
  EDM instrument checked at home testfield, repeatability of same known distances with the EDM instrument, and checking of readings of meteorological sensors.
- At regular intervals (not more than 3 months) - check 3.
  Low standard calibration on baseline (temporary field baseline or certified baseline) for values of IC parameters.
- On special occasions: after field accidents (shock or rough handling) -
  checks 1 & 2;
    - after service and repair including exchange of components -
      checks 2 & 3;
    - before using a leased EDM instrument - check 2;
      if no recent calibration values are available,
      check 3 should also be made;
    - before and after special high precision work - check 3.

Some illustrative examples: for short range use (< 300m) checks of only the additive constant and cyclic error are sufficient; for long range use (> 1000m) the scale error and the meteorological sensors (especially thermometers) must also be checked; if a combination of EDM instrument and theodolite are used, check of the painting error should also be made.

Note: It is recommended that a logbook be kept where all information about the performance of the instrument during the checks is recorded. This will give information about weaknesses so that particular attention can be paid to these during later checks, calibration and servicing.

5.3 HOW TO CARRY OUT THE CHECKS - RECOMMENDED ROUTINE PROCEDURES

Different methods and facilities for checking and calibrating EDM instruments and accessories are sometimes prescribed or recommended by manufacturers, authorities, national and international organisations (ISQ, DIN RICS, etc.) which are usually related to survey specifications. In what follows, routine procedures for checks which are everywhere easy to execute by surveyors in their normal professional daily work are recommended.

5.3.1 CHECK 1 - FUNCTIONING CHECKS.

These checks are affected according to the manufacturer's manual and any recommendations from the local authorities about field procedures. Regular checks and adjustments of the verticality of the optical plummet are also recommended. These checks are a natural part of the daily work of every surveyor who is interested in having equipment in good condition.

5.3.2 CHECK 2- PERFORMANCE CHECK ON HOME TESTFIELD.

The stability of the EDM instrument can easily be checked by comparing measurements on a home testfield with known lengths for different ranges. Such testfields consist normally of one marked instrument station at the office (indoors or outside) and three permanently mounted reflectors at typical distances for the usual working range of the particular EDM instrument (e.g. from 50m to 300m, See Fig 1.). The reference lengths of the lines are determined either with a more accurate type of distance meter or with the working EDM instrument immediately before and after each full calibration. In any case, this kind of testfield should be established each time a project is started for EDM checks during the whole period of the project. The first day's results will give the actual reference values and should be recorded in a logbook (and/or an disk or tape) for future reference.

If the results from Check 2 indicate significant differences for all the checked distances, it is recommended that the check be repeated very carefully. If the second comparison check confirms the result of the first, a change in the instrument's performance (or instrument station) is suspected and it is necessary to find out the cause of the change before using that instrument for the project. The next step is to carry out Check 3.

5.3.3 CHECK 3- CALIBRATION CHECKS: SIMPLE DETERMINATIONS OF THE IC PARAMETERS

The best way to do this is to use existing calibration baselines. If such baselines are not accessible for different reasons (which is the normal case in many places and countries) temporary short-range baselines, specific to the needs of the check, must be established.

5.3.3.1 CHECK 3.1 - DETERMINATION OF THE ADDITIVE CONSTANT (A)

For this purpose, a temporary baseline (about 50m) consisting of at least 4 points (A, B, C and D, see Fig 2) aligned in the same horizontal plane must be set out. Four tripods with forced centring can comprise the baseline. The distances between the tripods must be a whole number of the unit length ($U = \lambda / 2$) of the EDM instrument.

From the measurements of the six segments AB, AC, AD, BC, BD and CD the additive constant (a) is computed from the equations

AB+BC+CD-AD = -2a

AB+BD-AD=-a

AC+CD-AD=-a

with a final value of (a) from the mean of the three individual values.

Note: This new value for (a) is not affected by either scale or cyclic error effects. The method for its determination is suitable everywhere, easy to carry out, gives acceptable results and is not time consuming.

By analysing the results of Check 3.1 the following conclusions are possible.

1. If the new value for (a) is not significantly different from the "old" value, the changes detected by Check 2 probably come from the instability of the instrument station of the home testfield.

2. If the new value for (a) is significantly different from the "old" value, the whole check should be repeated to confirm the new value. Thereafter the effects of the error must be eliminated either by adjustment of the EDM instrument (by the user, or in an authorized workshop) or by application of the new correction to all subsequent measurements. lf adjustment is not possible (old type of instrument, workshop too far way, etc.) then Check 3.1 must be repeated once a week. Furthermore, it is recommended that a new and better determination of the IC parameters be made on a calibration baseline as soon as possible.

5.3.3.2 CHECK 3.2 - DETERMINATION OF THE CYCLIC ERRORS

After determination of the additive constant by Check 3.1 above, the amplitude (c) of the cyclic error is determined from measurements illustrated in Fig 3.

