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CANADA.

SPECIAL APPENDIX "B"

TO

REPORT OF MINISTER OF PUBLIC WORKS

FOR

FISCAL YEAR 1897-98

MEMORANDUM

ON THE

SELF-REDUCING SANGUET TACHEOMETER

AS ADAPTED TO PRECISION LEVELLING

IN CONNECTION WITH A NEW ROD

BY

R. STECKEL, M. Can. Soc. C.E.

Engineer in charge, Canadian Geodetic Levelling

OTTAWA
GOVERNMENT PRINTING BUREAU
1899

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LIST OF ILLUSTRATIONS

CONTAINED IN ACCOMPANYING POCKET.

I—"Tachéomètre Sanguet" (auto-réducteur) as adapted to Geodetic Levelling in connection with a new geodesic rod.

II—New geodesic rod with accessories, for use in connection with the Sanguet tacheometer. $\frac{1}{10}$ full size.

III—Details of new tacheometer rod and accessories, $\frac{1}{2}$ full size.

46, 47, 48, 49 and 50—Five typical double pages of proposed field book for tacheometric surveying and precision levelling combined, showing sights, readings, entries and computations required.

5 and 6—Two typical double pages of tacheometer field book, showing sights, readings, entries and computations required for geodetic levelling, without survey.

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"SANGUET TACHEOMETER"

FOR

PRECISION LEVELLING.

DEPARTMENT OF PUBLIC WORKS, CANADA,
CHIEF ENGINEER'S OFFICE, OTTAWA, 30th July, 1898.

E. F. E. ROY, Esq.,
Secretary, Public Works Dept., Canada.

SIR,—I have the honour to transmit herewith a Memo. with illustrations, on ..e self-reducing Sanguet Tacheometer as adapted by me to precision levelling with ..id of a new Geodesic Rod.

..you are aware, the purchase of one of these perfected tacheometers, modified ..dance with the views I communicated to Mr. Louis Coste, Chief Engineer .. .. Department, under date of April 16th, 1896, was upon his recommendation sanctioned by the Honourable the Minister, in the fall of 1896, and accordingly an order for the instrument was sent by me to Cabasson, of Paris, at the end of December of the same year. Owing to various delays caused principally by the unavoidably long correspondence I had to carry on with the maker and the inventor himself, Mr. Sanguet, relative to the projected modifications and additions to the original model of his invention, and difficulties experienced in making the said alterations, the improved tacheometer with its accessories reached Ottawa only in the ensuing September (1897). Again, the new geodesic rod I devised for use in connection with the modified self-reducing tacheometer, could for various reasons too long to enumerate, not be satisfactorily completed before July, 1898. Hence the reason for not submitting this Memo. to you at an earlier date.

$1\frac{1}{2}$

The Sanguet tacheometer supplied by Mr. Cabasson which bears the order number 115, is all that could be desired, both in point of construction and finish, as far as can be judged from a close indoor examination and a few verifications made on Parliament Square. It is what may properly be termed a universal surveying instrument, being admirably contrived for measuring, in all positions, distances automatically reduced to their horizontal projections, and that more accurately and expeditiously than these horizontal distances could be measured under the most favourable circumstances, with either chain, tape or any other measuring device, besides which the tacheometer is equally serviceable for levelling and taking horizontal and vertical directions and compass readings. I have no doubt that when tested in a practical manner in the field, our new tacheometer will prove satisfactory in every way for carrying on expeditiously and economically, not only the precise levelling and surveying operations, this particular instrument is more especially destined to be used for; but also all ordinary engineering field operations.

The new geodesic rods, of which there are three, were manufactured at Ottawa, inclusive of all the accessories, viz.:—in accordance with the drawings I furnished, and under my direct supervision; for being of home manufacture, the rods are none the less artistic pieces of workmanship. The woodwork was executed at the government workshop under the superintendence of Mr. F. Breton, clerk of works, the metal mountings and fittings by Mr. Geo. Bailey, of Wellington Street, and last but not least, the painting, inclusive of scale divisions, under the direction of Mr. Alfred Coté, who is in charge of the government paintshop; although not machine divided, the scales are remarkably neat and accurate, and the figuring is very distinct and striking.

I must confess that, notwithstanding many elaborate reports made on various occasions, by prominent engineers in different countries, to show the advantages to be gained by the regular and extended use of the ordinary stadia wire tacheometer for engineering field work generally, I was never favourably impressed by the results obtained with such instruments, taking into consideration the troublesome and bulky reductions, etc., which have to be attended to, and failed to see how such tacheometers could ever really be of much service to the engineering profession, except for reconnaissance work, running trial lines and other operations of a similar nature. I now feel satisfied, however, that in a comparatively short time we shall see the improved self-reducing Sanguet tacheometer or some similar apparatus take the place of nearly all other surveying instruments used at present for engineering purposes, and that chain or tape measurements of long horizontal distances will soon be a thing of the past.

With a view of verifying, in this country, all the good points claimed for this tacheometer, and at the same time affording the engineers of the Department an opportunity of becoming acquainted with its practical working, I would suggest that it should be used in making, under my direction, an accurate plan with level contour lines of Parliament Square, Major's Hill and Nepean Point, that is to say: a plan showing the precise boundaries and elevations of the ground of all our properties lying south of the Ottawa River as far back as Queen Street, and west of Sussex Street and the Rideau Canal up to Bank Street.

I may say in this connection:

1. That there is no such plan in existence, as far as I have been able to make out.

2. That aside from the great desirability and convenience of the Department having such a document at its command for its own particular uses, we have, on several occasions, been asked, in vain, for information that a contoured plan would readily have afforded.

3. That now a combined railway and highway bridge is being built, abutting on the Government lands of Nepean Point and railway companies are endeavouring to obtain access to the new Central Station by passing over the said lands and electric companies may also apply, in the near future, for the privilege of crossing them.

It therefore appears to me to be highly advisable that the survey in question be undertaken without delay, apart from any consideration such as that above put forward in reference to the desirability of testing the new tacheometer and accompanying rods in the field, on a large scale.

I would furthermore suggest that the re-levelling with the tacheometer and the new rods, of a 25 mile section or so of the continuous double rodded line of levels which I ran along the St. Lawrence with our U. S. C. & G. Survey geodesic level No. 1, be authorized, with the object of establishing a comparison between the results afforded by the two instruments and the two corresponding methods respectively; such levelling to be undertaken as soon as practicable without unduly interfering with more pressing work.

In conclusion, I may be permitted to point out to the Department:—

1°. That the information afforded by the precise levelling and gauging operations commenced under my direction in 1883–84, and carried on by me from year to year up to 1895–96, as regularly and expeditiously as more urgent official duties, and the funds granted by Parliament for such purposes would permit—has already proved of considerable practical utility and scientific interest, in connection with the improvement of the St. Lawrence Ship Channel and other extensive works, as also the Dominion Tidal Survey and various other Government and Municipal Services.

2°. That in view of the valuable results already secured, just referred to and the prospective reduction of all elevations, whether on land or water, throughout the Dominion to a standard datum plane coinciding with the mean level of the sea, viz., that of the Atlantic Ocean at the mouth of the St. Lawrence, as practised in all advanced civilized countries, it is very desirable that our Geodetic Levelling operations be resumed with as little delay as possible.

3°. That the advisability of continuing this work of national importance will be still more fully realized by perusing the exhaustive Report of the United States Deep Waterways Commission, dated Detroit, Michigan, December, 1896, which was transmitted by the President to the Senate and House of Representatives at Washington, January, 1897.

I have the honour to be, sir,

Your obedient servant,

R. STECKEL,

Engineer in charge, Canadian Geodetic Levelling.

THE SANGUET TACHEOMETER (SELF-REDUCING)

AS ADAPTED TO

PRECISION LEVELLING

IN CONNECTION WITH

A NEW GEODESIC ROD.

I believe I am quite safe in stating by way of introduction, that there is scarcely a single step of any importance to be taken in life, that does not involve the measurement of space in some form or other: linear, superficial, solid, angular.

Confining here our attention to linear spaces or distances, it is evident that when such a space is easily accessible all around, its magnitude may, in general, be readily ascertained by applying to it a properly constructed and verified standard of length, such as a chain, a tape, a rod, a foot rule, a scale, etc., provided always we are prepared to devote sufficient time and attention to the measuring and testing operations to ensure correct results.

This primitive method of measuring linear space has been followed from time immemorial and, it may be said, continues to be almost universally adhered to up to this very day with little or no variation, whether distances have to be determined in or out doors, notwithstanding many difficulties that are experienced. I believe it will readily be admitted by all those who have any knowledge of the subject, that the laborious measurements required between accessible points, in connection with the extensive field operations which are inseparable from the ordinary practice of a civil engineer and that of a land surveyor, are unquestionably those where the old method yet followed presents the greatest drawbacks.

The principal, if not the only reason of the backward condition of what might be termed the science of measuring distances between accessible points on a large scale, appears to be due to the fact that nearly all the measurements which have to be made in the field either for engineering or purely surveying purposes are horizontal measurements, and that previous to the time (not more than ten years ago) when Mr. Sanguet, President of the Society of Topographical Engineers of France, first brought out his perfected self-reducing tacheometer, there was no instrument available to civil engineers and land surveyors, that would enable them to measure horizontal distances expeditiously with the degree of precision and reliability required for the field work, whatever its nature, which is nowadays generally exacted of them to keep pace with the advancement of science in every other walk of life.

This statement may, perhaps, appear a little overdrawn to civil engineers and surveyors generally, as many have, no doubt, availed themselves, to a greater or less extent, of the facilities afforded by properly mounted stadia wire telescopes for making distance measurements with the aid of a suitably divided rod, or used such instruments as Edgeworth's stadiometer, Eckhold's omnimeter, or one or the other of the various kinds of ordinary or improved tacheometers of the Porro type with stadimetrical telescopes having supplementary lenses, such as Richers', Colonel Goulier's and other similar distance measuring theodolites which have been brought out since about 1860, or may be the more recent "Milner distance measurer and level." In this connection I would point out, that notwithstanding the superior mechanical skill displayed in the construction of most of the distance measuring instruments hitherto devised, and the fact that many of them have rendered good service when used for reconnaissance field work, and preliminary surveys for projected lines of railways, canals and other important public works, it cannot be denied that they have all proved to be sufficiently wanting in one particular or another, to prevent them from being extensively taken up by professional men, for use in their general practice for the purpose they were chiefly intended by their inventors and constructors, viz., measuring horizontal distances.

I do not intend to describe here in detail the short-comings of each one in particular of the class of instruments referred to so far as I might be in a position to do, for that would be a big undertaking, and I see no practical advantage to be gained by following such a course. I will content mysef by pointing out:

1. That, as a rule, the distances measured with those instruments are not the horizontal projections of right lines drawn between two stations, which alone are necessary for plotting purposes; but distances measured in each case in the direction of the line of sight, which have to be reduced to the horizon and otherwise corrected by means of computations more or less complicated according to the degree of accuracy aimed at.

2. That in nearly all such instruments the measurement of a distance is effected by comparing the micrometrical interval which separates two stadimetrical wires stretched on a diaphragm, with the distance or height intercepted on a carefully divided rod by the visual rays determined by the said wires.

Now, the height intercepted on a rod by two visual rays determined by stadia wires, is directly proportional to the distance from the rod to the anterior focus (in front) of the objective, when an ordinary astronomical stadimetrical telescope is used, and to the distance from the rod to the centre of the instrument, when such centre is rendered anallatical, that is to say, when the summit of the diastimetrical angle is moved from the anterior focus of the objective to the centre of the instrument, viz., by means of an extra lens interposed between the objective and the eye-piece, as was first done, about 1840, by Porro, a distinguished officer of the Piedmontese engineer corps. But readings taken on a rod held vertically with the aid of any one of the instruments just mentioned, seldom give us a horizontal distance, which is the only one we care to know when we want to make a plan of a tract of land, a railway, a canal, etc.; but almost invariably a length of some inclined line to which a correction or corrections—the so-called reduction to the horizon—must be applied before it can be used for plotting purposes.

And should we feel disposed to adopt the neither very simple nor very expeditious "method of obtaining linear distances, and also of taking levels on sloping ground, without moving the staff or the instrument," which is recommended by the inventor of the "Milner Measurer," in a leaflet issued about June, 1897, viz., by holding in every case the rod perpendicularly to the line of sight, which operation, if performed as suggested, must of necessity be, in a sense, mere guess work, the difference between two readings corresponding to the lines of sight determined by two stadimetrical wires would again give us but a distance, rod to instrument, along the inclined line of sight. Not only has this sloping distance to be reduced to a corresponding horizontal one; but it is furthermore necessary to diminish or increase, as the case may be, the length so obtained by the small distance intervening between the point on the ground at the foot of the rod of which the position is to be established, and the horizontal projection of the point of intersection of the rod as inclined, with the line of collimation or optical axis of the telescope produced.

True, it may be said, a correction such as that last described is not needed when a vertical rod is employed, or by holding a stadia horizontally over the point the position of which is to be established. As a matter of fact, the vertical stadia is almost invariably used because it is easier to maintain a rod correctly in this position than in any other; but on account of the obliquity of the axis of its divided face to the visual rays, when these are inclined, as is usually the case, the height intercepted on the rod by the wires is greater than that which would obtain, in the same conditions, on a rod held perpendicularly to the line of sight, therefore the distance computed with such a height used as the argument, is greater than that which actually intervenes between the rod and the instrument along the line of collimation, and has to be correspondingly corrected.

In view of the rather complicated and tedious corrections and reductions which are found to be an unavoidable accompaniment of the, at first sight, apparently very simple and attractive ordinary processes of stadimetrical distance measurements, when it is important to attain a certain degree of accuracy, it is not surprising that inventors should at different times have seriously applied themselves to devise mechanical means for securing horizontal distances by direct observation, as far as practicable.

Between, say 1850 and 1852, several ingenious devices applied to instruments of the Porro type and to others have been proposed at various intervals, chiefly by French and German authors, for reducing by means of special processes and manipulations, the distances measured to their horizontal projections, all of which met with but a limited measure of success. Among such may be cited : Porro's sthenallatic telescope, Peaucellier and Wagner's telescope, the Wagner Fennel reducing device and some tacheometers of Swiss construction with adjustable stadia wires, as regards the intervening space, so as to secure a constant generating number for one and the same distance, whatever the inclination of the line of sight.

Finally, there have been brought out since 1865, a few instruments which effect the reductions to the horizon entirely automatically, that is to say: where the positions to be given to the telescope to attain the desired end are determined by purely mechanical means, without one having to make either special readings, adjustments or other operations or computations.

In 1865, Mr. Sanguet, the inventor of the instrument which forms the subject of this Memo., constructed a distance measuring instrument to which he gave the name of "Longimêtre." Finding that this instrument had certain drawbacks, he modified it in several particulars and then gave to the public in 1866, his self-reducing tacheometer as first constructed by him. Again, at the Universal Exposition held in Paris in 1889, an instrument called Charnot's tacheometer was exhibited which much resembles Mr. Sanguet's original "Longimêtre," and although an ingeniously contrived, accurate and fairly serviceable self-reducing instrument in the true sense of the word, presents still some of the defects found to be inherent to the "longimêtre," and to the original model of the Sanguet tacheometer, and does not permit of combining hitherto unattained percision with complete and unfailing control of the results in the ordinary run of field operations, with the same extreme facility and feeling of satisfactions as with the more recent perfected self-reducing tachcometer known under the name of "Tachcomêtre auto-réducteur Sanguet." For this perfected instrument the inventor was justly rewarded with a gold medal at the same International Exposition of 1889, thus receiving the highest honour conferred on exhibitors in recognition of the merits of their contributions.*

After receiving from the Department the necessary authority for the purchase, direct from the makers, of one of these unquestionably original, ingenious and on the whole truly remarkable instruments modified as I had suggested, I lost no time in placing the order for the new "Tachéomêtre Sanguet" with Mr. Cabasson, of Paris, who is the sole agent for the same.

