# ABOUT GEODETIC INSTRUMENTS FITTED WITH GLASS CIRCLES

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About the middle of 1886 Joseph et Jan Fric̆ mechanics of Prague reported that they had fitted a theodolit with a glass circle, constructed for mining purposes. They brought this theodolit into circulation under the name "Duplex", and for using glass in making a limb, they wrote, in an article dealing with this subject, as follows: 'Who has ever had the occasion to observe the pureness of scratched in glass of a micrometer scale with light falling through, and has attempted to decide the parts of the minute scale, using a dense divided vernier at the light of a flickering mine lamp, would understand why we chose just glass as the material of the horizontal circle.'[1]

Concerning the material of the glass used that has been simply called mirror-glass, no details have been mentioned. Supposedly it consists of potassium containing slightly reflective 'crownglass' (the so-called Czech-crystallglass).

It would indeed be difficult to give a better explanation concerning the reasons for applying glass circles, than that of the Brothers Fric̆. This step, however, which was otherwise of great importance and perhaps opened up a new era in geodetic instruments, has never received due reaction, nor has this initiation been followed by other factories: till the beginning of the nineteen-twenties, when the Firm Zeiss in Jena issued a newly constructed theodolit, fitted with glass circle at the suggestion of H. Wild.

[1] Zeitschrift f. Instrumentenkunde. 1886. Heft 7.

As in the case concerning the glass circle, which is similar to that of many other inventions of more or less importance; modifications and inventions which are discovered ahead of their time, cannot be introduced and so do not become general, a certain advancement is needed; for this purpose as a matter of fact they must be reinvented before one could ascertain their usefulness and purpose in wide range, and in that case they may often become indispensable at the same time.

The glass disk applied by the Brothers Fric̆ was 8 mm thick, and was fastened by a conic hole in the middle onto the vertical axis in such a way, that it was pressed with its side to the metal disk standing at right angles to the vertical axis. It was fixed by canada balsam on this metal disk. The article emphasizes that the numbering of the divisions signifying round degrees caused great trouble. The numeration had been written on the disk before graduation, by means of a special pantograph constructed for this purpose because the figures could not be got on the small field of view of the reading microscopes with high magnification, if their height surpassed the tenth of a millimeter.

The divisions were scratched in with the aid of a diamond, applying rather a high pressure on the edge left free on the upper surface of polished glass, a little inward from the edge (figure 1).

In 1924 O. Eggert gave an account of a new theodolit with glass circles produced a little earlier by the Firm Zeiss in Jena. The

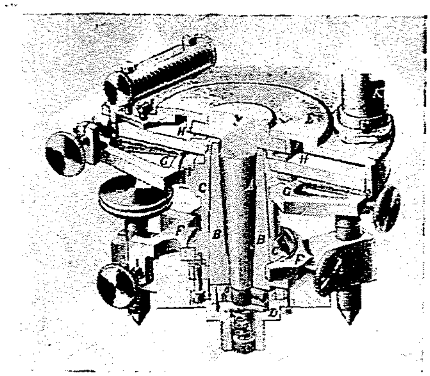

*Fig. 1*

first exemplar was placed at his disposal for testing and for his opinion (figure 2).

Eggert mentiones in the general description of the instrument that the material of both the horizontal and the vertical circle is of glass. The advantage of — this he emphasized — lies in the possibility of unifying a field of view of the image of the two indexes in the coincidence reading device applied to this instrument. Consequently, the reading can be simplified as only one reading microscope is required with its eyepiece near to that of the telescope. It can be gathered, from the description, that the division of limb on the outside mantle of the vacant cylindric glass body was made by etching. The illuminating beam of light projected into it from below, is turned by prismes in the diametral opposite part of the circle graduation, from where it is reflected by the reflecting surface, so that the point of the graduation mark is precisely signaled by the absence of reflecting. The images of two diametral graduation marks are unified, and at the same time the fine reading, being proportional of the size of the turning, is determined by turning a planparallel plate.[2]

[2] Zeitschrift f. Vermessungswesen, 1924. Heft 15. u. 16.

