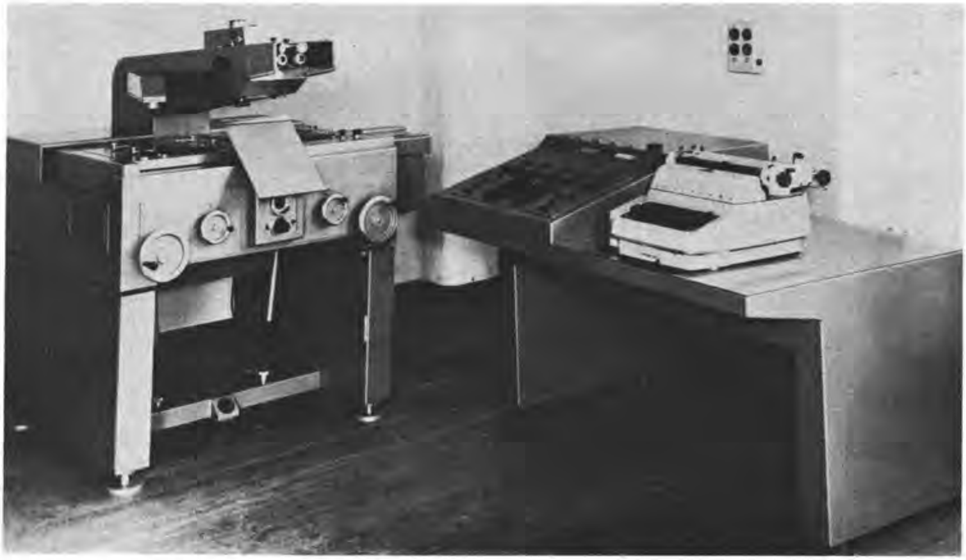

FIG. 1. Total view of Stecometer with automatic typewriter.

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The Stecometer with an Automatic Recording Device

A screw-type stereocomparator is designed for analytic applications

(*Abstract on next page*)

INTRODUCTION

AROUND THE TURN of the century the Jena Optical Works, upon the suggestion of C. Pulferich, built an instrument called the Stereocomparator which, though intended for astronomical purposes, initiated the era of Stereophotogrammetry. The measuring principle of this instrument is based on the effect of the *floating mark*, a stereoscopic mark which appears to float in space and which to this day represents an intrinsic part of stereoscopic measuring instruments. Whereas in the following decades the production of the Stereocomparator was followed up to 1951 by several other models of Jena photogrammetrical instruments—the last one having been the highly reputed Stereocomparator 1818—this instrument was predominantly adapted to terrestrial photogrammetry, even though its square format also permitted the evaluation of the aerial photographs.

Parallel with the development of electronic computers, a new branch of photogrammetry came into being, namely, analytical photogrammetry.[1] In contrast to the conventional projection or analog computers in stereo plotters, digital computers are used in analytical photogrammetry for transferring the results of spatial resections which lead from the photo coordinates to the desired topographic coordinates. Obviously, this will not be possible unless one wishes to plot individual control points rather than traverses as done for establishing additional control nets for cadastral purposes or for specific engineering, etc. In these provinces the numerical methods are being adopted to an increasing extent because they permit:

a. Improvement (though slight) in accuracy
b. Relieving the stereo-plotters
c. Taking into account systematic errors
d. Employing uncomplicated measuring instruments
e. Using measuring instruments for measuring photographs of any calibrated focal lengths
f. Precluding a number of subjective errors in the plotting process.