This gentleman placed me in direct communication with Mr. Sanguet, the inventor himself, with whom I entered into a full discussion of the pros and cons of the proposed modifications and additions to the original model of his instrument as got up for general use in France, with a view of securing a tacheometer: (a.) That would prove especially serviceable for precision levelling and for measuring correctly greater distances than those falling within the every day practice of a surveyor or an engineer at work in thickly settled countries, more particularly such long

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* A few years ago a new surveying instrument called the "Universal Tacheograph"—the joint production of Professor Victor Ziegler, widely known as a writer on geodesy, and Mr. C. Hager, a reputed scientific instrument maker of Luxemburg—was introduced into continental Europe and there received with much favour by surveyors and engineers. As its name indicates, this instrument belongs to the class of plane table theodolites, which instruments are intended for use only where the surveys required are of such a nature that the results of the operations performed can be plotted with advantage on the field, directly after being secured. It is stated, however, that there are various forms of such instruments made for special purposes.

The Ziegler-Hager Tacheograph is constructed in some respects on the same lines or according to the same principles as the "Tacheomêtre Sanguet auto-réducteur," and the chief merits of the two instruments are nearly alike. I am doubtful, nevertheless, whether, on the whole, the former would prove as serviceable as the latter to meet the requirements of the engineering profession in a new, sparsely settled country of large extent.

stretches as have to be measured when crossing wide streams, ravines, valleys, etc. (b.) That would permit of angles being measured in degrees and minutes, or according to the sexagesimal division of the circle, as is still the custom in Canada and English speaking countries in general, in place of the grades and centigrades of the centesimal division now almost exclusively used in France.

As a result of our deliberations, Tacheometer No. 115 supplied to the Department was constructed so as to meet my views just stated, as far as practicable: the fundamental principles of the original invention were, however, in no way departed from.

The modifications and additions just referred to which I considered necessary, will be described in detail, and the reason of their introduction explained, after we shall have gained an insight into the working and resources of this new measuring instrument from the following summary description of its parts and their combination, which is on much the same lines as that given by the inventor himself in the pamphlet he sends out with each tacheometer.

The "Tachéomêtre Sanguet" (see Illustration No. 1) is composed of two principal parts, one of which is destined for measuring azimutal or horizontal angles, and the other for measuring distances and declivities. The same as in all theodolites, the first part consists in a graduated horizontal limb which revolves about a vertical axis mounted on a metal stand having three arms, each of which is provided with a levelling screw *C*. An improved declination tube *D* is screwed to the under side of the divided circle.

The base of the second or upper portion is an alidade circle provided with verniers which turn round inside the divided circle, being concentric thereto. On top of this inner circle is fixed a horizontal bar *B* which carries to the right: a fork-shaped pillar *Y* with wyes for the journals of the transverse axis around which the telescope revolves to turn in, to the left: a divided vertical straight edge *FH*, and in the centre a spirit level *N*, for levelling the instrument.

As in all transits and theodolites, the rotation of the whole instrument about its vertical axis, as well as that of the alidade or vernier circle alone can be stopped at will, viz.: by tightening the clamp screws P' and P'', and the positions in azimuth of both the divided and vernier circles can be adjusted respectively with the aid of the tangent screws R' and R''.

At each end of the divided flat straight edge *FH* there is a lug *G*, fixed at right angles to its axis, and cylindrical guide holes are bored through both lugs on one and the same vertical axis. In these holes turn the close fitting ends of a prismatic guide rod *T*, which is parallel to the straight edge, and rests on the point of a vertical adjusting screw *R*.

A clamp carrying a vernier is fitted to the rod *T*, which can be moved from end to end and fixed at any point of its course by means of a tightening screw *P*. To this clamp is fixed in the middle of its rear face, a steel knife intended for use as a support for the telescope at its eye end.

The telescope is actually not in equilibrium when supported only on the journals of its transverse axis; the latter being secured to the telescope near the objective, viz., several inches from its centre of gravity. On the right and left hand sides of the telescope small steel straight edges *K* are fixed to the tube near its eye end, having their flat faces in planes perpendicular to the azimuth circle and those edges which rest on and slide over the steel knife, one at a time, parallel to the optical axis or line of collimation.

The inclination of the telescope can thus be modified at will; after having loosened the clamp *P*, we can slide it together with the telescope along the prismatic guide rod *T*, to screw it tight again when the object to be sighted comes within the field of view. The slow motion screw *R* enables us afterwards to rectify the pointing of the telescope in a vertical plane. The vernier carried by the clamp *P* indicates (usually) on the vertical divided straight edge, or scale of slopes, the inclination of the visual ray in decimal parts of the horizontal projection *r*, of the portion of the said ray extending from the axis of rotation of the telescope to the line of the knife edge, taken as unity.

The telescope of the "Tachéomètre Sanguet," is a simple astronomical telescope, simiiar to that of an ordinary inverting level, transit or theodolite, with but two wires at right angles to each other for sighting, and having no supplementary lenses or cross hairs or other lines for sighting purposes of any kind. As there is but one horizontal wire, it is clearly impossible to read on a speaking rod, a height above 0 different from that which the telescope points to, so long as the inclination of the latter remains unchanged. The measure of distances is based on several successive rod readings which are obtained as follows:—

The nut of the slow motion screw *R* is connected by means of a vertical crank, to the end of the short arm of a lev · *L* having as a fulcrum a horizontal axis imbedded at *M* in the rear face of the divided vertical straight edge or slope scale *F H*, and the long flat arm of which extends past the fork shaped pillar *Y* where it is terminated by a rounded handle. In the long flat handle *L* there is screwed near its free end, a cylindrical steel pin or peg, the flat end of which touches the lateral face of the fork shaped pillar while the lever remains in one and the same position; the upper side of the peg butting against one or other of four similar steel pegs or pins a, b, c, d screwed into the side of the pillar, along an arc of a circle described from the fulcrum axis as a centre; a being the lowest and d the highest of this series of pins.

Solicited by its own weight, by that of the telescope, and by the action of a spiral spring *S*, the prismatic guide rod *T* always tends to descend. And by drawing the long lever arm lightly to one side, so as to make the pin inserted in it clear that in the pillar against which it abuts, the rod *T* together with the short arm of the lever drops with a snap and the next higher peg in tne pillar is struck hard by the pin in the long arm in its upward motion; at the same time the telescope turns on its transverse axis.

As the lever *L* can take the four positions corresponding to pins a, b, c and d, the inclination of the optical axis or line of collimation of the telescope, can be made to assume four different values by the simple handling of this lever, which give us four readings on the rod affording differences that bear constant ratios to the horizontal distance to be measured. There being six such differences (for six is the number of possible combinations of four readings taken two by two), the result is that we have at our command six elementary ratios between rod interval and distance, of which any single one is sufficient for determining the distance of the rod from the instrument. I may here observe that the lever L with one arm, say ten times longer than the other, has evidently been brought into requisition by the inventor, with the important object in view of—so amplifying the very small arcs or heights, which the eye end of the telescope has to traverse to determine visual rays that afford readings on the rod differing only by from $\frac{4}{1000}$ to $\frac{10}{1000}$ of its distance from the instrument—as to render the use of an automatic device for the determination of the said small displacement of visual rays, practicable both as regards mechanical execution and facility of operation.

Now the three intervals $\overline{ab}$, $\overline{bc}$, and $\overline{cd}$ between consecutive pins, which are adopted for the tacheometer of the ordinary construction, bear to each other the ratios of the numbers 10, 8 and 4. That is to say: in the tacheometer of the common type the pins are inserted at such intervals in the side of the fork shaped pillar, that by raising or depressing the long lever arm through the distance $\overline{ab}$, the short arm will depress or raise the prismatic guide rod T and with it the telescope, through a vertical space equal to $\frac{1}{100}$ part of the radius r adopted for the unit of the scale of tangents or slopes, or which is the same thing, for the length of the perpendicular let fall from the centre of the transverse axis around which the telescope revolves, on to the vertical path described by the steel knife edge when sliding up or down along the rear of the guide rod, and hence such working of the handle of the long lever arm, will also cause a corresponding change in the rod reading equal to $\frac{1}{100}$ part of its distance R, or to $(0{\cdot}01)R$, from the same transverse axis.

Again, by moving the same long arm through $\overline{bc}$ the corresponding change which obtains in the rod reading is equal to: $(0{\cdot}008)R$, and finally by passing over $\overline{cd}$ with the lever, the rod reading will be altered by $0{\cdot}004R$.

In the ordinary "Tachéomêtre Sanguet" the four displacements of visual rays determined by the four pegs afford six corresponding rod intervals which are all different, and when arranged in the order of their importance, the values of these intervals are:

$$\overline{dc} = \tfrac{4}{1000}R,\ \overline{cb} = \tfrac{8}{1000}R,\ \text{ba} = \tfrac{10}{1000}R,$$
$$\overline{bd} = \tfrac{12}{1000}R,\ \text{ac} = \tfrac{18}{1000}R,\ \text{and } \overline{ad} = \tfrac{22}{1000}R.$$

The most generally useful of these six relations between the intervals intercepted on the rod and its distance from the instrument, is evidently the third, viz.: that afforded by a displacement $\overline{ab}$ of visual rays causing $\frac{1}{100}$ part of the distance R, or a height of $(0{\cdot}01)R$, to be intercepted on the rod.

With a view of controlling the readings and increasing the precision of the results, it is however advisable to combine two or three of the above six elementary ratios of rod interval to distance, whenever time will permit.

Thus if we combine:

1. $\overline{bc} = (0{\cdot}008)R$, and $\overline{bd} = (0{\cdot}012)R$, the following relations must obtain when all the readings are correctly taken, viz.:

$$\overline{bc} + \overline{bd} = (0{\cdot}020)R \text{ and } \overline{bd} - \overline{bc} = (0{\cdot}004)R = \frac{\overline{bc}}{2} = \frac{\overline{bd}}{3} = \frac{\overline{bc} + \overline{bd}}{5}.$$

2. The combination of $\overline{ac} = (0{\cdot}018)R$ with $\overline{ad} = (0{\cdot}022)R$, gives:

$$\overline{ac} + \overline{ad} = (0{\cdot}040)R \text{ and } \overline{ad} - \overline{ac} = (0{\cdot}004)R = \frac{\overline{ac} + \overline{ad}}{10}.$$

3. If we combine the three ratios: $\overline{ab} = (0{\cdot}010)R$, $\overline{ac} = (0{\cdot}018)R$ and $\overline{ad} = (0{\cdot}022)R$, the relations which afford us a means of checking in the office the operations performed on the ground are:

$$\overline{ab} + \overline{ac} + \overline{ad} = (0{\cdot}05)R \text{ and } \frac{\overline{ab} + \overline{ac} + \overline{ad}}{5} = \overline{ab}.$$

The last combination affords the greatest degree of precision attainable with a minimum number of pointings, it should always be used when great accuracy is desired. When an obstacle between the rod and the observer prevents making one or the other of the three readings without changing the position of the clamp P on the guide rod, it is usual to omit such reading altogether.

When the visible part of the rod is too short to permit of reading on it heights equal to: $(0{\cdot}018)R$ and $(0{\cdot}022)R$, the interval corresponding to $(0{\cdot}01)R$ is first read, after which having left the lever arm butted against the pin b, the clamp is moved up or down and the cross wire again made to bisect the zero mark by working the slow motion or micrometer screw R, that is to say: a new pointing is made which will enable us to read off the rod intervals corresponding to $\overline{bc} = (0{\cdot}008)R$ and $\overline{bd} = (0{\cdot}012)R$.

We have, in such case, the following relations to control the rod observations, viz.:

$$\overline{ab} + \overline{bc} + \overline{bd} = (0{\cdot}030)R \text{ and } \frac{\overline{ab} + \overline{bc} + \overline{bd}}{3} = \overline{ab}.$$

Now for determining the horizontal projection R of the radius vector of a point on the ground of which the position is to be established, that is to say: the distance from the rod to the transverse axis of the instrument reduced to the horizon, we have the relations:

$$R = 100\,\overline{ab} = \frac{100\,\overline{ac}}{1{\cdot}8} = \frac{100\,\overline{ad}}{2{\cdot}2} = \frac{100\,\overline{bc}}{0{\cdot}8} = 100\,\overline{bc} + \frac{100\,\overline{bc}}{4} = \frac{100\,\overline{bd}}{1{\cdot}2} = \frac{100\,\overline{cd}}{0{\cdot}4}$$

and by combination, 56 additional means of arriving at the value of this radius, such as:

$$\frac{100\,(\overline{ab} + \overline{ac} + \overline{ad})}{5} = \frac{100\,(\overline{ab} + \overline{ad})}{4} = \frac{100\,(\overline{ac} + \overline{cd}}{3} = \frac{100\,(\overline{ad} + \overline{bc})}{3}.$$

As it might be a matter of some interest to engineers to know for what particular reason the displacements of the visual rays were arranged for, so as to cause consecutive intervals to be intercepted on the rod, bearing to each other the ratios of the numbers 10, 8 and 4, when 10 and its submultiples 5 and 2, or some other simple numbers might apparently have proved equally well, if not better suited for the purpose intended, I may state that the ratios $\frac{10}{100}$, $\frac{8}{100}$ and $\frac{4}{100}$ were selected because, while they permit of combinations sufficiently simple being made, to render the finding out of mistakes in the office and the correction of the same a comparatively easy task, yet they necessitate, when passing from one reading of the series to another, an arithmetical operation which cannot be performed with such great rapidity, as to leave room for suspicion that the operator may have been tempted, in order to save time, to substitute for the actual supplementary rod readings asked of him, fictitious readings deduced by computation from the interval between the two first readings. It is moreover claimed: that the variety of the six elementary ratios corresponding to the numbers 4, 8, 10, 12, 18, 22, as given above, permits of properly adjusting the range of the instrument in accordance with the degree of precision to be attained and getting readily over difficulties which arise when a part of the rod is hidden from the observer by an intervening object.

From what I have just stated, it will be seen that the "Tachéomètre Sanguet" affords to engineers and surveyors, advantages and resources for the accurate measurement of distances in the field, far ahead of any presented by other instruments proposed as substitutes for the chain or steel measuring band or tape. Indeed it leads to results so much superior to the best secured with all other such instruments equally as regards accuracy, despatch and control of field operations, that I feel convinced the new tacheometer or measuring instrument, needs only to be placed in the right light before practical professional men and contractors to come into general use before very long to the exclusion of nearly all their other ordinary surveying instruments, excepting of course a suitably divided rod.

In support of this opinion I may state that while it is found, in general, that the result of a very good chain measurement is affected by an error in excess amounting to between 3 and 6 hundredths of a foot per 100 feet, the calculated mean error which one may make in measuring a distance of 100 feet, with the new tacheometer by combining three rod intervals, is but $\frac{28}{100}$ of a foot, and the results of numerous experiments show, that the mean error which actually obtains is even less than at the rate of 0·28 foot per 100 feet, viz.:—little over 0·2 ft. per 100 feet.

