



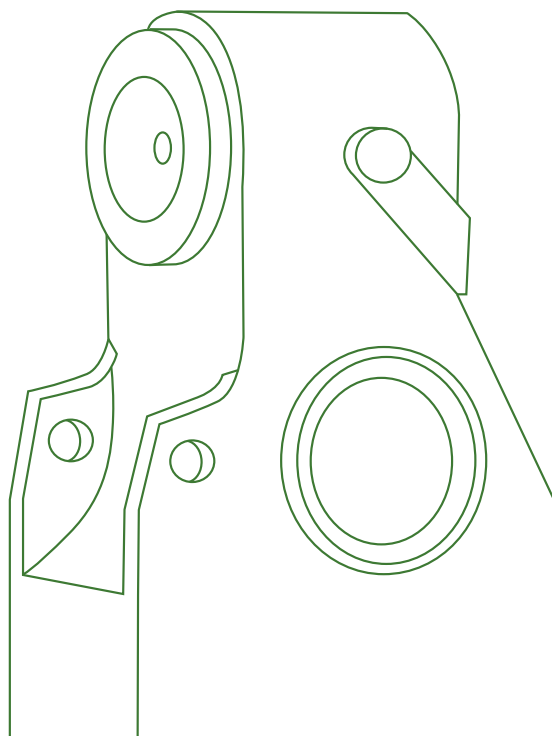
Spiegel-Relaskop®

by Dr. W. Bitterlich

Manual

Metric Standard

Metric CP



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Introduction

The Spiegel-Relaskop, essentially unchanged in design since it was introduced in 1955, fulfills all principle forestry measurement requirements throughout the world, as might be expected from a universal forestry instrument.

The construction of the Relaskop was initiated by the discovery of **angle-count sampling (ACS)** in 1947, a method which determines basal area density in forests by a simple counting method. The Relaskop automatically corrects for any inclination in the line of sight, making it possible to easily find the stand basal area in square meters per hectare either at breast height (1.3 m above the ground) or any other height. For this reason, the Relaskops are principally known in connection with angle-count sampling.

In addition, the Relaskop offers **quite a few other measurement applications in practical and scientific forestry**.

For example:

- Determining the horizontal distance, with automatic correction for the angle of inclination
- Measurement of tree height, or heights to particular upper stem diameters
- Measurement of upper stem diameters at particular heights
- Quick determination of the "slenderness" (height/diameter ratio) of standing trees
- Determination of form heights, and the volumes of standing trees by Pressler's formula
- Determination of slope angles

Of special interest for practical work:

- Relaskop as principle instrument of "variable plot sampling", which has the special advantage of selecting a basal-area weighted distribution (and which has been used more generally for the selection of trees to assess forest damage).

- In addition, the appropriate stem numbers per hectare can be derived from the ACS selection sample.

In scientific work and research, there are also the following special applications:

- Hirata's determination of the average stand height
- Strand's line sampling

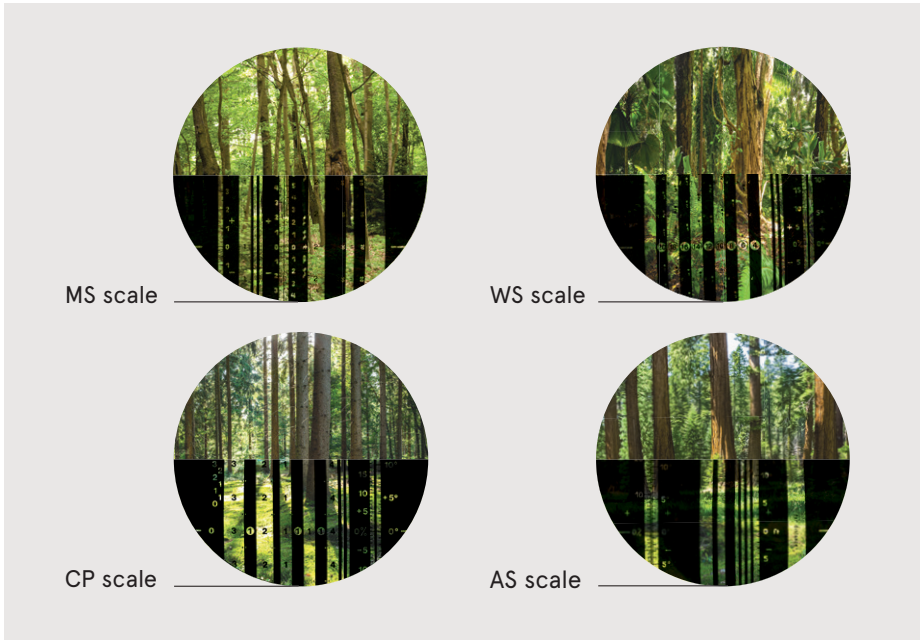
The sampling methods of Minowa-Strand, Minowa and Ueno

While the optical-mechanical functions of all Spiegel-Relaskops are the same, they are made with **four different types of scale**, according to their principal use. For more information on the differences between the scales *see p. 4-5*.

i In this manual the optical-mechanical functions and the field use of the Spiegel-Relaskop are described in detail and particularly the MS and CP scales. Detailed descriptions for WS and AS can be obtained by request.

At the end of this manual is added a description of optically measuring **distance** with the use of a **wedge prism**, **field glasses** and a **vertical base target**.

For further details of development, theory, methods, etc., see the book **"The Relascope Idea"** by Dr. W. Bitterlich (in English). It can be obtained from Silvanus (office@silvanus.at).



Different Scales

MS – Metric Standard, in previous years called "Metric Scale", is especially suitable for forestry conditions of temperate climates with tree diameters of up to 80 cm, and is especially marked for measuring heights from the standard distances of 15, 20, 25 or 30 m as introduced in general practice in certain regions.

WS – Wide Scale, also called "virgin forest scale", is a special scale developed for the measurement of large tree diameters at different heights, for ASC with large basal-area factors, and for simple surveying purposes. It may be used for the measurement in the metric system as well as in the English system of feet and inches.

CP – Metric CP combines the functions of the MS and WS scales. For this reason, it is a very versatile choice.

AS – US-American Scale has functions analogous to MS, but was specially designed for Northern America. The measurements are given in feet and inches.

