A Goniometer for Simplified Gait Analysis

L.E. Carlson
Mechanical Engineering
University of Colorado
Boulder, CO 80309
USA

and

M. Dewar
Bioengineering Centre
University College, London

ABSTRACT

Gait analysis is widely recognized as a useful tool in rehabilitation, both for diagnosis and evaluation of treatments and assistive devices. Such analysis covers a wide spectrum from subjective observation by a clinician to very sophisticated computerized measurement of forces, moments and displacements of the limb segments. The latter yields a wealth of useful information, but the technology for such analysis is resident in relatively few centers in the world. This paper describes a device to measure the angular displacements of the joints of the lower limb during gait. It is a very simple goniometer that can be utilized by clinicians with relatively low technological expertise in both developed and developing countries.

Probably the simplest device utilized to measure joint motion during gait is the electrogoniometer. While it provides a time history of the angular motion of one or more joints, clinicians frequently quantify such information by simply computing the total range of motion. The peak-reading goniometer described here is a low-cost device designed to measure range of motion without the need for any peripheral equipment.

The peak-reading goniometer is small, light and comfortably worn by the patient. It is self-aligning to maximize accuracy and minimize interference with gait. And, it is unambiguous and easily read.

QUANTIFICATION OF GAIT

One of the contributions of biomechanics has been the quantification of the displacements and forces present in the joints of the body. Such information has been used for pure research and to design joint prostheses, as well as for diagnosis and evaluation of treatment of a wide range of neuromuscular disorders.

Gait has received more attention than any other activity, because of its importance and also because it is a cyclic process that allows measurement and comparison. Parameters that are used to characterize gait can be loosely grouped into two categories: kinematic and kinetic.

The former include basic time-distance measurements such as stride or step length and cadence. Lamoreux (1971) has discussed the importance of measuring these parameters for any gait analysis. Further refinements may include durations of the various phases of walking (Murray, 1967) and patterns of foot-floor contact (Rancho Los Amigos, 1972). All of the above data can be obtained with foot switches and a walkway of known length on which a person can be timed to measure average velocity.

Further information can be gained by measuring joint motions. This has been done optically by cinefilm (University of California, 1947), video cameras (Jarrett, 1980) or special solid state cameras that can locate light-emitting diodes in space (Andriacchi, 1979). Another method is to use goniometers, instruments that are worn on the body to measure joint motion directly.

Kinetic parameters of gait include the forces and moments at the joints. Virtually impossible to obtain directly, these parameters are measured indirectly through the use of a force plate which records the external reaction forces. Knowing the magnitudes and directions of these forces, relative to the positions of the joints in space (measured optically), allows estimation of the internal forces and moments (usually by computer)(e.g., Paul, 1967).

Although complete characterization of gait would include all the above parameters, obtaining such data is an expensive task feasible only at large research centers. Much clinical use can be made of smaller subsets of data, such as joint motion. Also, joint motion measurement can be important in other tasks, such as arm movements in space.

GONIOMETRY

Although the use of mechanical goniometers to study joint motion dates back at least 45 years (Cave & Roberts, 1936), electrogoniometers have only been utilized for about 20 years (Karpovich and Karpovich, 1959). Most electrogoniometers utilize potentiometers to measure joint motion directly. They have been used to measure from one (Karpovich & Karpovich, 1969) to six degrees of freedom at a single joint (Kinzel et al., 1972).

Lamoreux (1971) first postulated the importance of self-aligning goniometers. The joints of the body are not pure hinge joints, but are polycentric; i.e., their instantaneous center of rotation moves as the joint is flexed. The instant center of the knee, for example, can move up to 2 cm. during flexion (Page, 1979).

Attempting to measure such motion with a single degree-of-freedom goniometer can cause inaccuracy and, more importantly, can interfere with normal motion.

Lamoreux (1974) utilized precision parallelogram linkages to make his goniometer self-aligning. More recently, researchers have produced a three degree-of-freedom electrogoniometer employing a clever molded polyurethane parallelogram chain to accomplish self-alignment (Cousins, 1975). Tata et al. (1978) used two potentiometers in a polycentric goniometer, but it only measures single plane motion.