Again, with a view of testing the practical working of the tacheometric method of surveying, a plot of ground 538·7 acres in area and containing 605 parcels of land having the form of elongated trapeziums was surveyed in France both in the ordinary way, viz.: by running lines between angles and measuring them with the chain, &c.. and also entirely with the aid of the new tacheometer and a properly divided and figured rod.

The survey of this plot of ground actually kept the party which operated in the ordinary way, 336 hours at work in the field, while the party that worked with the Sanguet tacheometer completed the whole field work in 121 hours. The party surveying with the tacheometer had to be more numerous than the other; but the cost of the tacheometer survey proved smaller than that made in the ordinary way, in the ratio of 411·4 to 789·6. So that it may be said that by the use of the new self-reducing tacheometer, the expense was in this case, reduced by one-half and the time spent on the work by two-thirds.

I may add that the "Tachéomètre Sanguet" was critically examined in detail and experimented with by the Official Commission appointed to examine the instruments of precision exhibited at the Paris International Exposition of 1889, and more recently by the "Commission extra parlementaire du Cadastre" of France.

Both these Commissions of scientific and practical men of the highest standing have rendered the verdic': that this is the most perfect instrument for surveying purposes that human ingenuity can well devise, and hence bestowed the highest encomiums on its inventor for his great achievement.

Finally, the Commission of Inventions, instituted at the National School of "Ponts et Chaussées" in France, strongly reported in favour of the extended use of the "Tachéomêtre Sanguet" by the members of this justly celebrated corps of engineers, and ordered the purchase of some instruments to be kept in their depot at the disposal of engineers who would require the same.

Let us return now to our special Tacheometer, No. 115. In this instrument: (*a*) The magnifying power has been increased from about 35 to say 50, which could be done without difficulty; the only slight drawback to the change being the little extra weight which had to be added to the instrument in lengthening the telescope from 10·83 to 15·83 inches and augmenting its diameter correspondingly, for, we had no supplementary lens to reckon with, intercepting a large portion of the light that passes through the objective, such as the lens used by Porro to render his telescope annallatic.

The increase in the power of the telescope was considered necessary in order to render the instrument more especially serviceable for precision levelling operations, and for the accurate measurement of greater distances than those falling within the every day practice of a surveyor or an engineer, in old settled countries like France, as already stated.

Now it would manifestly be of a little use to have at one's command a telescope of sufficient power to enable us to distinguish and bisect correctly a target stripe say 3,000 or 4,000 feet off, if we had not also the means of measuring very accurately the inclination of the optical axis when directed to the centre of this target, either in reference to the line of sight passing through the centre of another target fixed on a rod at a known distance from the former, or in reference to a truly horizontal line or one running in any given direction above or below the horizon. Hence:

(*b*) The ordinary slow motion or adjusting screw R on the end of which the guide rod, the clamp with knife edge and the eye end of the telescope are supported in common and by means of which they are adjusted in position, has been replaced by a micrometer screw with a pitch corresponding to 100 revolutions per inch, which is about the limit, as regards fineness of thread, where the number of revolutions indicated on a figured scale can still be comfortably read off with the naked eye.

Again, it is evident that the micrometer screw R together with the prismatic guide rod T and the knife edge should be placed as far as practicable from the axis of rotation of the telescope, otherwise some difficulty might be experienced to measure with precision, small spaces which could be easily distinguished looking through our telescope of increased optical power. It is also necessary that sufficient room be available between the transverse axis of the telescope and the longitudinal axis of the micrometer screw for the convenient installation of a spirit level with an air chamber at one end, and of a degree of sensitiveness commensurate with the small change of inclination produced by moving the micrometer head over one of its divisions.

Now, with a micrometer screw of the pitch settled upon, the most convenient length to adopt for the unit of the vertical scale of tangents, that is to say: for the radius $r = 1$ of the smallest circle that can be described from a point on the axis of revolution of the telescope near its optical axis as a centre, so as to be tangent to the path followed by the knife edge, would evidently be 10 inches or $\frac{5}{6}$ of a foot—for, in such case each division of a micrometer head divided into 100 parts would indicate a vertical motion of the screw equal to $\frac{r}{100{,}000}$ or $(0.000.010)\,r$. This dimension would be more than sufficient to satisfy all requirements in other respects, unfortunately, however, the increase of r from 16 centimeters=6·30 inches, its length in the Sanguet tacheometer as now usually constructed in France, to 10 inches, would render the instrument altogether too bulky and heavy to be used for the ordinary run of field operations. Hence:

(*c*) The minimum distance between the axis of rotation of the telescope and the knife edge (or the line of tangents) had to be reduced to 8 inches = $\frac{2}{3}$ ft. and the number of divisions on the micrometer head increased from 100 to 125, each of which still represents $\frac{1}{100{,}000}$ part of r or $(0.000.010)\,r$.

On account of the ordinary slow motion screw which is provided in tacheometer No. 1 under the prismatic guide rod for adjusting the inclination of the telescope, etc., being replaced by a fine micrometer screw R in tacheometer No. 115, (See Pl. I in pocket) the zero of the vertical or slope scale of this instrument—instead of being placed, as usual, near the centre of the flat vertical straight edge $F\,H$, and so as to correspond as nearly as practicable to a truly horizontal axis when the instrument is accurately levelled— was lowered to the foot of the said straight edge; the object being to eliminate all negative quantities from the field book, both as regards the vernier and micrometer readings, also to obviate the necessity of making such readings in contrary directions. On the vertical scale of tacheometer No. 115, a perfectly level line of collimation corresponds therefore very nearly to reading 0·50 instead of 0.

A detached chambered double faced level, O, is used on the telescope, the bubble tubes of which are ground to a circle of such radius that a division of the circumference $\frac{1}{12}$-inch in length will correspond to an angle of 5 seconds. This level has thus been rendered four times as sensitive as the single face level on the alidade bar, and about twice as sensitive as the double faced level used in the ordinary instrument. An air chamber is provided at one end to permit of regulating the length of the bubble according to the temperature of the atmosphere, etc., so as to keep it within convenient limits.

The diaphragm placed in the telescope for defining the position of the optical axis carries no cross wires or hairs. Instead, fine lines are engraved at right angles to each other, through the centre of the plane face of the outer or field lens of the Ramsden eye piece; the diaphragm serves to delimitate the pencil of rays disposed symmetrically around the line of sight which joins the intersection of the cross lines on the lens and the centre of the field of view afforded by the objective. Lines engraved on glass are preferable to wires or spider webs, as they are not affected by the humidity of the atmosphere, nor can they be broken, the eye piece has, however, to be adjusted to the proper length, according to the sight of the observer, to render the lines plainly visible to him.

The adjustment for collimation is made in precisely the same manner as when wires are used, viz., with the aid of four steel capstan screws V.

I have just mentioned double faced levels. Such levels do not appear to be much known outside of Continental Europe; but well deserve to be more widely known and better appreciated than they are, generally speaking.

A double faced level consists, as all other spirit levels, of a longitudinally curved glass vial or tube filled entirely with alcohol or ether, excepting a small volume of air imprisoned to form a bubble at the highest point of the tube. The bubble tube of such a level is, however, formed of two halves of semi-circular cross section, having their inner or concave surfaces ground longitudinally so as to assume a uniform convex curvature, and which are subsequently united along their sides and hermetically sealed at their ends after being filled with spirits, as just described. Scales having divisions suitably proportioned to the degree of longitudinal curvature are engraved on the upper and lower outside faces of the tube, symmetrically on either side of a plane passing through the centres of the generating circles of the upper and lower interior ground surfaces of the spindle shaped tubular envelope, and the whole glass tube when completed is inclosed in a brass tube mounted on a brass plate. So that, if the air bubble is brought to the centre of the divided portion of the double faced tube on one side, upper or lower, it will also lodge precisely in the middle of the scale engraved on the opposite side when the tube is reversed; the bottom being brought to the top, or vice versa.

When a double faced level is fixed to the side or top of a telescope, mounted as that of the tacheometer, it is evident that unless the air bubble, after being brought to the centre of the divided scale and summit of the tube on one side, also comes to rest in the centre of the scale when the telescope is inverted, by lifting the transverse axis out of its wyes and causing the journals to exchange places,—the optical axis of the telescope cannot be a truly horizontal line in either its erect or its inverted position—and that when the instrument is not in such perfect adjustment the horizontal line of sight must invariably lie midways between the pointings made with the telescope in the said erect and inverted positions.

Hence, in order to establish the correct elevation of a truly horizontal line of collimation, we need only take the mean of two rod readings, one of which is taken when the telescope is in its erect position, or say with the pinion head on top and the double faced level O on its right hand side, and the other when it is in its inverted position or with the level on its left side and the pinion head below the tube. For, by inverting the telescope, we not merely correct the first reading for the inclination of the line of sight to the horizon, but also for any error of collimation by which the said line might be affected.

It will thus be seen that by working with a double faced level, we reduce by one-half the number of readings that have to be taken when an ordinary pivot or geodesic level, with independent striding level, is used in carrying on precise levelling operations. For, in such case we have to make one reading with telescope erect and level direct, another with telescope erect and level reversed, a third with level reversed and telescope inverted, and a fourth with telescope inverted and level direct.

This is not the only advantage which can be claimed for the double faced level. By using this level we need no longer feel anxious lest some results might be vitiated on account of dust or dirt having adhered to the feet of the independent or striding level or to the collars on which it rests; nor are we likely to have to spend as much time in adjusting the level after carrying it for a short time over rough ground, and especially after jumping fences or ditches and climbing over rocks, as when working with a detached striding level, the steel spiral springs of which become easily distended or else flattened.

The double faced level need never be detached from the telescope during the progress of the field operations, whether they are carried on with the ordinary instrument (No. 1) or with tacheometer No. 115. In the latter case, when the instrumental work to be done from a station is completed, the recorder must lift the telescope, inclusive of level, out of the wyes to take it in a special leather case hung over his shoulder, to the next station, thus relieving the observer of 5½ pounds of the part of the instrument he usually has to carry and reducing the weight left in his charge to 20¼ pounds, tripod included. The tacheometer of the ordinary construction weighs but 18¼ pounds with tripod, exclusive of double faced level, which has a weight of from ½ to ¾ pound. The United States Coast and Geodetic Survey precision level weighs 23 pounds with tripod, not including the striding level which has to be carried separately.

Now a telescope with the magnifying power increased to about 50 diameters, permits of hundredths of a yard being read and thousandths of a yard being estimated on a rod suitably divided into hundredths and half hundredths of a yard, at distances up to from 275 to 350 yards according to the strength of the observer's eye sight. That is to say: when the telescope is pointed to zero on the rod the number of whole yards contained in the distance R, rod to instrument, may be read off directly by displacing the optical axis so as to intercept a height on the rod equal to $\frac{1}{100}$ of the said distance R, or equal to $0{\cdot}01R$, and tenths of yards can be estimated by the eye. It appears therefore that in order to be able to read on a rod the three intervals corresponding to: $\frac{10}{1000}$, $\frac{18}{1000}$ and $\frac{22}{1000}$ of a distance, without moving the clamp, it would be necessary to have at one's command a rod $0{\cdot}022 \times 350 = 7{\cdot}7$ yards in height, which is nearly double the length of the rods commonly used for precision levelling operations.

By making use of a rod 12 to 13 feet long, viz., a rod of as great a length as practical experience has shown can be easily held vertical, conveniently handled, carried in the field and put up for the transportation and kept tolerably straight and in good order generally, for any length of time, many of the sights that can be easily taken with a telescope of the power mentioned necessitate a second pointing and some a third pointing, in order to secure at every sight three consecutive rod intervals intercepted by visual rays, respectively equal to: $\frac{10R}{1000}$, $\frac{8R}{1000}$ and $\frac{4R}{1000}$

But it may be asked, what great necessity is there for establishing at every sight the values of the whole three intervals in question, in connection with precision levelling, considering it is not essential that the distance rod to instrument, be very accurately known for determining the difference in elevation between two points.

Quite true, it is not absolutely necessary to measure very correctly the distance from the instrument to the rod for such purpose; but it is very important for us to be in a position to exercise such a perfect control over all the rod readings, including those corresponding to the horizontal or fore and back sights, as will enable us to readily correct on the ground, or in the office, by means of the entries in the field book, any error that may be discovered after the removal of the instrument from a station whence an erroneous reading was made.

Now it is only by making the four rod readings required, to establish the length of each one of the three contiguous spaces intercepted by the horizontal wire in the positions of the telescope determined by the four pins or pegs, a, b, c, d, or failing which, by making all the rod readings found to be necessary to establish the length of each one of three corresponding spaces which are not all contiguous, that we can manage to secure the desirable perfect control in question, hence the advisability of invariably taking such a set of four or more readings whenever possible.

A little reflection will convince us that all the four readings mentioned are really essential to fully ensure the desired control.

Suppose for a moment, we confine ourselves to three readings, viz., those corresponding to the positions a, b and c of the lever; those readings will give us the intervals $\overline{ab}$, $\overline{bc}$, and $\overline{ac}$ bearing to each other the ratios of the numbers 10, 8 and 18.

Now let us say that instead of the true height b corresponding to position b, we read by mistake a greater height B, we will then have $\overline{aB} > \overline{ab}$ and $\overline{Bc} < \overline{bc}$, while $\overline{ac}$ retains its true value, and hence we have also: $\frac{\overline{aB}}{\overline{Bc}} > \frac{10}{8}$ and $\frac{\overline{ac}}{\overline{aB}} < \frac{18.}{8.}$

These inequalities are, no doubt, a sure indication that a mistake has been made somewhere; but they do not supply the means of locating the error. For this purpose a fourth reading, and an additional contiguous interval $\overline{cd}$ are indispensable; this interval will show us which one of the three spaces $\overline{ab}$, $\overline{bc}$, $\overline{ac}$ is right and therefore enable us to detect the wrong reading and correct it.

In the case just supposed, we readily find out that $\overline{cd} > \frac{4}{8}\,\overline{Bc}$ and $\overline{cd} < \frac{4}{10}\,\overline{aB}$; but that $\overline{ac} = 4{\cdot}5$ or very nearly so, which is as it should turn out, whence we necessarily conclude that readings a and c are right and that reading B is wrong, viz., too large. As will be shown further on, however, when two lines of precise levels are run simultaneously, or which is the same thing when a line of such levels is double rodded, more expeditious means of verifying and controlling rod pointings and readings are available than by taking supplementary readings as above explained—and in order to save time, can be taken advantage of when accuracy in the measurement of horizontal distances is only of secondary importance.