ABSTRACT: *The stereocomparator, originally for astronomy, plays an important role for photogrammetry by providing a reliable measuring instrument for analytic applications. Although highest accuracy can be obtained through the use of glass scale (Abbe), practical considerations justify the use of the precision screw (Pulfrich). Automatic read-out to a typewriter and punch tape or card punch are considered to be a modern necessity. Considerable thought is devoted to the design of the instrument including the basic frame (three legs), the trueness of the ways, reliable optics, digitization, environmental stability, styles of measuring marks, optical field of view and a "finder," choice of four magnifications, control panel and displays, the typewriter, 8-channel paper tape, operator comfort, and, above all, accuracy. The least count is 2 microns. The technical data include the size (51 by 41 by 51 inches for the measuring unit) and weight (1400 pounds for the complete system).*

Analytical photogrammetry thus fell back upon the first and original type of stereophotogrammetric plotter, that is, on the Stereocomparator, and considerably stimulated its production.

The experience collected by the combination of plotter and computer[2] led to a series of requirements and wishes without which a modern Stereocomparator cannot be put to economical use. These requirements do not so much refer to the point of accuracy (the mean error of coordinates of $m = \pm 3.5$ micron of the Stereocomparator 1818 even today is in accordance with practical requirements), but rather to the elimination of subjective error sources by way of the automatic recording of measuring data and of increasing the working productivity.

The long experience collected in Jena in mechanical and optical respects, and the newly added knowledge of late when using electric and electronic elements in the transfer of motions and in the analog-digital conversion,[3] led to the development in Jena of a novel type of Stereocomparator—the Stecometer with automatic recording device (Figure 1). This instrument not only embodies the requirements of analytical photogrammetry, but also general technical items such as operating comfort, elegance in shape, etc. It is composed of three constructional units, namely, the measuring instrument, control desk, and automatic recorder. As a fourth unit a card punch may be added.*

Mechanical Design of the Measuring Instrument

Greatest accuracy[4] in length measurements can be attained by adherence to the Abbe comparator principle. However, strict adherence to this principle in Stereocomparators leads either to relatively large-size instruments or to technical difficulties where small outer dimensions and entirely automatic rerecording are being asked for simultaneously.[5]

Both of these requirements are not allowable from a practical point of view. Extensive theoretical investigations have shown that with the mean error of ± 2 to 3 microns we are aiming at, we can afford to infringe upon the Abbe comparator principle.

It is for this reason[6] that we adopted the Pulfrich type of stereocomparator assembly as the measuring principle. Although increasing the plottable photo format to the internationally conventional size of 24×24 cm, relatively small outer dimensions were obtained. The compact and stable construction of the stereocomparator makes the instrument unsusceptible to its environment, especially against fluctuations in temperature, and ensures a high consistency in the measuring results.

* Fig. 1 shows a functional prototype in which the control desk and the recording unit still formed an instrument component. In the series-produced instruments the constructional units were separated as outlined above.

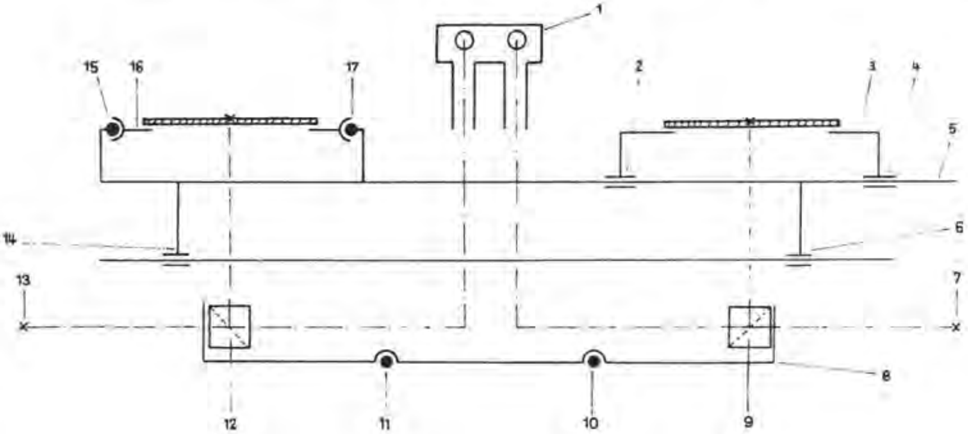

FIG. 2. Working principle of Stecometer (measuring instrument).