	AS	WS	MS	CP
Vertical Degree Scale (-60° – +70°)	yes	yes	no	yes
Percent Scale (-170 – +270 %)				
Topographic Scales	yes	no	no	no
Range of BAFs for bars	5-90 ft ² /ac ~1-21 m ² /ha	1-144 m ² /ha ~4-625 ft ² /ac	1-4 m ² /ha ~4-17 ft ² /ac	1-81 m ² /ha ~4-350 ft ² /ac
Even BAFs on Scale	5, 10, 20, 40, 90 ft ² /ac	1, 4, 9, 16, 25 etc. m ² /ha	1, 2, 4 m ² /ha	1, 2, 3, 4, 9, 16, 25 etc. m ² /ha
Range of DBH measurable	0,5 % – 9 %	0,5% – 24 %	0,5% – 4 %	0,5% – 18 %
Direct Height readings from these distances	66 units	4, 6, 8, ..., 20 units	20, 25, 30 units	100 units
CP Correction Scale for rangefinding	no	no	no	yes
Rangefinding Distances determined	66 & 99 feet 1	9 standard distances 4-20 m 2	15, 20, 25, 30 m 3	direct reading with attachment 4

Common to all scales: All readings automatically slope-corrected,
Diameter measurement within 0,5 % of distance to tree

- 1 Smaller values are possible with quarter bars
- 2 With use of vertical or horizontal target, resp. Wedge Prism Attachment with vertical base
- 3 Using Relaskop Distance Scale and a verticale 2 m-target
- 4 With use of horizontal staff of known length or percent scale with vertical 2 m-target or Wedge Prism Attachment with vertical base

Fundamentals of Angle-count Sampling (ACS)

1. Establishing the Tree Count

Angle-count sampling (ACS) provides a direct measurement of the forest basal-area density at a particular sample point (in m^2/ha or other appropriate units) by simply counting all the trees which have a **diameter exceeding a given "critical angle"**. The use of an angle is just a simple optical way of determining a proportion between the tree diameter and the tree distance from the sample point.

The tree diameter d will exceed the critical angle only if the distance to the tree is less than a proportional "critical distance" R , which is just a multiple of the tree diameter. If we use, for example, a critical angle of the proportion $d : R = 1 : 50$, it implies that any tree counted by the ACS method lies within a "marginal circle", the diameter of which is $2R = 100d$, and its area is therefore 10,000 times larger than the tree cross-section itself. Each tree cross-section counted in this way will therefore represent $1/10,000$ basal-area density, or $1 \text{ m}^2/\text{ha}$. The number of trees z counted in a full sweep by ACS gives the basal area G in square meters per hectare. When using critical angles with other proportions of $d : R$ the tree count z must be multiplied by a "basal-area factor" k to give G in m^2/ha .

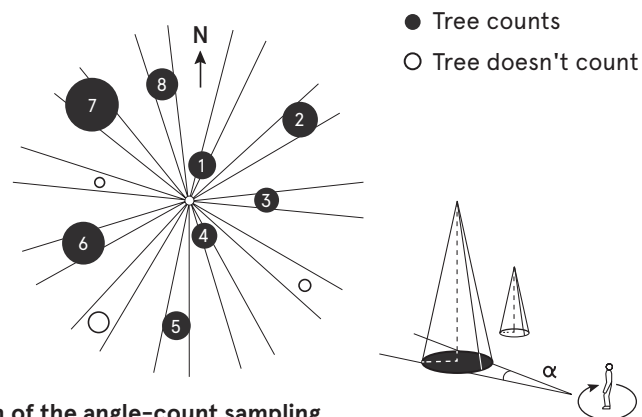


Fig. 1: Illustration of the angle-count sampling

When using angle-count sampling, the **general formula** is:

$$G \text{ (in } \text{m}^2/\text{ha}) = z \times k$$

The **requirement for counting** is as follows. If a is the horizontal distance between the center of the tree cross-section observed and the observation point, then:

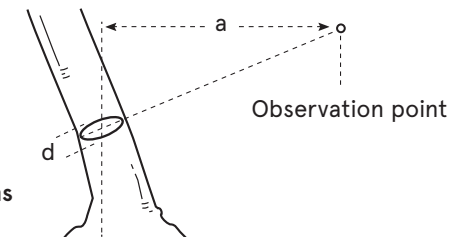
$$a < R$$

where R is a constant multiple of tree diameter. The following diagram serves as an example of a complete angle-count sampling process at a sample point. Starting from the north, and turning clockwise, we would count 8 cross-sections which exceed the given angle. In this diagram the angle proportion is $d:R = 1:50$ (for better visualization the diameters and angles are increased tenfold). Each black cross-section would correspond to its marginal circle by the proportion $(1/100)^2$, and this single observation point would imply a basal-area density of $8/10,000$ or $8 \text{ m}^2/\text{ha}$.

The technique for counting a leaning tree at breast height cross-section is illustrated below:

$$\begin{aligned} a &< R \\ a &< d \cdot 50 / \sqrt{k} \\ a &< d \cdot D_f \end{aligned}$$

Fig. 2: Counting conditions for leaning trees



Note that in the case of checking a so-called "borderline" tree (one which is questionable without more careful or additional measurement), the correct horizontal distance a is **from the observation point to the center of the tree cross-section observed**, not to the base of the tree. The correct diameter d is the one viewed from the observation point.

2. Basal-area Factor (k), RU-Width, Relaskop-Unit (RU), Distance Factor (Df)

In a full **360 degree sweep**, the basal-area factor **k** is the ratio of the basal area of each tree to its marginal circle in hectares:

$$k \text{ (in m}^2\text{/ha)} = (\pi d^2/4) / (\pi R^2/104) = (50 d/R)^2$$

where **d** and **R** are measured in the same units, e.g. in meters. The **width of band 1** is called a **Relaskop-Unit (RU)**, because for any number **n** of such RU-widths we have the simple formula:

$$k \text{ (in m}^2\text{/ha)} = n^2$$

where **n** can also be any fraction you decide to use. **The square of the number of Relaskop-Units n used for angle count sampling is the basal area factor k in m²/ha.**

Examples:

n = 2.5	k = 6.25 m ² /ha	n = 3 k = 9 m ² /ha
n = 3.25	k = 10.5625 m ² /ha	n = 4 k = 16 m ² /ha
n = 0.75	k = 0.5625 m ² /ha	etc.

Where the bands of the Relaskop scales are marked with such basal-area factors, they assume the use of full sweeps. If an angle-count sample is made using only half circles (a 180 degree sweep, e.g. on steep slopes), then the usual values must be multiplied by 2 (the "plot factor"). From the first equation on this page it follows that, the critical distance **R**, given a particular tree diameter **d**, and basal-area factor **k** is:

$$R = d \times 50/\sqrt{k} = d \times Df$$

where **Df = 50/√k** is called the distance factor.