Now, when a tacheometer is more especially intended for use as a levelling instrument, as is the case with No. 115, the horizontal fore and back sight readings are always the most important of the whole series, and the intervals to be intercepted on the rod by moving the lever L from one of the pins to a higher or a lower one, have necessarily to be reckoned on either side from the intersection of a horizontal line of sight with the rod, at whatever figure such a line may strike the scale; that is to say: almost invariably from a complex number including several decimals, instead of from a round or other exact whole number, as is usually done when distance measurements are made for ordinary purposes. There exists therefore, in the case of a tacheometer intended chiefly for precision or geodetic levelling, not the same danger of an observer being tempted to put in fictitious figures, in place of those that would be afforded by actual readings, in order to gain time, and there is no longer the same ground for hesitating to dispose the butting pins so as to determine visual rays that will intercept intervals on the rod, bearing to each other more simple consecutive ratios than those of the numbers 10, 8 and 4, which have been adopted for the ordinary tacheometer. Accordingly, for No. 115 the numbers used for such ratios were limited to two, viz., to 10 and its submultiple 5; the butting pins **a**, **b**, **c**, **d** being placed so as to give rod intervals corresponding to:

$$\frac{10R}{1000}, \quad \frac{15R}{1000} \quad \text{and} \quad \frac{20R}{1000}, \quad \text{in place of:} \quad \frac{10R}{1000}, \quad \frac{18R}{1000} \quad \text{and} \quad \frac{22R}{1000}$$

and the number of different ratios thus reduced from six to four, viz.:

from 4, 8, 10, 12, 18 and 22—to 5, 10, 15 and 20.

While with the ordinary tacheometer (No. 1) the sum of the rod intervals determined by the three pairs of rays, $\overline{\mathbf{ab}}$, $\overline{\mathbf{ac}}$ and $\overline{\mathbf{ad}}$, viz., the greatest height that can be intercepted by any three pairs of the four rays **a**, **b**, **c** and **d** is equal to $0{\cdot}050R$, the greatest corresponding rod space that can be obtained with tacheometer No. 115 is but $0{\cdot}045R$.

When, however, we take into consideration the fact that in tacheometer No. 115 the magnifying power and the radius r (or perpendicular distance of the centre of the conical gun metal axis of rotation of the telescope, from the plane travelled in by the steel knife edge), have been increased, viz., the former from about 35 to 50 and the latter from 6·30 to 8 inches, it becomes apparent that although the pencil of visual rays determined in the ordinary tacheometer by passing the lever L from pin **a** to pin **d** or vice versa, and which intercepts a height $(0{\cdot}022)R$ on the rod, has been slightly contracted, viz., so as to reduce this distance to $(0{\cdot}020)R$, it cannot be said that the accuracy of the results as regards distance measurements, has been diminished, indeed the reverse is the case, as we shall see presently.

At the same time a tacheometer such as No. 115, where the combination of four consecutive readings from a single pointing—which gives the best results as regards distance measurements—determines an aggregate rod interval of but $0{\cdot}045R$, is evidently not so well adapted on the whole for measuring distances, as a tacheometer of the ordinary construction, where the aggregate rod interval determined by the corresponding combination of four readings from one and the same pointing is exactly equal to $0{\cdot}05R$.

While in the latter case we have simply to multiply the sum of the rod intervals, or $0{\cdot}05\,R$, successively by two and then by ten, in the former, we have to multiply the sum of the said intervals, or $0{\cdot}045R$ by two by ten and then by 1·111111 . . . . . When, however, more than one pointing has to be made, in order to secure the four readings corresponding to the positions **a**, **b**, **c** and **d** of the lever, the conditions are reversed; that is to say, tacheometer No. 115 is, as a rule, more advantageous than the ordinary instrument.

That the accuracy of distances measured with the aid of corresponding combinations of rod intervals determined with tacheometers No. 115 and No. 1, is invariably greatest in the case of the measurements made with the former may be demonstrated as follows*:—

The errors we are liable to make under any circumstances are:—

1. Errors, Ec, of contact of the lever with each one of the butting pins, a, b, c and d.

2. The error, Ep, of the pointing made on the target line in the first position of the telescope, viz., say that determined by pin a.

3 The Errors, Er, in the rod readings for the other sights.

Let us consider the case of a rod observed on at a distance of 100 yards.

The error of contact may be estimated according to Porro at: $\frac{1}{200}$ part of $\frac{1}{1000}$ of a yard. The effect of this error is reduced in the ratio of the arms of the lever L, viz., as 8 to 1 on the ordinary instrument (No. 1) and as 10 to 1 in tacheometer No. 115; and it is amplified in the ratio of the space between the two points of suspension of the telescope, to the distance sought, viz., in the ratio of r to R, or of 0·1750 yard to 100 yards with tacheometer No. 1 and 0·2222 yard to 100 yards with No. 115. The mean error Ec on the rod caused by an error of contact between the lever and a butting pin is therefore in thousandths of a yard:

(a) With the ordinary tacheometer or No. 1:

$$Ec_1 = \frac{1}{200} \times \frac{1}{8} \times \frac{100}{0 \cdot 1750} = \frac{100}{280} = 0 \cdot 357 \text{ thousandths of a yard.}$$

(b) With tacheometer No. 115:

$$Ec_{115} = \frac{1}{200} \times \frac{1}{10} \times \frac{100}{0 \cdot 2222} = \frac{100}{444 \cdot 4} = 0 \cdot 225 \text{ thousandths of a yard.}$$

The mean error of a pointing Ep, deduced from special experiments made by an experienced operator with a rod put up at a distance of 100 yards under ordinary conditions, appears to be about $\frac{1}{4}$ of a thousandth of a yard.

Finally, the mean error of a reading Er made under the same conditions, may be assumed at $\frac{1}{2}$ thousandth of a yard for tacheometer No. 1, and for No. 115 at say $\frac{4}{10}$ of a thousandth of a yard, when the interval which separates the cross wire from the centre of the next lower target line is estimated by the eye, and at less than $\frac{1}{4}$ thousandth when the said interval is measured with the aid of the micrometer screw, or say on an average at 0·375 of one thousandth of a yard.

That such a degree of accuracy can be attained without difficulty, appears from the following considerations.

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* See "Les tachéomètres auto-réducteurs" par E. Prévot, Conducteur des Ponts et Chaussées, Paris 1895.

The magnifying power of the telescope being about 50, a division of one hundredth of a yard on a rod put up at a distance of 100 yards, is viewed in the telescope, in the same manner as a division $\frac{1}{1000}$ of a yard wide with the naked eye, when about 9 inches distant. It is not hard to satisfy one's self that under such circumstances, the tenth part of a hundredth yard division and even much smaller spaces, can quite easily be estimated with the eye, and therefore that the error we are exposed to make can easily be placed at from $\frac{1}{30}$ to $\frac{1}{20}$ of such a division.

Mean error of a distance *R* of 100 yards measured by means of the relations:

$$R = \frac{\overline{ab}+\overline{ac}+\overline{ad}}{0{\cdot}05} = 20\,(\overline{ab}+\overline{ac}+\overline{ad}) \text{ for tacheometer No. 1, and}$$

$$R = \frac{\overline{ab}+\overline{ac}+\overline{ad}}{0{\cdot}045} = 22{\cdot}22\,(\overline{ab}+\overline{ac}+\overline{ad}) \text{ for tacheometer No. 115.}$$

This operation comprises 1 pointing and 3 readings and hence 4 contacts. Moreover we have to bear in mind that while the error of pointing *Ep* does not affect the value of the whole number selected as a starting point for measuring the rod intervals, it modifies by the same quantity *Ep* each one of the succeeding readings. In making the sum of the rod intervals, the error of the pointing is therefore trebled, that is to say it is increased to 3 *Ep*. According to the theory of errors, the total error **E** of the sum of rod intervals $\overline{ab}+\overline{ac}+\overline{ad}$ determined at a distance of 100 yards is therefore in this case, in general:

$$\mathbf{E} = \sqrt{(3Ep)^2 + 3\,(Er^2) + 4\,(Ec^2)}$$

Now replacing the symbols by their values in thousandths of a yard, as above established, we have for the total error of intervals determined with tacheometer No. 1:

$$\mathbf{E}_1 = \sqrt{(3\times0{\cdot}25)^2 + 3\,(0{\cdot}5)^2 + 4(0{\cdot}357)^2} = \sqrt{0{\cdot}5625 + 0{\cdot}75 + 0{\cdot}5098} = \sqrt{1{\cdot}8225} = 1{\cdot}35$$

and for the total error of intervals determined with tacheometer No. 115:

$$\mathbf{E}_{115} = \sqrt{(3\times0{\cdot}25)^2 + 3\,(0{\cdot}4)^2 + 4\,(0{\cdot}225)^2} = \sqrt{0{\cdot}5625 + 0{\cdot}48 + 0{\cdot}2025} =$$
$$= \sqrt{1{\cdot}245} = 1{\cdot}115$$

The corresponding errors $\mathbf{E}_{R_1}$, $\mathbf{E}_{R_{115}}$ on the distances are:

$$\mathbf{E}_{R_1} = 1{\cdot}35 \times 20 = 27{\cdot}00 \text{ or } 0{\cdot}02700 \text{ yd.}$$

$$\mathbf{E}_{R_{115}} = 1{\cdot}115 \times 22{\cdot}22 = 24{\cdot}78 \text{ or } 0{\cdot}02478 \text{ yd.}$$

Mean error of a distance R of 100 yards measured by means of the relation:

$$R = \frac{\mathrm{ab}}{0{\cdot}01} = 100\,\overline{\mathrm{ab}},\ \textit{with both instruments.}$$

This measurement necessitates 1 pointing, 1 reading and hence 2 contacts, therefore:

For tacheometer No. 1 the total error $\mathbf{E}_1$, of the rod interval $\overline{\mathrm{ab}}$ determined at a distance of 100 yards is:

$$\mathbf{E}_1 = \sqrt{1 \times (0{\cdot}25)^2 + 1 \times (0{\cdot}5)^2 + 2 \times (0{\cdot}357)^2} = \sqrt{0{\cdot}0625 + 0{\cdot}25 + 0{\cdot}2549} =$$
$$= \sqrt{0{\cdot}5674} = 0{\cdot}7533.$$

and for tacheometer No. 115:

$$\mathbf{E}_{115} = \sqrt{1 \times (0{\cdot}25)^2 + 1 \times (0{\cdot}4)^2 + 2 \times (0{\cdot}225)^2} = \sqrt{0{\cdot}0625 + 0{\cdot}16 + 0{\cdot}1012} =$$
$$= \sqrt{0{\cdot}3237} = 0{\cdot}5687.$$

Here the corresponding errors on the distance are:

$$\mathbf{E}_{R_1} = 0{\cdot}7533 \times 100 = 75{\cdot}33 \text{ or } 0{\cdot}07533 \text{ yd. and}$$
$$\mathbf{E}_{R_{115}} = 0{\cdot}5687 \times 100 = 56{\cdot}87 \text{ or } 0{\cdot}05687 \text{ yd.}$$

Mean error of a distance R of 100 yards measured by means of the relations:

$$R = \frac{\overline{\mathrm{ab}} + \overline{\mathrm{bc}} + \overline{\mathrm{bd}}}{0.03} = \frac{100}{3}\left(\overline{\mathrm{ab}} + \overline{\mathrm{bc}} + \overline{\mathrm{bd}}\right) \text{ for tacheometer No. 1 and}$$

$$R = \frac{\overline{\mathrm{ab}} + \overline{\mathrm{bc}} + \mathrm{bd}}{0{\cdot}025} = \frac{100}{2{\cdot}5}\left(\overline{\mathrm{ab}} + \overline{\mathrm{bc}} + \overline{\mathrm{bd}}\right) \text{ for tacheometer No. 115.}$$

When carrying on levelling operations, it may be found convenient to use this relation, with the intervals counted from a single pointing made near the centre of the rod with the lever abutted against pin b.

In this case we have, therefore, as in the first, 1 pointing, 3 readings and 4 contacts; but the error of pointing, Ep, modifies the adjoining intervals $\overline{\mathrm{ba}}$ and $\overline{\mathrm{bc}}$ on each side in opposite directions, so that an error on ba is neutralized by an equal and opposite error on $\overline{\mathrm{bc}}$, and the only interval affected by Ep is bd. Hence:

$$\mathbf{E} = \sqrt{Ep^2 + 3\,(Er)^2 + 4\,(Ec)^2}$$

and replacing the symbols by their numerical values, we find for the total error of intervals measured with tacheometer No. 1:

$$\mathbf{E}_1 = \sqrt{(0{\cdot}25)^2 + 3\,(0{\cdot}5)^2 + 4\,(0{\cdot}357)^2} = \sqrt{0{\cdot}0625 + 0{\cdot}075 + 0{\cdot}5098} = \sqrt{1{\cdot}3225} = 1{\cdot}15,$$

and for the total error of those measured with tacheometer No. 115:

$$E_{115} = \sqrt{(0{\cdot}25)^2 + 3\,(0{\cdot}4)^2 + 4\,(0.225)^2} = \sqrt{0{\cdot}0625 + 0{\cdot}48 + 0{\cdot}2025} = \sqrt{0{\cdot}7450} = 0{\cdot}863$$

Again, the corresponding errors on the distance are:

$$\mathbf{E}_{R_1} = \frac{1{\cdot}15 \times 100}{3} = 38{\cdot}33 \text{ or } 0{\cdot}0383 \text{ yard.}$$

$$\mathbf{E}_{R_{115}} = 0{\cdot}863 \times 100 = 34{\cdot}52, \text{ or } 0{\cdot}0345 \text{ yard.}$$

If instead of the intervals being determined with one pointing made while the lever is abutted against pin **b** or against **c**, two pointings are made, the error of the pointing which is used for two readings is doubled, and we have for the total error of the intervals:

$$\mathbf{E} = \sqrt{Ep^2 + (2\,Ep)^2 + 3\,(Er)^2 + 4\,(Ec)^2}$$

Whence we deduce for the total error $\mathbf{E}_1$ of the intervals measured with tacheometer No. 1:

$$\mathbf{E}_1 = \sqrt{(0{\cdot}25)^2 + (0{\cdot}50)^2 + 3\,(0{\cdot}50)^2 + 4\,(0{\cdot}357)^2} = \sqrt{0{\cdot}0625 + 0{\cdot}25 + 0{\cdot}75 + 0{\cdot}5098} = \sqrt{1{\cdot}5723} = 1{\cdot}253$$

and for the total error of those determined with tacheometer No. 115:

$$\mathbf{E}_{115} = \sqrt{(0{\cdot}25)^2 + (0{\cdot}50)^2 + 3\,(0{\cdot}40)^2 + 4\,(0{\cdot}225)} = \sqrt{0{\cdot}0625 + 0{\cdot}48 + 0{\cdot}2025} = \sqrt{0{\cdot}9950} = 0{\cdot}997.$$

Once more the corresponding errors on the distance are:

$$\mathbf{E}_{R_1} = \frac{1{\cdot}253 \times 100}{3} = 41{\cdot}8 \text{ or } 0{\cdot}0418 \text{ yard, and}$$

$$\mathbf{E}_{R_{115}} = \frac{0{\cdot}997 \times 100}{2{\cdot}5} = 39{\cdot}88 \text{ or } 0{\cdot}0399 \text{ yard.}$$

The inventor of the "Tachéomètre auto-réducteur" has himself given the following formulas, which, he states, indicate the error we are liable to make on any distance R with the two first combinations above mentioned of rod intervals determined with the ordinary instrument (No. 1), viz.:

1st. By using the relation $\frac{\overline{ab}}{R} = 0{\cdot}01$:

$$\mathbf{E}_{R_1} = \overset{\textit{Yard}}{0{\cdot}04} + \frac{R}{4000} \quad \text{.......................................} \quad \text{(A)}$$

2nd. By using the relation $\frac{\overline{ab} + \overline{ac} + \overline{ad}}{R} = 0{\cdot}05$:

$$\mathbf{E}_{R_{115}} = \overset{\textit{Yard}}{0{\cdot}02} + \frac{R}{10000} \quad \text{.......................................} \quad \text{(B)}$$

By substituting 100 yards for R in equations (**A**) and (**B**) we have:

With ratio $\frac{\overline{ab}}{R} = 0{\cdot}01$:

$$\mathbf{E}_{R_1} = 0{\cdot}062 \text{ yard.}$$

With ratio $\frac{\overline{ab} + \overline{ac} + \overline{ad}}{R} = 0{\cdot}05$:

$$\mathbf{E}_{R_{115}} = 0{\cdot}030 \text{ yard.}$$

It may not be superfluous to repeat here that while the result of a very good steel tape measurement will be in excess from 0·03 yd. to 0·06 yd. per 100 yards, as already stated, the tacheometer measurement may indicate in very dry weather a deficiency of from 0·02 yd. to 0·03 yd. The difference of $\left\{(3+2)=5\right\}$ to $\left\{(6+3)=9\right\}$ hundredths may change sign in very cold and wet weather.

