COURSE 03: MEASURING DISTANCES

1. RIBBON MEASUREMENT :

Ribbon (Tape) measure is the most common and widely used method for determining distances. Its main drawbacks are that it depends on the terrain (uneven or not, steep or not, etc.) and its limited range (commonly used ribbon measures are limited to 100 m). The accuracy of the measurement is also limited and highly dependent on the operator.

Today, the decameter is used, single, double, triple, or quintuple, as it is much easier to handle. The name "tape" or "chain" has been retained, which has become the general term encompassing the decameter, double decameter, etc.

In the past, the chain was a true calibrated link chain used to measure lengths, also called a surveyor's chain.

Ribbon measures are divided into three accuracy classes: the following table lists the accuracy tolerances set by a European EEC (European Economic Community) standard. The values in the table being tolerances, if we want to obtain the standard deviation we just need to divide them by 2.7. For example, for a 50 m class II ribbon, the standard deviation on a measurement is ± 10.3 / 2.7 = ± 3.8 mm.

	10 m	20 m	30 m	50 m	100 m
CLASS I	± 1,1 mm	± 2,1 mm	± 3,1 mm	± 5,1 mm	
CLASS II	± 2,3 mm	± 4,3 mm	± 6,3 mm	± 10,3 mm	± 20,3 mm
CLASS III	± 4,6 mm	± 8,6 mm	± 12,6 mm	± 20,6 mm	

The length of a ribbon is given at a given ambient temperature (20°C in general) and for a given tension. For example, the steel ribbon is calibrated with a tension of 4.9 daN for a 50 m class I tape. The tension force to be respected is generally indicated on the tape. Tapes made of flexible materials are very sensitive to this tension (see the study of corrections in the following paragraphs).

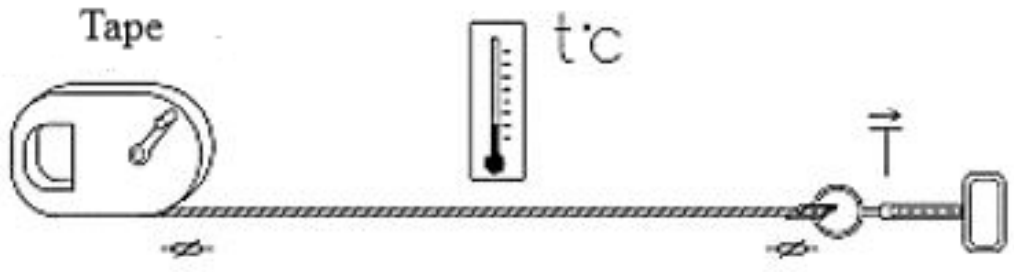


Figure 01: Precision ribbon measure

When performing fine measurements, the accuracy of which must be close to the ribbon tolerance, it is necessary to:

1. Hold the ribbon using a dynamometer to ensure optimal tension and avoid stretching it by pulling during the measurement: a force of 5 daN on a steel ribbon with a cross-

section of 0.2 × 13 mm2 is equivalent to a 5 mm stretch on a 50 m tape, which is the order of magnitude of the Class I precision tolerance. If the chain is suspended above the ground, the operator must adjust the tension of the dynamometer so that the chain error, i.e. the curved shape taken by the tape, is canceled out by the stretch due to the ribbon tension.

2. Correct the reading of the coefficient of linear expansion of the ribbon material (usually steel, with a coefficient of 11.10–6 °C–1, i.e., an elongation of 5.5 mm on a 50 m ribbon for an increase of 10 °C)
3. If the chaining requires several chain spans, align the different spans either visually or with surveying cards or stakes. An alignment error of 30 cm on a 50 m ribbon gives an error in the measured distance of 1 mm. In this case, the reading is greater than the actual value.

1.1 Measurements on Smooth Terrain

In surveying, the essential data is the horizontal distance between two points. Depending on the terrain configuration, this can be more or less difficult to obtain accurately on a production line.