Chao (1980) has reported the desirability of measuring three components of joint rotation. He has applied triaxial goniometers to the measurement of the lower limbs during gait and to the elbow. Like other systems, they utilize potentiometers and linkages to measure the rotations, resulting in an accurate although somewhat cumbersome device.

Electrogoniometers have several advantages: they can be very accurate (better than 1° resolution) and they measure the desired parameters directly, without the need for computerized computation. Thus, they are relatively inexpensive to produce and operate. On the other hand, they are mechanical gadgets which must be attached to the body and could therefore affect gait.

RANGE OF MOTION

A typical knee flexion pattern recorded by an electrogoniometer is seen in Fig. 1, from Lamoreux (1971). While such a record can convey much information to a skilled clinician, especially when compared to the patient's opposite leg, quantification of such data is desirable to provide numerical information which can characterize gait. This minimizes the subjectivity between clinicians and allows more meaningful comparisons over time.

Of the various parameters which have been used to quantify such information, range of motion appears to be one of the most important and widely used. Ellis et al. (1979) has shown that range of motion in the plane of progression is a simple yet very reliable parameter for characterizing subtle changes in gait.

Using an electrogoniometer to measure joint motion requires a certain amount of technical equipment, including a power supply, recorder and a cable trailing from the patient (or telemetry, less cumbersome but more expensive). At the other end of the spectrum is the simple protractor goniometer used in orthopedic examinations. Although this instrument can measure joint motion in a passive situation on an examining table, it cannot be used during active movements, such as gait.

The peak-reading goniometer was designed to bridge the gap between these two methods of joint motion measurement. It is totally self-contained, requiring no peripheral equipment, but it can be worn by the patient during active motion, recording the range of motion.

PRINCIPLE OF OPERATION

The peak-reading goniometer (PRG) consists of two functional parts: a <u>self-aligning linkage</u> and a <u>measurement part</u>. When a joint flexes, it can be thought of as a rotation of one body with respect to another about an axis which does not remain stationary during the motion. If a goniometer with a fixed axis of rotation is attached to a limb such that the goniometer and joint axes are not coincident, there will be an error between the goniometer angle and joint angle. Also, forces and/or moments may be introduced, affecting the joint motion. A self-aligning linkage is therefore desirable to provide extra degrees of freedom in translation while still transmitting rotation from one part of the goniometer to the other.

The PRG has two movable parts attached either side of the joint to be measured, constrained in such a way that one part can freely translate with respect to the other ±1 cm any direction in a plane and rotate 270° (i.e., it has 3 degrees-of-freedom). A parallelogram and slider linkage connects the two parts (Fig. 2), transmitting the rotation but not the translation. The principle is identical to the double-parallelogram of a drafting machine, which allows the scales to be translated anywhere in the plane of the board while maintaining the angular orientation.

Measurement is achieved by two movable disks, one a calibrated dial and the other a transparent disk with a scribed pointer. The disks are moved in opposite directions by a "wiper" rotated by the self-aligning linkage (Fig. 3). Simple brakes hold the disks at their maximum displacement until released when a hair spring returns the reading to zero. Regardless of the direction of angular displacement, this arrangement always records the absolute value of the range of motion, making the reading clear and unambiguous.

The arms of the instrument are inserted into sleeves sewn into two-way stretch elastic straps secured to the body with Velcro® (Fig. 4). The transparent plastic arms with scribed lines also allow the device to be hand-held and used as a conventional protractor goniometer. Each strap is designed to fit a wide range of limbs from thighs to forearms, and hip flexion is measured by adding an extension strap encircling the waist.

As listed in Table I, most of the major joint motions of the body can be measured with this goniometer, both actively and passively. Some of the motions require special attachments.

Measuring 20 mm thick and 55 mm in diameter, the goniometer is small enough to be unobtrusive for most joints but large enough to be legible to 2°.

SUMMARY

The peak-reading goniometer is a simple instrument for measuring the range of joint motion. Its compact size and self-aligning linkage allow it to be worn comfortably by a patient during active movements, providing an easy way of obtaining one significant parameter of gait.