In regard to **k=1** (band 1 on the scale), we have the special case already mentioned, where **Df = 50**. In this case 1 RU corresponds to a critical angle with a width of 2% of the horizontal distance, that is: **A width of 1 RU corresponds to 2% of the horizontal distance to the measured object.**

3. Treatment of Borderline Trees

Generally speaking, "**borderline trees**" are trees whose breast height diameter (d.b.h.) appears neither larger nor smaller than the RU-width. For **quick basal-area estimation**, such doubtful trees may be counted as **0.5 ("half-trees")** in each case, or for simplicity they may be counted as a 1.0 ("full-trees") every second time a borderline tree occurs. For careful work, however, it is necessary to determine if these trees qualify for selection by making an additional distance measurement (either by tape or optically) whenever there is a doubt. The multiple of the d.b.h., which depends upon the RU-width, must be larger than the horizontal distance to the tree to verify that the tree should be counted. For example: with RU-width 4, Df 25, and d.b.h. 36 cm the critical distance **R** = 36 x 25 = 900 cm. The measured horizontal distance is 897 cm, and the tree would therefore be counted. For large scale inventories, the examination of borderline trees is often extended to the consideration of **non-circularity of the stems**. The caliper-type measurement with reference to the direction of the sample point is used, rather than just the average diameter as measured with a diameter tape. **Metric CP** scale can help with this procedure by the use of "tolerance margins" around the critical angle.

4. Number of Stems per Hectare (St/ha)

Since each stem included in an ACS represents the same basal area (as specified by the **k** factor) the stems must exist in a number sufficient to add up to that basal area. We can therefore calculate the number of stems per hectare (**ni**) by dividing the **k** factor by the stem basal area for that tree (**gi**):

$$ni = k/gi$$

If a total of **z** stem were recorded in an ASC, the result is

$$St/ha = k/g1 + \dots + k/gi + \dots + k/gz$$

In regard to the volume sampling methods of **Kitamura** and **Kim Iles** the number of stems per hectare can also be derived from summing all **n**, where **n** = **k x h_{ci}/v_i**, with **h_{ci}** being the critical height of each tree, and where **v_i** is its volume – both values are usually found indirectly by calculation and stem form measurements (p. 22 - 23).



Fig. 3: Hand-held use

1	Eyepiece	5	Sun Shade
2	Clear window	6	Tripod Socket
3	Locking Brake Release	7	Neckstrap Attachment
4	Light Windows		

Description of the Spiegel Relaskop and its Handling

The instrument is small, and weighs approximately 350 grams. For measurements it can be held by hand, using the other hand or a staff for additional support, but it can also be used with the aid of a breast support, or preferably with a tripod or similar device (see Fig. 4).

During **hand-held use** (Fig. 3) you should take care to keep the light gathering windows (4) free of obstruction. The tip of the index finger rests upon the locking break release (3). The eyepiece (1) is kept close to the eye, and the other eye is kept open to give depth perception on the object being measured.

Inside the instrument there is a freely rotating wheel, which bears **scales consisting of black and white bands**, used for the measurement of widths, and with **scales calibrated for the measurement of heights** (see Fig. 5 – 8). Sighting through the eyepiece (1) of the Spiegel-Relaskop shows a circular field of view, which is divided horizontally by a sharp line – the measuring edge into an upper and lower part (Fig. 6, 8). For better illustration, **the measuring edge is marked M-M** in Fig. 6 and 8 (but not on the actual Relaskop scales!). The upper part allows a clear view into the surrounding terrain, and the lower part shows the scales, which are reflected upward by a mirror into the field of view from their position on the rotating wheel. While measuring work is done, the pendulum is released by depressing the locking break release (3) and the scale adjusts itself at the measuring edge according to the inclination of the line of sight. Partial release of the brake will help to quickly dampen the sensitive swinging pendulum to its final resting position. The full length of the MS and CP scales of the Spiegel-Relaskops are shown in Fig. 5 and 7.

Moving the instrument slightly upward and downward in front of the observing eye a very good accordance between the border of darkening (which is not sharp) and the measuring edge can be achieved. For observations against a bright background, e.g. against the sky, the sun shade (5) can be brought into position so that the scale is darkened without obscuring the view of the tree.



Fig. 4: The Spiegel Relaskop mounted on a tripod with lockable ball joints
 a – horizontal distance from the eye to the center of the tree Cross-section

More exact measurements are possible by the use of a tripod, which should be equipped with lockable ball joints (*Fig. 4*). The eye of the observer can be brought into the elongated axis of the tripod regardless of the inclination of the Spiegel-Relaskop. This is necessary because the angle of view measured by the bands have their vertex in the eye of the observer, and because the horizontal distance from the tree to the observer a is the distance from a hypothetical vertical line through the eye to the center of the tree cross-section observed.

Note: All readings (for measurements of either diameters or heights) are only correct when read directly at the measuring edge!



Tripod
 with ball joint adapter
 'Micro' and 'Mini'

Jacob Staff
 with ball joint
 adapter



Fig. 5: Metric Standard scale,
full length

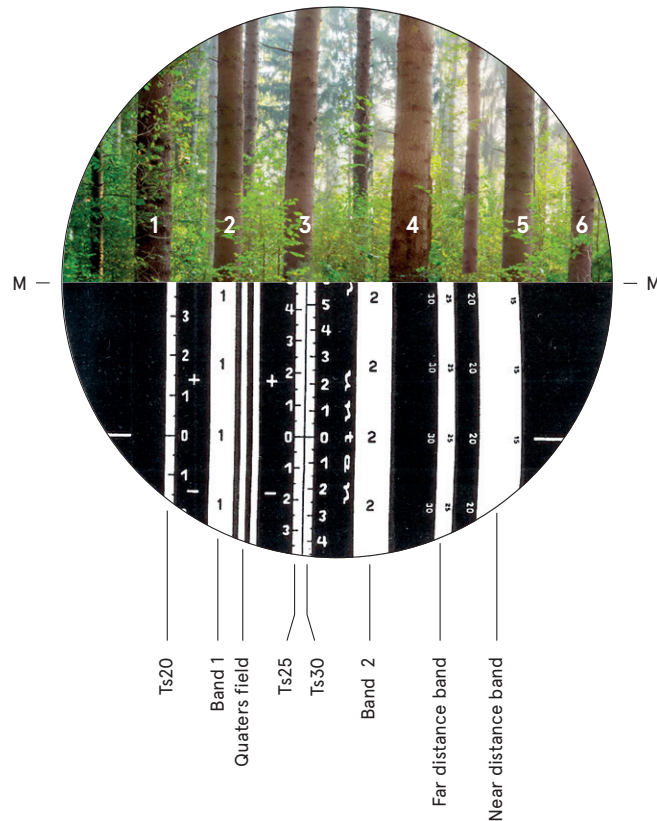


Fig. 6: Detail of the Metric Standard scale,
MM-measuring edge, from left to right:
Ts 20–height scale for horizontal distance of
20 m, band 1, quarters field, Ts 25–height scale
(25 m), Ts 30–height scale (30 m), band 2, two
bands of different width used in rangefinding

