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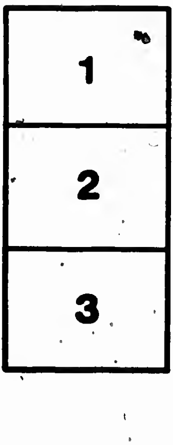

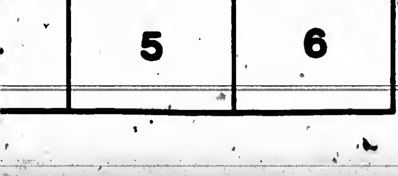

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THE ERRORS OF LEVELS AND LEVELLING

Part I.—On the Defects of Levels.

By Prof. C. H. McLeod, Ma. E., M. Can. Soc. C.E.

To be read on Thursday, 6th November.

As is well known levels are manufactured from glass tubes by grinding the inner surface of the tube with emery powder placed on an arbor rotating in a lathe, the arbor having been previously turned from a turn-plate to the desired curvature. The tube should be slowly turned about its axis, so as to present the whole of its inner surface to the arbor, giving when the grinding is completed a similar internal section for all planes through the axis of the cylinder. The surface intended to be uppermost should then be brought to the highest possible degree of polish. This completed, the ends are temporarily plugged and the tube filled with liquid. The level is then tested on a trier, and if the curvature proves to be uniform the ends are hermetically sealed and the centre line of the upper surface graduated in equally distant divisions.

The levels used on the ordinary engineering instruments can be made with sufficient accuracy by this method. In the practice of one of the best American makers, all levels of less delicacy than 5" per division of 2 mm. are machine made, in this manner. For levels having a scale value of from 1" to 5", such as are used for astronomical and geodetic instruments, it is necessary to apply local corrections after the level is first roughed out on the machine. As the level must be tested after every correction, this is a very tedious as well as most delicate operation, and indeed not infrequently ends in failure. It is very important that the upper interior surface should have the highest possible polish, and be entirely free from grains of emery or other foreign particles. The glass employed should be of the hardest and least hygroscopic kind, in order to avoid any deterioration of the accuracy of the level through chemical action on the glass by the liquid filling. The tube should be of uniform bore and thickness. The liquid most commonly employed for engineering levels is alcohol. A certain percentage of ether is sometimes added to the alcohol, in order to obtain greater fluidity and therefore increased sensitiveness in the level. Ether of naphtha is also sometimes used for instruments of this class. For the highest class of levels the filling liquid generally employed is sulphuric ether, with sometimes a small percentage of chloroform.

Too little attention is paid to the mounting of bubbles. The usual method of enclosing the glasses rigidly in a metal tube [illegible] give rise to such serious changes of form in the level as to render [illegible]y unreliable. Some examples of change of form due to the m[illegible]ill be given hereafter. Levels for "precise" work of all kinds should be connected with the frame at only two points, and should then rest on some yielding material such as cork or sheet lead, and be held in place by light strips of metal. The more delicate levels having a scale value of 3" or under require protection from air-currents or from rapid changes of temperature, due to radiation from surrounding objects, and should be enclosed in a glass tube. The ends of such levels are chambered—that is, there is a diaphragm cutting off from ½ to 1 inch of the end of the tube, the diaphragm having a small hole in it—to admit of adjusting the bubble to a standard length under varying temperature.

Having thus briefly reviewed the construction of levels we are brought to the object I have in view,—a consideration of some of the defects to which levels are subject.

Irregular Curvature.—This gives rise to a shift in the zero position of the bubble with each change in the temperature of the liquid, since the bubble shortens or lengthens more towards one end than the other as the liquid expands or contracts. An engineer's level having this defect will, when placed in adjustment at any one temperature, not be in adjustment for any other temperature. Where the level is used to measure angular values, as, for example, the inclination of the axis of an astronomical transit, it is obvious that the result will depend on the position of the bubble on the scale. Irregularity of curvature is unfortunately a common defect in engineering levels, and to it are no doubt due many of the discrepancies so often met with in levelling. Where the range in the scale value is not great, such an instrument may, with proper precautions, be used on engineering work, but would be quite inadmissible for astronomical purposes where the scale value is the important factor.