The basic body of the Stereocomparator rests on three feet on a cast iron structure, and carries the guide rails for those parts of the stereomicroscope that move in the y''-direction (8, 10, 11, of Figure 2) and for the main carriage moving in the x'-direction (5, 6, 14). Located on the main carriage are the two parallax slides.

The parallax movement in the y-direction is assigned to the left-hand photo carrier (15, 16, 17) and that in the x-direction to the right-hand photo carrier (2, 3, 4). The x'-carriage and the y''-carriage slide on flat or round ways, one of the ways always serving as a main guide rail while the counter guide rail serves as a support for the respective carriage. The two parallax carriages move on ball bearings.

The precision of all the ways, as well as suitable adjusting devices, ensure that the carriages move linearly and rectilinearly, or truly parallel to each other. The photo carriages are connected with the measuring spindles by means of cardans and spindle nuts. The spindles are of decisive importance for the accuracy of the Stecometer. Their manufacturing tolerance is so narrow that mechanical error-correcting devices may be dispensed with. Selsyn transmitters are connected through gears with the spindles whose rotations are transmitted to the control desk where the respective carriage feed is digitally displayed.

The driving elements (hand and foot wheels) are mechanically connected with the spindles and are arranged in front of the measuring instrument (Figure 1). The hand wheels for the main motions (x' and y'') are distinguishable from those for the partial motions (px and py) by their diameters. The foot wheels are coordinated to the hand drives for the parallaxes located on the same side. Their large diameters allow an extremely fine and exact adjustment of the vertical and horizontal parallaxes. The instrument is provided with several devices that considerably contribute towards increasing the plotting speed. These devices include rapid motor drives for x' and y'' ($v = 10$ mm/sec), as well as the optional use of hand or foot wheels for the parallax measurements, and a finder projector at the left y''-carriage permitting coarse setting of measuring points (see section dealing with the optical assembly of the measuring instrument).

There is no need for emphasizing that every precaution has been provided to prevent mechanical damage. These precautions include micro switches which automatically stop the motors at the range limits; furthermore, delay switches which, when suddenly reversing the motor, prevent the reversed motion until the carriage has stopped on its former motion; warning buzzers, etc.

Both photo carriers are provided with full swing, with the facility of reading angles off a vernier to 10°. Drive is optionally possible either by a fine adjustment or coarse motion; a clamping device ensures that the amount of swing be preserved.

OPTICS OF THE MEASURING INSTRUMENT

With the emulsion down, the photograph (5, Figure 3) is placed on the marking plate (6) and is illuminated from above by the lamp (1) through condenser lenses (2, 4) and a mirror (3). The brightness may be controlled by buttons located laterally on the eyepiece head. The beam-splitting cube (9, 12 Figure 2; 7, Figure 3), the images of one of the six