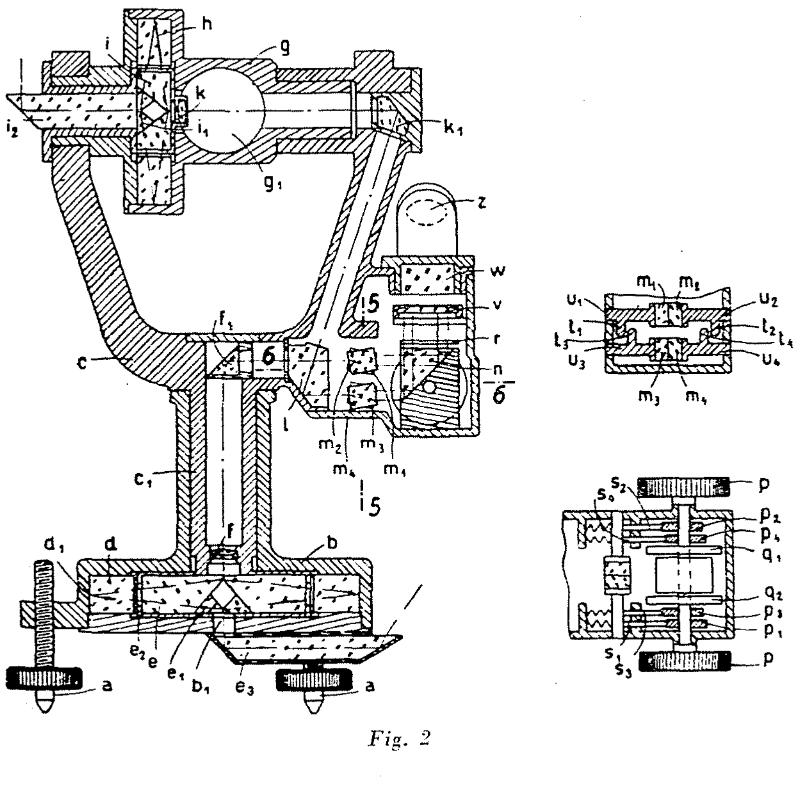

*Fig. 2*

The year after W. Schermerhorn reports the results of a comparison to other instruments. He has the same opinion of the advantages of this construction as has O. Eggert.[3] A year later the new theodolits produced in H. Wild's factory in Heerbrugg, appeared on the market, in which the graduation was made in a photographic way, the marks were made permanent by etching on the horizontal dividing surface of the limb, which was also a glass ring.

The different precision-mechanical factories one after the other took over the inestimable value of this solution, some — for example the Firm Kern in Aarau — could even increase the advantages of it, by application of a double graduation, reducing the length of the vertical axis and supporting the alidade by a ball-bearing on the rim of the under part of the instrument, outside of the limb. ("Doppelkreis" theodolit of Firm Kern), etc.

The foreign development did not remain without any influence on the Hungarian instrument industry. Scarcely a decade after the appearance of theodolites fitted with glass circles the manufacturing of 'Normal' theodolit begins in the factory for precision-mechanical and optical instruments of N. Süss, the predecessor of the Hungarian Optical Works. The peculiarity of this instrument was that one could not only find a common graduation in degrees beside measuring horizontal and vertical angles, but a tangent scale too, at the I index belonging to the left face so that it could be used as Szepessy's tangent rangefinder too. The inside lighting of the instrument was resolved in a simple but ingenious way, so that it was also suitable for underground measurings.

The use of the coincidence reading device, proposed by Wild, while being rather comfortable has resulted not only in a great increase of the accuracy of readings, without the difficulty of using a screw microscope, but has increased the accuracy of the measuring angles too. Moreover the sensitiveness of the reading device has surpassed the possibilities given by the accuracy of pointing. We can easily convince ourselves of this by creating two coincidences one after the other, belonging to the same pointing, on theodolit T. 3. There is no possibility of deciding precise by the hundredth of seconds, because the tenths also vary! Or repeating the reading of 0,1" of T. 2., we experience the uncertainty of the values of seconds too. Therefore it was reasonable to strive in increasing the accuracy of coincidence on one hand, and to simplify the reading device on the other hand, in order that the accuracy of pointing and reading should correspond to each other. Thus, the production of the instrument becomes more economic, and the misinterpretation usual in the engineering practice of to-day, cannot occur for the setting up of sensitive engineering structure e. g. a river bridge or a tunnel, the use of a theodolit fitted with more accurate reading device, is sufficient and there isn't any need of observing left and right face or repeating the measuring in other sets.

