DIRECT READING OPTICAL LEAF AREA PLANIMETER

K. SCHURER

Technical and Physical Engineering Research Service, Wageningen, the Netherlands

SUMMARY

An optical planimeter is described in which the light beam from a small source is collimated and subsequently focused on a photocell. It is shown that the area of even a thin leaf placed in the collimated part of the beam is measured accurately without the need for a correction for transmitted light. The instrument features linear response, digital read-out, high speed, good stability, five ranges of 50 up to 1000 cm^2, and an accuracy of 1 % of the range.

1. INTRODUCTION

Several devices for the measurement of leaf area have been described in the literature. The use of many of those is restricted to leaves of small dimensions or of specific shape. Though some general purpose instruments have been described as well, there was still a need for an accurate, relatively fast direct reading planimeter capable of measuring small as well as large leaves of all shapes. A working area of 1000 cm^2 should be available with the possibility of reducing it in a few steps to 50 cm^2. The accuracy should not be less than two percent of the working area.

2. SUMMARY OF METHODS

Several different techniques have been devised and used for measuring the leaf area.

The mechanical planimeter is an accurate but rather cumbersome instrument, cf. KRANZ (1964). It is unsuited for all those cases in which a large number of leaves have to be measured. Variants like counting squares, weighing, measuring length and width or one of the two alone are less accurate, still rather laborious, and restricted to leaves of a regular, simple shape.

A fast alternative is estimating the leaf size by comparison with a limited number of known samples (HUMPHRIES & FRENCH 1963). With this method the error of a single measurement is large, and therefore a large number of leaves has to be measured to obtain statistically significant results.

The other methods aim at a compromise between speed of measurement and accuracy. Air-flow instruments, where the leaf partially obstructs an air-stream, have been reported to give satisfactory results (JENKINS 1959 and MAYLAND 1969), especially with smaller leaves. The optical analogue of this principle, where the leaf partially obscures a beam of light, may offer the best solution for larger areas.

Apart from instruments for special purposes, like a scanning instrument described by MURATA & HAYASHI (1967) for long, narrow leaves (e.g. Gramineae), this summary gives a fair listing of the various methods in use for the measurement of leaf area. The most promising choice for a large general purpose instrument is obviously the optical planimeter.

3. DIFFUSE VS. COLLIMATED ILLUMINATION

A major problem in large-area optical planimeters is the creation of an evenly illuminated field of the dimensions required. A solution can be sought in two essentially different ways. The first one, chosen by KRANZ and by MOELKER (1966), employs preferably extended light sources like fluorescent tubes, with additional diffusing screens for producing an even, diffuse illumination. The alternative choice is the use of a small light source and a large diameter lens in order to produce a collimated beam of light (MILLER *et al.* 1956). In the first type of instrument the photocell can be used without additional optics; in the second type another lens is required, which focuses the light beam on a spot not larger than the photocell.

Diffuse illumination offers some obvious advantages, *viz.* low cost and relatively few problems in reaching an even illumination, the major disadvantage being the instrument's sensivity to light transmitted by the leaves. The leaf acts as a good diffuser: the flux transmitted by a leaf is completely diffused. The diffuse type instrument responds in the same way to any diffuse flux in its working plane. In the collimating instrument, however, a diffused flux is not brought to focus on the photocell, which therefore "sees" only a negligible part of the flux transmitted by the leaf. The actual error depends on properties of the leaf such as chlorophyll content and thickness. Leaves of *Ficus elastica* give no transmission errors in either instrument, whereas we have measured diffuse transmittances with leaves of *Lactuca sativa* and *Cichorium endivia* of up to 50% for green light, 25% for red light, and 15% for blue light. The maximum error with the same leaves in a collimated beam was found to be 0.3%.

Disadvantages of the collimating instrument are its higher cost, due to the use of large area lenses, and the difficulties encountered in creating an evenly illuminated field. For reasons of space and weight plastic fresnel lenses are employed, which exhibit a marked decrease in transmission from the center to the rim. This phenomenon necessitates the application of some means of correction when the intrinsic high accuracy of the instrument must be realised.

The freedom from a "transmission error" of the collimating instrument disposes of the extra work of measuring a correction factor and applying this factor to all measured values, as required with diffuse illumination. The same quality contributes to a better accuracy, because the accuracy of the readings is not lowered by the error in the correction factor.

We have been led by the foregoing reasoning to adopt the collimated beam principle for our large area planimeter, since both speed and accuracy were primary goals of our design. The first description of an instrument based on this principle is by Miller *et al.*, who gave a good account of the potentials and the difficulties of this design. A simplified version has been described by Davis *et al.* (1966). The simplification was attained at the expense of accuracy and speed of operation, both of which are considered important for our instrument.