1.1.1 Smooth and Horizontal Terrain

If the terrain is smooth and gently sloping (less than 2%), it is possible to simply place the ribbon measure on the ground and assume that the horizontal distance is read directly (Figure 2). The accuracy achievable in a measurement is at best around ± 5 mm at 50 m for a Class I ribbon measure

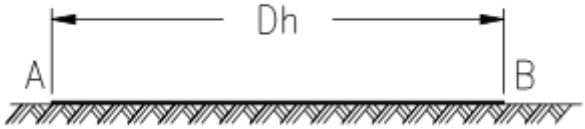


Figure 02: Ribbon measure on horizontal ground

1.1.2 Regularly Sloping Terrain

If the terrain is not perfectly horizontal, the distance should be measured along the slope. To determine the horizontal distance accurately, the difference in height ΔH between A and B or the slope p of AB (Figure 3) must be measured.

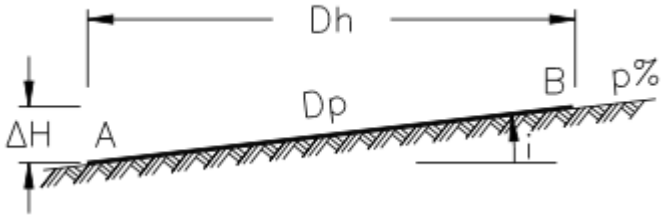


Figure 03 : Mesure au ruban en terrain en pente régulière

Dh = $\sqrt{\boldsymbol{Dp^2 - \Delta H^2}}$

P=tani

The accuracy is of the same order as previously, i.e. 10 mm at 50 m.

$$\mathbf{Dh} = Dp \cdot \cos i = Dp \cdot \sqrt{\frac{1}{1+tan^2 i}} = \frac{Dp}{\sqrt{1+P^2}}$$

1.2 Measurements on uneven or steep terrain

The ribbon cannot be stretched on the ground due to its undulations. Furthermore, the slope (or distance to be chained) is such that the distance Dh cannot be directly measured.

1.2.1 Measurement by horizontal steps

This method requires the use of a spirit level and two plumb lines in addition to the chain and the surveying cards (or stakes). It is time-consuming to implement and the process is not very precise.

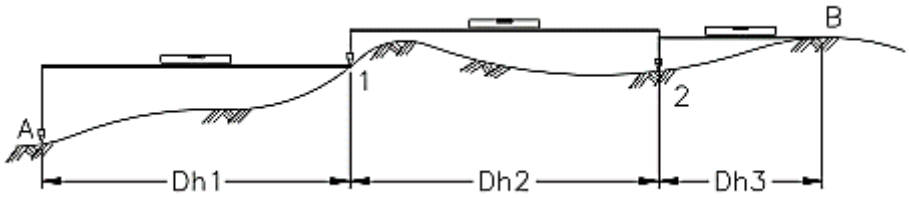


Figure 4: Ribbon measure using horizontal steps

Note that: **Dh = Dh1 + Dh2 + Dh3**

1.2.2 Suspended measurement

A wire made of stable material (Invar) is stretched above the ground. The tension is maintained constant by weights (Figure 5). The operator must measure the difference in height ΔH between the vertices A′ and B′ of the wire suspension tripods to be able to calculate the length Dh based on the measured inclined distance Di:

$$Dh = \sqrt{Di^2 - \Delta H^2}$$

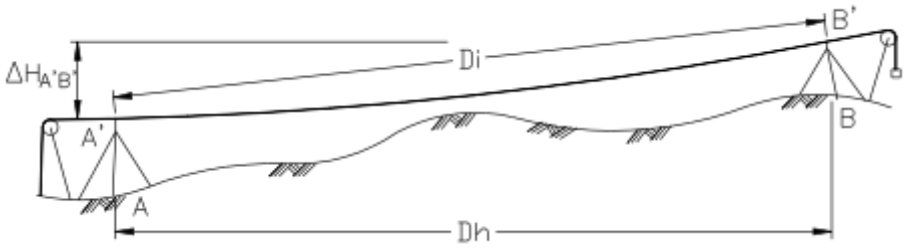


Figure 5: Measurement in suspended mode

We can calculate the distance error due to the chain shape of the wire. It is even possible to cancel out the chain error by carefully choosing the tension to apply to the wire.