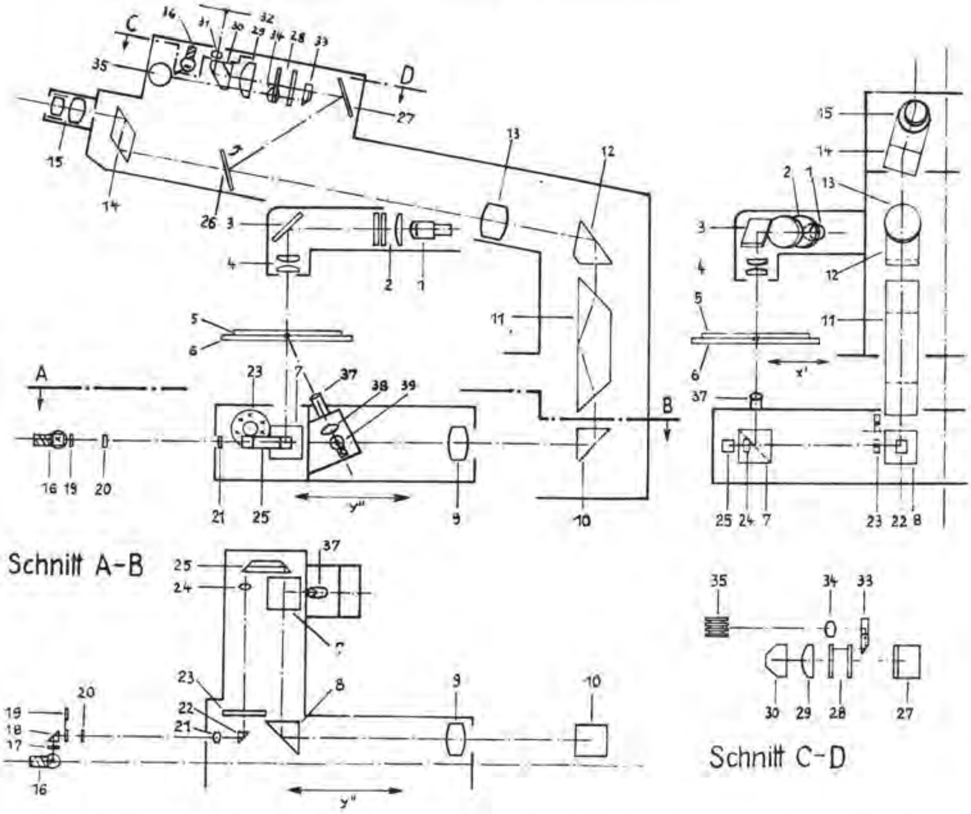

FIG. 3. Optical path in the Stecometer (measuring instrument). *Schnitt* means "section."

measuring marks (7, 13, Figure 2; 23, Figure 3), and the measuring image are optically fused and jointly transmitted into the fixed eyepiece (15) by means of the prisms (8, 10, 11, 12, 14, Figure 3) and the objective (9, 13).

The measuring marks are luminous marks. They are located on the revolving reticle (23, Figure 3) and are illuminated by a lamp (16) through condenser lenses (17, 20, 21) and prisms (18, 22). They are fused by the negative lens (24) and the reversing prism (25) in the optical viewing path. Furthermore, situated in the optical path of the measuring marks is the color filter (19), which permits of setting in three colors (white, green and orange). The diameters of the measuring marks in the image plane are given in Table 1.

The optical parts (Figure 3: 7, 8, 9, 21, 22, 23, 24, 25) are installed in the mobile y''-carriage (8, Figure 2). The optical path between the objectives (9, Figure 3) and (31) runs parallel. With the aid of the amici prisms (11) each of the two photographs may be optically rotated. Although the partial rotation is intended to eliminate the swing, the joint rotation of the two amici prisms permits observation of the vertical parallaxes as horizontal parallaxes, and of the ortho-stereoscopic or pseudo-stereoscopic observation of the photographs.

TABLE 1. DIAMETER OF FIDUCIAL MARKS

Shape	*φ mm*	*Shape*	*Inside φ*	*Outside φ*
small dot	0.02	small ring	0.02	0.03
medium-size dot	0.04	medium ring	0.04	0.06
large-size dot	0.06	large ring	0.07	0.10

The photo frame and the fiducial mark are critically focused at the same time by turning the left-hand jacket of the eyepiece. Eyepieces are interchangeable, permitting four magnifications in all. The data compiled in Table 2 show the excellent quality of the optics. An especially outstanding feature is the large diameter of the visual field and the practically uniform resolving power both for high and low contrast.

To the same extent as the large diameter of visual field, also the *finder-projector* (fitted to left of the y''-carriage 37, 38, 39) contributes towards increasing the measuring speed; it produces a luminous spot about 5 mm in diameter in the image plane. The projector is switched on simultaneously with the interior illumination of the Stecometer and facilitates the rapid location and setting of the next measuring point, which applies in particular when using the rapid drive.