Description of the Scales

1. Metric Standard

The tangent scales labeled **Ts20**, **Ts25** and **Ts30** are used for the direct measurement of tree heights from **distances of 20, 25 and 30 m** respectively. **At 15 m**, half the readings of the 30-meter height band can be used. The height bands (tangent scales) have direct height readings in meters for use at the appropriate horizontal distances. At other distances they at least define equal vertical sections. The readings on the Ts scales frequently must be estimated in fractions of the smallest units, and it is therefore essential to keep the instrument as steady as possible (this applies to all other measurements as well), and to brake the swinging pendulum skillfully with the use of the brake release (3) shown in *Fig. 3*.

To the right of Ts20 there is **Band 1**, with a basal-area factor $k = 1$. Next to it is the "**quarters field**", with two black and two white "quarter bands". The combination of **band 1 plus the quarters field** corresponds to a **basal-area factor of 4**. This arrangement was chosen because of the proportion 1:25 represented by basal-area factor 4, which is the same proportion used in the **Ts25** scale next to it. This facilitates the rapid determination of the "**slenderness**" of trees (similar to the **height : diameter ratio** often seen in North American forestry literature) and the use of "Pressler's form height" in d.b.h. units. The width of **band 2** is corresponding to a basal-area factor of 2. Band 1, the quarters field and band 2 are all reduced automatically by the cosine of the angle of inclination whenever the brake is released, which causes the rotating wheel to adjust to the angle of inclination toward the object being measured. The results of all measurements are therefore adjusted to a **horizontal projection**, as is customary with map information.

Far to the right of the scales there are two white bands of different widths, which are used for **range-finding in conjunction with the vertical 2-meter target**, see p. 24. In these bands, the angles of inclination are reduced by the squared cosine, therefore resulting in a kind of "Reichenbach's distance measurement" and producing results directly corrected for the cartographic projection of the terrain.

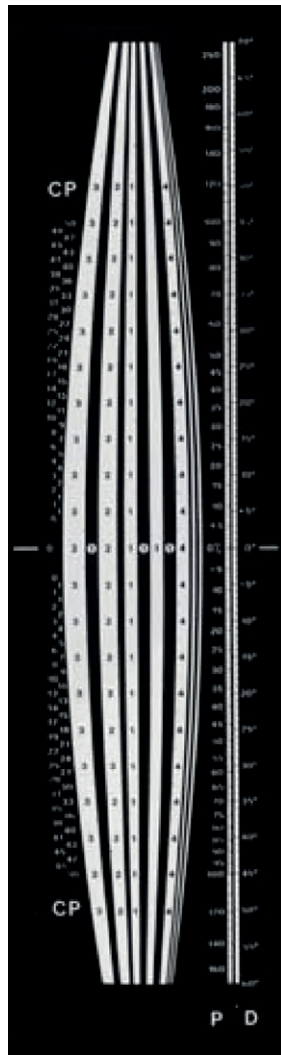


Fig. 7: Metric CP scale,
full length

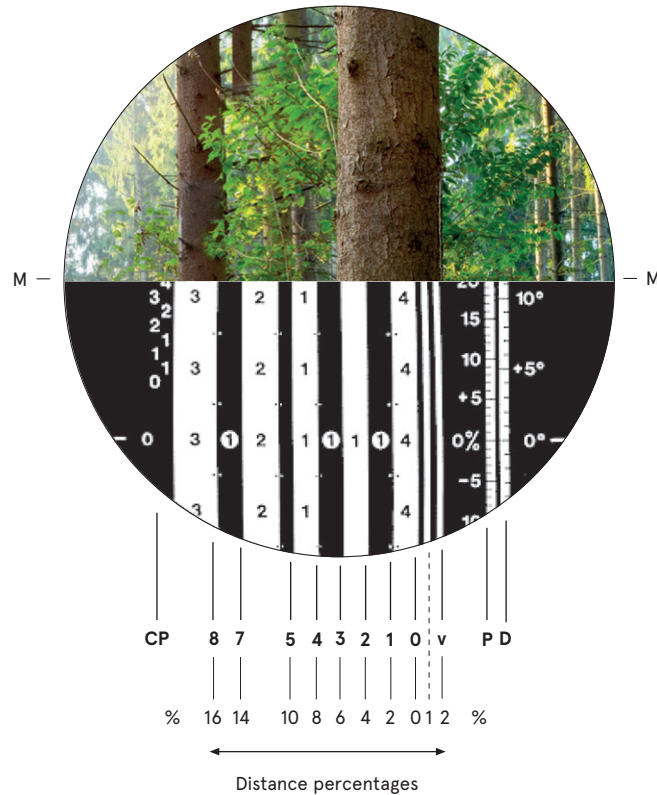


Fig. 8: Detail of the scale Metric CP

- MM Measuring edge
- CP Values of the correction percentages
- 0-8 Number of Relaskop Units
(without 6),
1 RU = 2 distance percentages
- O-v Quarters field
- P Percentage scale
- D Inclination in degrees

2. Metric CP

Spiegel-Relaskop Metric CP combines many of the advantages of MS and WS, it has **basal-area factor 3** available as a separate white band, includes tolerance margins for borderline trees, and has the CP-values for squared cosine corrections listed along the left side of the scale.

"CP" is an abbreviation for "correction percentage". On the far left are the CP-values. During the optical measurement of distance using a wedge prism and the vertical base target (for details see p. 24) the CP-value, which corresponds to the angle of inclination at the measuring edge, will give the percentage for reducing the reading of the vertical base target in order to calculate the horizontal distance.

To the right of the CP-values are the white bands with the basal-area factors $k = 3, 2$ and 1 which are labeled at intervals along the white bands. Any bands labeled as 1 are also equal to one **Relaskop-Unit (RU)** in width, which **corresponds to 2% of the horizontal distance** (compare p. 8). Next to band 3 is a single RU band 1 , then a black and white pair (which together are 2 RUs in width), then four more single RU bands. The left part of **band 4** is also one RU in width. The right side of band 4 is divided into **four quarter bands**, comprising another RU in total. Band 4 is therefore 2 RU in total width.