This method produces satisfactory results in precision measurement, but it is time-consuming to implement. Millimeter accuracy is achieved for spans of around 100 meters. It is applicable to a ribbon measure.

1.3 Precision Measurement: Calibrating a Ribbon Measure

To perform high-precision measurements with a ribbon measure, it must be calibrated. This is done by measuring the length of a known base with great precision.

1.3.1 Constructing a Precise Calibration Base

One method involves using Invar wire measurement. This process is also used for calibrating distance meters: currently, this calibration is mostly done by interferometry, which ensures accuracies of around 0.01 mm over 100 m.

Invar wire allows the creation of known bases with sub-millimeter accuracy over ranges up to one kilometer (measurement in suspended mode).
Calibration bases with a length of 120 m, known to the nearest millimeter, are made available to surveyors by the land registry office of major cities. The DRIR (Regional Directorate for Industry and Research) issues calibration certificates for precision tapes (class I).

1.3.2 Calibration Correction

The actual value of a measurement is expressed by:
L exact = L measured. (1 + KE)

kE is the calibration coefficient determined by measuring the length of a known calibration base.
The term CE = kE. L Measured is called calibration correction.
The operator reads the value indicated by the ribbon on the known basis: if the ribbon is too long, it reads too small a value; conversely, if it is too short, it reads too large a value.

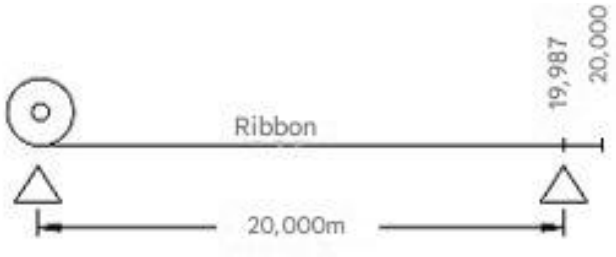


Figure 06: use of a calibration base

For example, a double decameter indicates 19.987 m when measuring a base of 20.000 m (figure 6). It is therefore too long by 0.013 m and gives values that are too small. It must be corrected by 0.013 m every 20 m.



Figure 07: Measure with the calibrated ribbon

The expression of the calibration coefficient is:

$$\mathbf{kE} = \frac{\mathbf{L\ base - L\ indicated\ by\ the\ ribbon}}{\mathbf{L\ indicated\ by\ the\ ribbon}}$$

In the case of Figure 7, we obtain kE = $6.5.10^{-4}$
If the operator measures a length of 20.000 m with the same ribbon (Figure 6), it is actually 20. (1 + $6.5.10^{-4}$) = 20.013 m.
If he measures a length of 18.655 m in the field, its "real" value is:
Exact L = 18.655. (1 + $6.5.10^{-4}$) = 18.667 m.
Le terme $m_E = \frac{L\ base}{L\ indicated\ by\ the\ ribbon}$ is called calibration module. We therefore have
kE = m E – 1, here mE = 1.00065.

1.3. 3 Temperature Correction

A ribbon is generally calibrated at a temperature of te = 20 °C. The expansion correction is positive if the temperature is above the calibration temperature; in this case, a ribbon that is too long will produce results that are too small; see Figures 5 and 6. This correction is negative if the temperature is below the calibration temperature; in this case, a ribbon that is too short will produce results that are too large. If you measure in the summer, in the sun, the temperature of the steel ribbon can reach 50 °C; this can be measured in the field using room or contact thermometers.