What represents a further improvement of the Stereo-comparator equipment as a whole is the photographic target image recording device. This device now permits the production of a photographic record of a 24×24 mm. section of the photograph on a 1:1 scale together with the fiducial mark and a point number, where formerly a sketch had to be drawn in order to fix points of special interest. The format of the target image is 24×36 mm. To this end, the folding mirror (Figure 3; 26) is swung into the optical path for the purpose of conveying the light beam into the camera via the fixed mirror (27), diaphragm (28), field lens (29), roof prism (30), and lens system (31). The camera then records the photo section in the film plane (32).

The four decimal counting mechanism (35) is projected into the optical path (through the lens system 34 and the reversing prism 33) and is then recorded next to the photosection in the film plane (32). The counting mechanism is illuminated by the lamp (36). The camera (without lens) is attached to the comparator by means of an adapter. A photograph of the target image is shown in Figure 4.

FIG. 4. Photo of target image.

Arrangement and Function of the Control Panel

The control panel is the link between the measuring instrument and the output units, namely, automatic typewriter and card punch. In the control desk the measuring data are converted from the analog form (spindle rotations) into the digital form (numbers, certain contact makers), where they are optically displayed, prepared for the output units, and worked down in series by a program control. This work is attended to by individual constructional units (Figure 2).

The spindle rotations are transferred with the aid of selsyn transmitters.[2,3] In this way the mechanical connections have been replaced by purely electrical and flexible connections between the separate instrument components and thus afford maximum utilization of the available space.

The selsyn transmitters actuate the adjoined digital counters through suitable gearings. Each counter records six places. With three places before and three places after the decimal point, millimeter values were indicated to an accuracy of exactly 0.002 mm. The fine and coarse counts (Figure 5) have been separated because, with counter readings to 0.002 mm. and with the motor drive of the photo carriages in the measuring instrument, the last (and most exact) counter wheel cannot be expected to withstand the continuous high stress in the long run. The coarse count refers to the first four places. In accordance with the spindle rotation the fourth counter wheel (unit 0.1 mm.) is driven continuously. It is connected with the three counter wheels ahead of it in the shape of a pedometer. The fine count refers to the second and third place after the decimal point. The fine counter remains at rest until the time when the reading is taken or the record made. It is not until then that the

TABLE 2. OPTICAL PROPERTIES OF STECOMETER

Magnification	6×	9×	12×	18×
φ of exit pupil (mm.)	3.3	2.0	1.2	0.8
φ of visual field in the image plane (mm.)	32.0	30.0	25.0	17.5
Resolving power in lines/mm.				
at high contrast	45	65	76	90
at lower contrast	45	63	72	85

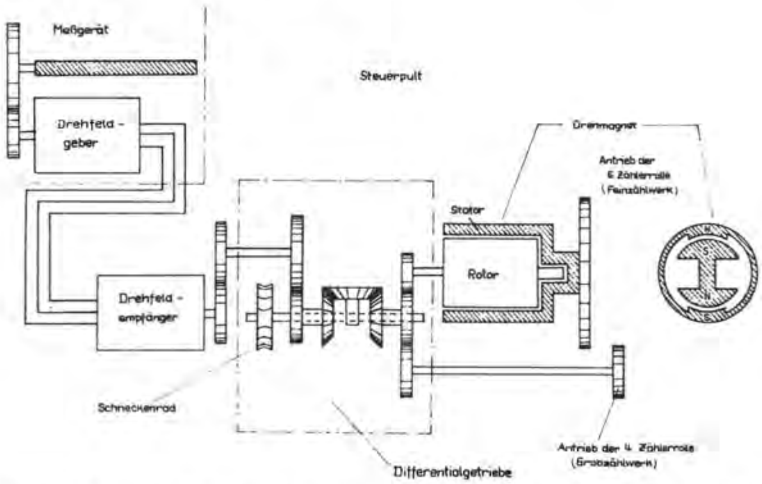

FIG. 5. Diagram of gearing (section) of the Control panel. 1 Rotary magnet, drive of the 6th counter roller (fine-counting mechanism), 2 Stator, 3 Rotor, 4 Drive of the 4th counter-roller (coarse counting mechanism), 5 Differential gear, 6 Worm gear, 7 Rotary-field receiver, 8 Rotary-field transmitter, 9 Measuring instrument.

follow-up process is briefly effected by means of a rotary magnet.

