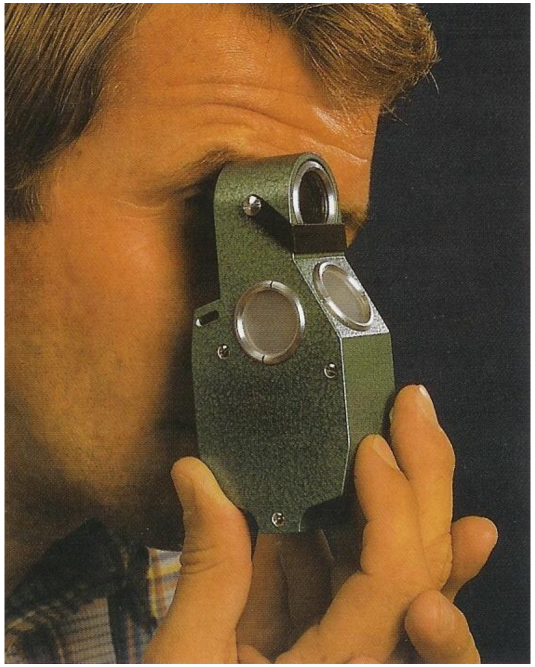
CONTENTS

SPIEGEL-RELASKOP®

by Dr. W. Bitterlich

Wide Scale



Authors: **Walter Bitterlich**
Co-authors: **Benno Hesske, Gerlinde Ruthner**
English edition: **Richard K. Hermann, John F. Bell, Kim Iles**

THE SPIEGEL-RELASKOP®
With WIDE SCALE

By Walter Bitterlich

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, however, the Relaskops offer 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 total 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:

- Relaskops are the principle instrument of "variable plot sampling", which has the special advantage of selecting a basal-area weighted distribution (and which has recently 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.

In order to utilize the precision of diameter and height measurements inherent in the Relaskops a **micro attachment** was constructed, which can be attached to a tripod with a special **tilting head**. These accessories in combination with the Spiegel-Relaskop Metric CP are suitable for precision measurements, which previously required the Tele-Relaskop, under the assumption that the power of the naked eye is sufficient and that special techniques are used (see separate booklet "Precision Measurements", obtainable at Relaskop-Technik).

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.

These are: **MS - Metric Standard**
WS - Wide Scale
CP - Metric CP
AS - American Scale

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

Wide Scale, also called “virgin forest scale”, is a special scale developed for the measurement of large tree diameters at different heights, for angle-count sampling with large basal-area factors, and for simple surveying purposes.

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

The **American Scale** has functions analogous to MS, but the measurements are given in the American forestry dimensions of **feet and inches.**

A comparison between the possibilities of the different scales see Table 1 (page 4).

In this manual the optical-mechanical functions and the field use of the Spiegel-Relaskop are described in detail and particularly the WS scale. Detailed descriptions for the MS, CP and AS scales can be obtained by request. The appropriate manual is, of course, delivered with each instrument.

At the end of this manual a description of a special **scale light** for use in **bad light conditions** is added**.**

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 RELASKOP-TECHNIK VERTRIEBSGes.m.b.H., Salzburg, Austria.

Table 1: The SPIEGEL-RELASKOP® by Dr. Bitterlich and its different scales

Common to all Relascope Scales:

All readings automatically slope-corrected
Diameter measurement within ½% of distance to tree

Differences between Relascope Scales:

	AMERICAN	WIDE	METRIC STANDARD	METRIC CP
Vertical Degree Scale (-60 to +70 degrees) Vertical Percent Scales (-170 to +270 percent	yes	yes	no	yes
Topographic Scales	yes	no	no	no
Range of BAFs	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	½% - 9%	½% - 24%	½% - 4%	½% - 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 *⁰	9 standard distances 4 -20 m *¹	15,20,25,30 meters *²	direct reading with attachment *³

*⁰ smaller values are possible with the quarter bars
*¹ with use of vertical or horizontal target, resp. Wedge Prism Attachment with vertical base
*² using RELASKOP distance scale and a vertical 2 m-target
*³ 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)

1.0. Establishing the Tree Count

Angle-count sampling (ACS), in **North America** often known as **“Variable Plot Sampling” or “Point Sampling”,** provides a direct measurement of the forest basal-area density at a particular sample point (in square meters per hectare 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 2 R = 100 d , 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 m²/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 (BAF)** to give **G** in m²/ha. When using ACS, the general formula is

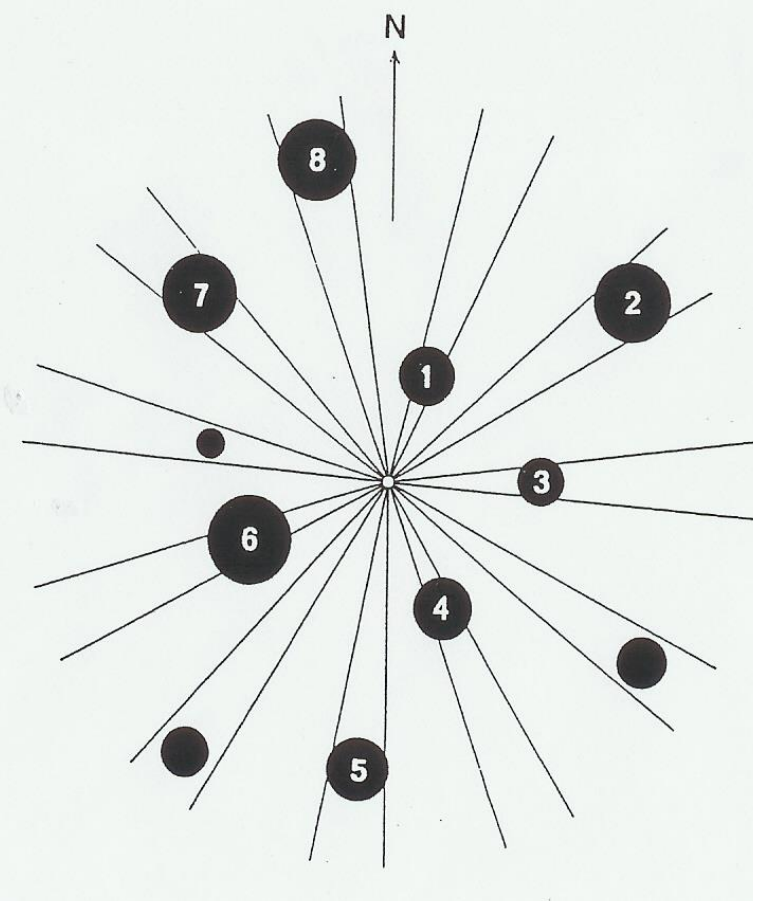
$$G \text{ (in m}^2\text{/ha)} = z \times k \qquad (1)$$