Joint	Motion	Passive	Active	Modifications for Active Measurements
Ankle	(dorsi/plantor flex	Yes	Yes	Special shoe band required
	(inversion/eversion	Yes	Yes	" " " "
	(rotation	Yes	No	---
	(flex/ex	Yes	Yes	---
	(varus/valgus	Yes	Yes	For limited knee flexion
	(rotation	Yes	No	---
Hip	(flex/ex	Yes	Yes	Waist extension band
	(abd/adduction	Yes	?	---
	(rotation	Yes	No	---
Wrist	(flex/ex	Yes	Yes	Remove one band.
	(pro/supination	Yes	Yes	Remove bands, attach handle.
	(ulnar/radial dev.	Yes	Yes	Somewhat awkward.
Elbow	- flex/ex	Yes	Yes	---
Shoulder	(flex/ex	Yes	Yes	Special shoulder attachment
	(abd/adduction	Yes	Yes	" " "
	(hum. rotation	Yes	No	---

TABLE I. Joints suitable for measurement by the Peak Reading Goniometer

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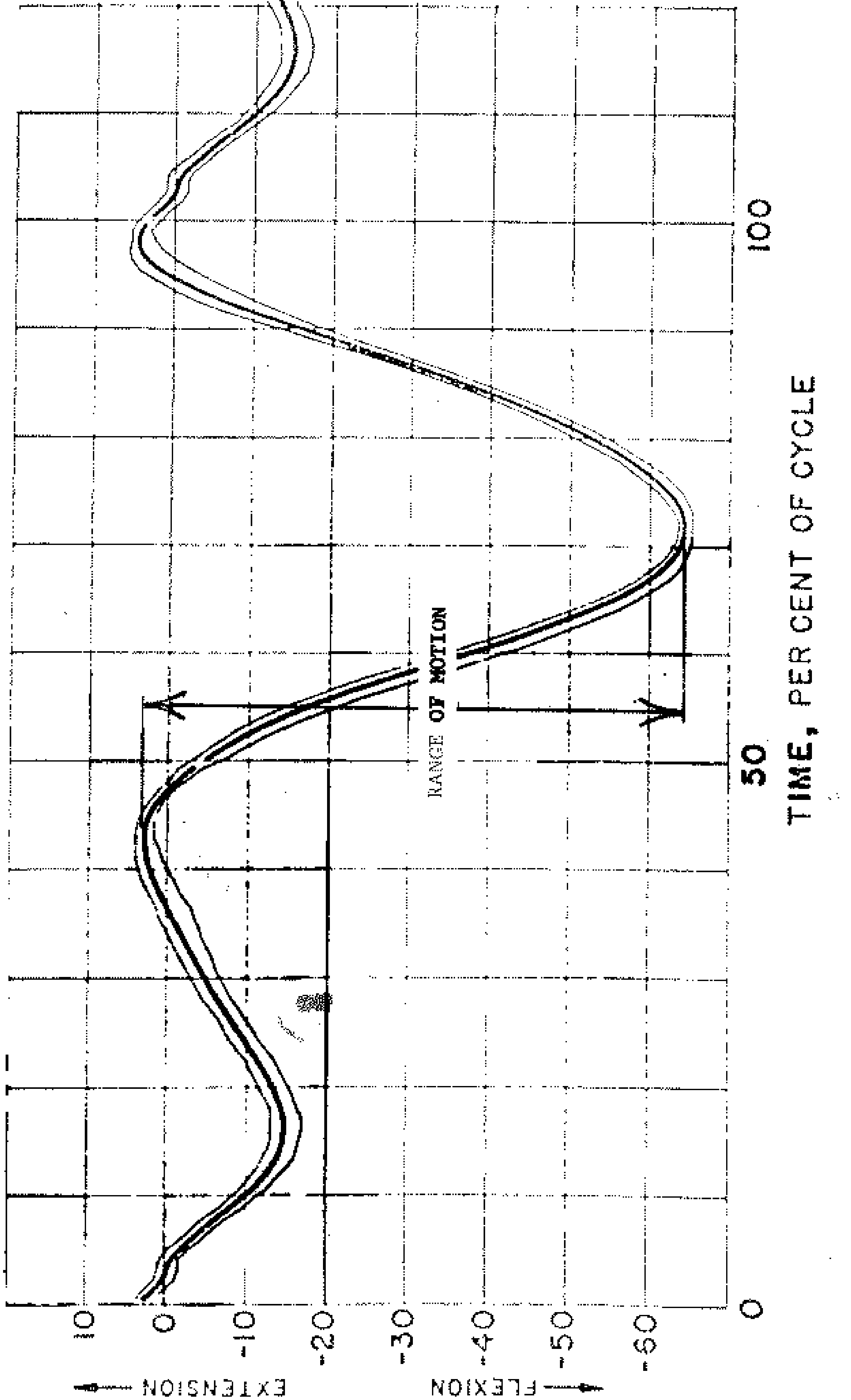