The rotary magnet is an electro-magnetic coupling consisting of a two-pole rotor and a two-pole stator, the windings of which are through slip rings fed with direct current as soon as the following-up takes place. The stator as well as the rotor are seated the same as the coarse counter, so that the rotor of the rotary magnet is continuously actuated. The stator remains at rest as long as the coupling is not alive. Only when the current is switched on will the stator orientate itself by the shortest route relative to the rotor and will cause the fine counter to follow. During that period a magnet brake blocks the rotor. The rotary magnet operates entirely contact-free.

FIG. 6. Inside view of control panel.

It offers a minimum resistance to mechanical coupling devices and follow-up motors and at the same time operates with greatest possible functional reliability.

Figure 6 shows the constructional arrangement of the elements (1—selsyn transmitter, 2—gearings, 3—rotary magnet, 4—counters). To afford perfect reading, the continuously driven counter wheels (the 4th and the 6th) require aligning so as to make the numbers appear in the reading windows in full size. As for the following-up of the last two counter rolls, the aligning process will be automatically effected by pressing the reading or the recording key, a process lasting about three seconds. During this period the selsyn transmitters remain blocked and no measurements can be made. In order to be able to release the block while the measuring data is written by the typewriter, provision is made for a buffer store (5, Figure 6) for the measuring data.

This storage is automatic if the recording key *R* is depressed (in conjunction with the following-up of the last two counter wheels and with the aligning process). This is brought about by cam plates rotating synchronously with the counter wheels (Figure 7). With the cams in aligned state, they stand opposite to certain contacts corresponding to the numbers. By a minor lateral movement of the entire group of contacts, the contacts will be closed and remain so up to the completion of the entire recording process. The feeding of the measuring data from the store to the typewriter is controlled by a program drum which, besides the exact

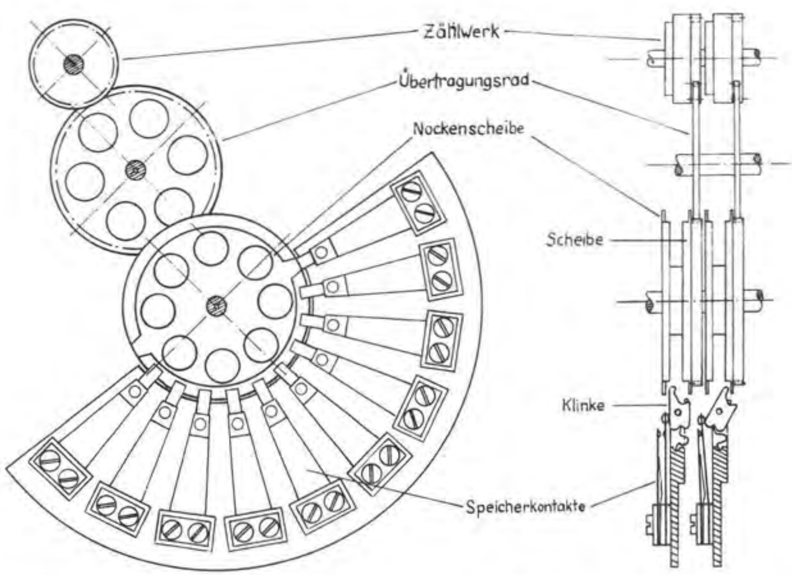

FIG. 7. Principle of counter store in the control panel of the Stecometer. 1 Counter (Zählwerk), 2 Transmission wheel (Übertragungsrad), 3 Cam plate (Nachenscheibe), 4 Disk (Scheibe), 5 Pawl (Klinke), 6 Storage contacts (Speicherkontacte).

pulse control, determines the writing sequence, decimal points, jumps and the carriage return.