The coefficient of expansion of steel is k = 1.08.10–5 °C–1. We therefore obtain:
L exact = L measured · [1 + 1.08 · 10^{-5} · (t -te)]

1.3.4 Tension Correction (or Elasticity of the Tape)

As with any measurement, calibration must be performed at a known constant tension of the tape: this is done using a dynamometer or a weight attached to the ribbon suspended above the ground. The elongation ΔL in meters of a steel ribbon subjected to a tension T is expressed as follows:

$$\mathbf{\Delta L = LT/ES}$$

L: length of the ribbon expressed in m.
S: constant cross-section of the ribbon in mm2.
E: modulus of elasticity of the steel E = 21,000 daN/mm2.
T: tensile force expressed in daN
The "exact" length is then:

$$\mathbf{L\ exact = L\ measured \cdot (1 + KT)}$$

Where: KT = ((T-T0))/ES
kT is called the tension coefficient.
T0 is the calibration tension (≈ 5 daN).

1.3.5 Chain correction:

When measuring in suspended mode, the ribbon takes on a so-called chain shape (free deformation of a chain stretched between two points A and B; figure 8)

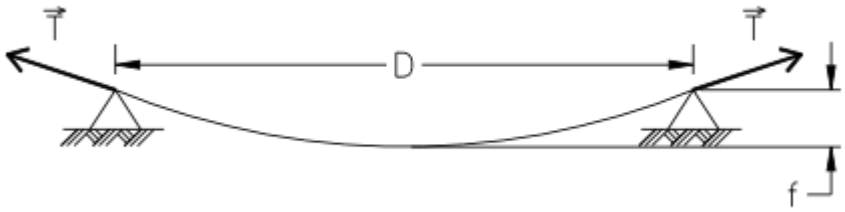


Figure 08 : Chain effect on a measure in suspended mode

The sag f of this chain can be reduced by increasing the tension but cannot be canceled out. The correction is always negative because the chain effect is identical to an elongation of the chain.

It is expressed as:

L exact = D=L measured · (1 + Kc)

$$k_C = -\frac{p^2 \cdot D^3}{24 \cdot L \cdot T^2}$$

T is the chain tension (daN).
D is the straight distance between the belt supports (m).
L is the length along the belt, i.e., Lmeasured.
p is the weight of the belt per meter of length (daN/m).
The specific gravity of steel is 20.10^{-3} daN/m.

2. OPTICAL MEASUREMENT

Optical measurement, now rarely used, is an indirect measurement. The desired distance is calculated from auxiliary measurements and is not traveled by the operator equipped with a standard.

2.1. Parallactic Method

This type of parallactic measurement requires the use of a theodolite and a stadia. A stadia is a ruler with two sights (triangular or circular) whose spacing is known (usually 2 m). Invar stadias are available for high-precision measurements. The stadia is equipped with a spherical level and a sight to adjust its perpendicularity relative to the line of sight A′ B′ (Figure 9).

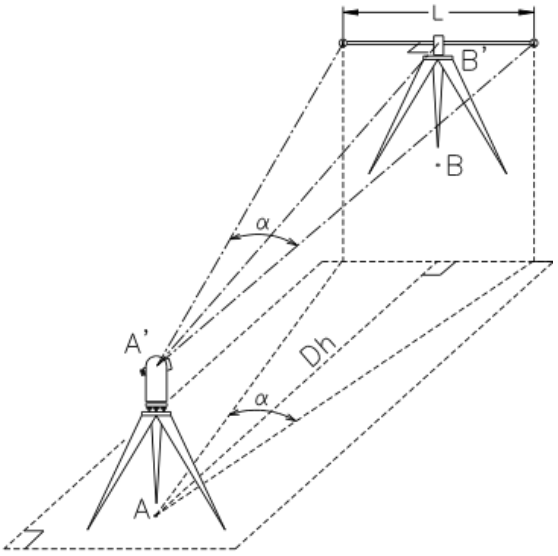


Figure 09 : Parallactic Mesure

Projected onto the horizontal plane passing for example through point A, we obtain:

$$\tan\frac{\alpha}{2} = \frac{L}{2Dh} \Rightarrow \boxed{Dh = \cot\frac{\alpha}{2}} \text{ avec } L = 2 \text{ m}$$

2.2. Stadimetric Method

Stadimetry is a less precise method than the previous ones. It allows for the indirect measurement of a horizontal distance by reading the length intercepted on a staff by the stadimetric wires of the aiming reticle.