4. DESCRIPTION OF THE INSTRUMENT

Since our aims were much the same as those of Miller, our design was developed along the same general lines. We incorporated, however, a number of improvements resulting in easier operation, greater speed, and better long-term reliability.

Fig. 1 shows an outline of the optics of our instrument. The beam of light from lamp L is reflected by a plane mirror M_1 and directed upward through a correction plate C. The beam is focused by fresnel lenses F_1 and F_2 over mirror M_2 on to a silicon cell S_1. A second silicon cell S_2 directly monitors the output of the lamp. The specimen is placed between two glass disks G_1 and G_2. The optics are housed in a light-tight housing, the upper part of which can be rotated

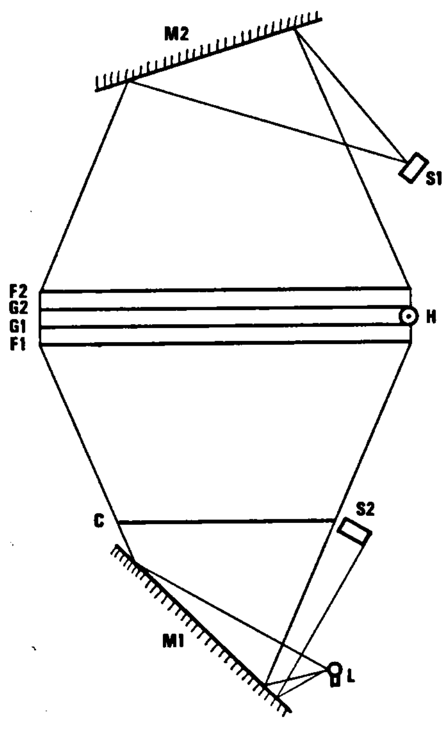

Fig. 1. Outline of the optics. L lamp, M_1, M_2 plane mirrors, C correction plate, S_1, S_2 silicon photocells, F_1, F_2 fresnel lenses, G_1, G_2 glass discs, H counterbalanced hinges.

around the hinges H to give access to the measuring stage. The glass disk G_1 is level with the top of the lower part of the housing.

The lamp L (Philips quartz halogen lamp type 7027, rated at 12V 50W) is operated about 20 percent below its rated voltage to increase the expected life. Lamp power is provided by a constant voltage transformer. The lamp is designed for use in a vertical position with an undistorted light beam emerging in a horizontal direction. The mirror M_1 deflects the beam over 90° towards the measuring stage. The lamp is housed in a seperate compartment closed with a glass window, to allow ambient air to flow through the lamp housing for cooling purposes without the risk of dust deposition on the optical components.

The correction plate C must have a transmission that is low in the centre and rises with the distance from the centre. The response of the uncorrected instrument showed a sufficient degree of circular symmetry to allow the use of a

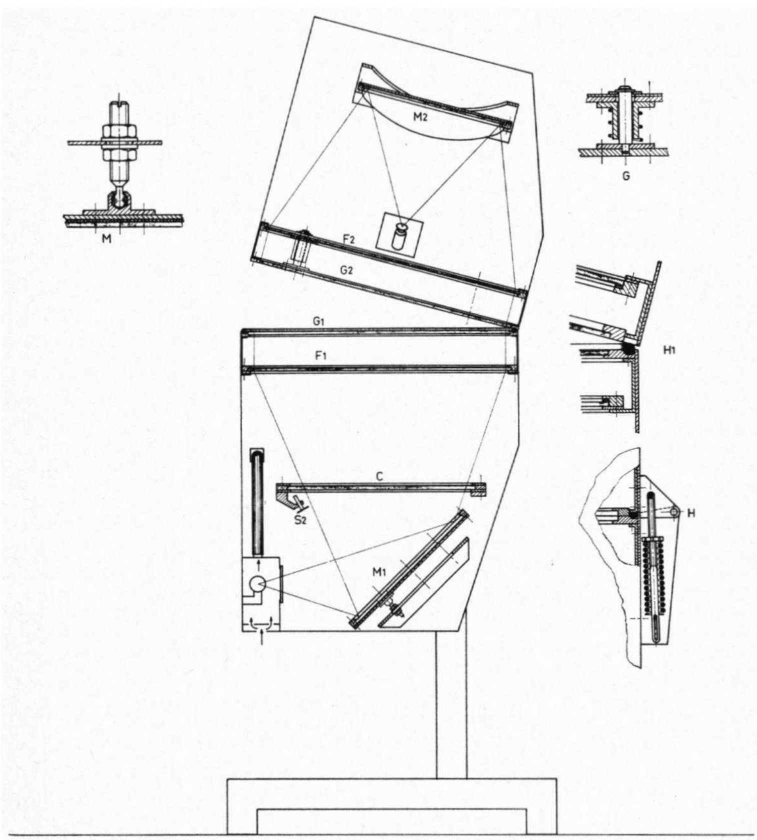

Fig. 2. Mechanical design of the planimeter. M mounting screw (3 for each mirror), G detail of spring-loaded mount of G_2, H'detail showing soft gasket for a light-tight seal, other letters have the same meaning as in Fig. 1.