Fig. 1 Normal knee flexion during gait, measured by an electrogoniometer (Lamoreux, 1971).

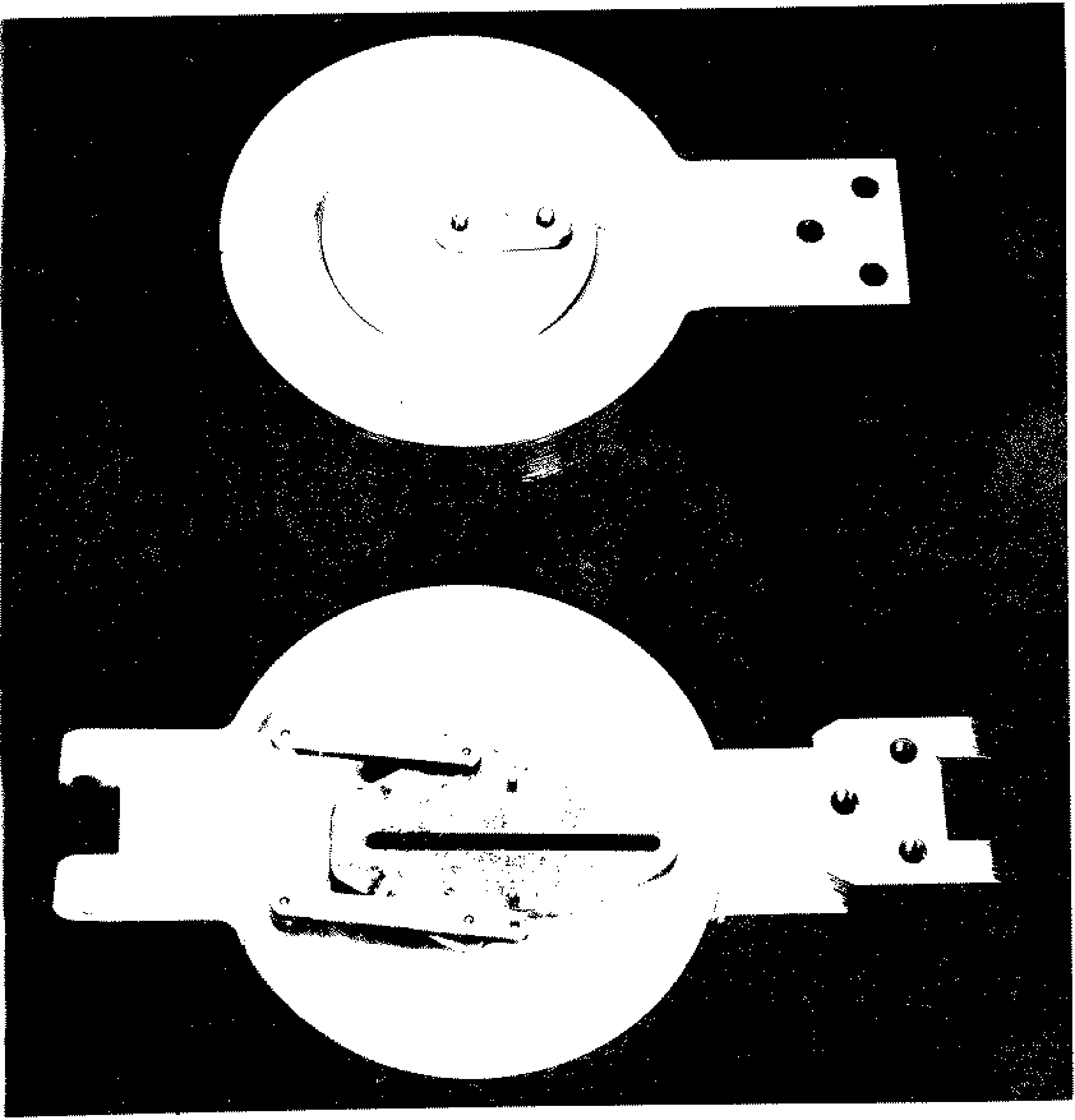