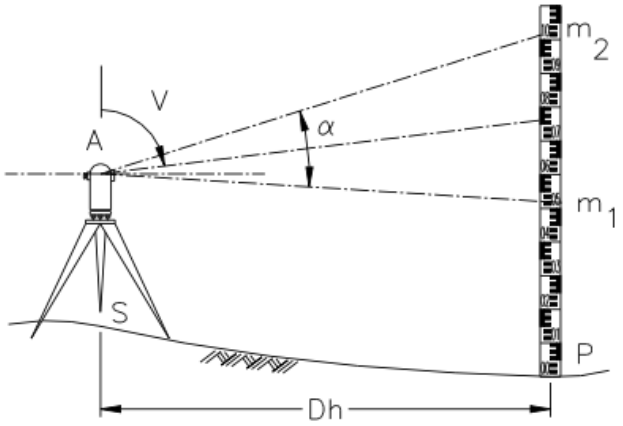


Figure 10 : Measurement by stadimetry

Point A, the optical center of a theodolite, is located vertically above the point stationed at S; the operator aims at a staff placed at P and takes the reading intercepted by each wire on the staff, i.e. m 1 and m2

The horizontal distance can be expressed by1:

$$\boxed{Dh = \frac{m_2 - m_1}{2\tan\frac{\alpha}{2}} \sin^2 V}$$

If the aim is horizontal, (V = 100 gr); we obtain: $$Dh = \frac{m_2 - m_1}{2\tan\frac{\alpha}{2}}$$

If the angle α is constant in the device used, we have Dh = K (m2 – m1) $\sin^2$ V.

The constant: $$K = \frac{1}{2\tan(\alpha/2)}$$

is called the stadimetric constant. It is generally equal to 100; this is why the expression for Dh becomes:

$$Dh = 100(m_2 - m_1)\sin^2 V$$

2.3. Clisimetric Method

Using a theodolite or tacheometer stationed at point S, take two sightings on a vertical staff held at M, corresponding to two readings l1, l2 and at two inclinations î1 and î2 with respective slopes p1 = tan î1 and p2 = tan î2

If l0 denotes the fictitious reading that would come from a horizontal sighting, we can write:

$l_2 - l_0 = p2.\ Dh$

$l_1 - l_0 = p1.\ Dh$

$l_2 - l_1 = (p2 - p1).$

Dh …… Dh = $l_2 - l_1$ / p2 – p1

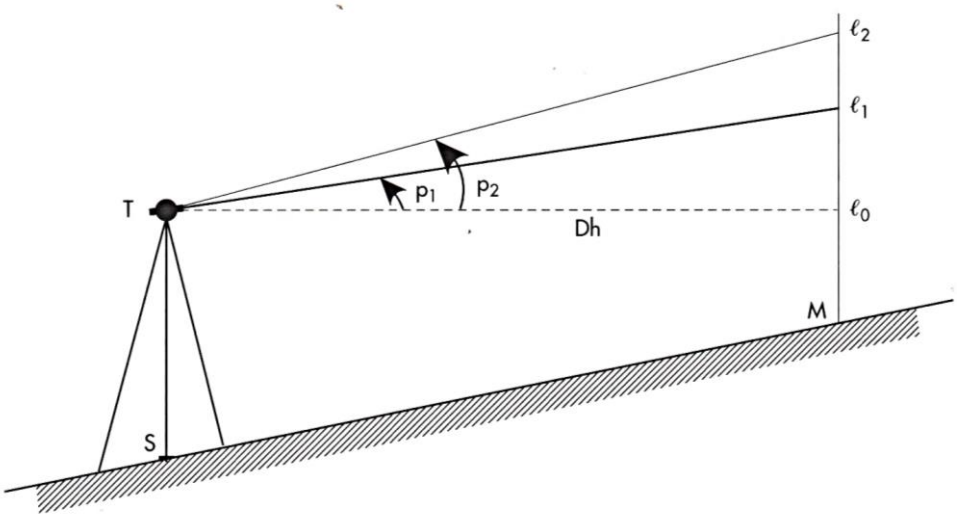


Figure 11 : Clisimetric distance

3. ELECTRONIC MEASUREMENT

2. Principle

Electromagnetic waves refer to light waves and radio waves; in a homogeneous and isotropic medium, they propagate in a straight line at a finite and constant speed.

