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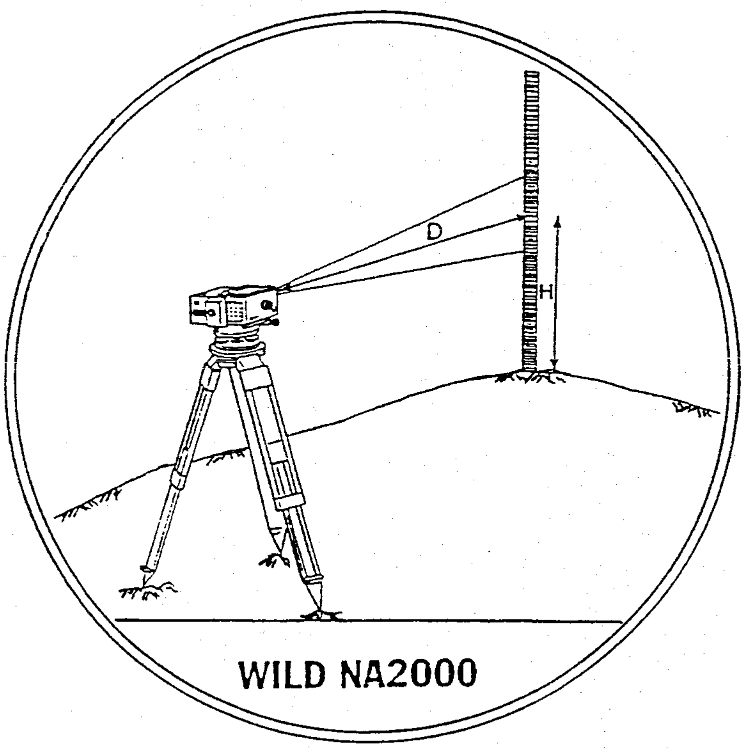
EVALUATION OF NA2000

A NEW DIGITAL LEVEL

by
Jean-Marie Becker
Bengt Andersson



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EVALUATION OF NA2000 - A NEW DIGITAL LEVEL

by Jean-Marie Becker and Bengt Andersson

Huvudinnehåll

The Wild NA2000 from Leica is a digital levelling instrument - the first of its kind. NA2000 measures height difference and distance automatically by using special bar coded levelling staffs. This report contains a short description of the system.

In addition, the results of function and production tests carried out by The National Land Survey (NLS), are given and some suggestions for the improvement of the NA2000 system are presented.

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1. INTRODUCTION

1.1 Historical review

Attempts to automise and make the levelling process more efficient have been going on for a considerable time through both method and instrument development.

Advancement concerning equipment does not occur everyday, especially with regard to instruments themselves. It is, therefore, particularly interesting to be able to present something new in this report: the Wild NA2000 system from LEICA, which is an automatic electronic levelling system consisting of a self-levelling, electronically recording instrument and coded levelling staffs. (6, 9, 10, 12)

With this instrument we have almost reached full automation, something we have striven to achieve for many years, i.e. the work done by the operator is limited to the "push of a button" after setting up, making level and sighting. Taking readings, recording, calculating as well as displaying results is done automatically.

Important milestones, in the past, marking the development of instruments can be summarised as follows;

* 1951: Ni2 from Zeiss Oberkochen, the first so called selflevelling instrument (which worked well), with a pendulum instead of a spirit level, which simplified work and increased production.

* 1972: Ni002 from Zeiss Jena, the first self-levelling pendulum instrument having a quasiabsolute horizon (two symmetrical pendulum positions) as well as rotating eyepiece and the crosshair placed in the objective. The instrument made possible the now familiar motorization of the levelling procedure thanks to its technical features. (2)

* 1987: RENI 002 from Zeiss Jena , the first instrument to have electronic micrometer reading and an integrated data collector for data recording and computing. This marked a half way stage in the process of automation. (3)

Other attempts with, amongst other things, "digital levelling staffs" which record automatically the "impact" of the instruments laser beam on the staffs, have been made in Germany by, amongst others, Schlemmer, Caspary and Heister. (13)

In Sweden too, praiseworthy efforts were made which resulted in AGAs Geoplane, with its rotating laser beam which could be registered by a detector that slid along the levelling staff.

Other attempts that have been made were with "electronic tachymeters", either in classical on foot levelling (FL) or the motorized levelling (ML) technique. (2, 3, 4, 7)

Furthermore, since 1983 an international project, R.P.L.S. (Rapid Precision Levelling System) has been running where amongst others the USA, Canada and Finland are working towards total automation of the entire levelling process. Results to date are of the same standard as Sweden (The National Land Survey) has achieved using Motorized Trigonometric Levelling techniques (MTL).

1.2 The aim of the study

Within the National Land Survey of Sweden there is a great deal of knowledge and experience concerning geodetic surveying methods especially within the area of levelling where we have actively contributed to the development.

The National Land Survey, by tradition, carries out extensive surveying work and for this purpose needs suitable techniques and equipment. In order to run the work as efficiently and rationally as possible, the National Land Survey makes continual studies and carries out tests of new equipment and techniques and also provides advice and instructions.