The other trend, i. e. that for making coincidence more clear and definite, this has been asserted on the larger theodolits used for measurings with greater accuracy (double graduation, double circles etc.).

The simplifying factor comes into prominence on the newest, here constructed theodolites[4] fitted with glass circles. Accordingly the magnifiying power of the telescope is lower than usual (below 20×) but the illuminating power of it is rather good, and so its resolving power is the most suitable for surveyings. (Figure 3.)

The objective-aperture diameter of the telescope is 25 mm, its length is constant, the image of a pointed signal can be made sharp by an internal focussing lens. A knurled ring, placed on the telescope before the eyepiece, serves to move the focussing lens. By means of the distance measuring wires of the telescope, tacheometric measurings can also be made, if a multiplication constant 100, and a vertical staff are used. The telescope is anallatic, it has therefore no adding constant. The shortest focussing distance is of 1,5 m. The reading device is the most simple, because the

[3] Zeitschrift f. Instrumentenkunde. 1925. Heft 1.
[4] Gamma Optical Works

glass micrometer scale placed in the microscope's field of view which divides the distance of two graduation marks of the limb — i. e. 1 degree — into 6 or 12 parts and the position of the preceeding graduation mark of fixed by the knurled disk with a smaller diameter in horizontal and vertical sense, while using the other knurled coaxial disk, which is somewhat further backwards, for the slow-motions, a fine pointing can so be produced.

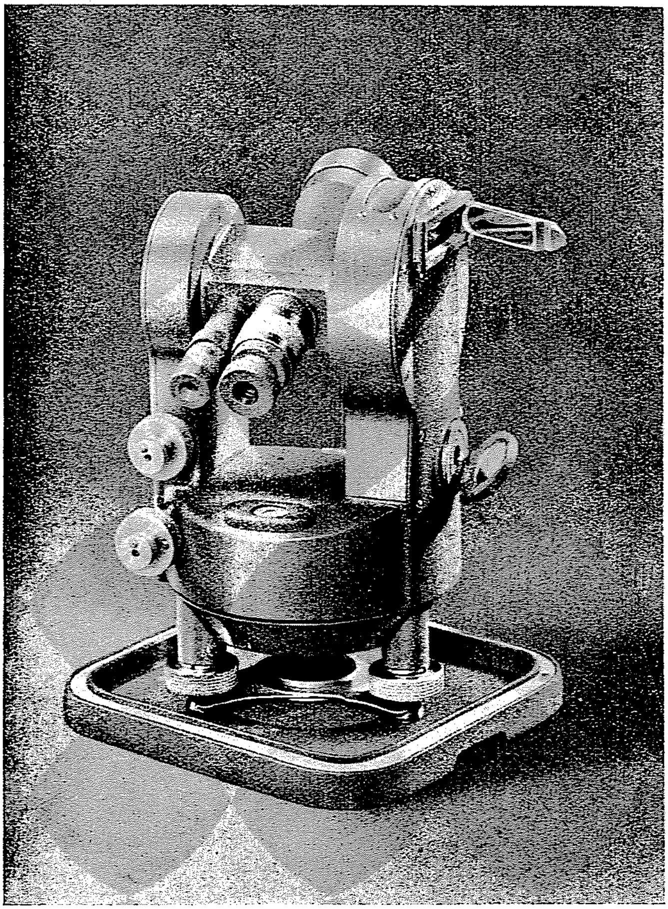

*Fig. 3*

limb a simple estimation can be decided on within the parts, but undoubtedly, with sufficient accuracy. The theodolit type E-l produced by Gamma Optical Works, has further particularities, besides the above mentioned ones. It is conspicuous that the two clamps and the slow-motion screws are above each other and coaxial. The alidade can be In consequence of the small dimensions of the instrument these screws can both be reached and operated without any difficulty, whether from the side of the eyepiece or from the objective side, in the corresponding telescope position.