To the right of the quarters field lies the "percentage scale" **P**, used for many kinds of height measurement (see p. 26), and which measures height segments as a percentage of the horizontal distance to the tree. At the far right there is the final scale **D** which measures the sighting angle in degrees and can also be used to measure height.

The black and white dots along the edge of the bands for $k = 3, 2, 1$ and 4 are to facilitate the **determination of borderline trees**. Whenever a tree edge lies between these marks ("tolerance margins"), it should be checked accurately by using a diameter tape, or taken for a subsample to determine deviations of cross-sections from circularity (see p. 9).

Measurement Techniques and Their Use

1. Determination of Basal-areas Using Angle-count Sampling (B-Measurement)

Decades of practical experience with angle-count sampling, under very different conditions throughout the world, have produced not only a large number of publications in the international forestry literature but a number of improvements in the Spiegel-Relaskop as well. The authors book "**The Relascope Idea**" gives a survey of the development of the methods of Relaskop techniques. In this manual only the most important practical procedures will be discussed.

1.1. For Quick Basal-area and Volume Estimates

In this illustration we will use only band 1, found on the Relaskops described in this manual. Standing at a sampling point in the forest, the observer makes a sweep of the surrounding trees and compares the breast height diameter (d.b.h.) to **band 1**, always along the measuring edge. The brake must be released to insure automatic slope correction. The observer wishes to count each tree whose apparent width is larger than **band 1**. In Fig. 6 you can see that the tree diameters marked by the numbers 1, 3, 4, 5 and 6 are larger than 1 RU-width, and should be counted. Tree number 2 (placed to show this effect) is exactly 1 RU-width, and is a genuine "borderline tree". Therefore it will be counted as a "half tree" of 0.5 in the tree count. You can also see that all the other trees are considerably smaller than 1 RU, and should not be counted. The result of the sample is a count of 5.5 trees.

All that is required is a simple count of trees larger at d.b.h. than band 1. The locking brake release (3 in Fig. 3) must be pushed to insure an automatic slope correction.

The number of stems counted at each sample point, separately by species, can simply be multiplied by the estimated form height (where **form height is V/G**) to get the volume per hectare for each tree. The sum gives the total volume per hectare.

For example: In a full sweep from one sampling point we find 12 spruce, 8 fir and 4 larch which are larger than band 1. The count also implies the basal-area density of all three species, namely:

$$\begin{array}{r} 12 \text{ m}^2/\text{ha of spruce} \\ 8 \text{ m}^2/\text{ha of fir} \\ \underline{4 \text{ m}^2/\text{ha of larch}} \\ 24 \text{ m}^2/\text{ha of basal-area in total} \end{array}$$

This gives the following approximate volume density per hectare:

a) As a fast approximation, if we estimate the height of all trees to be 30 meters, and the form height as half the total height (15 meters), we would get:

$$\begin{array}{r} 180 \text{ m}^3/\text{ha of spruce} \\ 120 \text{ m}^3/\text{ha of fir} \\ \underline{60 \text{ m}^3/\text{ha of larch}} \\ 360 \text{ m}^3/\text{ha of total volume} \end{array}$$

b) For a somewhat more exact result, if the average height is estimated or measured separately by species, we might get spruce at 31 meters, fir at 29 meters and larch at 30 meters. We can then multi-ply the assumed form factors of 0.5, 0.6 and 0.4 to convert these total heights to form height as follows:

$$\begin{array}{l} \text{Spruce: } 31 \times 0.5 = 15.5 \text{ meters (form height)} \\ \text{Fir: } 29 \times 0.6 = 17.4 \text{ m} \\ \text{Larch: } 30 \times 0.4 = 12.0 \text{ m} \end{array}$$

and therefore:

$$\begin{array}{r} 12 \times 15.5 = 186.0 \text{ m}^3/\text{ha of spruce} \\ 8 \times 17.4 = 139.2 \text{ m}^3/\text{ha of fir} \\ \underline{4 \times 12.0 = 48.0 \text{ m}^3/\text{ha of larch}} \\ 373.2 \text{ m}^3/\text{ha of total volume} \end{array}$$

Such a result is only valid for a single point of observation. In a stand covering an area of about 2 hectares one estimate of this kind is not sufficient. It would be better to make the same measurements at approximately 4 sample points, distributed uniformly through the area, and then obtain an average for each tree species in this manner.

1.2. B-measurement for Well Controlled Samples

1.2.1. Choice of Basal-area Factor

The angle-count could be carried out exactly as described in Section 1.1 by using bands 2, 3 or 4. If, for example, band 2 was chosen as the critical angle for the tree count, then approximately half the number of trees would be expected. This tree count would be multiplied by the basal-area factor of 2 in order to get the basal-area density per hectare. The same reasoning would apply to band 3 or 4.

In rare cases, one or more of the **quarter bands** may be used for angle-count sampling. The basal-area factors would be: with one quarter band 1/16, with two 4/16, with three 9/16, four quarters is the same as band 1, with 5 quarters (1 RU plus 1 quarter) 25/16, with six 36/16, and with seven 49/16. The distance within which a tree will be counted depends, as seen in formula 5, partly on the tree diameter **d** (usually d.b.h.) and partly on the distance factor (**Df**). The combination of the two items determines the radius of the marginal circle **R**. The **Df**, in turn, is a direct function of the basal-area factor **k**. Using **d = 30 cm** for tree diameter:

At basal-area factor k in m ² /ha	1	2	3	4	9	16
Width RU	1.00	1.41	1.73	2.00	3.00	4.00
Distance factor Df	50.00	35.36	28.87	25.00	16.67	12.50
Critical distance R in m	15.00	10.61	8.66	7.50	5.00	3.75

The choice of the basal-area factor depends first upon visibility in the field, and secondly upon the purpose of the tree count. If the ACS stems serve not only for

the determination of basal-area density, but also are sample trees for more general purposes in a large scale inventory, there must be strict demands on the accuracy of the selection. This can only be achieved by the use of small marginal circles and large basal-area factors.

There are also statistical considerations, which indicate that average stem counts between 7 and 14 are best. This also may influence the choice of the basal-area factor see e.g. "*The Relascope Idea*", p. 13.

1.2.2. Arrangement of the Sampling Points

This is best done by a systematic sampling grid. A fixed grid of squares, rectangles or equilateral triangles is placed over the sampling area and a sample point is installed at each node of the grid (chosen on the map and transferred to the field, of course).