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

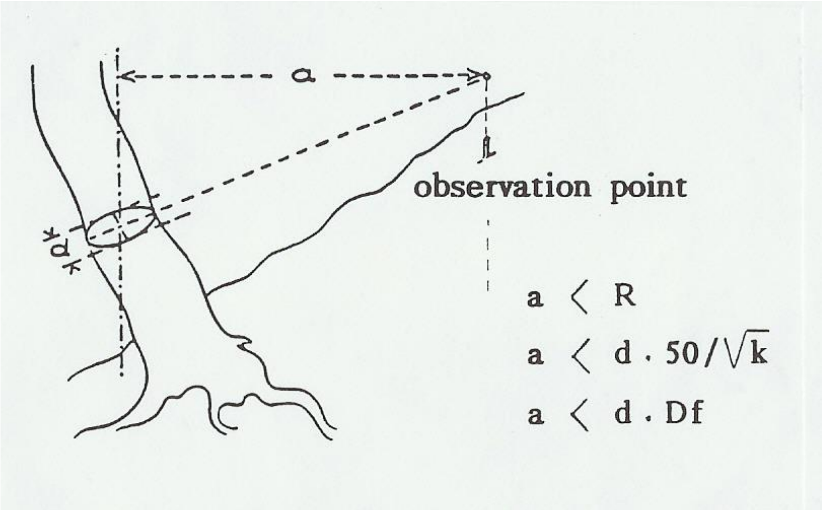
$$a < R \qquad (2)$$

where **R** is a constant multiple of tree diameter.

The following diagram may serve as an example of a complete ACS 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 m²/ha.



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



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.

2.0. 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:

$$k \text{ (in m}^2\text{/ha)} = (\pi\ d^2/4) / (\pi\ R^2/10^4) = (50\ d/R)^2 \qquad (3)$$

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:

$$\mathbf{k \text{ (in m}^2\text{/ha)} = n^2} \qquad (4)$$

where **n** can also be any fraction you decide to use.

- Note:

The square of the number of Relaskop-Units n used for angle count sampling is the basal area factor k in m²/ha.

The bands of the Relaskop scale 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”).

Using formula (3), the critical distance **R**, given a particular tree diameter **d**, and basal-area factor **k** is:

$$R = d \times 50/\sqrt{k} = d \times Df \qquad (5)$$

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

In regard to k = 1, 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.

3.0. Treatment of Borderline Trees

Generally speaking, **“borderline trees”** are trees whose breast height diameter (dbh) appears neither larger nor smaller than the RU-width as seen through the Relaskop. 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 dbh, 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 dbh 36 cm the critical distance
R = 36 x 25 = 900 cm. If he measured horizontal distance is 897 cm, then the tree would 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.

4.0. 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 ($\mathbf{n_i}$) by dividing the **k** factor by the stem basal-area for that tree ($\mathbf{g_i}$):

$$n_i = k/g_i$$

If there are a total of **z** stems counted at a sample point, the combined number of stems per hectare is calculated as follows:

$$St/ha = k/g_1 + ... + k/g_i + ... + k/g_z \qquad (6)$$

It should be mentioned, in regard to the volume sampling methods of **Kitamura** and **Kim Iles**, that the number of stems per

hectare can also be derived from summing all **n** , where n = k x h_{ci}/v_i , with $\mathbf{h_{ci}}$ being the critical height of each tree, and where $\mathbf{v_i}$ is its volume – both values are usually found indirectly by calculation and stem form measurements (see page 24).

Description of the Spiegel – Relaskop and of its Handling

The Spiegel-Relaskop is a compact, ruggedly constructed instrument (see Fig. 1), that 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. 2, 3 and 4).

During hand-held use (Fig. 1) 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.

The use of a breast support is illustrated in Figure 2. More exact measurements are possible by the use of a tripod, which should be equipped with a movable center-column (Fig. 4a) or with lockable balljoints (Fig. 4b). In either case, 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 ofthe observer, and because the horizontal distance **a** from the eye to the observer is the distance from a hypothetical vertical line through the eye to the center of the tree cross-section observed.

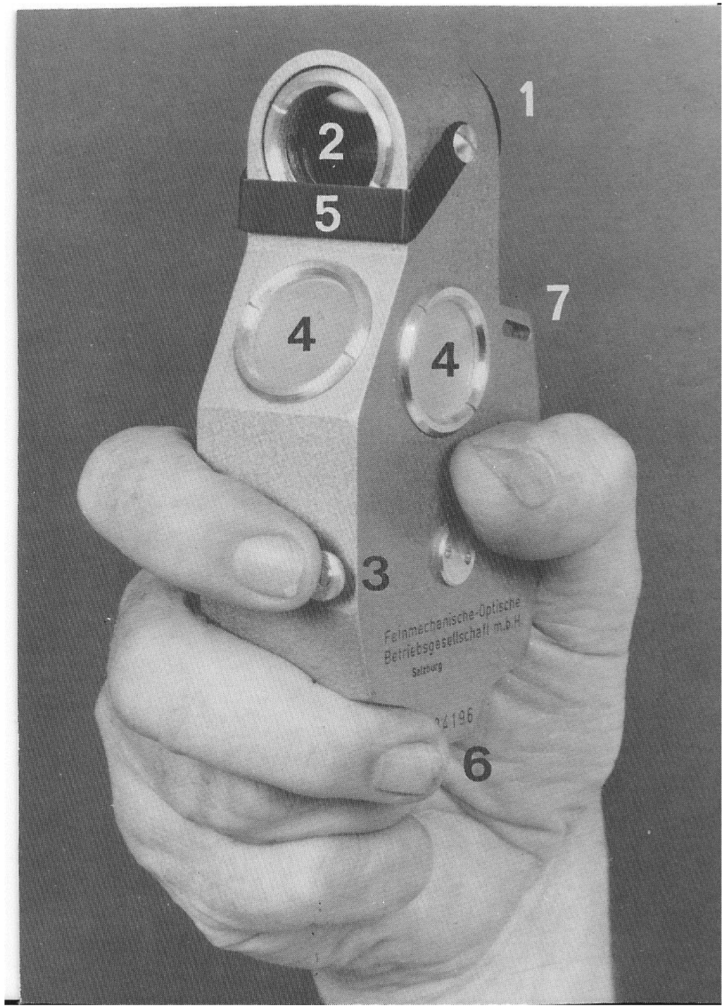


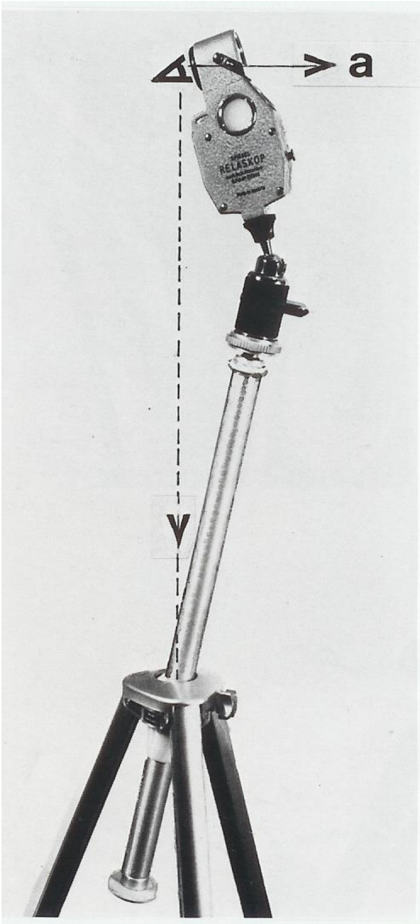
Fig.1: The Spiegel-Relaskop and its handling