With the butting pins placed as above described, it is evident that so long as the actual difference of level between the horizontal optical axis or line of collimation of the telescope and the zero of the rod remains within the limits of the latter, or say within from 4 to 5 yards, and the distance, rod to tacheometer, does not exceed 300 yards, it is always quite possible, not to say easy, to obtain with tacheometer No. 115 a sufficient numbe of rod readings to determine three intervals which are either themselves contiguous, the same as the spaces intercepted with one pointing, or that will correspond to these spaces, provided we take care to have the lever butted against the proper pin, previous to finally setting the telescope truly level with the aid of the micrometer or slow motion screw and the sensitive double-faced level, for taking the horizontal fore or back sight.

As regards the distance, it may be said that it happens very seldom that the atmosphere is sufficiently clear and pure and the light as well as the ground suitable, for us to venture taking even 300-yard sights on each side of the instrument, for any length of time, and this distance may properly be considered to be the extreme limit, which should not be overstepped in carrying on geodetic levelling operations. It is only under exceptionally favourable circumstances that a few sights between 300 and 400 yards long can be taken consecutively in running lines of precise levels.

With a view of devising a rational and expeditious method of taking series of combined level and distance readings for geodetic levelling purposes, or sets of geodesic readings with tacheometer No. 115—after having levelled the horizontal limb or circle of the tacheometer by means of the three ordinary thumb levelling screws and the level tube fixed on top of the cross-bar—let us take a series of readings on a four yard rod 200 yards distant, with the long lever L successively butted against the pins a, b, c and d, and commencing with reading 0, while the lever is kept in place by pin a, and let us designate by P_{R}, the series of intersections of the pencil of visual rays determined by the pins a, b, c, d, with the rod.

In such case we evidently subdivide by means of the said pencil of rays, the full height figured on the rod into three parts: 0,2, 2,3, and 3,4, which bear to each other the same ratios as ab to bc to cd, intersecting as we do. the rod with the four rays in question; at 0 at the foot; at figures 2 and 3 near the middle, and at figure 4 at the top. Now, if any one of the four rays producing the series of intersections P_{R} be level, it is clear that the three additional intersections and corresponding readings required for geodetic levelling purposes are secured without any special pointing being necessary, that is to say, without the clamp P and knife edge having to be moved up or down on the prismatic guide rod T.

The four positions of the pencil of rays determined by the pins a, b, c, d, corresponding to position P_{R}, in each of which a different one of the said rays is horizontal may be termed the fundamental positions of the standard pencil of rays required for the purposes of precision levelling, and the level rod pointings 0, 2, 3 and 4 corresponding to these positions may be called the fundamental series of level pointings and designated by the figures (0), (2), (3) and (4), where (0) denotes a level pointing to figure 0 with the lever L butted against pin **a**, (2) a level pointing to figure 2 with the lever butted against pin **b**, (3) a level pointing to figure 3 with this lever butted against the pin **c**, and (4) a level pointing to figure 4 with the telescope while the lever L is butted against pin **d**.

For distances, tacheometer to rod, of less than 200 yards, a level pointing may strike more or less above or below its corresponding fundamental position, according as the distance differs more or less from 200 yards, without a special pointing becoming necessary for the purpose of securing the intersection whether of the upper or of the lower visual ray of the corresponding pencil **a**, **b**, **c**, **d**, with the rod. But when the said distance exceeds 200 yards, such a special pointing becomes indispensable to attain the said end, and occasionally even a second one.

Now, as the intervals $\overline{3-4}$ and $\overline{2-3}$ are only one-half as large as the interval $\overline{0-2}$, it is evidently best for us to secure, as much as practicable, the special pointings required at the lower end of the rod, which can be managed by abutting the lever against that particular pin which corresponds to the fundamental level reading next above the intersection of the horizontal line of collimation with the rod, whenever this is possible. That is to say, by butting the lever against pin **d** for all level readings between 3 and 4 yards; against pin **a** for all readings between 2 and 3 and against pin **b**, for all level readings between 1 and 2 yards.

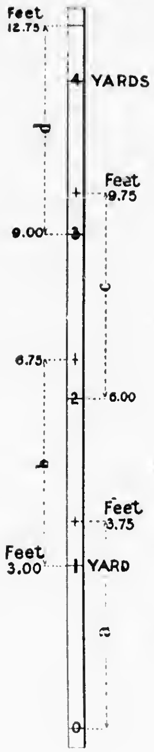
In all cases, however, where the level reading strikes the rod between the figures 0 and 1, it will be best to start our series of readings with the lever abutted against pin **a**, for by so doing we raise the fundamental level pointing (0) less than we would have to depress the next higher pointing (2).

With a rod about $4\frac{1}{4}$ yards long, such as that proposed to be used, the pins **a**, **b**, **c**, **d**, may continue to be used respectively for $\frac{1}{4}$ yard above the figures 1, 2, 3 and 4; this extra $\frac{1}{4}$ yard is, however, chiefly intended to cover any small error in the horizontality of the line of collimation, that may result from the provisional levelling of the instrument with the aid of the level tube N fixed on the cross bar instead of the more sensitive level O attached to the telescope.

The subjoined table shows that by operating in the manner indicated, it is only when the distance—rod to tacheometer—exceeds 250 yards, that a second special pointing becomes indispensable to secure a complete set of four standard rod readings, and then only when the level pointing strikes the rod between figures 2 and 3.25 yards, or between 6 and 9·75 feet.

The sketch in the first column of the table given on next page shows at a glance the limits between which each one of the pins **a**, **b**, **c**, **d**, should, as a rule, be used for maintaining the telescope in a level position with the aid of the long lever, in order that the complete set of four rod readings in question may be obtained with a minimum number of pointings

SERIES OF READINGS with fundamental level pointings (2), (3), (4), lowered one yard (3 ft.) and with the same raised $\frac{1}{4}$ of a yard ($\frac{3}{4}$ ft.); also with fundamental pointing (0) raised $1\frac{1}{4}$ yards $3\frac{3}{4}$ ft). (See sketch in margin.)



Distance Instrument to Rod.	Fundamental Level Pointings	Extreme Readings, a, b, c, d, in Yards.	Number of Special Pointings required to secure a complete set of four Standard Readings.
100 yards..	(0)	a = 0·000, b = 1·000, c = 1·500, d = 2·000	None.
		a = 1·250, b = 2·250, c = 2·750, d = 3·250	"
	(2)	b = 1·000, c = 1·500, d = 2·000, a = 0·000	"
		b = 2·250, c = 2·750, d = 3·250, a = 1·250	"
	(3)	c = 2·000, d = 2·500, b = 1·500, a = ·500	"
		c = 3·250, d = 3·750, b = 2·750, a = 1·750	"
	(4)	d = 3·500, c = 3·000, b = 2·500, a = 1·500	"
		d = 4·250, c = 3·750, b = 3·250, a = 2·250	"
200 yards..	(0)	a = 0·000, b = 2·000, c = 3·000, d = 1·000	None.
		a = 1·250, b = 3·250, c = 4·250	One extra pointing.
		c = 3·250, d = 4·250	
	(2)	b = 1·000, c = 2·000, d = 3·000	
		b = 2·000, a = 0·000	One extra pointing.
		b = 2·250, a = 0·250, c = 3·250, d = 4·250	None.
	(3)	c = 2·000, d = 3·000, b = 1·000	
		b = 2·000, a = 0·000	One extra pointing.
		c = 3·250, b = 2·250, a = ·250, d = 4·250	None.
	(4)	d = 3·000, c = 2·000, b = 1·000	
		b = 2·000, a = 0·000	One extra pointing.
		d = 4·250, c = 3·250, b = 2·250, a = 0·250	None.
250 yards..	(0)	a = 0·000, b = 2·500, c = 3·750	
		c = 3·000, d = 4·250	One extra pointing.
		a = 1·250, b = 3·750	
		b = 1·750, c = 3·000, d = 4·250	"
	(2)	b = 1·000, c = 2·250, d = 3·500	
		b = 2·500, a = 0·000	"
		b = 2·250, a = 0·000, c = 3·500	
		c = 3·000, d = 4·250	"
	(3)	c = 2·500, d = 3·250, b = 0·750	
		b = 2·500, d = 0·000	"
		c = 3·250, b = 2·600, a = 0·000	
		c = 3·000, d = 4·250	"
	(4)	d = 3·000, c = 1·750, b = 0·500	
		b = 2·500, a = 0·000	"
		d = 4,250, c = 3·000, b = 1·750	
		b = 2·500, a = 0·000	"
300 yards..	(0)	a = 0·000, b = 3·000	
		b = 1·250, c = 2·750, d = 4·250	One extra pointing.
		a = 1·250, b = 4·250	
		b = 1·250, c = 2·750, d = 4·250	"
	(2)	b = 1·000, c = 2·500, d = 4·000	
		b = 3·000, a = 0·000	"
		b = 3·250, a = 0·250	
		b = 1·250, c = 2·750, d = 4·250	"
	(3)	c = 2·000, d = 3·500, b = 0·500	
		b = 3·000, a = 0·000	"
		c = 3·250, b = 1·750	
		b = 3·000, a = 0·000	Two extra pointings.
		c = 2·750, d = 4·250	
	(4)	d = 3·000, c = 1·500, b = 0·000	
		b = 3·000, a = 0·000	One extra pointing.
		d = 4·250, c = 2.750, b = 1·250	
		b = 3·000, a = 0·000	"

THE NEW GEODESIC TACHEOMETER ROD.

An indispensable adjunct to every tacheometer is a properly constructed and suitably divided rod. Of course any kind of levelling or telemeter rod answers, in a way, for use in connection with the "tachéomètre auto-réducteur," some better than others, yet I know of none, which altogether satisfies, in my estimation, the requirements of an ideal tacheometer rod that can be used advantageously for ordinary engineers' and surveyors' field work as well as for precision levelling operations.

I therefore ventured to add a speaking levelling and measuring rod constructed in accordance with the particular views I entertain in this respect, to the already long list of such rods of various patterns which are in existence. The proposed geodesic rod, inclusive of all the accessories required for carrying on successfully tacheometric operations of all kinds is shown on illustrations Nos. II and III, which are to be found in the accompanying pocket, with details enlarged; the figures being accompanied by explanatory references.

The new rod is similar, as regards general construction, to the geodesic levelling rods **E** and **F** designed by me, which have been used exclusively for some ten years past, on the geodetic levelling operations carried on under my direction on the St. Lawrence, etc., for the Public Works Department, viz.: ever since the rods were returned to the Department from the Indian and Colonial Exhibition held at London in 1886; but instead of having a scale of feet, tenths and half-tenths with a white target line 0.008 foot wide, painted at every half tenth of a foot on a black strip on either side, like the said levelling rods, the new rod has its scale marked out in white as follows, on a black ground or strip 0·05 foot wide, painted on one side of its face, viz.:—

1st. When the foot is adopted as the unit of lineal measure, at the quarter, half, three quarters and whole tenths of a foot, by white target lines 0·02 foot wide, connected in the centre by a white bead 0·005 foot wide; the whole and half-tenth white stripes being left the full width of the scale strip, but the quarter and three-quarter tenth lines only one-half this width. The half-tenth target lines are further distinguished from the quarter-tenth lines by black points painted at their inner ends, and the whole tenths from the quarter and half-tenths by heavy black lines run across the whole width of the space left for the figures beside the scale strip.

2nd. When the yard is adopted as the unit of length, the scale is marked out by white target lines 0.004 yards wide at each hundredth and each half a hundreth of a yard, which are connected in the centre by a white bead 0.001 yd. wide; the whole hundredth lines being left the full width of the scale strip, but the half hundredth lines only one-half this width. The direction in which the readings are increasing is moreover shown by four heavy black lines of gradually increasing lengths, put in opposite the first, second and third quarters of each tenth and at the upper end of the same.

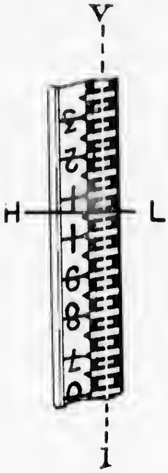
The figures denoting the feet or yards are painted red, while those indicating the tenths are painted black and a little smaller than the former; each figure invariably having its centre opposite the centre of the corresponding division. On the rod divided into yards, the number of whole yards cut off by the cross wire above 0 is also indicated in the centre of each tenth of a yard, by a corresponding number of dots painted red.

A rod with a scale of yards and decimals has the advantage of being less charged with figures than a self-reading rod subdivided into feet, tenths and hundredths, but a rod divided into feet, such as shown on plates II and III in pocket, is perhaps better adapted, on the whole, to the requirements of the engineering profession. With a view of facilitating the precise determination of rod intervals at short range, supplementary division lines, one-half hundredth of a foot centre to centre, have been drawn in black along the whole length of the foot scale, so as to interfere as little as practicable with the clearness of the main white target lines.

The indiscriminate use of one and the same target line or stripe or series of target lines of the same width, for very short as well as for comparatively long sights, does not appear to me to permit of the observer making uniformly accurate pointings througnout, or of the eye estimating with a uniform degree of precision the space that intervenes between the apparent line of intersection of the horizontal wire with the rod and the nearest division work of the rod scale.

In operating with the self-reading telemeter or tacheometer rods at present in use, so far as I am aware, it is apparently taken for granted that the subdivision by the eye of, say one centimeter or any other standard interval, into decimal or other aliquot parts, leads to the same relative degree of accuracy in the results whether it is effected at a distance of say 5 or 6 meters, or at 100 or 200 meters, and in all cases where no micrometer measurements are made the smallest subdivisions read off and recorded are usually either thousandths of a meter or thousandths of a foot, whether the rod is put up very close to the instrument or very far from it. Yet, it must be admitted we can, in general, no more determine the elevation of a level line of sight with the same degree of accuracy, by locating it with the eye within the limits of a centimeter division of a rod only 5 or 6 meters off, as by locating it within the same rod division, at a distance of from 100 to 200 meters—than we can lay off an angle of a given number of degrees and minutes with a 3-inch protractor as accurately as with a 3-foot circle; an error made at 5 meters is, in comparison to the distance, evidently much greater than the same error in the reading made at a 100 or 200 meters from the instrument.