The density of the sampling points will depend upon the variability of the sampling unit, the tree diameters found, and the sampling accuracy desired. For older stands, using a basal-area factor of 4 and full sweeps, the following can be recommended:

Sample points/hectare	Spacing of the square grid	Size of sample area (in ha)
4.0	50.00	up to 4
3.8	51.30	from 4 to 8
3.5	53.45	from 8 to 16
3.1	56.80	from 16 to 32
2.6	62.02	from 32 to 64
2.0	70.71	more than 64

This recommendation is not in accordance with statistical calculations of sample size for large inventory areas, but is based on practical experience in forestry. The accuracy can be further improved by using basal-area **factor 3**, or **even 2**, at the same density of measurement points.

1.3 Critical Height Sampling

Good theories have an effect on the future, and are forerunners of practical work – as can be seen in this case. Kim Iles has found that using **Kitamura's formula**, which samples critical height as a measurement, is an ideal solution for a **smoothly increasing growth sample with continuous forest inventory**. After some initial measurements using the Tele-Relaskop, the subsequent field work can be done using the Spiegel-Relaskops with Metric CP or Wide Scale.

The critical height is defined as the height of the stem below the point where the critical angle used in ACS exactly matches the cross-sectional diameter. According to the formula derived by Kitamura, the sum of all critical heights (of one sweep) times the basal-area factor k gives the volume density in m^3/ha directly.

In respect to measurements using permanent observation points in the forest, it is desirable that the size of the area sampled grows proportional to the tree cross-sections and the larger distances between them, a requirement that angle-count sampling fulfills very well in general. Unfortunately, this growing is discontinuous when the d.b.h. represents an equal density in $\text{m}^2/\text{hectare}$ (as determined by the basal-area factor k) as it does with the usual methods. For example, if a tree grows enough to become a "borderline tree" it **suddenly "jumps"** into the sample with the full weight of its basal area and number of trees per hectare. This has a large effect upon the results, especially with large basal-area factors.

For the sampling of forest growth as suggested by Kim Iles, the sampled elements are the critical heights h_c . When multiplied by k they represent the volume density in m^3/ha , and have the special advantage that the change in the sampled area is not discontinuous (in leaps and bounds) but will change smoothly. New sample trees "creep" unnoticeably into the sample with the small weight of their initial critical height, and later gain steadily in importance. The practical measurement of critical heights in the forest can not be made directly, but must be made indirectly using the advantages of taper functions (see *"The Relascope Idea"*, p. 113 and 123 – 125). The values must usually be obtained by 3-point on single trees or parts of stems see p. 31.

Sampling for increment measurements from permanent sample points requires much more work for the initial installation than for the remeasurements. For instance, it is possible to make tables of the locally appropriate r -values (or other parameters for taper functions) of tree species and parts of stems (e.g. lower, middle and upper part) and to use these without change over a considerable period. The constant distance between the sample point and the tree is determined exactly at the first measurement and is unchanged for all subsequent measurements. The appropriate measurements at a later time require only the Spiegel-Relaskop (Metric CP or Wide Scale) to obtain the measurement of every diameter in RUs, as well as to obtain a careful measurement of tree height on all sample trees.

2. Distance Measurement (a-Measurement)

2.1. Horizontal Target

For this purpose Metric Standard makes exclusively use of the basal-area factor 4. If the band width (with the pendulum swinging freely) exactly matches the width of the horizontal target, then the horizontal distance is 25 times the width of the horizontal target. For example: with a horizontal target of 80 cm, the distance at which this will exactly match the factor 4 band will be $80 \times 25 = 2000 \text{ cm} = 20 \text{ m}$.

By using a horizontal target with a graduated scale, the width matching basal-area factor 4 can be read off in centimeters, then multiplied by 25 to calculate horizontal distance. Scale graduations of 4 cm correspond in this case to horizontal steps of 1 meter.

Using the Spiegel-Relaskop **Metric CP** the constant width of a horizontal target can be read off in **distance percentages** (see Fig. 8). The size of the target, divided by the number of distance percentages, indicates the distance. The scale also relates **each 1% of the horizontal distance in centimeters to one meter horizontal distance in meters**. For example: The horizontal staff of 120 cm gives a reading of 9.2%; therefore 1 % corresponds to a length of $120/9.2 = 13.04 \text{ cm}$, and the horizontal distance is equal to 13.04 m.

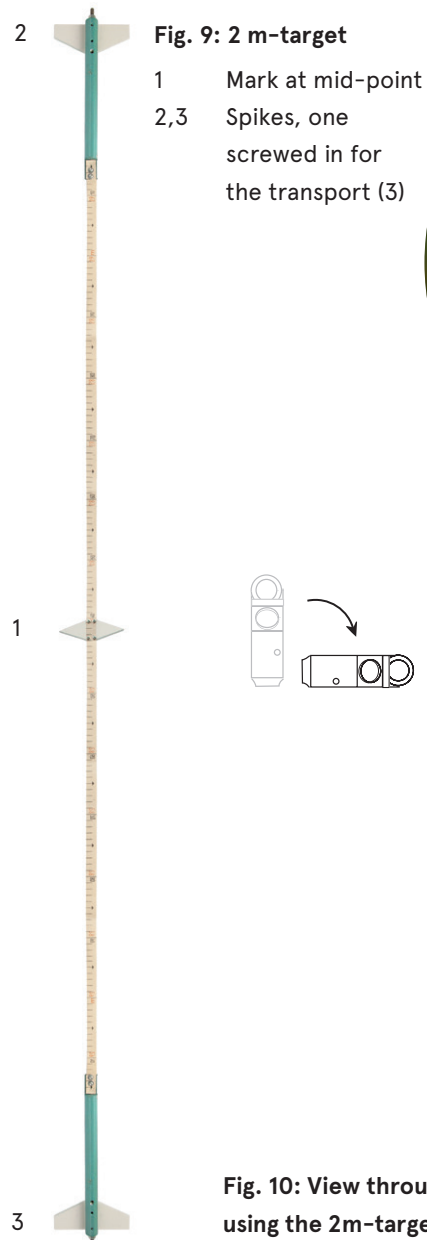


Fig. 10: View through the Spiegel-Relaskop Metric Standard using the 2m-target for distance measurement

2.2. Vertical Target

For this purpose, a **2-meter target** is used, which can be obtained with the Relaskop. The unit is equipped with two highly visible marks on a handle at each end and a mark at its midpoint (1). Two spikes (2 and 3) are screwed in for transport, and then attached to the back of the target to fasten the target to the tree stem.