1	eyepiece	5	sun shade
2	clear window	6	tripod socket
3	locking brake release	7	neckstrap attachment
4	light windows		

Fig. 2:
The handling of the Spiegel-Relaskop using the breast support

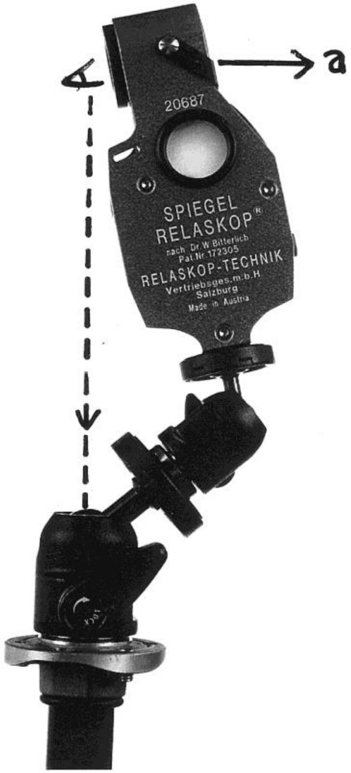
Fig. 3:
Folding breast support with leather straps

Fig. 4: The Spiegel-Relaskop, mounted on a tripod
a – horizontal distance from the eye to the centre of the tree cross-section



4 b: Tripod with lockable balljoints

4 a: Tripod with a movable center-column



Inside the instrument there is a freely rotating wheel, which bears **scales consisting of alternating black and white bars (bands),** used **for the measurement of widths**, and with **scales calibrated for the measurement of heights** (see Figures 5, 6 and 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 and 8). For better illustration, the measuring edge is marked **M-M** in Figure 6 (but not on the actual Relaskop scale!). 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 WS scale of the Spiegel-Relaskop is shown in Figure 5.

- Note:

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

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.

Description of the Wide Scale

The Wide scale is designed for use in measuring **large diameter trees** and to provide **large basal-area factors.**

The main area of the scale resembling the shape of a stave, consist of alternating white and black bars (Fig. 5). The width of this scale i referred to as a "field of measurement". The right margin of the field o measurement consists of 4 narrow bars, 2 white and 2 black. These 4 bars form the "quarter field", which has the same width as the larg white bar adjoining to the left. This width is equivalent to on **Relaskop-Unit (RU)**; i.e., to the **basal-area factor (BAF) k = 1** (m²/ha) in variable plot cruising. The width of the quarter fiel corresponds also to the plot radius factor **Df** 50 m, or to about 2 % o the scale **P** (Fig. 5). The width of each of the 5 black and 5 white bars t the left may be assumed to be the same as that of the quarter field or th first large white bar.

The stave-like taper of both ends of the group of bars correspond to a reduction of width by the **cosine** of any angle of inclination whe sighting an object. The group of bars is being cut horizontally by th **measuring edge** at a point that depends on the degree of tilt needed fo sighting. When you view the target from the measurement point th scale is adjusted to show you the same number of bars you would see i you were floating vertically above of below that point and sightin horizontally. The effect of all this is to **automatically convert slop distance to horizontal distance.**

To the right of the quarter field are two scales. The one marked **P** gives percent slope and the other marked **D** gives degree of angle (see Fig. 5).

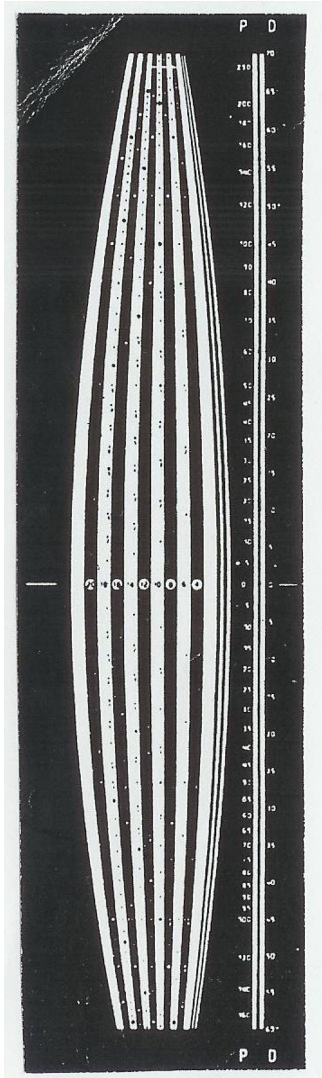


Fig. 5: Wide scale, full view

The zero corner of the measuring field is formed by the boundary between the quarter field and the first white bar ("0" in Fig. 6). Full units are read from the right to left, while quarter units are read from the zero corner to the right. To facilitate counting full units from the zero point to the left, each bar carries a number. The number of each bar reappears along the bar's left border at intervals that are equivalent to the distance of the 5-degree intervals on scale **D**. These numbers are hatched and slightly smaller (e.g., numbers pointed at by the two lower pairs of arrows in Fig. 6) than the subsequently discussed "Ladder numbers" to avoid confusing these two different kinds of numbers.

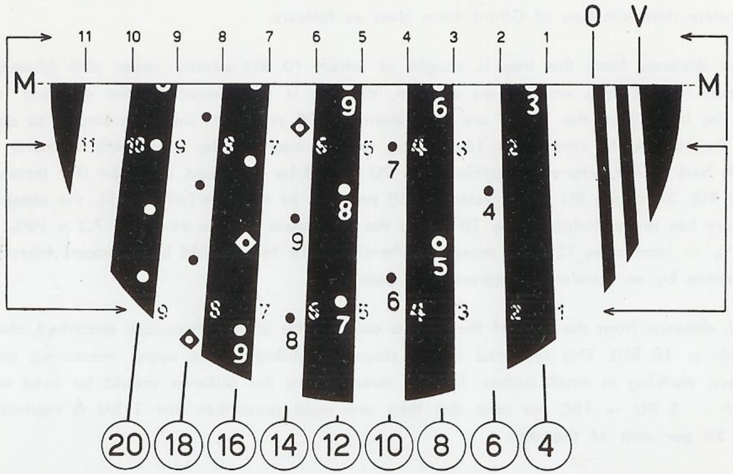


Fig. 6: Wide Scale Terms and Symbols. MM = measuring edge. 0 = zero point of the scale. From the zero point whole RELASKOP units (RU) are counted to the left, and quarter units (RU/4) are counted to the right. 1, 2, 3, ...11 = Numbering of bars and their left edges or corners (along M-M). Numbers to designate bars are hatched and are pointed at by the four lower horizontal arrows. V = the right limit of the quarter field. The encircled even numbers 4, 6, 8, ...20 indicate horizontal distances in meters that have to be used with the ladder scales in the bar above the encircled number. Each encircled number is double that of the number of the appropriate bar (e.g., bar 2 for a = 4, bar 3 for a = 6, and so on). The ladders consist of points, rings and diamonds. Ladders are numbered only from 1 to 9. The values 10, 20 and 30 are marked by the diamonds, the values 15 and 25 are marked by rings. In this illustration, the scale is so dissected by the measuring edge that for distance a = 4 the ladder value is h = 3. Consequently, one reads therefore h = 15 at a = 20. All values are in meters, but other units of length may be used instead.