In addition to the four coordinates x', y'', px and py, the program drum also controls the writing of the point number (eight-place maximum) which, together with still further functions, may be set at the operating keyboard (Figure 8). Particular attention was devoted in this case to the wide adaptability of the recording device, which is a specially distinctive feature of a modern type of comparator. Users are afforded the following facilities; setting of optional starting figures for x', y'', px, py and of the running point counter P; employment of the running point counter P and the manual keyboards $H\text{I}$ and $H\text{II}$; reversal of the direction of rotation of all counters (P, x', Hy'', px and py); breaking of the connection between counter and spindle as well as between counter and automatic recorder; recording of special symbols charac-

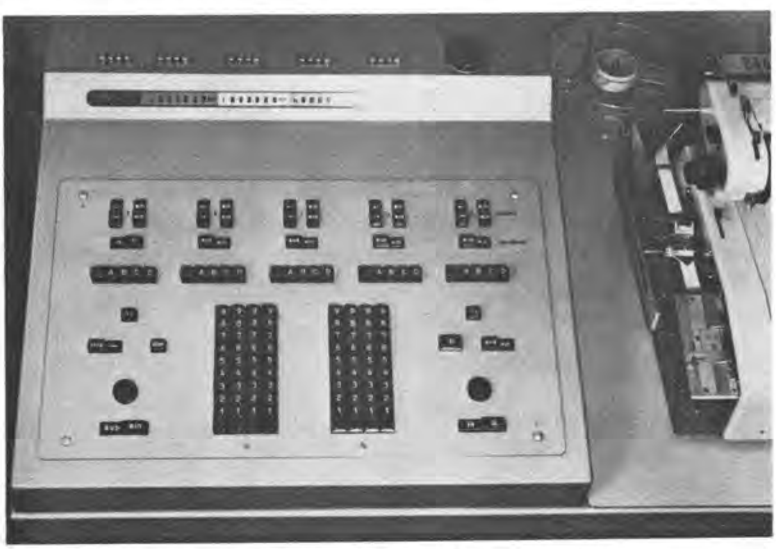

FIG. 8. Operating keyboard of control panel.

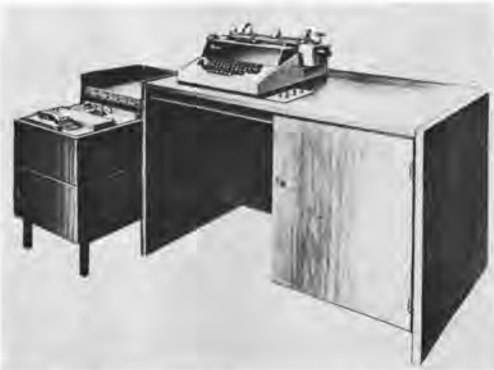

FIG. 9. The Automatic Typewriter Soemtron 527.

terizing points for relative, absolute orientation, etc.; cancellation key for discarding erroneous dings. For all of these operating facilities corresponding well-arranged keys or double-push keys have been provided on the control panel (Figure 8).

The main operating keys are the reading key *A*, the recording key *R* and the measuring key *M*. The measuring key must be in depressed state during the measuring process. For reading the measuring data, the reading key *A* must be depressed. The recording process is released by depressing the key *R* or the pedal switch located between the foot wheels of the measuring instrument. This may be effected both from the measuring as well as from the reading position. The great adaptability of the control panel is furthermore emphasized by the facility of readily connecting to it a desk computer in place of the automatic typewriter[7], which thus results in a new combination of instruments taking full advantage of the merits of the analytical methods and offering at once the working result, viz: the topographic coordinates.