These properties allow for the measurement of distances; an emitted wave that travels a direct round-trip distance Dd returns to the point of emission with a delay that is a function of the path length.

An electronic distance-measuring instrument is therefore a device that produces a train of electromagnetic waves, projects it onto a reflector, analyzes the echo, and converts the delay of the received wave into a distance; in short, it is a transmitter-receiver complete with a calculator that displays the distance in digital form.
The "oscillator, generator-modulator" assembly emits a light wave (light-emitting diode or laser diode) whose source is neither point-like nor strictly focused relative to the transmitting optics. The beam emerging from the emission optics is therefore a conical beam; the “light spot”, visible or not, generated by the latter therefore increases in diameter as one moves away from the instrument. In order to return sufficient energy for the measurement, it is necessary to increase the reflecting surface as soon as a certain length is reached; the ranges are therefore a function of the number of elementary reflectors attached..

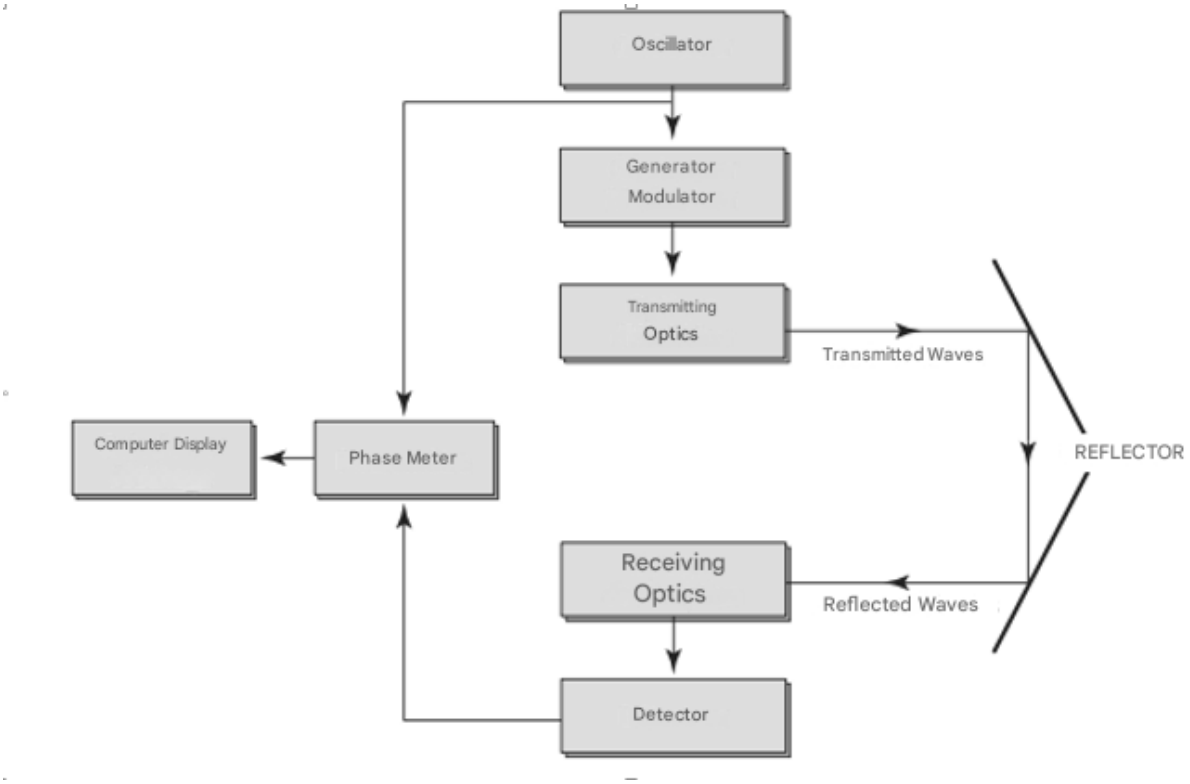


Figure 12: principle of a distance meter

2.1 Distancemètres de topographie

Distance meters are modular or integrated.