Bars 2 to 10 contain **tangent scales for measuring tree diameters at steps of one meter below and above the observer's horizon**. These height scales, referred to as **"ladders",** appear as rows of points in the right portion of a bar. They are marked by numbers from 1 to 9, and by symbols from 10 upward. The values 10, 20 and 30 are marked by squares that stand on one corner and have a point in the center. The values 15 and 25 are represented by small rings. Intermediate values can be obtained quickly by counting from the nearest value of 5. Maximal height of each ladder is "30", or 70 degrees plus and 60 degrees minus, respectively.

Ladder values indicate meters above or below the horizon, if observations are made at the appropriate distance from the tree. The appropriate **horizontal distances a** from stem to eye of the observer (see Fig. 4 and 8) are given as **even meters from 4 to 20**. The numbers appear in circles at the zero point of the ladders (Fig. 8). The appropriate ladder can even be found without reference to the number at zero point. Doubling the position number of each bar indicates the appropriate base line for the respective bar-ladder. For instance, the ladder for a = 12 m can only be in the sixth bar, for a = 14 m in the seventh bar, and so on.

Measurement Techniques and Their Use

The name **"Relaskop"** stems from the notion of **"Relative"** optical measurements, where all horizontal (diameter and basal area factor) and vertical (height) measurements are made as a percent of the horizontal distance to the tree. Almost all functions of the Relaskop can be seen in this light. It is true that some of the scales are **direct reading** from certain distances, but these readings are always best understood as relative measurements first, which are then converted into units of measure by comparison to some actual horizontal distance.

Example:
The Relaskop might measure the fact that the diameter of the stem at the base of the tree is 2.5 % (of the horizontal distance to the tree), the height is 126 % of that distance, and the crown is 45 % of the total height. These are all simply relative measurements, but they tell us a great deal already. We know that the "**height-to-diameter ratio**" of the tree is 50.4 to 1 (126 % ÷ 2.5 %). We know that if the tree falls toward us, it will hit us. We might guess that the crown is long enough to indicate a healthy and responsive tree.

These things are all known **without** knowing the distance to the tree. They can be converted to any unit of measurement we may later choose to use.

Example:
If we find that the distance to the tree is 20 meters, we can compute that the tree is (20 x 1.26) = 25.2 meters tall,
the crown (20 x 0.45) = 9 meters long,
and the diameter is (20 x 0.25) = 0.5 meters.

All uses of the Spiegel-Relaskop can be viewed in this same way. A horizontal or vertical relative measurement is taken, and later con-verted into units (if necessary) by making a direct or indirect measure-ment of horizontal distance.

This is an important point, since many of the measurements in forestry are themselves ratio measurements. As we have just seen, the **Height-to-Diameter Ratio** (sometimes called “slenderness ratio”) and “**Percent Crown**” can be obtained without knowing the distance to the tree, but many field crews still take time consuming and tedious measurements by routine, without thinking about how to do it strictly **by relative measurements**.

Because relative measurements are simpler questions, they ge-nerally have simpler answers and **simpler field work**. In many applications, this translates to real savings in effort of greater pre-cision in measurement. Often, when field measurements (particularly in height) seem difficult, the tendency is to make estimates instead. Crown percent is an example of this. A field crew which does not know how to efficiently use their instrument may end up getting a biased set of **estimates** when they could just as easily have had a precise set of **measurements**.

Worse yet, the field crew may be told to obtain “height to the crown base”, when in fact the organization is just using this to calculate percent crown. The field crew could get that relative measurement much more easily. Whenever a measurement is made you should be asking **“is there some relative measurement which would do as well?”.**

- 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!

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

Decades of practical experience with angle-count sampling (ACS), 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. Other publications, many of which are collected in consecutively numbered volumes of FOB publications (mostly in the German language), can be obtained from Relaskop-Technik free of charge. In this manual only the most important practical procedures will be discussed.

Tree count **in dense forests** usually requires **large factors for basal area**. They are readily available in the **Wide Scale Spiegel-Relaskop**.

The square of the number of Relaskop-Units **n** used for tree count is the basal-area factor (BAF) **k** in m²/ha ($k = n^2$) (see page 8).

The following basal area factors are associated with a given number of RU's (compare also Fig. 6):

Number of Full and Quarter Bars	Basal-area Factor k m²/hectare
1.00	1.00
1.25	1.56
1.50	2.25
1.75	3.06
2.00	4.00
2.25	5.06
2.50	6.25
2.75	7.56
3.00	9.00
3.50	12.25
4.00	16.00

Since determination of diameter at breast height generally is of little value in **oldgrowth or tropical timber**, tree counts to obtain basal-area will employ **measuring heights from 4 to 10 meters above ground.** Finding the desired height for measurement is accomplished most expediently by means of a bamboo pole placed vertically beside the tree. An even fraction of the measuring height, chosen as large as possible, should be indicated on the pole by two clearly visible marks (for instance, i = 4 m at measuring heights of 4, 8, 12 or 16 meters). The known rod-interval (in this example i = 4 meters) is measured with the **P**-scale as accurately as possible (for instance, as 23 %) and then multiplied for the desired measuring height (for a 12 meter height, 23 % x 3 = 69 %). The percent value thus obtained (69 % in this example) is used to measure from the base of the tree (either ground or stump) upwards and to indicate the de-

desired measuring height (12 meters in this example). When the two sightings are above and below eye level, values of the **P**-scale have to be added. However, if both readings are above or below eye level, the difference (ignoring the sign of the reading) must be calculated.

The rod interval obtained in **p** percent (p = 23 in this example) also can be used directly for d-measurements. Since 1 RU = 2 % and i/p gives the length that is equivalent to 1 percent of the respective distance, then **1 full RU = 2 [i/p]** which is [(2 x 400)/23] or 34.78 cm in this example). With this method, there can be made from one point not only a tree count but also a determination of diameters at heights not accessible directly from the ground. If diameters of each log are determined in this way, total tree volume can be computed directly rather than using volume tables (after reduction for bark thickness).

If horizontal distance **a** is carefully mesasured, the position of any desired measuring height **h** can be found by [h % = (h/a)], where h % is the vertical angle from the base of the tree. As an example, if you want to measure at 8 units above the tree base from a distance of 20 units then the difference in the **P**-scale will be (8/20 = 40 %) from the base of the tree. If the base P angle is –16 %, then sight at +24 % above horizontal to find the point of measurement.

1.1. Relative Basal Area

The Relaskop will select any type of tree proportional to its basal-area in the stand. If 30 % of the selected trees are forked, then 30 % of the basal-area in the stand is in forked trees. If 47 % of the trees selected are too small to be harvested, then 47 % of the basal-area in the stand is in trees too small to be harvested. Each tree, once selected, represents the same amount of basal-area – regardless of its size (see also 4.0. page 10). The ability of the Spiegel-Relaskop to **automatically weigh the values of trees by their-basal area** is a major advantage of the Bitterlich ACS sampling method.