Whatever may be the kind of rod used, the readings should always be taken along the centre line or axis of the row of target stripes or other division marks, for, when the line of sight is inclined to the horizon and the face of the rod oblique to the vertical plane swept out by the axis of the telescope, the plane passing through the transverse wire and the optical axis no longer cuts the rod invariably in a direction **HL** parallel to the longitudinal axis of the target lines; but in general, obliquely thereto, as shown by the figure in the margin, and it becomes indispensable to take all the readings on one and the same vertical, $\overline{\mathbf{vl}}$, if correct rod intervals are to be obtained. The bead which connects all the target stripes serves as a reminder to the observer, that the rod intervals are all intended to be measured along the axis or centre line of the row of white target lines painted on the rod.



Instead of estimating the distance between the apparent intersection of the horizontal wire with the scale on the face of the rod, and the centre of a white target line, this space can be more accurately measured with the aid of the micrometer screw; leaving the distance, tacheometer to rod, to be determined in the ordinary way; for, it is always easier to subdivide a small rectangular space correctly into equal parts, than to cut off the said space any other aliquot part, whether at one end or the other.

The new rod is well adapted for making such precise measurements at all distances at which the power of the telescope and the state of the atmosphere permit of making the said measurements. When a very long sight has to be taken, as across a river, a gully, etc., two, three or four moveable targets can be fixed at known heights above 0 on the rod and the corresponding intervals determined on the vertical scale, or scale of tangents of the tacheometer, very accurately measured with the aid of the micrometer screw which gives directly the $\frac{1}{1,500,000}$ part of a foot and a still smaller space by estimation, whence the rod reading corresponding to a level optical axis and the horizontal distance, rod to tacheometer, can be easily deduced, without there being any necessity for signalling to the rodman to move his target up or down.

Four standard target positions are indicated by white lines painted on, or by grooves cut into the sides and rear faces of the rod, which determine three consecutive intermediate intervals bearing to each other the ratios of the whole numbers 10, 8 and 4, which ratios are the same as those of the intervals between the pins of the "Tachéomêtre Sanguet" of the ordinary construction. These lines or shallow grooves correspond with figures 0·3, 2·58, 7·14 and 12·84 feet above 0, the intervals determined by them are therefore disposed in the inverted order of those determined by the pins **a, b, c, d,** of the said tacheomêter (No. 1); the largest interval (10) being at the top and the smallest (4) at the foot of the rod. The ordinary series of intervals has been inverted on the rod in order to prevent it, as much as possible, from being rendered top heavy and difficult to handle during strong winds when the four targets are put on.

The same as geodesic levelling rods **E** and **F**, the new tacheometer rod consists of three battens or scantlings of mahogany B_1, B_2, B_3, which when put together form a continuous rod 13·02 feet or 4·34 yards long. The bottom scantling or lower face bar B_1 measures 6·51 feet or 2·17 yards in length, exclusive of the ball support O of phosphor bronze, 0·10 foot or 0·03 yard high, added at the foot; it embraces the portion of the divided scale extending from 0 up to 6·36 feet or 2·1225 yards and thence down to—0·150 foot or—0·050 yard. The lower 3·900 feet or 1·300 yards, or from—0·150 foot or—0·050 yard to 3·75 feet or 1·25 yard, is square in cross section; measuring 0·15 foot or 0·05 yard by 0·15 foot or 0·05 yard—and the upper 2·610 feet or 0·8725 yard, or from 3·75 feet or 1·25 yard to 6·36 feet or 2·1225 yards, is flat and measures 0·15 foot or 0·05 yard by 0·078 foot, or 0·026 yard. The top face bar B_3 is flat and measures 0·15 foot or 0·05 yard in width, 0·078 foot or 0·026 yard in thickness and 6·51 feet or 2·1675 yards in length; it embraces the portion of the scale between 6·360 feet or 2·1225 yards and 12·87 feet or 4·29 yards. The intermediate bar B_2 serves to connect the upper with the lower half of the scale and measures 0·15 foot or 0·05 yard in width by 0·072 foot or 0·024 yard in thickness, by 6·51 feet or 2·17 yards in length and extends from division 3·75 feet or 1·25 yard to division 10·26 feet or 3·42 yards.

The original intention was: 1st. To make the rear bar out of the same piece of mahogany as the other bars and apply it to the back of the latter in a reversed position, so that any tendency to warping or twisting in the face bars might be checked by a probable equal and similar working of the rear bar in an opposite direction. 2nd. In order to prevent the portion of the face bar B_3, which projects 2·61 feet or 0·8725 yard above the upper end of the intermediate or connecting bar B_2 from warping, this bar was to be formed of two halves (mahogany and pine) each 0·039 ft. or 0·013 yd. thick, screwed or dowelled and glued together and parafined. This plan had to be abandoned as the wood available would not stand this treatment without giving such signs of warping and twisting, that it was considered unsafe to rely on the bars remaining straight after being exposed to the weather.

Thereupon, it was decided to build up each one of the bars which are respectively 0·072 foot or 0·024 yard and 0·078 foot or 0·026 yard thick, of three battens, a piece of clear white pine $\frac{4}{10}$ of the total thickness of a bar being interposed between two pieces of mahogany that form each $\frac{3}{10}$ of the said thickness, and all three firmly glued together. This plan gave satisfactory results; the desired increased rigidty, of the upper 2·61 feet of the face bar B_3, which project above the connecting bar, B_2 in the rear, and hence are unsupported by the same, was secured without any trace of twisting or warping being noticeable in the battens after they were glued together.

The intermediate or connecting bar B_2, is firmly secured to the face bars, by means of steel fillister head screws S with large heads screwed into circular brass socket plates P, sunk into the face bars, three to each bar; each plate being fixed to the bar by two small brass screws s_1. A groove is cut on each side of the rod to serve as a guide for sliding a target T of the ordinary construction with clamping screw C, from top to bottom along the face bars. On this target, which is made of aluminum to secure a minimum weight, a narrow stripe L, is painted in the centre for use when comparatively long sights are taken and wider rectangular marks *M* on either side for very long sights. The target *T* is exactly 0·50 foot or 0·17 yard long and 0·40 foot or 0·14 yard wide, out to out, and can be fixed in position so as to bring its centre exactly at any desired height above 0 by means of two metal strips **t** soldered on its reverse side with their outer faces precisely 0·20 foot or 0·07 yard on each side of the said centres. It has also a centre line painted on the back all round by means of which it can be placed closely in position at any one of the standard heights of 0·3, 2·58, 7·14 and 12·84 feet above 0 indicated on the sides and the rear of the rod, by white lines or grooves. These heavy white lines or grooves are, however, intended to serve only as guides for fixing the targets provisionally in position at the said standard elevations above the 0 of the rod; the final close adjustments of targets should in all cases be made with the aid of the metal strips **t** just described, which are better suited for the purpose.

The foot of the rod is shod with a brass shoe *H* firmly secured to the wood with three brass screws **w** extending from front to rear of shoe; the face of the shoe is cut out between the fillets so as to reduce its height to 0·140 foot or 0·046 yard, viz., to a level 0·0100 foot or 0·0020 yard below the zero point, in order that the whole of the scale above this point may be entirely painted on wood, so that the zero target line (a very important one for tacheometric measurements) may not become defaced by the accidental rubbing of branches, weeds, &c., against the brass, on the field, or when the shoe is removed from the rod for packing it in a box, which would be quite likely to happen soon, if the zero line was painted on brass at the extremity of the rod, as is often done.

The shoe carries on one side a circular level l mounted on parallel plates with three capstan adjusting screws **a** working against spiral springs; this level is used by the rodman in all positions in which a similar level l inserted in the rod about 3·5 feet or 1·17 yard above the foot and which will be presently described—cannot be seen by him—on account of being too high up or because he cannot stand in rear of his rod, or for some other reason.

One half of the number of rods used should have the circular level on the right hand side and the other half on the left hand side of the shoe, for it happens sometimes that the projecting level as fixed on one side, prevents the rod from being held up vertically, while it would not thus interfere with the proper holding of the rod if it were attached on the opposite side.

To the lower plate under the lower level l can be fixed, when found requisite, a gauging attachment provided with a straight or hook pointer j, for the accurate determination of water levels.

The pointer j proper is screwed into the end of a brass tube **k** with lateral openings or slits, which slides along a steel centre pin **P** and can be fixed at any desired height on the pin by means of either of two clamp screws **e**. The steel centre pin is divided lengthwise into hundredths of a foot or yard by marks cut all around it, and thousandths of a foot or of a yard can be read (and ten-thousandths of a yard estimated) by means of an index division **d** of fivehundredths of a foot or ten thousandths of a yard engraved on the sliding tube, on each side of the slits or openings which are cut in the said tube, to expose the divided pin to view. A small brass pin i screwed into the steel centre pin at its lower end, prevents the tube from sliding off altogether, should we inadvertently omit to tighten either of the clamp screws. The point j,—the tip of which is level with the underside of the ball support *O*, when the slide is closed up tight against the projecting head of the pin **P** and the index on the tube is opposite the 0 on the pin,—can be lowered by 0·10 foot or 0·05 yard at a time, by adding extension rods **r** provided for the purpose. The steel pin is bored out in the centre and contains a hollow spring bolt which is terminated at its upper end by a barrel shaped head that causes the three prongs into which the bolt is split to close up when forced up or down through an appropriately tapered opening turned in a steel bushing inserted in the centre of the lower parallel brass plate under the level l.

The ball support *O* of phosphor bronze, 0·10 foot or 0·03 yard high, already referred to, has been added to the rod for use in connection with a cast iron foot plate *F* having a cavity turned on top about 0·138 foot diameter and 0·033 foot deep, which forms part of a sphere of 0·09 ft. radius. This support is kept in place by a tapered brass pin **q** which passes through one side of the brass shoe, the wooden rod and the brass shank of the ball and is screwed at the other end into the opposite or rear side of the shoe. The pin being made with a taper, presses the shoulder of the ball tight up against the flat end of the shoe every time, without fail.

The ball is not inserted in the rod so as to be precisely in the centre between the front and rear faces of the shoe; but with its axis 0·067 foot back of the divided face. The sum of this distance and the horizontal projection of the interval between the centre of the tacheometer and the centre of the axis of revolution of the telescope, viz., $\frac{1}{2}\,r = 0{\cdot}333$ foot, gives us for the constant to be added to the distance—centre of tacheometer to axis of rod—the round number 0·4 ft.

Should it be found desirable to use convex headed pins and stakes and nails for supporting the rod, instead of placing it in a spherical cavity on a cast iron foot plate, the ball support can be removed and a shank *V* with disc fitting exactly the hole in the bottom of the shoe, substituted; if preferred, truncated pyramids of hardened steel can, of course, also be inserted in the shoes to be used as supports, as practised on the United States Geological Survey.

For tacheometrical operations, in general, the use of a foot plate with a spherical cavity in connection with a corresponding ball support on the rod, is however, calculated to give the best results. For, a rod with such a support placed on the concave surface of a spherical segment must necessarily, when held up plumb, always have its longitudinal axis in one and the same vertical, so long as the plate remains undisturbed, no matter in what direction the face of the rod may have to be turned, or how many times we may have to remove it from the plate before the work is completed from a station.

The same cannot be said when a rod with a flat base is used in connection with convex headed nails or turtle back foot plates, when the rodman can barely help shifting his rod latterly more or less, at every turning point. In taking directions or measuring horizontal angles with the tacheometer, the rodman is instructed to place his rod with its face as nearly as possible perpendicular to the line of sight, and the vertical wire is brought in line with the axis of the rod by dividing the black points opposite the long white target stripes into two parts of equal area.

As already stated, at a point about 3·17 feet or 1·17 yard above the foot of the rod, a second circular level 1′ mounted on parallel plates by means of three hexagon headed adjusting screws X with spiral springs, is inserted in the rod, viz., in an opening N of rectangular section with sides and top flaired out towards the rear, so as to enable the rodman to clearly distinguish the bubble and plumb his rod without having to stoop.

A circular level in every respect similar to level 1′ might be inserted in the rod at a point about 1 and $\frac{2}{3}$ feet above 0, as a substitute for the level 1 on the side of the shoe, in which case any precise water level required would have to be determined by means of a separate pointing apparatus or hook gauge. A circular level encased in the rod is not so liable to be deranged, than one projecting on one side; but when in the former position it is, on the whole, not so easy for the rodman to see it distinctly and compare it with the upper level. Moreover, if the two spherical levels were both inserted in the rod, we could not set it up plumb without removing every time the struts from their sockets in the rear, which is not always indispensable nor yet desirable, as for instance, when we are taking levels of the ground where it is sufficient for all purposes to read within the nearest half tenth or so of the true elevation and where a slight variation in position is of little or no consequence.

With a view of assisting the rodman in holding his rod steadily in a truly vertical position, he is provided with a double knife-shaped wooden handle D, which he can pass transversely through a slit cut in the centre of the rod at a height of about 4 feet above 0, partly in the rear or connecting bar B_2 and partly in the front bar B_1.

When not in use the double or knife handle is housed lengthwise in a corresponding recess cut in the rear half of bar B_1, near the foot of the rod, viz:—with the flat side sunk flush with the face of the bar. The recess is undercut at the lower end so as to prevent the rounded point of the knife from leaving it, when the handle end is secured in place, and permit of the latter being tilted up by pressing down the point with the thumb, when we wish to remove the knife from its recess. The upper or handle end, is prevented from falling out of the rod by means of a short spring bolt b, inserted in the side of bar B_1 with its head left flush with the wood, and which passes through an eye screwed in the end of the handle, viz.:—when the spring is released after being pulled out to clear the way for the eye.

The rodman is moreover, provided for the same purpose, with a steel shod and brass tipped hardwood strut U armed with a pruning knife for cutting away branches that obstruct the view in the line of sight, which he can plant in a vertical plane directed upon the tacheometer, and thus effectually stop all oscillations of the rod to and from the latter, which are the most important to avoid.

When, with the object of securing the very highest degree of accuracy that can be attained in the determination of rod intervals and corresponding elevations and distances with the tacheometer, we are prepared to devote to the field operations the additional attention and time needed to measure with the aid of the micrometer screw, etc., as above described, the spaces intervening between the point of intersection of the cross wire with the rod scale and the centre of the next lowest target line, it is advisable when practicable, to use two plain light strut poles some 6·6 feet long, made of steel tubing, such as T_1, T_2 on Illustrations II and III, for the purpose of keeping the rod, steadily in a vertical position, instead of placing only one wooden strut with pruning knife in the line of the tacheometer; the steel struts being planted one on each side of the said line, as may be found most convenient.

Indeed it is quite possible, not to say probable, that in this country at least, the rodman will generally find it most advantageous to use either one or two light steel tube struts like T, as may be considered most advisable, to the exclusion of the rather heavy wooden strut with pruning knife and to carry a small hatchet when required, for clearing away branches, etc.

In order to enable the rodman to carry along two such struts with ease, provision is made for securing them to the rod by means of two ring clasps fixed to its rear face, viz.:—one (Y_2) to the brass shoe and the other (Y_1) on top of the intermediate bar B_2, at a point $6\frac{1}{3}$ feet above 0. When a rodman is ready to proceed from one turning point to the next, he can pass the rounded top of either strut through one of the rings of the upper clasp, Y_1, and then force the pointed end on which an annular cam c is riveted, into the corresponding socket or ring of the lower clasp, Y_2, pushing aside with the aid of the cam, one of the flat springs g fixed to the shoe of the rod, and thus effectually preventing the tube from sliding back through the clasp ring. When the tubes have again to be taken off the rod for use as struts, the rodman has only to pull them upwards with sufficient force to cause the cams to clear the springs and then remove them from the rings by pulling them downwards, slightly out of the line of the two clasps.