2.1.1 Modular

3.1 **Surveying Distance Meters**

They can be attached to the telescope of a theodolite and tilt with it (Figure 13).

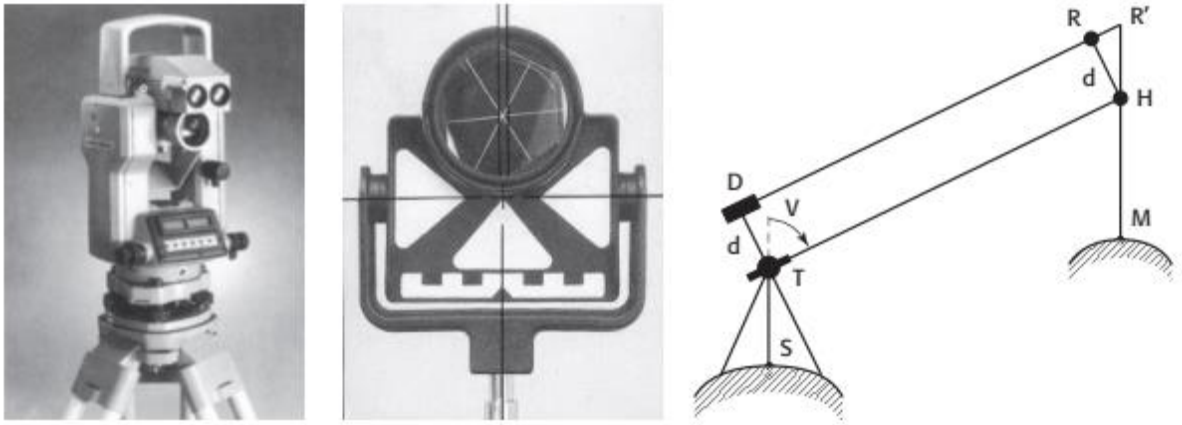


Figure 13: Superimposed scope and distance meter

The height offset d between the transmission-reception axis and the parallel optical axis is found between the reflector R and the sighting indicator H, the measured distance DR being equal to the desired distance TH when the prism is tilted perpendicular to the telescope. If the reflector is not tilted, the measured distance DR' must be corrected when the sight is clearly inclined: RR' = – d □ cotan Ṽ (negative if Ṽ< 100 gon, positive if Ṽ> 100 gon).
Modular distance meters mainly complement older optical theodolites; some models are coaxial with the telescope

2.1.2 Integrated:

The distance meter is located in the theodolite's telescope, with the optical axis also being the transmission-reception axis, which eliminates any offset correction.

2.2 Reflectorless Pulsed Lasers

The instrument sends hundreds, or even thousands, of laser pulses to a target for a fraction of a second, which reflects part of them back to the transmitter; the displayed distance is the average of hundreds, or even thousands, of measurements of the round-trip time of a pulse. This technology, which offers very short measurement times, high precision, measurements on moving objects, and, above all, reflectorless measurements, is currently being implemented in surveying on distance meters as well as on specific equipment, including:
– Class 1 laser binoculars, European standard EN 60825, which defines the highest level of eye safety: Vector-Leica (Figure 3.22), maximum range 2500 m, accuracy approximately 2 m, equipped with a magnetic compass and a clinometer with electronic display allowing three-dimensional positioning of the measured length; the Lem 300 Geo, from Jenoptik, with shorter ranges.



Figure 14 : Laser binoculars

– **The laser meter,** a class 2 laser which prohibits looking into the visible beam. The Leica DistoTM (figure 15) for example, particularly popular in interior surveys, reaches over 100 m with an accuracy of a few millimeters; data entry, organization, processing and storage via alphanumeric keyboard, connectable to any PC.



Figure 15 : Disto ™