The **relative basal-area by species** is given by the abundance of each species in the counted trees. If 20 % of the counted trees are are maple, then 20 % of the basal area of the stand is maple (subject to sampling errors, of course). If the height of the sample trees in each species is approximately equal then roughly 20 % of the gross stand volume will also be in maple.

- Note:

No measurements on counted trees are needed to get estimates of percentages by species.

1.2. Choosing a Basal-Area Factor

The most efficient basal-area factor for sampling chooses from 4 to 8 trees on the average during the sampling process. Other BAFs are not wrong, just less efficient. A few sample counts should tell you if the BAF is about right. In addition, if you know the approximate basal-area of the stand beforehand, you can calculate the appropriate BAF by the formula:

Desired BAF = (stand BA ÷ desired tree count)

This, of course will be rounded off to an easily used scale for the instrument.

1.3. Stand Volume Determination

Many inventory needs are fulfilled by basal-area alone. When actual volume is required, some tree measurements are needed. The usual procedure is to measure a valid sample of the counted trees for volume, using a **volume table** appropriate to that species. A ratio is then established between the volume and basal-area of each sample tree. This is called the **"VBAR"** or **"Volume to Basal Area Ratio"**. The VBARs are averaged for the measured trees. The stand

volume is the basal-area of the stand multiplied by the average VBAR. For methods to make this sampling more efficient, see the book "Log Scaling and Timber Cruising" by John F. Bell.

When no volume tables are available, or when they cannot be reliably made because of the tree form, there is one direct estimate of tree VBAR: this is called **Critical Height Sampling** by **Kim Iles** (see also pages 9 and 10).

For trees that are counted with the Relaskop, measure the distance from the stump to the point where the stem diameter is just "borderline" (or the merchantable point, whichever comes first). This distance is a direct sample for the VBAR of the tree. Average these measurements for the counted trees and you have a direct estimate of average VBAR (in this case you have outside bark volume).

1.4. Approximate Methods

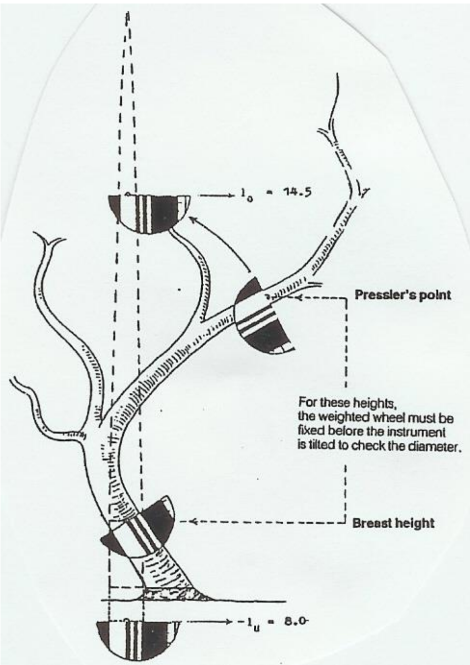
1.4.1. Form Height and Volume Measurement Using Pressler's Formula ("fh/d" Measurement)

This technique for the 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 Spiegel-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".

For the use of the Spiegel-Relaskop in the practical application of this technique there are several publications by the author. These can be obtained for users of the instrument free of charge from RELASKOP-TECHNIK VERTRIEBSGes.m.b.H., Salzburg.

Figure 7 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 the first white bar (0 to 1) plus the quarter field (see Fig. 6), Pressler's point is then found by matching the upper stem with the white bar. 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. 7: Illustration to Pressler's Point

1.4.2. Rough Approximation

There are also other ways to get the volume with less precision, but perhaps adequate to the task at hand. Many inventory needs are only for approximate volumes. The Spiegel-Relaskop makes the tree counting procedure for basal-area quite simple already. Only average VBAR is still needed. An approximate average VBAR can be retrieved from **past samples** and used directly. In this case no measurements are needed except the tree count. This will be particularly appropriate if the stand heights were approximately the same as in the past cruises, since VBAR usually varies directly with tree height.

There is a second, more reliable rough approximation. From old cruises, or special studies, you can determine **the ratio of VBAR to total or merchantable tree height.** This ratio will be fairly stable within a conifer species, especially for gross volume. Net volume will be more variable. With this ratio known, only a random sample of counted trees needs to be measured, and only for height.

If you need just a rough estimate of volume, use 1/3 of the stand height as an estimate of VBAR. Once you have an actual sample available, calculate average VBAR by dividing stand volume by stand basal-area. Compare this to average stand height to get a more appropriate value for the ratio of VBAR to stand height.

1.5. Number of Trees

The number of trees counted with the Spiegel-Relaskop does not translate directly into numbers of trees per hectare. To do this you must know how many trees each counted tree "represents", and that depends upon its size (see also page 9). This relationship is called the **"Tree Factor" (TF)** or in some literature the **"Stand Table Factor"**. Each tree counted with the Relaskop represents a number of other trees of the same size, and together they add up to a basal-area given by the **k** used. The basal-area of the tree must be calculated. Next, the "Tree Factor" is determined by dividing **k** by that tree basal-area.

For Wide scale the TF is calculated as follows:

TF (trees per hectare) = (RU^2) ÷ (basal-area of tree in meters^2)

The basal-area in square meters of a tree diameter in centimeters is calculated as follows:

Basal-area in meters^2 = 0.000078540 x (diameter in cm)^2
[constant is pi ÷ (4 x 10 000)]

Example:

k = 2 m^2/ha, for a 30 cm-tree:
TF = (2 ÷ 0.0707) = 28.3 trees/ha

After this calculation is done for each of the trees on the sample point, add them up to get the number of trees per hectare. For many sample points, average the results. If the numbers of trees are kept for each diameter class, a stand table can be formed showing the numbers of trees in each diameter class.

You can also combine numbers of trees in other ways. For instance, you can accumulate the number of trees below merchantable size or the number of trees which were diseased.

When trees are selected with an angle gauge like the Spiegel-Relaskop, with its automatic weighting by area, but you want to get simple average of the trees (such as would be derived from a simple fixed plot) the number of trees is used to "weight the sample".

Example:

Two trees are selected with the Relaskop on a sample point. The height of a 30 cm tree is 21 meters, and the height of a 50 cm tree is

35 meters at an ACS sample. We wish to know the simple average height such as would be produced with a fixed plot. With k = 2 m^2/ha, they represent the following number of trees per hectare:

One 30 cm = (2 ÷ 0.0707) = 28.3 trees /ha
One 50 cm = (2 ÷ 0.1963) = 10.2 trees/ha
(for a total of 38.5 trees per hectare)

Therefore, the weighted average height is:
[(21 m x 28.3) + (35 m x 10.2 trees)] ÷ (38.5) = 24.71 meters

Other averages can be similarly weighted using the number of trees the "counted trees" represent to get simple averages.

1.6. Large Basal-Area Factors for Subsampling

It may seem that really large basal-area factors are not of use in the ACS system. This is not necessarily the case. Suppose that we only wished to select every 10th tree during the cruise in order to subsample for some characteristic. If we normally used a **k** of 4 to count trees, then if we use a **k** of 40 to select the subsample trees we would get about 1 in 10, subject to some sampling variation. This is a simple method, and is easy to verify for quality control. It may also provide a good way to subsample for VBAR trees during ordinary ACS forest inventory.