For safe keeping or transportation over long distances, the three bars of which each rod is built up can be disconnected by taking out the screws which hold them together, and the shoe can also be thus removed, viz., in order to permit of a set of three complete rods inclusive of shoes, ball supports, pointer tubes, six aluminum targets, six steel tube steadying struts and other accessories being snugly packed into a wooden box not exceeding $7\frac{1}{2}$ feet in length by 0·71 feet in width and 0·65 foot in height outside; total weight of box, with rods and accessories complete 100 lbs. See figure 7, Ill. II.

When the rods have to be transported only over comparatively short distances, the bars B_1, B_2, B_3, can be screwed together, with the divided faces placed over each other and the lower level and the bronze ball support protected by brass caps as shown on illustrations II and III; for this purpose the screws used in mounting the rod are amply sufficient. I may observe that the rod bars while thus screwed one on top of the other, when not in use are effectually prevented from taking a slight set one way or the other. See figure 1, Ill. II.

In order that this may be easily accomplished, an enlarged oblong brass plate P_1 carrying two tubes or sockets t_1, t_2 threaded with the same tap as all the other screw plates, but in opposite directions, is inserted into bar B_1 near the top, in place of an ordinary circular plate or button, another threaded tube or plate is inserted in the same bar near its foot, viz.: between the two battens on each side of the target groove, before they are glued together, and a third supplementary threaded tube on a circular plate is inserted into bar B_2 near its upper end. All these tubes are disposed so as to traverse the face bars in the space reserved, on one side of the rod, for the figures and at places where they do not disguise the latter any more than they interfere with the target stripes or line divisions. Three extra screw holes corresponding to the tubes are also bored in the rod, viz., one (h_1, h_2) at each end of the bar B_3, and one (h_3), near the top of bar B_2. Moreover, in order that the upper clasp Y_1 may be of service for keeping the steel tubes T_1, T_2 in position on the back of the rod, as well, when it is put up for transportation, as when it is mounted for operating in the field,—instead of being fixed directly to bar B_2, this clasp is screwed on the top of a thin brass band about $\frac{3}{4}$-inch wide, passing over the top or rear face and sides of this bar. In the centre of the band a tube is brazed to its underside, which is imbedded in bar B_2 right down to the brass plate in bar B_1 affording a passage to the screw which connects intermediate bar B_2 with front bar B_1, and the ends of the band rest on bar B_1 and are turned in sufficiently, to butt against the bottom of the groove in the side of the rod along which the aluminum target slides up and down, so that when bar B_2 is removed the band with clasp is still properly supported and effectually prevented from turning round.

I will now place before the Department a few typical pages of a proposed field book with columns disposed so that the book may be of service, not only for registering geodetic levelling operations; but also all other kinds of engineers' and surveyors' field work carried on exclusively with the tacheometer and accompanying rod.

In these five double pages (See illustrations Nos. 46, 47, 48, 49 and 50 in accompanying pocket) I made all the entries that could be required in carrying on a series of supposed field operations, in black; the office work generally in red, and the mental computations in green, with a view of showing in a practical manner the work to be done by using the self-reducing Sanguet tacheometer, generally, for surveying and levelling operations, as a substitute as well for the chain, as for the transit or theodolite and the spirit level. The field operations and computations indicated are typical of those required in running simultaneously two lines of geodesic levels in cases where accuracy in the horizontal distances, is deemed to be as great a desideratum as precision in the elevations.

It will be seen that in column 1. we enter :—

1. The nature of the sight, whether it is a fore, back or intermediate sight taken for levelling purposes alone or for levelling and surveying purposes combined, or simply a sight taken for establishing the position of a survey point. The word sight is printed and we have only to prefix the proper qualifying adjective as required.

2. The number of the station occupied with the tacheometer, viz., after the printed words " From St."

3. The distinguishing letter of the particular rod used, viz., after the printed words " To Rod."

4. The point or station at which the rod is put up.

5. The series of continuous levellings to which the sight belongs, if deemed necessary.

Columns 2 and 3 are required for entering :—

1. Rod readings in feet A, B, C, D, which are obtained with the long lever successively abutted against pins a, b, c, d.

2. Vertical scale readings in decimals of radius $r = \frac{2}{3}$ foot, of vertical circle described from a point on the axis of rotation of telescope near the optical axis tangent to the path followed by the knife edge, viz., readings (a), (b), (c), (d) and (0), (1), (2), (3)........................., (n), which we obtain either by sighting sliding targets fixed at the standard elevations of 0·3, 2·58, 7·14 and 12·84 feet above 0, which are indicated by special marks on the rod, or by directing the line of sight to such targets fixed at any other elevations that might be found more suitable in particular situations, such as 1, 2, 3, 4.........................N, feet above 0 of rod.

In column 4 are to be entered :—

1. Rod intervals Δ in feet determined by readings A, B, C, D, such as $\overline{AB}$, $\overline{AC}$, $\overline{AD}$; $\overline{BA}$, $\overline{BC}$, $\overline{BD}$, etc., with the long lever arm abutted against pins a, b, c, d.

2. Scale intervals δ, in decimals of radius $r = \frac{2}{3}$ foot, which are determined either by scale readings (a), (b), (c), (d), obtained by directing the line of sight successively to sliding targets fixed at the standard elevations of: 0·3, 2·58, 7·14 and 12·84 feet above 0 of the rod or to the target lines at the said elevations—or which are determined by scale readings (1), (2) (3), (4) ....(n), corresponding to sights taken to sliding targets fixed at any suitable elevations above 0, such as 1, 2, 3, 4..................... N. feet.

3. The sum $\Sigma\Delta$, of the rod intervals Δ just described, which are determined in each case, viz.: in feet.

4. The sum $\Sigma\delta$, of the scale intervals δ, which are determined as just stated, viz.: in decimals of radius $r = \frac{2}{3}$ foot.

Column 5 contains :—

1. The collimation or height of the optical axis of the tacheometer above datum, which is represented by C. In each one of the series of continuous levellings, A, B, of a double rodded line the collimation is equal to the sum of the backsight and the elevation of the zero point of the rod; but for intermediate sights, the height of the optical axis of the instrument is assumed to be equal to the mean value of the two sets of collimations of the continuous series of levellings, such as: $\frac{1}{2}$ (11·05562 + 11·04760) = 11·05061 on field book page 49 in accompanying pocket.

2. The rise or fall I_0 to the zero of the rod from the transverse axis of the telescope, viz: $I_0 = R \{ (n) - c) \} - N$, where (n) denotes the scale reading cor-

responding to the lowest sliding target or target line observed on, viz:—at N feet above 0, and c is a constant having a value in the immediate vicinity of 0·5, such as 0·49925, the value assumed for the set of typical field operations submitted, which represents the precise scale reading when the optical axis is in a truly horizontal position.

3. The elevation of the zero point of the rod, viz.: $E_0 = C - R\{(n) - c\}$, in which relation the symbols have the same meaning as above.

4. The radius R of the vertical circle passing through the optical axis and having its centre on the axis of revolution of the telescope and its circumference tangent to the rod directrix along which the scale divisions are laid off, or to this line produced.

$$R = 100\ \overline{AB} = 200\ \overline{BC} = 200\ \overline{CD} = 100\ \overline{BD} = 4\left\{\overline{BA} + \overline{BC} + \overline{BD}\right\} \times 10 =$$

$$= 2\ (\overline{AB} + \overline{AC} + \overline{AD}) \times \left\{10 + 1 + 0{\cdot}1 + 0{\cdot}01 + \ldots\ldots\right\} =$$

$$\frac{5{\cdot}7}{\overline{ba}} = \frac{4{\cdot}56}{\overline{bc}} = \frac{2{\cdot}28}{\overline{cd}} = \frac{12{\cdot}54}{\overline{ad}} = \frac{6{\cdot}84}{\overline{bd}} = \frac{17{\cdot}10}{\overline{ba} + \overline{bc} + \overline{bd}} = \frac{28{\cdot}50}{\overline{ab} + \overline{ac} + \overline{ad}}$$

In column 6, the readings of the three verniers, A, B C, which give the directions of the survey lines, are entered.

The actual direction of a line is indicated by vernier C in degrees, minutes and half minutes. Vernier A gives the correct number of degrees, less 180° plus $\frac{2}{5}$ of the total number of minutes indicated by vernier C, and vernier B indicates the same number of degrees as vernier A plus 15° and the remaining $\frac{3}{5}$ of the total number of minutes. So that: 1. The sum of the minutes read with A and B must always be equal to the minutes read with C. 2. The degrees read with B must be equal to the degrees indicated by C less 180° and to the degrees read with B less 15°. If these relations do not obtain, it is a sign that an error has been made; any one erroneous reading, taken with either of the verniers, can always be corrected by means of the other two readings.

Column 7 is reserved for notes relative to state of weather, description of points, water surfaces, &c.

In column 8 sketches are drawn showing the features of the country traversed, the lines run and levelled, &c. The computations of heights and distances, which have to be measured with the aid of micrometer scale intervals corresponding to known rod intervals, are also made in this column, as well as any other arithmetical operations that may be found necessary.

As already stated, the standard target positions marked on the rod are at: 0·3, 2·58, 7·14 and 12·84 feet above 0 and determine consecutive intervals of 2·28, 4·56 and 5·7 feet, which bear to each other the same ratios as the intervals $\overline{ab}$, $\overline{bc}$ and $\overline{cd}$ between the pins a, b, c, d, of the ordinary tacheometer, pattern No. 1, viz., the ratios of the whole numbers, 4, 8 and 10. These intervals have been selected because they are found to be, on the whole, perhaps better adapted for making accurate distance measurements, independently of levelling than any other.

In view of the fact that as shown above, by using the "Tachéomètre auto-réducteur": 1. No corrections are required owing to any want of parallelism of the optical axis to the horizon indicated by the sensitive telescope level, whatever may be the distance, rod to tacheometer, provided we use the mean of two readings, one of which is taken with the telescope in the erect position and the level in the direct one, and the other with the telescope in the inverted position with the level reversed. 2. Horizontal distances can be measured with extreme facility, within the error limits of 0·06 foot and 0·12 foot per 100 feet, respectively, by taking advantage of the relations: $R = \frac{\overline{ab}}{0 \cdot 01} = 100\, \overline{ab}$ and $R = \frac{\overline{bc}}{0 \cdot 005} = 200\, \overline{bc}$, it is clear:

(*a.*) That in any case only corrections for curvature and refraction need be applied, and these only when the difference between the fore and back sights exceeds say 3 or 4 feet.

(*b.*) That when the computations of such corrections by means of the automatically determined horizontal distances, tacheometer to rod, have to be made only for such small distances as the differences in length between fore and back sights approximately equalized by pacing with the aid of a passometer—preferably one with stem attachment for setting the needles to zero at will—they become extremely easy and simple, in fact so simple, that the results sought can readily be deduced from an attentive inspection of the factors involved and entered at once in th level book without any figuring whatsoever being requisite. For, in such case, the corrections in question may be calculated mentally with more than sufficient accuracy for all purposes, at the uniform rate of 0·000002 foot of rod interval per foot of horizontal distance, as shown in green on the sample pages of the proposed tacheometer book.

Now an approximation to equality in the lengths of the fore and back sights quite sufficient for the purpose intended can, as a rule, be readily secured, by leaving the disposition of the rod stations, as just explained, entirely in the rodmen's hands, without there being any absolute necessity for the whole staff to lose a portion of their time in endeavouring to more closely equalize the intervals between the rod and the instrument by means of stadia measurements, than can be done by the rodmen left to themselves: a ceremony which must often prove much more tedious to the observer than he anticipates, chiefly on account of his signals to the rodmen to move their rods being wrongly interpreted by them, for want of attention on their part, or for other reasons.

The ordinary corrections for curvature, refraction, inclination, &c., which according to the geodesic methods now followed, have to be applied to all readings without exception, will thus be required only in special cases, viz.: when the rough ground or other difficulties encountered, absolutely preclude the practical equalization of the back and fore sights or the reading of the rod scale without the use of the sliding targets, or would cause unwarranted loss of time and a corresponding increase in the expense.

In order that precision levelling operations may be carried on expeditiously and economically in the manner proposed, it appears desirable that at least three intelligent and attentive rodmen be employed.

On a double rodded line the distance between two consecutive fore sight and two consecutive backsight points may be taken at from 10 to 25 paces. As regards the proper distance to be left between an instrument station and an adjoining fore or back sight point, that depends largely on the configuration of the ground, the state of the atmosphere, the power of the telescope, &c., but as already stated, it should not exceed 300 paces when a tacheometer such as No. 115 is used, and in general should be much less.

The first sight indicated on the typical pages of the proposed field book is one taken from station 49 to rod **E** at station 48. After levelling the tacheometer and setting vernier *C* on the direction taken from station 48 to station 49, increased by 180 degrees, viz.: on $72°+25\frac{1}{2}'+180°=252°+25\frac{1}{2}'$, the telescope is directed to station 48 by the observer, who clamps both parallel plates and completes the adjustment of the line of sight in the direction of the rod with the lower tangent screw R'. As the distance appears to him to exceed 1,000 feet, he measures it with the long lever abutted against peg **b**, making a pointing on the 0 of the rod which the recorder enters in column 2; the stations 49 and 48, and the rod, **E**, having been previously entered by him in column 1 and a sketch made in column 8 showing the proposed operations from station 49. The observer now draws the lever lightly sideways, so as to make it clear pin **b** and cause it to strike pin **c**, when he takes the rod reading 6·962 which the recorder enters in column 3. Finally verniers *A*, *B*, *C*, are read and the directions entered in column 6, viz.: $72°+10'$, $87°+15'$ and $252°+25\frac{1}{2}'$. That vernier *C* was correctly set is shown by the fact that we have:

$$87°-(252°-180°-72°) = 15° \text{ and } 10+15 = 25 \text{ minutes.}$$

As this sight is taken chiefly with a view of fixing the directions to be taken from station 49, in reference to those taken from station 48, it is considered sufficient to measure this distance with one rod interval, viz.:—the interval $\overline{BC}$ determined by two readings *B* and *C* made with the lever *L* abutted against pins **b** and **c**. In such case, as we have seen, it suffices to multiply the difference between readings *B* and *C*, viz.: 6·962, by 200 in order to obtain the radius *R*. This gives us 1392·4 feet for *R* which number is entered in column 5, and the sum of the readings, which is here 6·962—there being only one reading made—is put down in column 4.

The second sight taken is a back sight from station 49 to Rod **E** put up at point No. 9, which particulars are, as before, entered in column 1 by the recorder. The observer having found by trial that when the axis of the telescope is nearly horizontal, the line of collimation intersects the rod near the foot, the lever is abutted against pin **a** and the telescope again levelled, viz., with the aid of the micrometer screw, when reading $A = 0·539$ is taken and entered in column 2. The telescope is now inverted and the double faced level reversed, by causing the journals of the transverse axis of the telescope to change wyes, and the steel straiget edges fixed to the sides of the telescope near its eye end, one of which always rests on the knife edge, to exchange places simultaneously.