The clamp can be turned only with a part of the whole revolution, and yet the fixing or solving is perfect. The superfluous turning of clamp, and so the handling for a considerable time of the instrument can be avoided, the instrument can be brought to an absolute standstill in the shortest time, which is needed for observation.

intensity of light, and this possibility sufficient to satisfy the indispensable requirements of the pointing illuminated signals, in case of underground measurings. The box-level which serves for levelling the instrument, and the vertical circle level have such sensitiveness

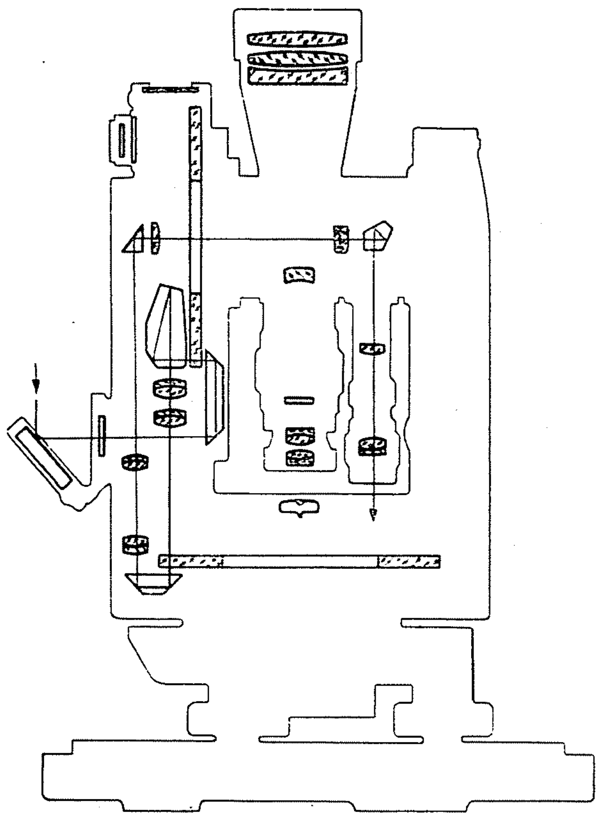

*Fig. 4*

The other speciality of this instrument is, that the horizontal and vertical circle, made of optical glass, and the glass plate of cross wire can be illuminated by only one reflecting mirror, or if there isn't enough diffuse illumination for the working place, an electric lamp with low voltage can be fixed in place of the mirror, which is sufficient to make the circles and cross wire visible. The illumination of cross wire happens by means of a variable

that accurate levelling of the instrument and the reading off of the vertical angle can be done with equal speed. (Figure 4.)

The instrument is suitable for simple levelling too, if we make its plane of direction horizontal by using the vertical circle.

So the instrument can be used on wide fields of practical engineering with sufficient accuracy, without making the observation tiring either by the extreme magnification, or by the superfluously sensitive reading device, and without involving the observer in making mistakes of the nominal accuracy of reading.

Preparing and building-directing works occurring in the fields of road-, railway- and hydraulic-engineering can be quickly and accurately accomplished by this small, and not too heavy instrument.

The vertical axis is cylindrical and for its relief a concentric steel bearing ball is applied below it. Therefore the running of the alidade is independent of the weather, and is always equally light and so exact that a second index is not needed at all. In this way the expensive and sensitive optical equipment which is needed for projecting over the graduation marks, can be omitted, and yet the required accuracy can be reached, by observing face left and face right.