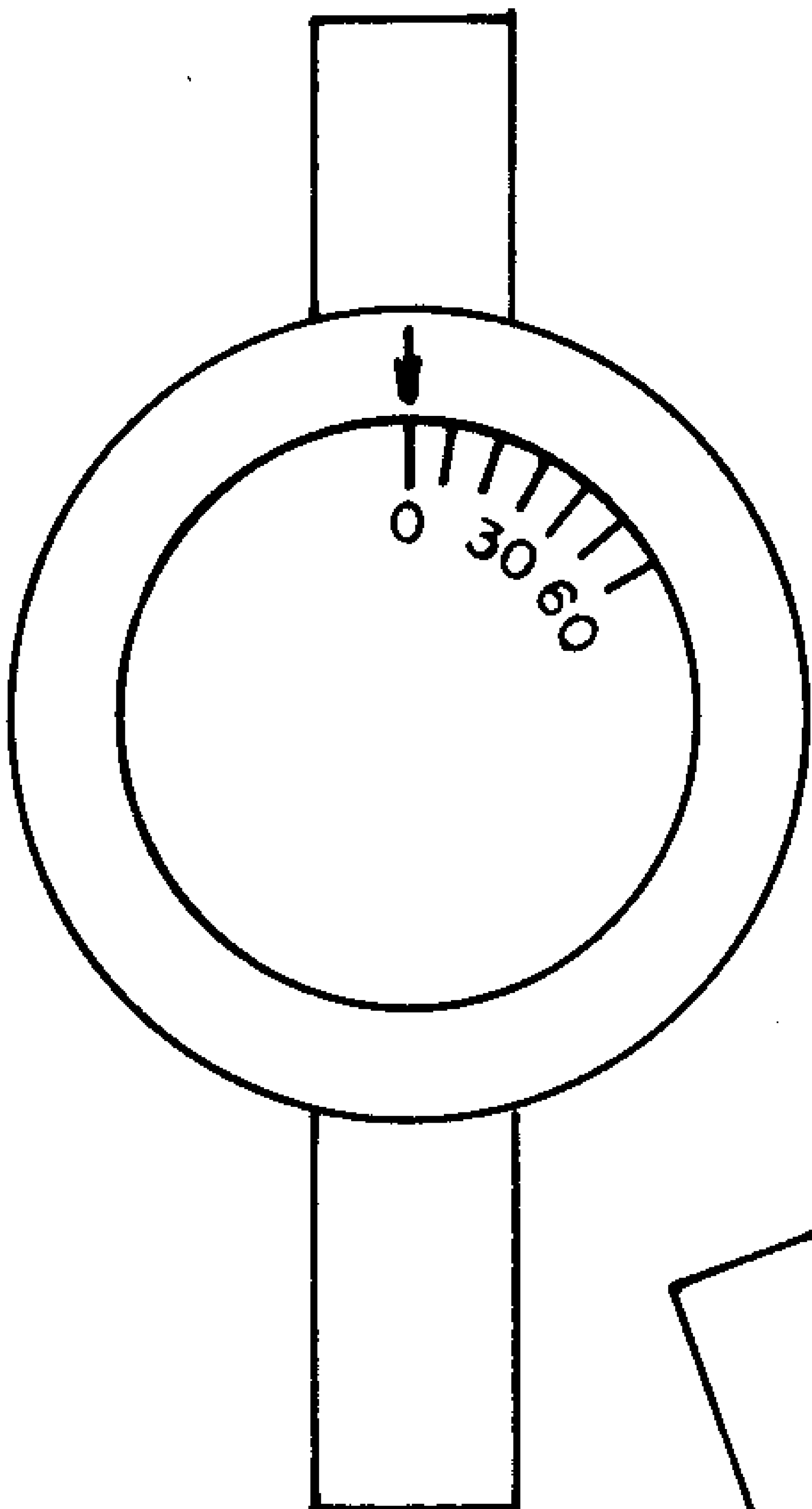
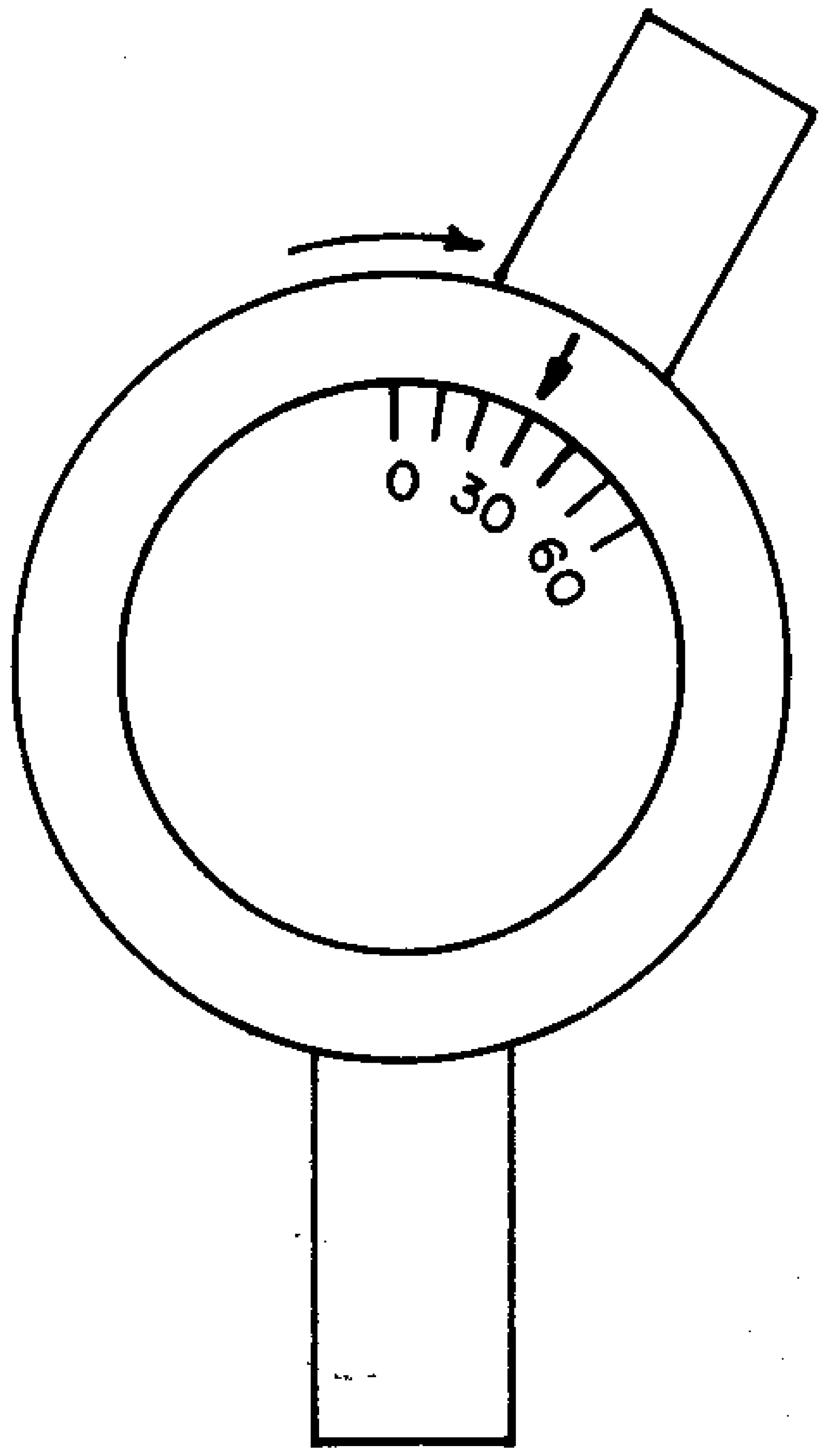