The Spiegel-Relaskop **Metric Standard** makes it possible to locate the horizontal distances of 15, 20, 25 and 30 meters using the 2-meter target by following this procedure: Find the approximately correct distance from the tree axis without regard for slope and visibility. From this temporary point, press the brake release and view the midpoint of the 2-meter target (see Fig. 9). Lock the brake when the measuring edge is exactly on the mark at the midpoint of the target. Turn the instrument counter-clockwise by 90 degrees to a horizontal position, and again view the target with the right eye. It is an advantage if the left hand is holding the right one, and the index finger is supporting the instrument near the sun shade.

The usually horizontal measuring edge now stands vertically, and the bands are on the right side of the field of view (Fig. 10). All further measurements are made between the edge of band 2, labeled "unten" and the edges of the two white rangefinder bands in the upper part. Measurements are always made exactly along the measuring edge, which is now vertical. The measuring edge is matched with the 2-meter target so that the lower mark of the target matches the lower edge of band 2, and the upper mark of the target matches the other edge of the rangefinder band for the desired distance. Walking back and forth slightly will bring the marks into exact correspondence with the edges of the rangefinding bands. One can normally assume that the angle of inclination will not change considerably. Should this be the case, one should once more sight at the midpoint of the target with the pendulum released and repeat the procedure.

Fig. 10 shows an illustration of the scale seen through the Spiegel-Relaskop when the distance from the stem is exactly 20 meters. In the same way, the horizontal distances of 15, 25 and 30 meters can be located.

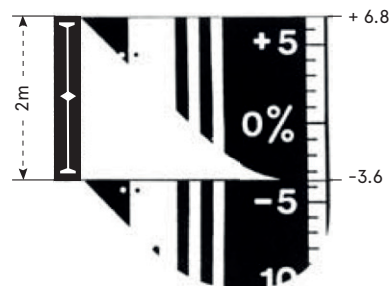


Fig. 11: Distace measurement using the 2 m range-finder target and the percentage scale of the Spiegel-Relaskop Metric CP

When using the Spiegel-Relaskop **Metric CP** the height interval i of the vertical target (in this case 2 meters) can be measured in percent from the observation point using the **P** scale and estimating to the nearest tenth of a percent. The length of the target i divided by the measured percentage p gives the height corresponding to 1%, and multiplying by 100 gives the horizontal distance.

For the example in *Fig. 11*, the horizontal distance is calculated as follows:

$$\begin{aligned} i &= 2 \text{ meters} \\ p &= +6.8 - (-3.6) = 10.4 \\ a &= (2/10.4) \times 100 = 19.2 \text{ m} \end{aligned}$$

Note: Whenever the target is not situated on the side of the tree along the axis, but on the side facing the observer, this additional distance must be added to the horizontal distance!

3. Height Measurement (h-Measurement)

Important hint: Whenever the height or distance measurements are made in sloping terrain, the automatic correction of the Relaskops for an inclined angle of view is of special advantage!

Using the Spiegel-Relaskop **Metric Standard**, height measurements are made from the standard distances of 15, 20, 25 and 30 meters using the three height bands

labeled Ts20, Ts25 and Ts30. The Ts30 band is also used at a distance of 15 meters, but the readings are divided by two. At the appropriate distances, the readings on these tangent scales give meters directly, with fractions being estimated.

The upper reading minus the lower reading gives the height. Since the base of the tree mostly lies below a level horizon, making the reading negative, the absolute values of the readings must be added.

With the Spiegel-Relaskop **Metric CP** all height measurements on standing trees, such as total height, stem height at particular diameters, crown length as well as the determination of slenderness of Pressler's height, etc., can be measured from any distance using the **P** scale (i.e. in percentages of the horizontal distance). If the percentage readings to the top and the base are designated p_o and p_u , then the general formula for heights is:

$$h = a (p_o - p_u) / 100$$

Note: All readings are correct only at the measuring edge! Since the parts of the scale above the measuring edge are not visible, one must observe the sequence of the numbers to interpolate properly.

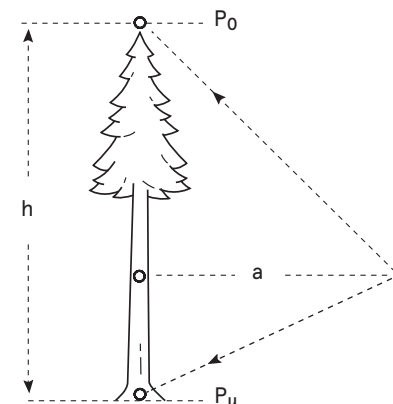


Fig. 12: Height measurement with the Spiegel-Relaskop Metric CP

4. Measurement of Upper Stem Diameters (d-Measurement)

The Spiegel-Relaskop **Metric Standard** uses **band 1 (= 1 RU)** and the quarter bands to the right of it. The width of the quarter field as a whole corresponds to 1/50 (= 2%) of the horizontal distance, half the field to 1/100 (= 1%), and a quarter to 1/200 (= 0.5%).

Note: Half of band 1 gives a width in centimeters which corresponds to the distance in meters.

The relationship is therefore:

at a distance of 10 m, half of band 1 = 10 cm.

at a distance of 15 m, half of band 1 = 15 cm

at a distance of 20 m, half of band 1 = 20 cm

at a distance of 25 m, half of band 1 = 25 cm

at a distance of 30 m, half of band 1 = 30 cm

All other relationships for the total width of the measuring field corresponding to each tree distance follow this pattern, for example: At a distance of 20 meters, the width of band 1 represents 40 cm, each quarter to the right represents 10 cm, and fractions of 10 cm can be estimated. The combined measuring fields (band 1 + the quarters field) correspond to a width of 80 cm.

The Spiegel-Relaskop **Metric CP** has a **very wide measuring field for the determination of stem diameters**, as seen in Figure 8. Because of this, it is possible to be quite near to the stem when determining the diameters, and there is **no requirement to use fixed distances**. The general formula for a stem diameter **d** is as follows:

$$d \text{ (in cm)} = a \text{ (in meters)} \times b \text{ (in \%)}$$

In *Fig. 8* the scale of the distance percentages is shown having its zero point in the middle of the quarters field. During measurement, the left edge of the stem should

match the edge of one of the bands with an even percentage value (e.g. 6%) so that the right edge of the stem falls within the quarters field (the right half of band 4) to obtain the best estimate of the fractional part of the percentage. In the example, the diameter width would be read as 7.7%, which is multiplied by the distance to the tree in meters to calculate the diameter in centimeters.