A level which was made for McGill College some years ago, to be used as a striding level for a transit-theodolite, has a scale value running somewhat as follows, from end to end:—12", 37", 34", 22", 20", 3", with a portion of the ends flat or of reversed curvature. This instrument is of course worthless. When I add the fact that its maker has made and can make good levels, you will agree that every level, no matter what may be the reputation of the maker, should be subject to most careful test before being put into use.

Difference of sectional area of the ends of the tube also gives rise to a shift in the zero, since for a given change of temperature the air space at one end will be altered in length to a greater or less extent, according as it is towards the smaller or larger end of the tube. Where the grinding tool has been carefully applied around the whole circumference and the tube is of fairly uniform diameter, the condition of equality in the two ends is most perfectly fulfilled.

Roughness of the upper interior surface, arising from imperfect polish or from small particles of emery adhering to the glass, will give results which at first sight closely resemble those arising from irregular curvature. The bubble is held back by the rough particles, while the level is turned through a considerable angle, thus giving the appearance of increased scale value, and when the bubble finally breaks away, it moves through several divisions of the scale as if the curvature at that point were very much flattened out. A level, which was recently sent to me for examination, gave a reasonably uniform scale value for long runs, but when it was examined more closely showed great irregularity. Two points were found on the tube, at which the tests showed there must be some obstruction. In fact, the bubble held in one position through a change of inclination of 6". Examination with a magnifying glass revealed very minute particles of emery embedded in the glass at each of the points. After these were removed the level was found to be of very uniform scale value and sensitive at all points. Such a defect in an engineering level would render good work impossible, and would, in addition, be very annoying to the observer, inasmuch as it would be difficult to keep the bubble in the centre, unless indeed the obstruction happened to be at one end of the bubble when in its central position. The common defect of sluggishness and uncertainty in the position of rest is no doubt largely due to a rough surface, though doubtless also to some extent arising from the character of the liquid filling. When there is such roughness of surface the position of rest of the bubble is noticeably affected by the velocity with which it moves. When the position of the level is quickly altered the bubble over shoots its mark and is held beyond the proper resting place. When, on the other hand, the level is very slowly moved, the bubble will not quite reach its true position of rest. In these cases a slight tap on the glass will usually suffice to bring the bubble to its true position. Up to a few years ago all the levels I had met of the manufacture of a certain well known London maker had this defect. The level of the telescope of one of the 5" transit instruments in McGill College, the scale value of which is 25", may be made to take up a position in this way, anywhere within a range of 7", or up to a maximum of 3".5 from its true position.

Levels are subject to change of form, either from a change in the glass itself or from the pressure due to change of form of the mounting, under the influence of temperature or otherwise. The latter may be guarded against by a proper form of mounting. The former, whether from permanent structural changes in the glass or from temporary changes under varying temperature, can only be met by an investigation of each individual level. If there be a permanent change of form there is of course liability to an irregular change of curvature, rendering the instrument worthless as an instrument of precision. The only example of this kind of change which has come under my notice is an excellent level made by one of the best American makers. It is described by the maker as made from the best kind of Bohemian glass. It is needless to state that the possibility of any change of form is stoutly denied by the makers. Here, however, is the evidence in the case:—

Purchased in April, 1883, and forwarded by the maker to Prof. W. A. Rogers, then of Harvard College Observatory, for examination and determination of the scale value. The level was placed in wyes attached to the cube of the meridian circle of Harvard College Observatory, and adjusted so as to be parallel to the optical axis of the telescope. The scale values were read off on the circles in a series of seventeen separate determinations, extending from April 6th to April 25th. The resulting mean value of one division was 2″.19 0.02.