2.0. Diameter Measurement (d-measurement)

2.1. Measurement of Relative and Actual Diameter

To measure diameter, align the left edge of the tree with the left edge of the **RU** (white or black band) that is closest to but less than the diameter of the tree. Allow the part of the tree that is less than a full **RU** to fall over into the quarter bands (RU/4). Add the total **RU**'s represented by the diameter of the tree (see also Fig. 8).

To measure the **relative diameter** at any point on the stem of the tree, first measure the apparent size of the tree in **RU**’s. Use the smaller bands to get an accurate reading.

To calculate the **actual diameter** use the following formulas, where **a** is the horizontal distance to the tree:

d (cm) = number of RU’s x [a meters x 2 % x 100cm per meter]

There are some convenient distances for measuring diameters. It is not necessary to make measurements from these distances, but it makes the computations simple. For the Spiegel-Relaskop it is also convenient to use **½ RU** (1 % relative measurement). This **half-band** gives a **width in centimeters which corresponds to the distance in meters.** The relationship is therefore:

at a distance of	10 m, the half-band	=	10 cm
	15 m		15 cm
	20 m		20 cm
	25 m		25 cm
	30 m		30 cm

- **Note**

The average diameter of the trees counted with the Relaskop as an angle gauge will **not** be the average for the stand. To get this average you will have to calculate the number of trees represented by each tree counted (see 1.5.).

2.2. Measurement of Upper Stem Diameters

Measurement consists of two steps**, finding the desired height of the stem and measuring the actual diameter**. Angles are employed in both steps. Since angles give only relative values, they have to be supplemented by an absolute measure. The base line

distance a is best suited as an absolute measure. An **even value in meters from 4 to 20** is recommended because it allows use of the already described ladders and it simplifies computation of diameter. The length of the selected base line should be measured with a tape.

The closer the observer is to the diameter to be measured the greater will be the accuracy of measurement with the Spiegel-Relaskop. However, too steep a sighting should be avoided. For instance, a diameter at 10 meters above the observer’s horizontal eye line should not be measured from a distance of 4 meters, but from 10 or 12 meters.

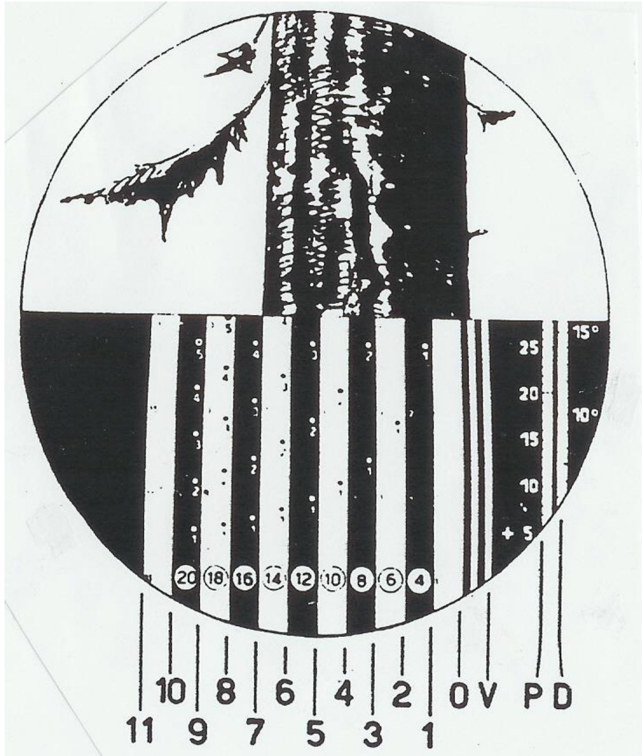


Fig. 8: Example of Diameter Measurement Using Wide Scale

Example Fig 8:

Base line is 18 meters; point of measurement is situated 5 meters above eye level. First count the full RU's to the left of zero and then the remainder in the quarter bars (RU/4), or estimated fractions thereof to the right of zero: the left edge of the stem coincides with the edge of bar 7, or 7 RU to the left of zero. From zero to the right edge of the stem one reads 1 RU/4 + 0.6 RU/4.

RU and RU/4 are converted to centimeters by using the distance of the base line. If distance in meters is **a**, then **1 RU = a x 2 cm** (conversion is simple, since suggested a-values are even and therefore result in even centimeters for 1 RU/4):

for a = 18 meters 1 RU = 36 cm and 1 RU/4 = 9 cm. The diameter is therefore 7 RU x 36 = 252 cm

1 RU/4 = 9 cm

0,6 RU/4 = 5.4 cm

266.4 cm.

Double ladder distances can be employed for measurements of very tall trees. In this instance, the ladder units are equivalent to 2 meters instead of 1 meter. The percent scale **P** has to be used to determine the height of the measuring point when difficult terrain or other circumstances do not permit working with any of the base lines (2 to 20 meters), indicated along the zero line. The **P**-scale indicates the desired height, below or above eye level, as a percentage of the length of the base line. For example: a = 25 m, 1 % = 25 cm. If 7 meters above eye level is desired as a point of measurement, the sight has to be raised until 700 cm ÷ 25 cm = 28 units of **P** are indicated by the measuring edge. Thus, 1 RU is equivalent to 50 cm, and 1 RU/4 = 12.5 cm. What falls into the quarter field is estimated best as tenths of an RU rather than as RU/4 or fractions thereof; e.g., 0.4 RU, instead of [RU/4 + 0.6 RU/4]. Doing so simplifies conversion: 7.4 RU x 50 = 370 cm.

3.0. Height Measurement (h-measurement)

3.1. Measurement of Relative and Actual Height

Height is another important measurement which the Spiegel-Relaskop can measure quite accurately. There are two vertical measurement scales, the **D**-(= degree) and the **P-**(= percent) scales (see pages 15 and 16).

The appropriate scale to get the **relative height** of a tree is the "percent" scale, which is also common to many other forestry instruments. This scale is actually the tangent of the angle. An angle with a tangent of 0.24 is said to be "a 24 % angle" on the **P-**scale.

For tree height two measurements are taken, one to the base of the tree (usually the stump) and another to the "top" measurement. The two segments are subtracted to get the length along the stem **as a percent** of the horizontal distance to the tree.

Example:

The illustration in Fig. 9 shows two typical situations taken from the same distance but different elevations:

+ 60 % - (- 25 %) = 85 %

or: + 100 % - 15 % = 85 %

Any set of measurements taken along the vertical line (**v**) will have the same **result,** since the tree height is always in the same proportion to the constant horizontal distance between the tree and the vertical line "**v**".

- **Note:**

It is important to check carefully when one of the sightings is near zero, because it is very easy to reverse the positive and negative reading or to interpolate in the wrong direction.