Usually, **5 RU (= 10%)** plus the quarters field will suffice for width measurements of this kind. Taking the small black band to the right of band 2 gives an additional **1.17 %**, and in combination with band 2, which is **2.83 %**, gives a total of **4 %**. To utilize the widths fully in some special case, one can add to the standard 16 % of the scale an additional **3.46 %** with the use of band 3.

All measurements of width are made with the pendulum released!

5. "Slenderness" ("h/d" Measurement)

In forestry, the "slenderness" is the height of a tree in multiplies of the breast height diameter. This reference number is often used to judge the danger of snow damage to conifer forests. As a rule, the trees concerned are only examined, whether their "slenderness" exceeds a certain value (for example "70").

The useful parameter of tree "slenderness" is **easily determined with** the Spiegel-Relaskop **Metric Standard** in this way: Regardless of the viewing angle, release the pendulum and find the distance from the tree where the d.b.h. coincides with band 1 plus the quarters field. Then use the units of the tangent scale Ts25, which is just to the right of the quarters field, to measure the height from the top to the base of the tree. This measurement gives a direct reading of the "slenderness".

When using the Spiegel-Relaskop **Metric CP**, follow the same procedure, but use the percentage scale to measure height and divide the result by four to calculate the slenderness.

6. Form Height and Volume Measurement Using Pressler's Formula ("fh/d" Measurement)

This technique for simple determination of the volume of standing trees was introduced into forest mensuration by Pressler in the 19th century, and is a **particularly efficient application of the Relaskop**. Locate the point on the stem at which the diameter is exactly half as large as the diameter in breast height.

The height to this point (Pressler's height) above a point estimated to be 50 to 70 cm underneath the base of the tree **times 2/3** gives in best approximation the **form height (fh)** which we must multiply by the **basal-area in breast height (g)** in order to get the **stem volume (v)**. A detailed proof of the theory is found by Pressler himself and is contained in "The Relaskop Idea".

Here is an example with an illustration, which shows that the **fh/d measurement gives a good approximation of stem volume even on abnormally crooked tree stems**, and is therefore a **"lifejacket" when all other methods fail**: By changing the appropriate distance from the tree, the breast height diameter is made to match band 4, Pressler's point is then found by matching the upper stem with band 1. The pendulum must be fixed before tilting the instrument. In order to measure Pressler's height, one must imagine the crooked stem to be straight, as indicated in the illustration. **A measurement connected to an estimate is still better than no measurement at all!**

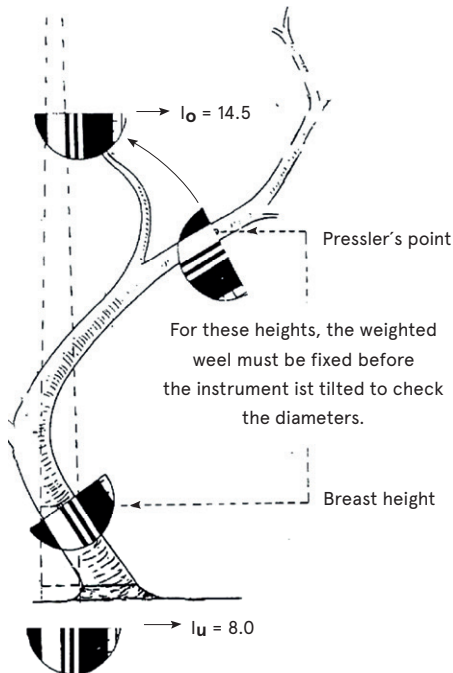


Fig. 13: Form height measurement with Spiegel-Relaskop Metrisch CP

7. Three-point Measurement with Tripod

After selecting a suitable observation point (preferably on the uphill side of the tree) take the readings for the inclination p to the diameter at breast height and for the width b at that point. Then take the readings for the inclination p_2 and width b_2 of a second point higher on the tree. Each of the readings for p and b are taken with the instrument in the same position. In this example $p = -34$ is read on the percentage scale. For measuring width, the left edge of the tree must be aligned with the left edge of one of the RU bands so that the right edge of the tree falls within the quarters field.

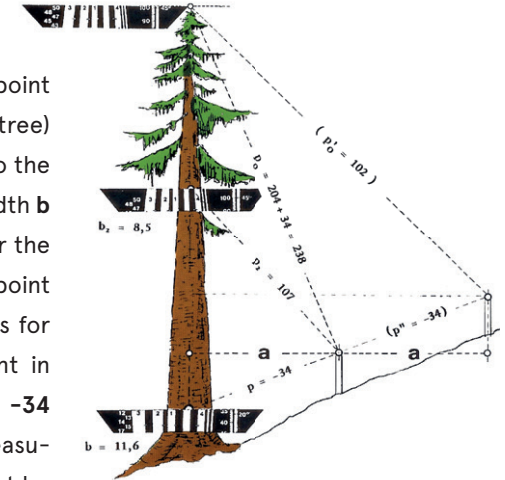


Fig. 14: Example of a three-point measurement on a single tree

Now count the full RUs to the left of 0 (Fig. 8) (1 RU = 2%), the quarter fields to the right of 0, and estimate to the nearest 1/10 RU. In this example the relative value of b is therefore equal to **11.6 %**. Multiplying by the distance a in meters will give the absolute value of the diameter in centimeters:

$$d \text{ (in cm)} = a \text{ (in m)} \cdot b \text{ (in \%)}$$

At the second point higher up the tree, follow the same procedure ($b_2 = 8.5 \%$). From this same point near the tree, if possible, measure the inclination p_0 to the top of the tree and calculate the tree height h (see also page 24):

$$h = a \cdot (p_0 - p) / 100$$

If it's not possible to see the top of the tree from the current position (at distance a), or the angle of vision is too steep to read the percent scale, then follow this pro-

cedure: Select a new position where the distance a is doubled, but maintain the same angle of inclination p'' to the d.b.h. which you had before (p). For this optical measurement look for equal CP values! One can get p_o by doubling p_o' and adding p'' .

If p'' was different from p , the procedure would also be correct as long as the reading was taken in the direction of the former position of the instrument (not the d.b.h.). Remember to take the different heights of the instrument into account!

If it is also necessary to make width measurements at the doubled distance, the calculation of b in the distance a is made by doubling the readings.

In the same way, this method can be extended to measurements from triple (or other) multiple distances of a , which may be an advantage in connection with continuous forest inventory for increment measurements (Critical Height Sampling by Kim Iles, *see p. 22-23*).

 We also offer Spiegel-Relaskop **repair services**. For more information, please contact us at office@silvanus.at.

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