The level was then forwarded to Montreal, and has been in continuous use as a striding level for an astronomical transit up to date. It has received three severe jars, falling from the transit instrument to the floor,—first in June, 1883, the second in   and the third in   On April 1 and 2, 1884, the scale value was determined on a level trier in the workshops of Messrs. Hearn & Harrison, and gave a mean value from three sets of sixteen determinations each, of 2″.10 with an inappreciable probable error. The value of one revolution of the screw on this trier was measured by comparison with an Elliot Bros.   gauge, which was itself verified by comparison with a standard bar by Professor Rogers.

During the years 1889 and 1890 several determinations at different times and under various conditions have been made on a level trier in McGill College, the screw of which has been compared with the gauge above referred to; the results of these comparisons are given with table below:—

Date	Temperature of the air	Length of Bubble	Resulting Scale value.
1889			
Jan. 30th	47	51 mm	2″.63
May 16th	62	37 mm	2″.48
July 15th	69.5	35 mm.	2″.56
July 15th	69.5	54 mm	2″.58
		Average value in 1889	2″.56
1890			
Feb 22	75°	51 mm.	2″.56
March 6th	45	39 mm.	2″.60
Sep. 20th	65	43 mm	2″.54
		Average value in 1890	2″.56

In order to discover if the change in form was in any way due to straining by the frame, the glass tube was removed from its frame and binding screws immediately after the test on Sept. 20th last, and in one hour was again examined and gave the same result. There has undoubtedly been a decided change of form in the glass, and that as was to be expected from the method of mounting without external strain. Fortunately there is no evidence of serious change in the uniformity of the curvature. The final form which the glass now seems to have attained may have been reached several years ago, but certainly not within three years after it had left the hands of the maker. These results would point to the desirability of the finished levels being kept in stock for one or more years by the makers, in order to give time for any change of form to reveal itself. Such inquiry as I have been able to make has failed to discover a maker who adopts this precaution. It is well known that a similar trouble has arisen in the case of the glass used for thermometers, but here the makers recognise the need of seasoning the glass before the thermometer is graduated and put on the market.

An examination of the table given above will also show a slight change of scale value, due to temperature. Although small, amounting only to about 0″.0015 per degree Fah., it is of quite sufficient importance to take into account in a longitude determination, amounting as it does to about one-tenth of a second of arc for our average range of mean temperature in the year.

I am unable to offer any observations of my own in illustration of temporary changes of great extent in a level—unstrained by its mounting; but that there are such, and very serious ones, rendering the instrument quite unfit for delicate measurements, the following extract from a paper read at the Montreal meeting of the American Association for the advancement of Science, by Prof. W. A. Rogers, will show:—"In "order to show the necessity for repeated and continuous observations "for the determination of the value of one division of the level, I record "here my experience with the companion level of the instrument known "as the Russian transit (H. C. Observatory). It was made in the "workshop of the Pulkowa Observatory.

"I began the observations about 8 o'clock in the morning of Nov. 13, "by comparing the readings of the circle with bubble first at the mid "dle of the tube and then at the extreme end. Proceeding in this way "with each five divisions in succession, I was surprised to find, not only "a continued diminution of the value of one division, but a well-defined "shifting of the zero of the level. By noon I had nearly completed the "examination for the first half of the divisions. I then opened the "shutters for an observation of the sun. After an interval of ten "minutes, observations with the level were resumed, when it was found "that the value of one division, determined from the same space as "before, had increased by one-fourth of its mean value. It will be "sufficient to give in illustration the results of the observations on three "days.

Nov. 13. Nov. 14.
"Shutters closed 1 div = 1.76" Th. = 38° 1 div = 1.20" Th. = 40°
Nov. 15.
1 div = 2.06" Th. = 47°
Nov. 13. Nov. 14.
"Shutters open 1 div = 2.08" Th. = 65° 1 div = 2.06" Th. = 70°
Nov. 15.
1 div = 1.78" Th. = 36°"

Subsequent observations made under different conditions confirmed these results. Professor Rogers adds.—"It is hardly necessary to say "that this level has been discarded as worthless. On the other hand, "the mounted level furnished with the Russian transit proves to be an "excellent one."