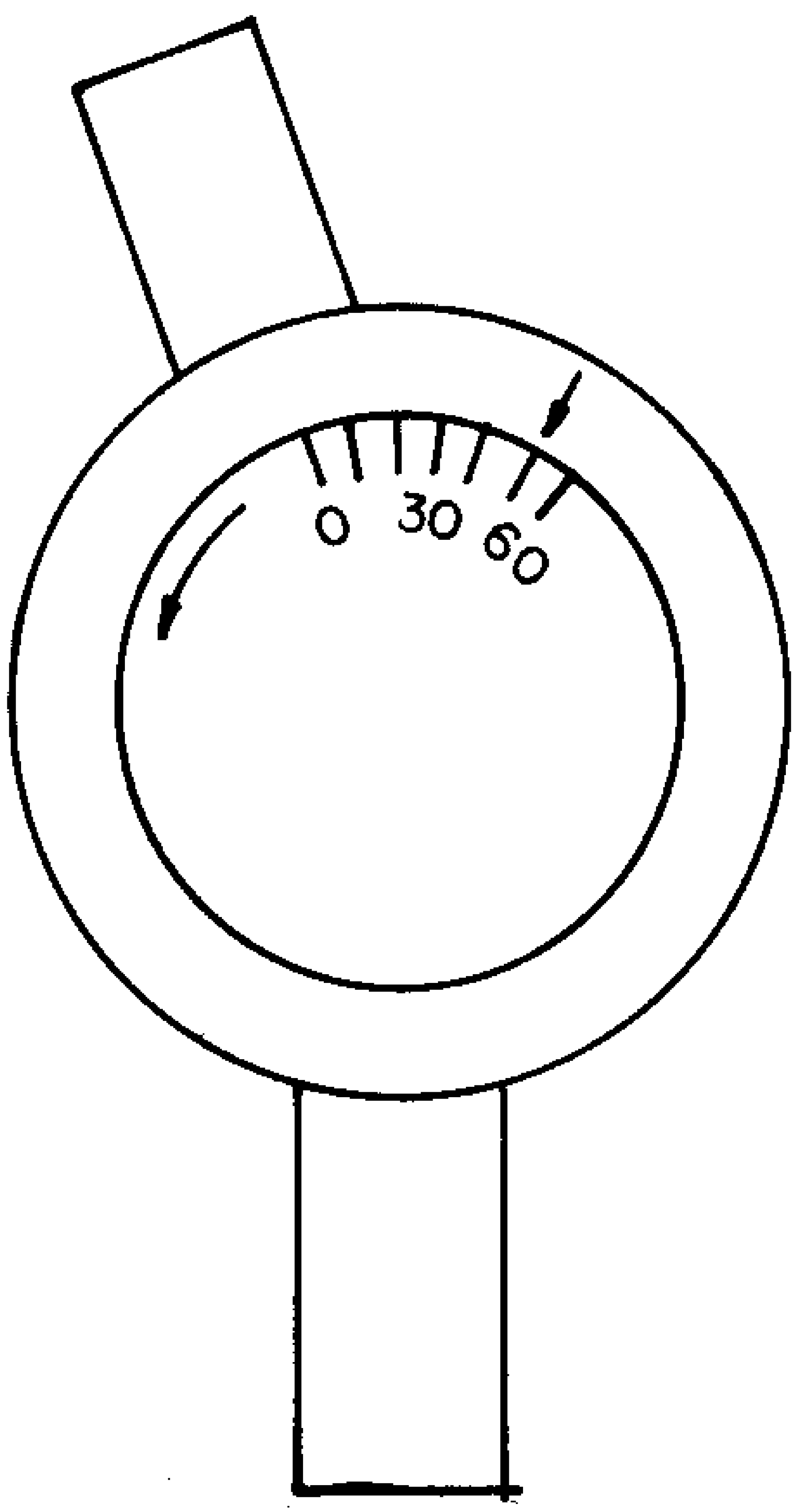
Fig. 2 Parallelogram and slider linkage for self-alignment