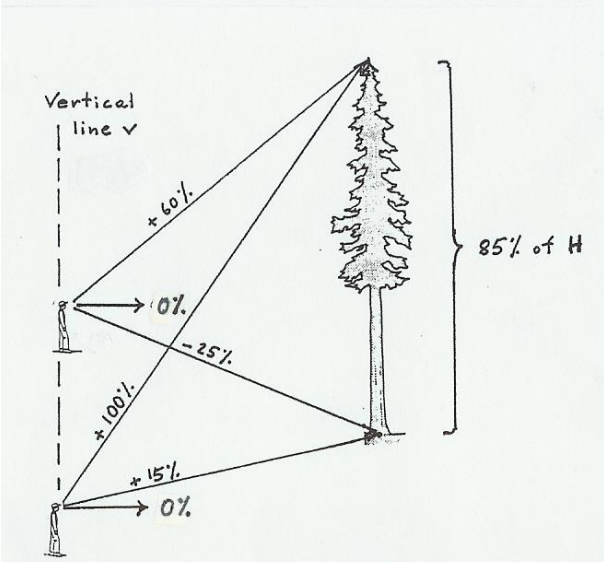


Fig. 9: Measuring Relative Height from 2 Elevations

Once you have the relative height, the **actual height** is obtained by multiplying this percentage by the horizontal distance to the tree. In most cases, the slope distance is measured, then converted to horizontal distance using the cosine of the angle of slope.

Example:
36 units measured along a slope angle of ± 15 degrees is:

36 units x 0.9659 = 34.77 units of horizontal distance
[cos (15 degrees) = 0.9659]

If tree height is measured at 85 % with the Relaskop, then the actual height is:

0.85 x 34.77 units = 29.55 units

The “ladder scales” of the Wide scale Spiegel-Relaskop show direct readings of height from 4, 6, 8, 10, 12, 14, 18 and 20 units of distance (see pages 17 and 18). Normally these are used for distance in meters. It is easy to use half or twice these distances as well.

3.2. Other Height Measurements

3.2.1. Defect Position

The position of defects on the tree can be quickly noted on a tree using the percent scale. These can be converted to tree height if the distance is later measured.

Example:
One might note “conk at + 22 %”. Along with “base at – 20 %, top at + 60 %, horizontal distance of 20 meters” you could calculate the exact position of the conk. Even without the horizontal distance you could specify the relative position on the stem: 3 sightings give the relative position, adding the horizontal distance gives the actual position (see Fig. 10).

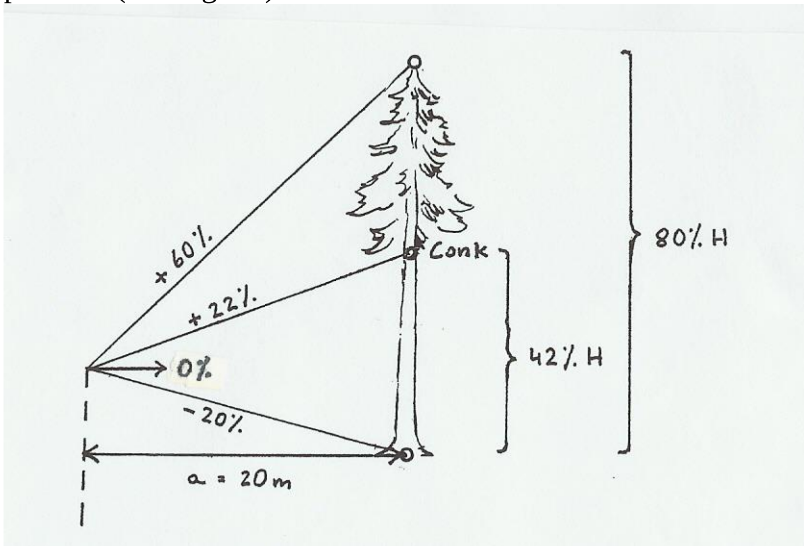


Fig. 10: Measuring the position of a defect
Relative position of conk: (42/80) = 52.5 % of tree height
Actual position of conk: 20 x 42 % = 8.4 m above tree base

3.2.2. Crown Ratio

The **crown ratio** is often of interest in making silvicultural prescriptions. Crown ratio can be easily measured **without knowing the distance** to the tree by using the percent scale. The ratio of the percent between the top and bottom of the tree vs. the percent between the top and bottom of the crown is easy to observe. The **actual height-to-live-crown**, another measurement used in silvicultural research, can be calculated if distance **a** is measured (see Fig. 11).

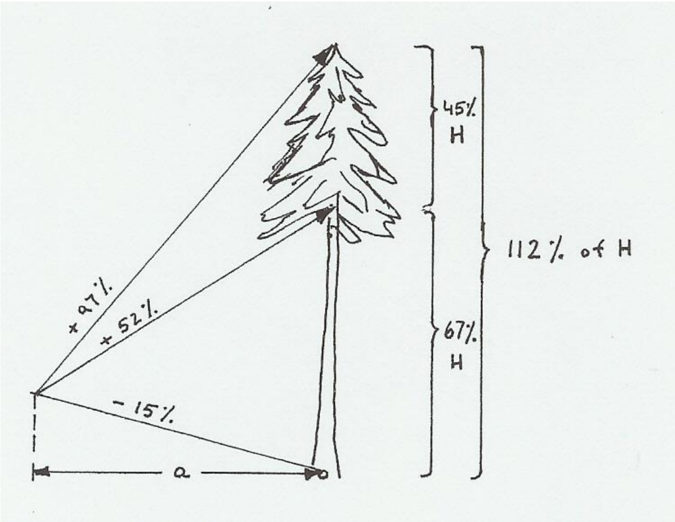


Fig. 11: Simple Calculation of Crown Ratio
Relative crown size ("percent Crown"): % Crown = (45/112) = 40.2 %
Height to crown: (67/112) x tree height = 59.9 % x H

3.2.3. Merchantable Point

3.2.3.1. Percent of Diameter

In some systems, the merchantable height of the tree is defined as a fixed percentage of diameter (at dbh or some other point). This point can be easily **located** using the Spiegel-Relaskop.

Say, for instance, that the merchantable point is defined as
30 % of dbh. When sighting the dbh suppose that it is 2 RU wide from where you are standing. The merchantable point will be 30 % x 2 RU = 0.6 RU in width. Scan up the tree until you locate this point (using the small bands).

In order to locate this point, distance does not need to be known. To get the actual height, a distance must then be measured. For reasons of visibility, it may be more convenient to actually measure this height from another position once the correct point has been identified on the tree.

3.2.3.2. Fixed Diameter

Have an assistant stand beside the base of the tree and show the appropriate image for the merchantable top by using a target of that size. It is handy if a piece of waterproof paper is kept for this purpose. Note the number of RU's the target covers (say 0.2 RU for example). Simply scan up the tree until you see the tree stem cover this same number of RU's. This will be the merchantable top (outside bark, of course). You do not need to know the distance to the tree to find the point. Convert Relaskop readings to actual distances as noted in the above example if you need to do so.

Any bar or combination of bars can be used for this comparison. Simply match the known target with the tree stem covering the same apparent width and you will be looking at the same diameter (there is a small theoretical correction here, but for practical purposes it can be ignored).

Another technique is to measure a fixed distance where the Relaskop bars are equivalent to a convenient fixed width. You can then look for a number of bars corresponding to the merchantable top you are seeking (see page 29).