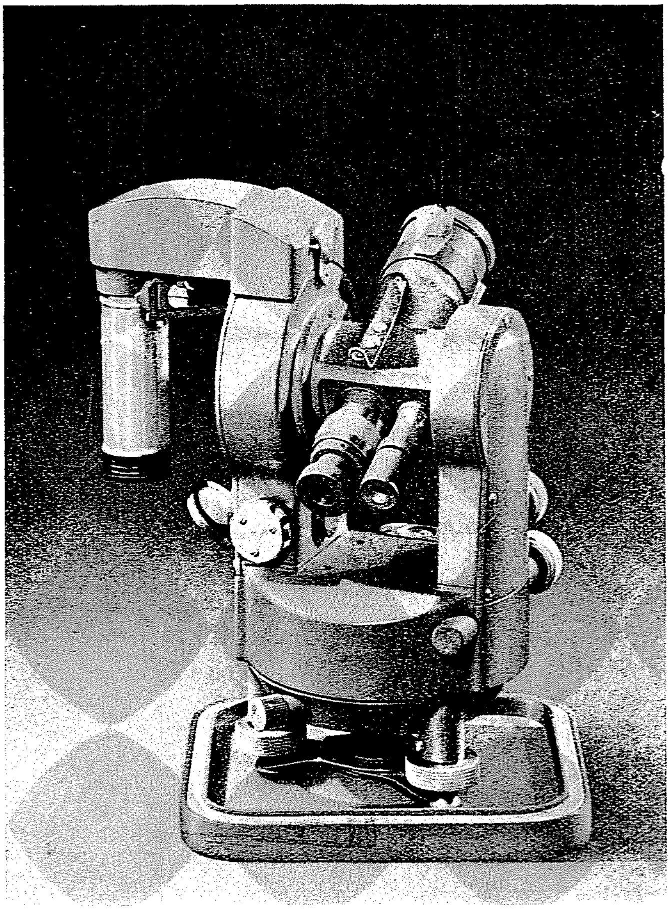

Fig. 5

For transporting, the instrument can be placed in a well shaped metal case, equipped with a lifting handle of leather and rubber packing band. The instrument is fixed on the lower part of this metal case in such a way, that it can be placed on the tripod together with the bottom-plate. Therefore transporting the instrument from one station to the other, there is no need to take it down, but only the metal bell-cover is to be placed on it, and the instrument can be carried together with the tripod.

Gamma's mining theodolit type E—2 is quite similar in its appearance and inside arrangement, to the one described above. Yet two differences can be observed. One is that the upper, turnable part of the instrument can be lifted together with its vertical axis, out of the levelling head after loosening a locking screw, and transferred to the similarly formed levelling heads placed before on other tripods used for this purpose. These levelling heads hold the signal target (mira) too, which is used for pointing, and can be illuminated. In this case three levelling heads of the same form and two miras are required, which gives the possibility of setting up the instrument and mira quite concentrically in 0,05 mm. (Figure 5.)

This equipment can be very advantageously used in cases of underground measurings during the pauses of transporting, that can be stopped frequently only for short times in narrow adits, though in this case the traverse stations are signaled by miras mounted on tripods, only for the period of measuring. In most cases measuring with 'lost points' gives sufficiently good result, though there is no difficulty in making the traverse stations by little hangers in the roof, and under the tips of plumb bobs, suspended to them, the instrument can be set up concentrically, because the required mark can be found on the telescope.

The consol, constructed to this instrument, serves the same purpose, it even makes the tripod unnecessary while the latter is applied, as interruption of the transportings in the adit, is needed. The other difference is in the illuminating equipment of the cross wire. This is a projective ring, which can be placed on the objective casing of the telescope, and uses the illumination of the working place for reflecting the light required for pointing, into the telescope.

The theodolit type MOM D. 1. serves to satisfy more exacting demands. There is no field of engineering survey where a theodolit fitted with an optical micrometer reading device of 6" sensitiveness, would not be adequate. The instrument is equally suitable for surface and underground works, where the sensitiveness of 6" is acceptable. In closely built town districts or in industrial establishments, furthermore, in underground surveyings, it is of the greatest advantage that the upper part of the instrument can be lifted out of the levelling head, and can be concentrically exchanged for the signal which serves for pointing, and can be illuminated.

The optical equipment of the telescope with a 25 fold magnification, is excellent, its illumination and resolving power is outstanding. The focussing of the telescope is made by an internal lens, which can be moved forwards and backwards by turning a knurled ring mounted on the tube of the telescope.

Otherwise the instrument shows in its outside construction certain similarity to the theodolit type E. 1. mentioned above, especially in relations the situation of the clamps and the slow-motion screws. The bubble of the vertical circle level, however, is to be set by the coincidence of the bubble ends, and it is an important difference, that an optical centering device built into the alidade serves for centering the instrument above the point. The correct position of the instrument can be controlled by turning the alidade round the vertically adjusted axis.