Here, then, are two levels made in the same workshop,—the one proving to be a good instrument, the other totally unreliable. A difference in the quality of the glass is the cause to which one would naturally refer this discrepancy, and this suggests an investigation of the permanence of form of the different kinds of glass, one which, so far as I am aware, has not yet been undertaken. The peculiar behavior of this level, under the conditions of the test improvised, emphasizes the necessity of shading levels from the direct heat rays of the sun, a practice which is always insisted on in geodetic levelling, and which with little trouble might be adopted for the more important lines of levels in railway or canal work. A shade over the level is also important on account of the errors in reading the bubble, arising from the sun's rays falling obliquely upon it, giving a different illumination to the opposite ends.

Examples of change in the form of [illegible] due to the varying strain in the mounting are only too abundant. In two Dumpy levels, on which the glass tube is held in a brass case and plaster of Paris, the scale values were determined as follows:—In one 21."5 at 66° Fah. and 17."1 at 20° Fah., and in the other 26."7 at 67° Fah. and 24."0 at 20° Fah., giving respectively changes of 1" for each 10° and 17° of temperature. The mere change of scale value is not the important point in such levels, but the associated circumstance of which there can scarcely be a doubt that a change in the zero of the level takes place with each change of scale value, putting the instrument which may have been placed in adjustment at a given temperature out of adjustment for any other temperature.

Since the introduction of ether as a filling fluid in levels, it has been found that in some level tubes so filled a deposit has occurred on the surface of the glass, and the accuracy of the instrument in consequence either greatly impaired or destroyed. The rough particles hold the air bubble and prevent that freedom of motion so essential in a good level. Dr. F. Mylius has shown that these deposits occur through the action of the small quantity of water remaining in the ether on the potash or soda in the glass. It is a matter of very great difficulty to fill a level tube with perfectly dry ether. Dr. Mylius used rosin as a re-agent in his investigation since it imparts a yellowish colour to ether but imparts a bright red colour to water.

By adding some rosin to a tube filled with ether at the ordinary temperature of a room, and then lowering the temperature of the tube and the liquid considerably, small globules of water were found to be separated from the ether and to deposit themselves on the walls of the tube, becoming visible by reason of the bright red colour caused by the rosin.

He demonstrated also that these small particles of water retaining their places very shortly became saturated with potash or soda from the glass, and that after the lapse of a few weeks small particles of potas sium or sodium appeared within the drops. Where an acid is present in the filling material, as is usually the case, the deposit will take place in a crystalline form. Dr. Mylius and others have found that these deposits are more likely to occur in glass rich in alkalies, while in those having a large proportion of lead they are less likely to occur. The harder the glass the less likelihood is there of the deposits occurring. Also that they are more likely to occur where the surface is rough than where it is highly polished. To demonstrate this he roughened a delicate level tube previously uninjured, and found after the lapse of some weeks deposits occurring on the roughened surfaces.

Where such substances as alcohol and water are used for the filling material, the formation of crystals is prevented since the alkalies extracted from the glass will go into solution. Alcohol is, however, not sufficiently mobile for delicate levels. Experiments on the use of other fluid substances, such as benzoline, petroleum and chloroform have been made, but in them also the deposit of water occurs. The solution of the difficulty seems to lie in a proper selection of the glass. Flint glass having a large proportion of lead is not suitable owing to its softness and liability to alter its form. The choice of glass would seem to lie between Bohemian glass containing chalk, thermometer glass containing zinc, and crystal glass containing lead.

When we consider the many defects to which a level is subject, it becomes obvious that it is an instrument which, while it is capable of yielding results of the highest accuracy, is also one to be used with great precaution. In fact, it can only be considered an instrument of precision when subjected to careful examination and test during the period covered by the observation in which it is being employed, and under conditions similar to those in which it is being used.