3.3. Average Height

When trees are chosen by an angle gauge they are selected with an automatic "weighting" by their basal-area, so the average height of these larger trees is usually higher than the average of a set of trees on a fixed plot where each tree has an equal chance of being measured. If desired, the simple average height can be calculated by weighting the selected trees by the "tree factor", which tells how many trees each selected tree represents (see pages 27 and 28).

The simple average of tree heights (when selected with an angle gauge) produces an automatic weighting which gives the so-called **"Lorey Height"**. This is useful in many calculations in forestry. In most cases, the Lorey Height is preferred as an indication of stand height, since it gives a larger representation to larger trees. The stand basal-area, multiplied by the Lorey Height (times a constant) equals stand volume.

4.0. Distance Measurement (a-measurement)

4.1. To Establish a Desired Distance

With horizontal base: Use distance factor 10 (Df 10) which is equivalent to 5 RU and given by the width 05 of the Wide scale. Length of the rod should be 1/10 of the distance that is being measured. Horizontal distance is obtained with pendulum disengaged. Sloping distance is found when the pendulum is arrested at zero degrees.

With vertical base: Use Df 10 and rod as described above. For slopes up to 60 percent, $\cos^2$ correction can be approximated closely enough to determine horizontal distance by the following procedure. Sight at the center of the rod positioned at a distance estimated to be approximate to the distance desired. Read on **P** the slope of sight.

Add half of the value of the obtained reading. Tilt the instrument further until the new value can be read at **P** and arrest the pendulum. (e.g., first reading - 24 percent, final positioning at - 36 percent). Without touching button **3** (see Fig. 1), the Spiegel-Relaskop is now turned counterclockwise along the axis of sight until it is in horizontal position. By this motion, the width of measurement to be employed is brought into a vertical position. The next step is to coincide measuring width 05 with the vertically positioned staff by either moving forward or backward.

4.2. To Determine An Unknown Horizontal Distance

Use a large vertical base and use the **P**-scale, preferably employing a tripod. The height interval **i** (in meters), known through the vertical base, is being measured in percent from the observer's position. Fractions of a percent should be estimated to the nearest one-tenth. The percent value obtained for **i** (difference or sum of both readings) is to be called **p**; as is **i**, the desired horizontal distance **a** is expressed in meters.

Since $$\mathbf{i} = \mathbf{a}\ \frac{\mathbf{p}}{\mathbf{100}}$$

Then $$\mathbf{a} = \frac{\mathbf{100\ i}}{\mathbf{p}}$$

To judge the precision of the procedure more closely, the equation for horizontal distance **a** is differentiated with respect to **p**:

$$\frac{\mathbf{da}}{\mathbf{dp}} = \frac{\mathbf{-100\ i}}{\mathbf{p}^2} \text{ or, because } \mathbf{p} = \frac{\mathbf{100\ i}}{\mathbf{a}}$$

$$\frac{\mathbf{da}}{\mathbf{dp}} = -\frac{\mathbf{a}^2}{\mathbf{100\ i}} \quad \text{or} \quad \mathbf{da} = -\frac{\mathbf{a}^2}{\mathbf{100\ i}}\ \mathbf{dp}$$

An error **dp** contained in the measured percent value **p** will be less effective as distance error **da** the larger **i** is. At the same time, however, this error will increase with the square of the distance.

Example:
a = 20, i = 4, da = dp; if for instance, a plus error of 0.2 percent is made in the measurement, it will show as a minus error of -0.2 m for distance. But if for the same base length of i = 4, distance **a** is only a = 10, then da = -1/4 dp, i.e., the distance error amounts to just –0.05 m.

This example demonstrates the necessity for a long vertical base and the importance of progressive increase in the precision of measuring percent with increasing distance. Greater precision can be obtained by use of a tripod and repetition of readings. To what maximal distance measurements can be made will depend upon the requirements for accuracy of the results.

5.0. General Surveying Applications

If the Spiegel-Relaskop with Wide scale is used on a tripod, it is suitable for a variety of surveying purposes within the range where the naked eye can resolve details.

A panoramic head on the tripod makes possible dividing the full turning cycle into 24 equal sectors of 15 degrees each. Within each of these sectors, individual degrees can be determined by means of the Relaskop-Units. When sighting horizontally, the band width of an **RU** is equivalent to an angle of 1º 08' 55"; however, when the sight is lowered about 29º 20', or 56 %, and the pendulum locked in this position, then each **RU** equals one degree and thus may be used for measurements. Fractions of a degree have to be estimated. For such an estimate, the quarter field may be employed.

Vertical angles can be measured either with scale **D** within a range from -60º to +70º or with the percent scale **P**. The **P**-scale gives differences of elevation in percent of distances, something that has been discussed already. Differences of elevation also may be determined with a level when markings on the rod can still be discerned with the naked eye. The **P**-scale is particularly suitable for leveling and determining cross profiles.

It is also possible to perform rough topographic surveys measuring horizontal angles as described above, taking distances with the help of a tape or by optical means and measuring elevations with the **P**- or **D**-scale.

Topographic description and orientation: It is better to use the Relaskop-Units **RU** than some rough estimate with your thumb. These units offer you a continuous scale of horizontal angles which quickly may be compared with your view from the sample point. The same is true for vertical angles which may be measured or transmitted by means of the **P**- or **D**-scale.

To fix surveyed points when their marks, such as boundary stones or stakes, are damaged, or to mark the location of pipe lines under ground, we can use tape measurements from fixed objects, like buildings, and large stones. With the help of the Wide Scale Spiegel-Relaskop, we can substitute for these tape measures by reading the width of houses, of windows, or of large stones in **RU**, viewed from the point in question. (It often is easier to use **RU** than tape-measurements for such purposes). It is also suitable to use diameters of trees for locating points, although it is necessary to consider the growth in diameters during longer intervals.

Example:
During road construction, a boundary stone must be eliminated temporarily because its location must be excavated. Its later location

will be a few meters deeper. Triangulation by tape measurements to neighboring trees is not accurate enough, because the slopes to the present point and to the future point are very different. So it is better to use the Wide-scale Relaskop combined with angle measurement from the boundary-stone before its elimination. Beginning from a given unobstructed direction, the horizontal angles to all neighboring trees should be measured and also the “relative width” of each tree diameter breast height in **RU**. Due to the automatic reduction of widths for slope by the Relaskop, all relative measurement will remain the same, regardless of the fact that the point in question will be located a few meters deeper than before.

RELASKOP LIGHT -Illumination for the scale of the Spiegel-Relaskop®

The Relaskop-light is a clip-on instrument, easy to operate and fits on instruments even delivered decades ago!

Especially designed for use **in dense forests and in bad light conditions** the even illumination along the reading line gives an **excellent picture of all the stripes and figures of the Relaskop-scale.**

The Relaskop-light is clamped on in front of the instrument right over the front-window and is fixed instantaneously by a spring. The light is switched on and off by pushing the button on the cap. For permanent light change the caps and the light goes on and off by a short turn of the threaded cap. For electrical power a standard type of battery “Mignon 1.5 V” is used.

Fig. 12:
The Relaskop Light
ready to be clipped on