The horizontal and vertical circles have the same diameter, both are made of optical glass, the graduation can be illuminated by a turnable mirror or by an electric lamp with low voltage from the same position, and the graduation of both circles can be observed in the field of view of the reading microscope, which is turned beside the eyepiece of telescope, at the same time. Otherwise, the horizontal circle can be turned on '0' in any beginning direction, the setting screw which serves for this purpose is to be found on the side of the levelling head in a protecting case. The general arrangement, which originates from Wild, with the aiming placing of clamps and slow-motion screws, assures the comfortable and speedy use of this instrument. The

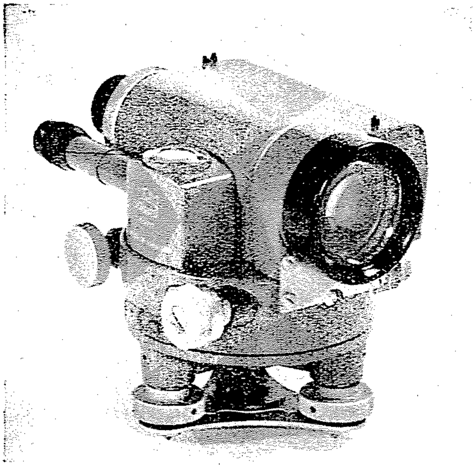

*Fig. 6*

telescope is fitted out with a rangefinder, with constant wire distances, and as it is anallatic, there is no need to pay attention for any addition constant, besides the multiplication constant of 100. A water-proof metal case serves as transporting for the instrument, which protects it against the pernicious influence of both dust and humidity.

MOM put a newly constructed level on the market using the mark: N—1. It is notable of its small extense and the compendious cramming of the parts in the instrument. The short telescope, only 160 mm long, but with a 28 fold magnification and 40 mm objective aperture and level tube are in a common cast casing which serves at the same time to protect the glass limb too. The instrument has no horizontal clamp, it has a regulable friction, whereby the pointing can be done with extraordinary swiftness. (Figure 6.)

The closed construction of the instrument gives the greatest protection against the effects of dust and humidity. The practical placing of the parts gives proof of experiences collected through long practice.

The telescope has internal focussing, a knurled ring, placed on the telescope behind its eyepiece which serves for moving the focussing lens. Beside the telescope is the eyepiece of the reading device. The image of the graduation marks of the vertically trans-illuminated glass circle is reflected by a prism in the direction of the eyepiece. This prism is placed in a common case with the box level, serving for setting up, between the tilting screw, with horizontal axis, and the horizontal slow-motion screw.

The one degree graduation is written on the upper surface of the glass circle where the even graduation marks are numbered. The micro-meter scale has 6 or 10 parts, according to the circle graduation in 60 or 100 degree system. Therefore the minutes, possibly half minutes, can be read by direct estimation. The arrangement of the circle is double centered (like repeating theodolit) it can be set in the required beginning position by a screw placed on the levelling head in a protective cap.

The sensitiveness of the level tube is 20" per 2 mm. Placing the bubble in the middle occurs by settine the bubble ends in coincidence. As this adjusting can be controlled with a magnifier of 2,5 fold magnifying power it can be accomplished with great accuracy. Owing to this fact one can count on a $\pm 2{,}5$ mm mean-error per kilometres. The field of view of the telescope is fitted out with stadia hairs with a multiplication constant of 100, and the telescope being anallatic the horizontal distances can be gained by making the difference of readings on stadia hairs, if the line of sight is horizontal. The instrument can be transported in a light metal case fitted out with a carrying strap and rubber packing. The instrument can be fixed by turnable fasteners on the bottom-plate, the case can be locked with a key.

Foreign and home experiences dating back many decades could be successfully realised in the construction of the instruments, made known above. Both the "Gamma" and the MOM did their best to satisfy the ever increasing demand of the technical public, as far as possible. We hope, that these instruments will also be followed by further constructions, the practicability of which will meet every requirement, not only of civil engineering, but also of the more accurate requirements of geodesy.

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