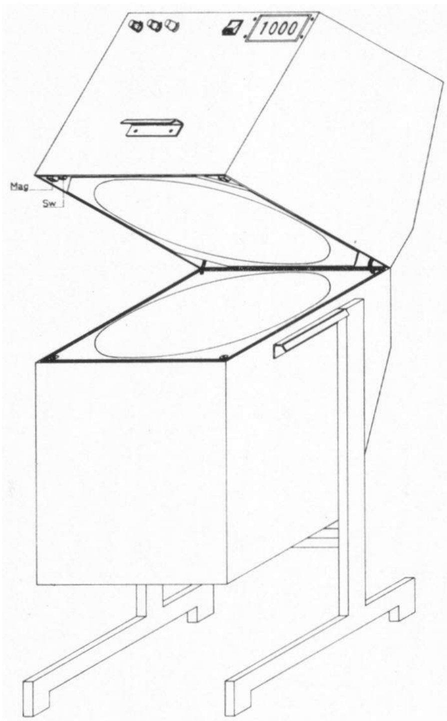

Fig. 3. View of the completed planimeter. Mag closing magnets, Sw microswitch. The front panel shows the digital meter and controls for full scale, zero, and range selection.

correction plate with the same symmetry. A satisfactory correction could be obtained with a semi-transparent mirror made by evaporation of a suitable amount of aluminium from a short distance onto a glass disk. The correct radial variation of the density of the mirror was obtained after some trials in which mirrors have been made whilst varying both the amount of aluminium and the distance between the source and the glass disk.

The lenses F are large area plastic fresnel lenses (Cryton Optics type 22, focal length 483 mm, diameter 406 mm). L and S_1 are at the focus of F_1 and F_2, respectively.

The mirrors M (200 mm in diameter, 4 mm thickness, first surface Balzers Alflex-A coating) serve to permit L to be used in its proper position and to reduce the height of the instrument.

The photocells S (Siemens silicon cells, type TP61) have been chosen for their far better linearity as compared to that of the selenium cells used in the instruments of Kranz, Moelker, Miller *et al.*, and Davis *et al.* As a matter of fact, no alinearities due to the silicon cells were observed. The length of the light path can be adjusted by varying the position of photocell S_1. The mirrors M are mounted on three screws to enable a correct alignment of the optics.

The mechanical design of the instrument is shown in *figs. 2* and *3*. The case has a height of 880 mm, a width of 400 mm, and a depth of 450 mm. Legs are

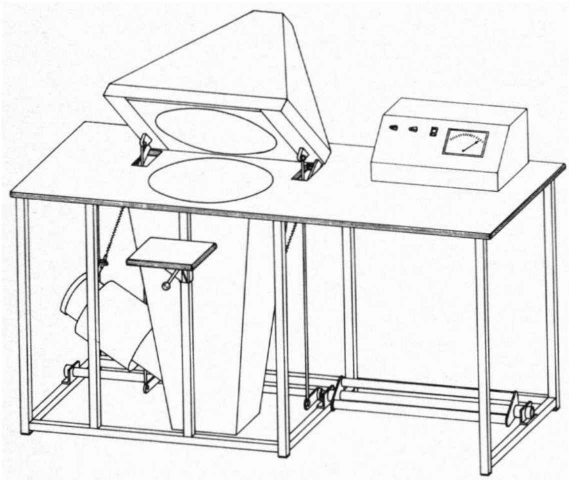

Fig. 4. View of the desk-type design.

provided to bring the working plane 760 mm above the floor. Some special features are the use of counterbalanced hinges to prevent the top part from falling down accidentally, the use of small magnets to give a positive closing and the use of a spring loaded mount for the upper glass disc G_2 to allow for varying thickness of the specimen. The working area is limited by a steel mask to the surface area desired, i.e. a circular area of 1000 cm^2 or a rectangular one of 500, 200, 100 or 50 cm^2.

In an older design (*fig. 4*) the instrument was built in and on a desk. The top can be opened by means of a treadle and a link bar. In this way the operator has both hands free for the measurements. Provisions have been made for measuring leaves without detaching them. To this end a small table can be attached to the front of the instrument. The pot with the plant is put on it, and the height of the small table is adjusted till the petiole of the leaf to be measured is level with the measuring stage. The petiole should have a minimum length of 50 mm for this purpose. In the older design only one lens is used; F_1 is omitted. The reason is a practical one: the lens type used then (Cryton Optics type 15, focal length 356 mm, diameter 375 mm) showed much larger aberrations, which were still acceptable when using one lens, but they would prohibit exploitation of the full lens diameter when two lenses were used. Thus the leaf is placed in a diverging light beam. To minimize the errors caused by this configuration the distance between lamp and lens has been chosen relatively large, *viz.* about three times the diameter of the lens.