The measurements are made from one instrument station to a reflector placed successively at a number of points R1, R2, etc. evenly distributed over a unit length. All measured distances are compared with known ("true") values obtained by higher order measurements. Finally, by computation of the discrepancies (measured - true) the amplitude (c) of the cyclic error can be determined by variations around the mean value (a) of the additive constant determined by Check 3.1.

Note: In many cases Checks 3.1 and 3.2 can be made simultaneously by combining the requirements for both checks in one temporary baseline.

5.3.3.3 CHECK 3.3 - FREQUENCY CHECK: SCALE ERROR (K)

Large frequency errors can be detected by repeated measurements of well-known reference lengths (about 1 000m or greater) during regular performance checks (Check 2). First, the atmospheric corrections and the additive constant (a) must be applied to the measured distance. Then, if the detected change in the reference distance exceeds 3 times the standard deviation quoted by the manufacturer, checking with a frequency counter should be carried out. This kind of check is difficult or impossible to carry out under field conditions.

For the determination of the scale error, it is recommended that a frequency counter is used to determine the modulation frequencies (if possible at different ambient temperatures) and compare them with the design values in order to calculate the scale correction parameters. Such a calibration demands some warm-up time for temperature stabilisation of the frequency. This method of laboratory calibration is more accurate than calibration on field baselines because it is less sensitive to the influence of external factors such as the atmosphere and range. If the frequency error is found to be greater than 1ppm, it is advisable to make an adjustment, otherwise the measurements must be corrected.

5.3.3.4 CHECK 3.4 - THERMOMETER AND BAROMETER

Thermometers and barometers are very sensitive to rough handling (scale displacement, jumps in the mercury column) and should be checked often. This is possible by regular comparisons between all the instruments in the field or to a reference instrument kept in the office or hotel room. Daily visual checks (Check 1) are recommended.

Calibrations are normally made in a laboratory at least once a year and should include determination of zero-point and graduation (scale) error corrections at different temperatures and pressures. The error values found by calibration should be recorded before the instruments are adjusted so that measurements made before calibration can be corrected if necessary.

Barometers can often be adjusted, which is not the case for thermometers unless they are of the electronic type, so correction tables must be established and used for the correction of future readings to allow for graduation (scale) errors which remain after adjustment.

If significant discrepancies are found (exceeding three times the standard deviation of a reading) the instrument should be adjusted. If the discrepancies are unstable, the instrument should be replaced.

5.3.3.5 CHECK 3.5 - POINTING ERROR

The check of the pointing error can be made indoors or outside as follows. The procedure for a particular instrument is normally described in the manufacturer’s manual.

The reflector is set up about 30m from the instrument Station (EDM instrument on theodolite). The direction corresponding to the maximum return signal is found. Then distances corresponding to this direction and to adjacent directions (defined by turning the theodolite through known small horizontal and vertical angles) are recorded. In this way the pointing error is "mapped" and the magnitude of the pointing error can be found. Then the direction for maximum return signal and the pointing of the telescope to the target are made to coincide by following the manufacturer’s instructions in the manual. This procedure normally means setting the telescope to the target and then adjusting the EDM instrument by horizontal and vertical adjusting screws until the maximum return signal is obtained.

6. RECOMMENDATIONS

As mentioned previously, different participants (users, owners, regulatory authorities, manufacturers) are all directly or indirectly involved in the measuring process, contribute to the final result and are responsible for it. Some recommendations and suggestions for these participants are now made.

6.1 THE USER (OBSERVER, SURVEYOR) SHOULD:

- demand at delivery the final test document for the EDM Instrument from the manufacturer;
- be familiar with the equipment and know its technical possibilities and limitations over the whole working range (technical specifications);
- follow the manufacturer's instructions (operation, check and adjustment) given in the manual;
- establish "home" testfield facilities for routine checks of performance;
- record the raw data for all observations, including temperatures, pressure and input ppm correction values;
- monitor the Instrument's health by regular routine checks (1, 2 and 3 above), record every action in a logbook and if necessary arrange for a re-calibration:
- use an appropriate EDM instrument for each type of work and use valid values for the IC parameters;
- check that the actual values of the corrections (IC parameters) allow the accuracy specification to be met;
- check regularly all other components of the equipment (thermometers, barometers, tripod, optical plummet etc.);
- inform the manufacturer about abnormal changes (instabilities, repeated faults, weaknesses);
- send to the factory for adjustment, service or repair any EDM Instrument which does not meet the technical specifications (errors consistently larger than specified).

6.2 THE OWNER (SURVEY COMPANY, SURVEY ORGANISATION) SHOULD:

- understand the need for regular checks and calibrations;
- give the surveyor enough time, facilities, training and equipment (home testfield) to do the work;
- ensure that the surveyor makes the checks regularly, that calibrations are carried out and that the results are recorded in a logbook;
- buy only equipment appropriate to the task, with the final calibration document from the manufacturer;
- insist that the regulatory authorities establish, or otherwise make available, official calibration facilities;
- inform the surveying community about their experiences.