The errors of collimation and of inclination of level to optical axis being thus balanced, a second rod reading (0·541) is taken with the lever abutted against pin **a**, which is entered immediately under the first (0·539) by the recorder. Subsequently we take reading $B = 7{\cdot}326$ with the lever resting against **b** and enter it in column 3. As $(7{\cdot}326 - 0{\cdot}541) \times 2$ would evidently strike above the upper end of the rod, the observer now makes a new pointing on say 5·000 with the lever remaining against **b** which is entered in column 2, and he afterwards completes the set of four readings by passing the lever successively to pins **c** and **d** and taking the corresponding readings, viz.: $C = 8{\cdot}3925$ and $D = 11{\cdot}785$ which are entered in column 3 by the recorder.

The third sight taken is a foresight from station 49 on rod **F** at point 10. As before, after having found out by trial that the horizontal optical axis will strike the rod a little below figure 5, the lever is butted against pin **b**, and the telescope set perfectly level with the aid of the micrometer screw—when the two readings $B = 4{\cdot}876$ and $B = 4{\cdot}873$ are taken consecutively with the telescope and level respectively in the erect and inverted and in the direct and reversed positions; also readings $C = 8{\cdot}383$ and $D = 11{\cdot}902$ with the lever successively held in position by pins **c** and **d**. As 11·9 less 4·8 is equal to 7·1, it is evident that a new pointing B is necessary for taking reading A. The lever is therefore returned to pin **b**, the intersection of the cross wires directed to figure 9·000 on rod which pointing (B) is entered in column 2, and the lever handle lowered so as to strike pin **a**, when reading $A = 1{\cdot}974$ is taken and recorded.

Next in order comes another foresight, viz.: that from station 49 to rod **F** at point 11, when a similar set of operations is performed; this time beginning with direct and reversed level readings: $D = 11{\cdot}826$ and $D = 11{\cdot}830$ and ending with reading $A = 1{\cdot}494$; an extra pointing $B = 8{\cdot}000$ having had to be made.

The last of the set of four sights required from station 49 for precision levelling and distance measuring or general surveying purposes, is a back sight on rod **E** at point 8. In this case it is found that it is best to take the direct and reversed level readings with the lever arrested by pin **c**, viz.: $C = 9{\cdot}156$ and $C = 9{\cdot}160$, so that one pointing may suffice for the whole set of four.

If it is important that the correct positions of the levelling turning points be established, points Nos. 8, 9, 10 and 11 have again to be sighted, for the purpose of registering the directions indicated by the verniers, as shown in column 6.

Sights are now taken to rod **F** at station 50 and to rod **G** at points $9\frac{1}{4}$ and $9\frac{1}{2}$ and the directions of those points duly noted. A single rod interval is deemed to be sufficient for the determination of each one of the points last named, which are specially described in the column headed "Notes, etc.", The interval read is that $\overline{AB}$, which affords $\frac{1}{100}$ part of the distance R.

From station 50 the first sight is again taken to the station last occupied, viz.: 49, for the purpose of setting the tacheometer right in reference to the meridian or axis of ordinates fixed upon at the start, and also for verifying the distance between the said stations as measured from station 49; the upper limb or interior circle having previously been clamped with vernier C set at the figure read from station 49—when the telescope was pointed in the opposite direction—increased by 180 degrees, or at $243° + 11'$.

The back and foresights from station 50 are also taken and recorded in a similar manner as from station 49; but the intermediate sights to points Nos. 14, 15, 16 and 17 have to be treated somewhat differently from the intermediate sights taken to station 50 and to points 9¼ and 9½ from station 49.

Point 14 is too high up to be levelled to in one sight, hence the inclination has to be measured by means of the scale of tangents and the micrometer screw, the horizontal distance has however been determined in the most expeditious manner possible, viz. by using the relation $R = 100 \times \overline{AB} = 100 \times 8{\cdot}543 = 854{\cdot}3$ feet.

Here by pointing the optical axis to the 0 at the foot of the rod, the scale reading: 0·39752 obtains. But when the telescope is truly horizontal the scale reads: 0·49925, hence the tangent of the inclination from the instrument to 0 is ·39752—·49925 — 0·10173 and the rise to 0 = 854·3 × (0·10713) = 86·9079 feet, which being deducted from the collimation 11·0506 gives 97·9585 feet for the elevation of 0 at point 14. Again, point 15 is too far off to permit of a rod being used without a sliding target and the same remark applies to point 16. We therefore take in the case of point 15, the scale readings (*a*), (*b*), (*c*), (*d*) determined by the sliding targets *A*, *B*, *C*, *D* fixed at figures 12·84, 7·14, 2·58 and 0·30 feet on the rod, and perform in column 8 the numerical operations required to deduce the distance from the relation $R = \frac{\overline{AB} + \overline{AC} + \overline{AD}}{(\overline{ab} + \overline{ac} + \overline{ad})}$ which represents in this instance: $\frac{28{\cdot}50}{0{\cdot}01729} = 1648{\cdot}35$ feet.

The elevation of point 15 is arrived at by multiplying the tangent of the angle made by the optical axis when directed down to the target fixed at 0·3 above the zero on the rod, with a truly horizontal line, viz.: (0·50352—0·49925 = 0·00427) by the distance 1648·35. This gives us 7·03845 which number plus 0·3 viz.: 7· 33845 ft. must be deducted from the collimation to obtain the elevation: 3·71216 ft. of the zero point of the rod at survey point No. 15.

When the point of which we desire to establish the position and elevation is one of only secondary importance, such as for instance No. 16, it is sufficient to make two scale readings, viz.: (*d*) = 0·50146 and (*a*) = 0·49518, when the relation: $R = \frac{\overline{AD}}{\overline{ad}} = \frac{12{\cdot}54}{{\cdot}00628}$ gives us the distance: $R = 1996{\cdot}81$.

In this case the elevation of the zero point is equal to:
11·05050—[(0·50146—0·49925 = 0·00221) × (1996·81) = 4·41295]—0·3 = 6.33755 ft., the whole of which is worked out in detail in column 8, where the figures can be easily turned to for verification, if found necessary.

So far, no correction for curvature and refraction was applied, it being assumed that the elevations arrived at proved sufficiently accurate for all purposes.

When, however, we desire to determine correctly the elevation of a water surface, such as that of the brook at point 17, or the height of some other important point from a station on the continuous double line of levels, it becomes necessary to take the effects of the earth's curvature and the refraction of the atmosphere, into consideration, and to apply corrections accordingly.

The readings A and B on rod **F** at point 17 easily give us the distance between station 50 and point 17, which is equal to $100\ (B-A)+0{\cdot}4=590{\cdot}5$; also the uncorrected elevation of the zero which is found to be equal to:

$$11{\cdot}05061 - \frac{(6{\cdot}912+6{\cdot}906)}{2} = 4.14161$$

where as already shown, 6·912 and 6·906 represent the rod readings in the erect and inverted positions of the telescope and the direct and reversed positions of the level, viz.: when the line of sight is very nearly horizontal in each case.

As detailed in column 8—the mean length of the back sights whence collimation 11·0505 was deduced is equal to 939·60 feet—and the corresponding correction required to determine the effects of curvature and refraction is 0·01855 while the correction needed in the case of the foresight of 590 feet is only 0·00731, the diffirence to be applied to the 0 being thus 0·01124, which when deducted from the uncorrected elevation 4·14161 gives: 4·13037 for the correct elevation of the zero of rod **F**. Finally, in order to arrive at the elevation of the water surface, we have further to subtract from 4·13037 the height of the 0 above the water. This height is equal to 0·25 foot, the height of the index or 0 of the pointer scale, (which is at the same level as the zero of the rod) above the underside of the ball support—plus the reading 0·114 foot afforded by the index of the said scale, when the point touches the water—or in all 0·364 foot. A small table of corrections required for curvature and refraction at every 100 feet, up to say 1200 feet or more, printed in each field book, will prove very convenient in this connection, for use in the office or on the ground.

Now, if we had decided to follow for the fore and back sights the still more accurate, although somewhat longer method of determining the elevations above referred to, which consists in measuring with the aid of the micrometer screw and vertical scale the distance i between the apparent intersection of the horizontal wire, (or line engraved on the field glass of the eye piece) with the rod scale and the next lowest whole hundredth foot division, instead of estimating the said interval with the eye—we would have to take four micrometer readings, in addition to the rod readings, as shown in the case of the back sight from station 49 to point 8, and compute the thousandths, and ten and hundred-thousandths to be added to the feet, tenths and hundredths entered in column 2, page 47 of tacheometer book. The first micrometer reading (28·0) entered in column 2, page 47, shows the position of the micrometer drum, with the telescope in the erect and the double faced level in the direct position with bubble in centre of glass tube. The second reading (31·0) indicates the position of the micrometer head for a pointing made with the telescope and level in the same relative positions on the whole hundredth of a foot next below the horizontal sight first taken. The third reading (17·2) shows the position of the micrometer head for a pointing made to the same whole hundredth division with the telescope inverted, and the level reversed and the fourth reading (22·0) shows the position of the micrometer head with the telescope inverted and the level reversed.

The micrometer reading corresponding to the mean horizontal pointing is, in the case under consideration, equal to: $\frac{28{\cdot}0+22{\cdot}0}{2} = 25,$

and the mean micrometer reading corresponding to the pointing on the next lowest whole hundredth division to: $\frac{31{\cdot}0 + 17{\cdot}2}{2} = 24{\cdot}1$.

Hence, considering: 1st. That, as already explained, the pitch of the micrometer screw is such that by turning its head right or left over one division the prismatic guide rod with knife support is moved up or down through a space equal to the $\frac{1}{100.000}$ part of the radius $r = 1$, of a circle drawn from a point on the axis of rotation of the telescope as a centre in a plane perpendicular to the said axis so as to be tangent to the plane followed by the knife edge. 2nd. That the interval intercepted on the vertical scale by any two lines of sight bears to the interval intercepted on the rod between the same lines, the ratio of ($r = 1$), to R—the horizontal distance from the said axis of rotation to the rod—we have in the present case for the interval i between the intersection of the truly horizontal line of sight with the rod and the hundredth division at 9·15 pointed to from station 49:

$$i = \frac{(25 - 24{\cdot}1 = 0{\cdot}9) \times R}{100{\cdot}000} = \frac{0{\cdot}9 \times 605{\cdot}24}{100{\cdot}000} = 0{\cdot}005447.$$

This space i when added to 9·15 gives for the precise reading of the back sight from station 49 to point No. 8: 9·155447 feet, in place of 9·158 feet the mean of the two heights estimated by the eye, and for the precise collimation from station 49 of series of levels B: 12·264477 feet instead of 12·26763 feet.

It would be interesting to know how a line of levels A 25 miles long or more, run entirely according to the method just described, would compare with a line B run simultaneously with the rod intervals i all estimated by the eye. It is my intention to establish such a comparison at the first opportunity that will present itself.

In the case of a single rodded line of precision levels, it is advisable, although not indispensable, not to remove the tacheometer from a station until the recorder has entered three distinct rod intervals in column 4, and satisfied himself, by comparing them rapidly with each other or with their sum or with their mean, that no material error has been committed; the remaining entries in columns 4 and 5 can be made in the office. When, however, the line of precise levels is double rodded, such as that indicated in the typical pages of field notes given above, this verification of readings on the spot can be made in a more simple manner and the field work correspondingly expedited, viz.: by comparing the difference between the two back sight readings taken from the station occupied with the difference between the two corresponding foresight readings taken from the previous station. For instance, before leaving station 50 we would compare the difference between the back sight readings to points 11 and 10, or 10·612 − 3·657 = 6·955 feet with the difference: 11·830 — 4·876 = 6·954 feet, between the corresponding foresight readings taken on the same points from station 49, and finding the two to agree within 0·001 foot, would conclude that all the operations have been correctly performed.

Furthermore, when such a double rodded line of levels is run exclusively with a view of establishing permanent bench marks and determining the precise elevations of the same in reference to the mean sea level or some other datum plane, together with perhaps some important water or railway levels in a part of the country of which the topography is well known and correctly indicated on existing maps, and where therefore, accurate measurements of distances and angles with the tacheometer for locating the line or for any other similar purpose, would be superfluous, the ordinary run of field operations required from any of the tacheometer stations—such as Nos. 49 and 50 of the supposed operations recorded above on sample pages 46 to 49 of the proposed field book—can be limited to those entered on sample double field book pages 5 and 6 to be found in the pocket which accompanies this Memo. On these two double pages, the observations, entries and computations which have to be made on the ground are, as heretofore, indicated in black, they are moreover numbered in blue in the order in which they should be taken, the office work required also is shown, viz. in red, and the mental calculations in green, as before.

From the indications given on sample double pages 5 and 6 in accompanying pocket just referred to, it will be seen that the rod readings from each station, sixteen in number, are to be taken in the following manner; however being invariably supposed to be abutted against that particular pin of the series a, b, c, d, which permits of the greatest number of standard readings determined by these pins being made without changing the position of the clamp on the prismatic guide rod, according to the directions given above to that effect, viz. :—

(*a*) *With the telescope in the erect position—milled head of the slide pinion on top—and the attached double faced level in the direct position, or on the right hand side looking towards the objective :—*

(1) A level foresight pointing (1,686). See Ill. numbered 5-B, in pocket together with an adjacent distance reading (11·310) on the rod furthest ahead of the station occupied (50).

(2) A level backsight pointing (10·617) and a distance reading (0·850) on the furthest rod in the rear.

(3) A level foresight pointing (8·534) and a distance reading (12·827) on the nearest rod ahead.

(4) A level backsight pointing (3·663) together with a distance reading (8·181) on the nearest rod in the rear of the tacheometer station.

(*b*) *With the the telescope in the inverted position—milled head of the rack pinion which works the slide underneath the tube—and the attached chambered level in the reverse position, or on the left hand side :—*

(5) A level foresight pointing (8·531) together with an adjacent distance reading (12·827) on the nearest rod ahead.

(6) A level backsight pointing (3·657) and a distance reading (12·687) on the nearest rod in the rear.

(7) A level foresight pointing (1·683) and a distance reading (11·307) on the furthest rod ahead.

(8) A level backsight pointing (10·612) and a distance reading (5·730) on the furthest rod in the rear of the station occupied.

Here all the pointings are checked simply by repeating them and the same may be said of some of the distance readings. But all such repetitions are made at sufficiently long intervals of time, to become virtually fresh determinations of practically the same elevations and corresponding rod spaces, for, under ordinary circumstances neither the diaphragm nor the level of the telescope is ever sensibly disturbed during the short time spent between two consecutive stations. Besides, by comparing the difference (6·955) in the elevation between the two backsight level readings taken from any station (50), with the difference (6·954) which obtained between the two corresponding level foresight readings from the preceding station (49) as proposed, we cannot fail to detect at once any notable change in the discrepancy in readings caused by a defective collimation or an imperfectly adjusted telescope level, and hence can make a proper allowance for the same, or proceed to rectify the adjustment on the spot as may be found most desirable.

The method of carrying on geodetic levelling operations with the "Sanguet Tacheometer" and the new rod just described, will prove much more expeditious than that generally followed by the United States Coast and Geodetic Survey with the geodesic pivot level and their rod with chain target and the similar method adhered to by me for some fifteen years past, in the running lines of precision levels along the Richelieu, the St. Lawrence, &c. With the new method, the number of entries to be made in the field book becomes reduced by about one-half and nearly all the ordinary, somewhat bulky, computations are dispensed with, without the precision and reliability claimed for the present geodesic methods being in any way lessened. I believe, on the contrary, that more precise results are likely to be secured and at less expense.

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