a) 0°



b) 30° Clockwise



c) 20° Counterclockwise

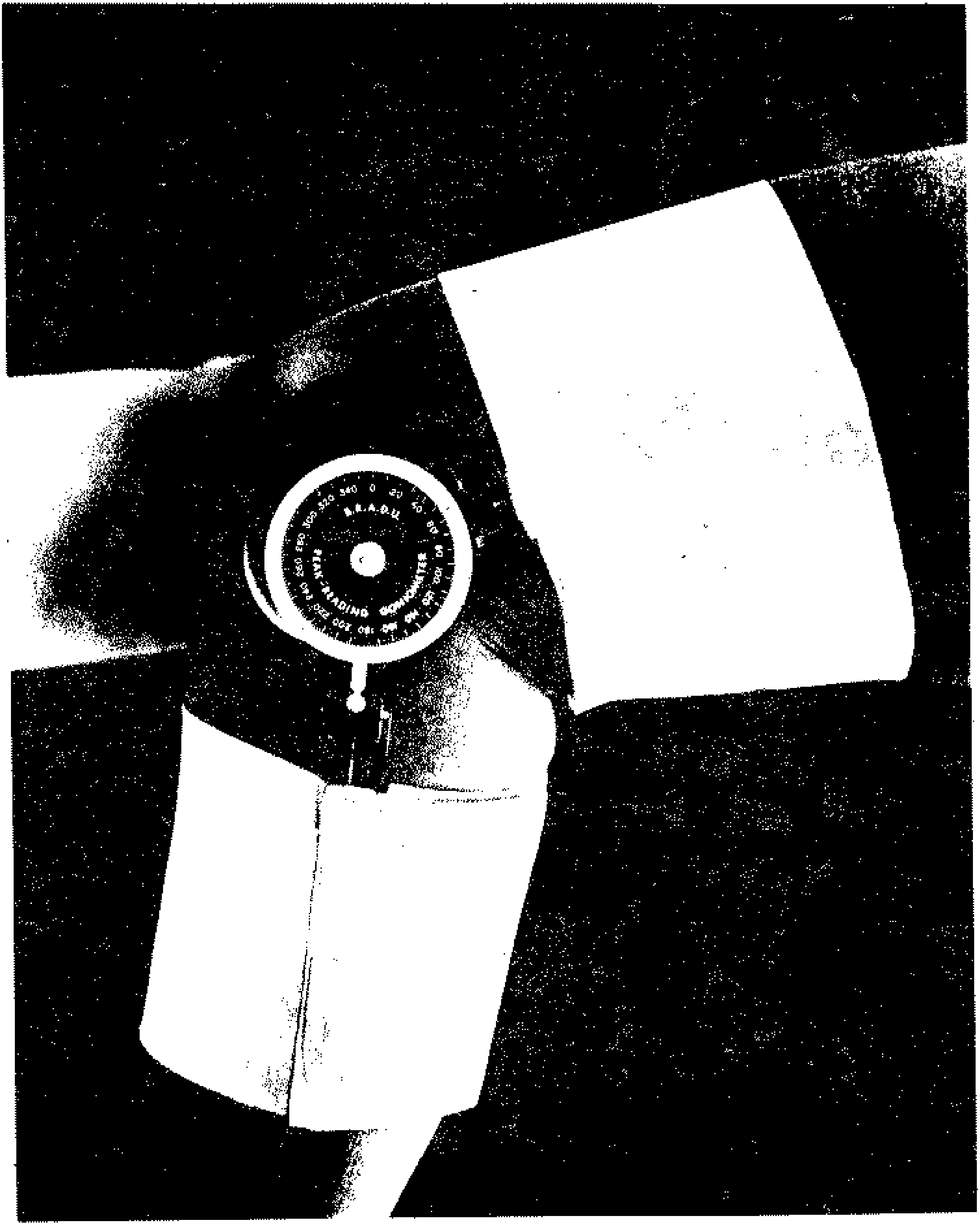


Fig. 4 Peak-reading goniometer measuring knee flexion