THE AUTOMATIC TYPEWRITER SOEMTRON 527

As an output unit an automatic typewriter of the Soemtron 527 type is used (Figure 9). Combined in a neat writing desk are the electrical typewriter, the tape punch, a punch-tape reader, and the respective converters and decoders. The automatic typewriter has a power unit of its own and is connected with the control panel by a cable which transmits through the program-control electrical impulses to the magnets of the typebars and to the magnets for the movement of the typewriter carriage.

Typing occurs at a rate of 10 characters per second. The tape punch operates parallel with the typewriter in such a manner as to produce the clear-text protocol and punch tape simultaneously. In the standard equipment the tape reader operates on the eight-channel system. This system is not only reliable but in addition affords considerable mechanical advantages when intending to control a typewriter fully alpha-numerically. This is actually the case in the Soemtron 527-type which is used.

The tape reader not only permits typing in clear text any letter texts, such as measuring notes, letterheads, etc., recorded on perforated tape; they also permit the production of duplicates of the perforated type. This facility again emphasizes the versatility of the equipment for data processing purposes. Numerous users of these instruments for historical, technical and methodical reasons employ these instruments in the five-channel system (International Telegraph Analphabet No. 2), even though this code affords but little protection from transmission errors. For this reason the Soemtron 527 may be also supplied for the five-channel code, although in this instance the typewriter cannot be controlled fully alpha-numerically. Only the digits, the carriage movements and the special symbols referred to in the paragraph about the control panel will be punched.

An assessment of the equipment made by various manufacturers for the perforated tape technique in conjunction with computers, office machines, bookkeeping machines, and other data-processing equipment, indicates a certain trend for the eight-channel system. Hence, we recommend to all those photogrammetric areas that are beginning to build up a data-processing system to employ the eight-channel code from the outset.

EFFICIENCY OF THE STECOMETER

The performance of an equipment is influenced by a whole series of factors. It is not only the expected accuracy that is decisive, but first of all the working productivity; and it is for this reason that special attention has been devoted to these specific points. In the paragraphs about the mechanical and optical setup and about the control panel, detailed reference has been made in this direction. Time studies for a single pair of airphotos (67 points including the fiducial marks, average separation of 75 mm.) made by photogrammetrists using the Stecometer for the first time, resulted in 2.50 minutes of time for each stereo setting. Observers accustomed to the instrument achieved a saving of 35 per cent of the time. The finder-projector described before was not used for these tests. A comparison with the values given in reference

1 shows that very good results for stereocomparators had been achieved.

For ascertaining the accuracy, measurements were carried out on precision grid plates[4]. The tests were made in the presence of numerous professionals from home and abroad. The mean measuring accuracy of coordinates obtained in these tests were, adjustment according to: Hallert, $\pm 1.9\ \mu$; Helmert, $\pm 2.4\ \mu$.

In the aforegoing, the principal features of the Stecometer have been explained representing an instrument fully justifying the requirements of analytical photogrammetry and data processing and which in a successful way continues the tradition of Jena-made Stereocomparators.

Technical Data

MEASURING INSTRUMENT
- Maximum photo-format—24×24 cm.
- Measuring ranges:
  - x' and y''—0 to 280 mm.
  - P_x—10 to +130 mm.
  - P_y—40 to +40 mm.
- Full swing, reading accuracy—10ᶜ
- Speed of rapid drives—10 mm./sec
- Enlargement—6×, 9×, 12×, 18×
- Fiducial marks—6 shapes
- Colors of measuring marks—3 different colors

CONTROL PANEL—least reading and recording unit —0.002 mm.

WRITING SPEED—10 characters per second

DIMENSIONS
- Measuring instrument—1300 mm.×1050 mm. ×1300 mm.
- Control panel—650×970×1050 mm.
- Automatic typewriter—1130×750×730 mm.

WEIGHTS
- Measuring instrument—about 400 kg.
- Control panel—about 150 kg.
- Automatic typewriter—about 75 kg.

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