6.3 THE MANUFACTURER (SERVICE WORKSHOP, AGENT) SHOULD:

- give clear information about technical specifications, including the implemented values for additive constant, scale correction, meteorological corrections, nominal refractive index, etc.:
- give realistic Information about the EDM instrument's measuring facilities and limitations;

- supply a copy of the final test document with the EDM instrument;
- make a calibration after repair or exchange of an instrument and give a copy of the result to the owner/user;
- include in the operating software some automated routines for daily checks with a requirement for a response from the user;
- inform owners/users of on-board software upgrades;
- include a program for calibration procedures and calculation of the IC parameters on different types of baselines, with or without known lengths;
- include an "internal logbook" where the user and manufacturer store all relevant information about checks and calibrations, for example who performed the check or calibration, where, and when;
- inform and warn owners/users about any faults or weaknesses of a particular series which may be discovered;
- remind the owner periodically about the importance of carrying out routine checks and of regular servicing (by service contracts) and call in the instrument for service when it is due.

6.4 THE LEGISLATIVE AUTHORITY SHOULD:

- specify that all new EDM instruments should have a calibration certificate;
- make it possible for the EDM instrument to be calibrated by establishing permanent calibration facilities (baselines indoors or outside and/or laboratory facilities) covering the full working ranges of instruments in use, and in sufficient quantity around the country;
- specify clearly which type of instrument should be used for which type of work (technical specifications, official recommendations);
- give instructions when only EDM instruments with a valid calibration can be used;
- inform users, owners and manufacturers about check and calibration facilities, working recommendations and official regulations;
- include obligatory quality control in all public tenders.

6.5 UNIVERSITIES AND OTHER INSTITUTIONS FOR TECHNICAL EDUCATION SHOULD

- examine, test and report on all new and current instrumentation;
- ensure that students are trained to carry out routine checks of EDM instruments.

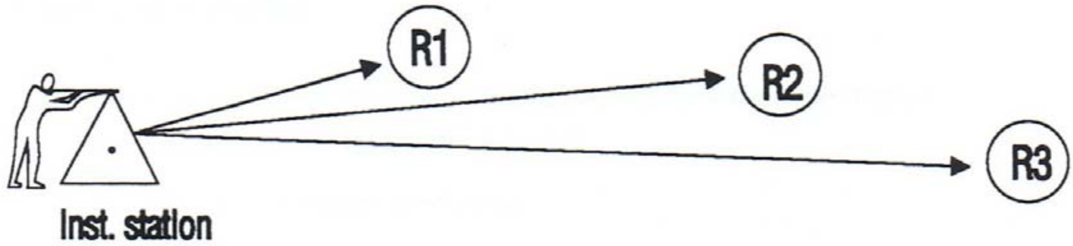

Fig. 1

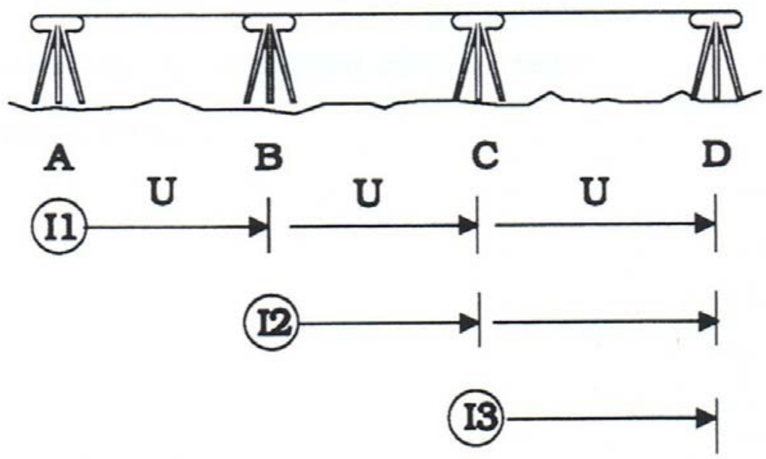

Fig. 2

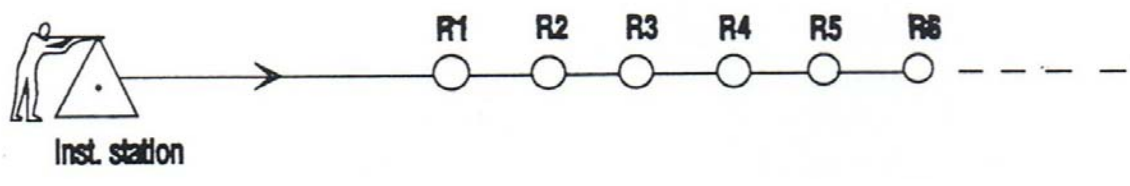

Fig. 3