The lay-out of the electronics is shown in *figs. 5* and *6*, for analog and digital meter read-out, respectively. In both cases controls are provided for zero and full scale and in both cases the difference measurement implies that the meter reads zero for zero leaf area and 1000 for 1000 cm^2 of leaf area (measuring stage fully covered).

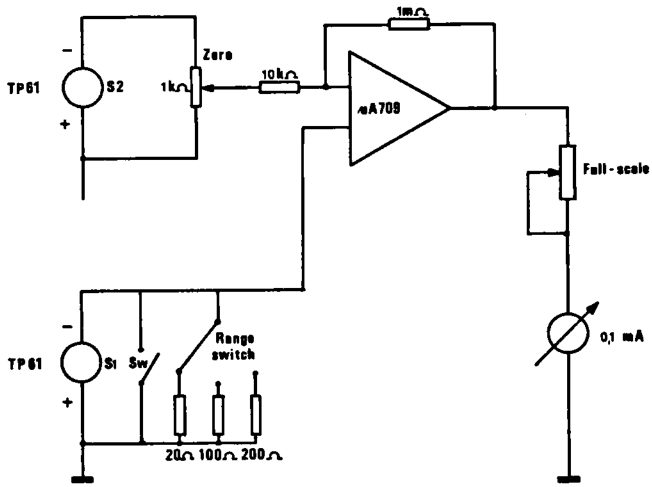

Fig. 5. Electrical diagram for analog read-out S_1, S_2 photocells, Sw microswitch, range switch for ranges 1000, 200 and 100 cm^2.

The range switch is used for bringing smaller working areas to full scale. The use of cell S_2 furthermore prevents the zero reading from drifting, provided that sufficient care is exercised to clean the glass discs in the measuring stage whenever appropriate.

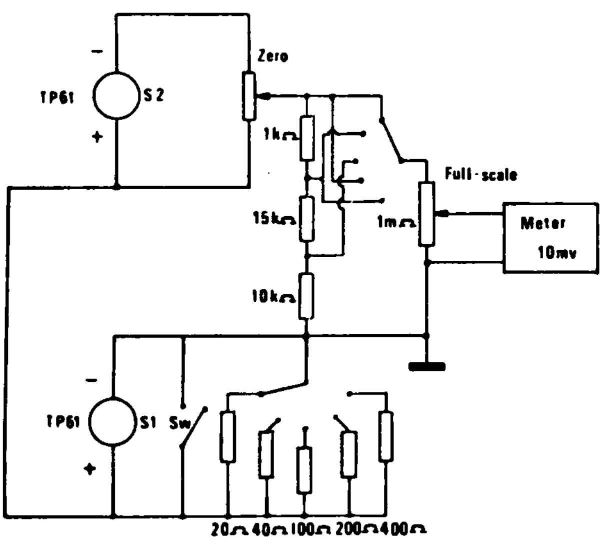

Fig. 6. Electrical diagram for digital read-out range switch for ranges 1000, 500, 200, 100 and 50 cm^2.

5. PERFORMANCE

The planimeter proved to be easily used. Measurements can be made at high speed with still good accuracy.

Extensive tests of the instrument were carried out regarding linearity, sensitivity to transmitted light, the same to false light, equal sensitivity over the whole of the measuring stage, and preservation of the specifications for smaller working areas.

Deviations from a linear response are within 0.5 percent over the whole range. The sensitivity to transmitted light does not materially differ from the value given in the discussion on the illumination principles. As a matter of course there is a response to transmitted light that has not been diffused. With different samples of tracing paper, for instance, a direct transmittance of 1 to 10 percent was observed. With leaves, however, there is complete diffusion of the incoming light flux, and hence no photocell response. No erroneous response to strong light sources in the neighbourhood of the instrument has been found. To prevent overload of the measuring system in case a strong light would shine into the opened top part, provision has been made with a microswitch Sw to short the photocell S_1 upon opening the top. The switch is mounted in the top part and is actuated immediately upon opening the top.

The instrument's reading for a given sample area varies slightly over the working field. These variations could be kept to within 1 percent of the working field in a 500 cm^2 prototype and to within 2 percent in the older 1000 cm^2 design. The larger variations are caused entirely by the large aberrations of the lens in these instruments. In the newer 1000 cm^2 design a value of 1 percent is attainable again.

The overall accuracy is limited by the varying response over the working area. Other factors liable to affect the accuracy (transmission or chosen meter system) are found to add very little to this major error. The use of masks does not significantly change the accuracy in either direction. Measurements can be made with working areas down to 50 cm^2 to the same accuracy of 1 or 2 percent of the actual working area.

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