This report, describing the evaluation of LEICA WILDs new levelling system NA2000, is a concrete example of how this work is done in practice. The following are dealt with below:

- description of the NA2000 system
- function tests
- production tests
- compilation and comparison of results
- conclusions and suggestions

2. DESCRIPTION OF THE NA2000 LEVELLING SYSTEM

The NA2000 is the first digital levelling system to have an almost completely automated measuring procedure. The system includes a levelling instrument as well as specially adapted staffs.

2.1 Levelling instrument

The NA2000 has the same mechanical and optical components as a classical levelling instrument (e.g. Wild NA2), but differs in that the human eye has been replaced by 256 photodiodes (for infra-red light). The photodiodes capture the bar code image of the staff and convert this image to a digital signal which is then compared with a stored reference signal of the staff image.
Because the angle of view in the instruments optical system is only 2 degrees, the sensor deals with a section of only 7,0 cm of the staffs bar code graduation at the minimum sighting distance of 1,8 m. At a sighting distance of 100 m the corresponding section on the staff is approximately 3,5 m (see fig 1). The NA2000 also gives the distance to the staff, which is computed with the help of positional changes of the focussing lens (approximate distance).

The NA2000 can also be used as a classical levelling instrument.

All readings can be taken electronically and are stored automatically in an internal recording module (REC module) for processing or transfer to a computer. Additional information (point numbers, codes etc) can be entered via the control panel. Work progress and results can be easily followed on the display.

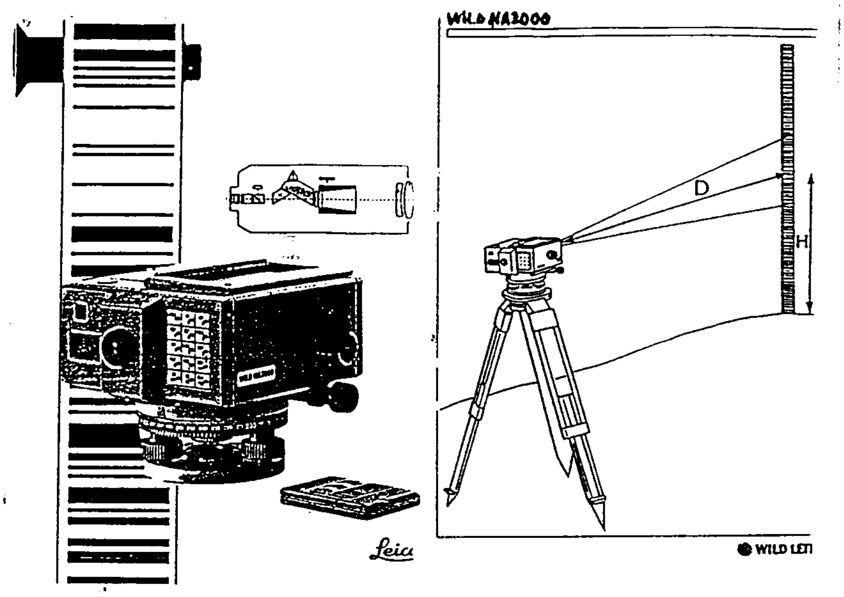

Figure 1

2.2 Levelling staffs

Special levelling staffs have been developed for the NA2000. These so called "standard staffs" are extremely light (5 kg incl. carrying case) and consist of three 1,35 m long sections which are put together as required giving staff lengths of 1,35 m, 2,70 m or 4,05 m. On one side of the staffs there is a special graduation with binary bar codes (2000 lines for a staff length of 4,05 meters alternatively black and white). On the other side is a normal graduation for optical readings in connection with classical levelling. Both types of graduation start at the base of the staff.

The coefficient of expansion is large, just under 10 ppm / degree Celcius (°C).
For precise levelling, prototype invar rods of 3 meters length and with the same type of bar codes are available. The graduation does not, in this case, start from "the zero point" but approximately 30 cm up from the bottom of the staff.

2.3 Surveying procedure

- set up the instrument and make level (manually)
- switch on the instrument and select program (manually)
- sight the levelling staff and focus (manually)
- press the red button whereupon the sensor is activated (manually)

Then follows the automatic so called electronic part of the measuring procedure.

- compensator position and positioning of focussing lens
- approximate determination of sight height and image scale
- precise determination of position and code scale on the sensor and, with the help of calibration constants, computation of a definite staff reading and sight distance
- processing and presentation of the result on the display in accordance with the selected program etc.

The entire automatic process takes only 3-4 seconds, depending on prevailing light and visibility conditions.

The digital evaluation of the staffs bar code image compared to the reference image stored in the instrument uses the method of correlates and with two parameters: height and scale. For a more detailed explanation of how this digital process is carried out, please refer to Wilds publications, H. Ingensand (9, 10)

A number of resident programs are available offering menu driven survey procedures, for example:

- Measure only: for single point measurement (distance and height)
- Start levelling: for starting line levelling
- Continue levelling: continues line levelling with simultaneous computation of the heights of intermediate points (bench mark ties to the starting point)
- Check and adjust: for checking and adjusting the instruments collimation error
- Data erase: clears the REC module
- SET: for setting instrument parameters

3. TESTS CARRIED OUT BY THE NATIONAL LAND SURVEY (1, 8, 11)

During autumn 1990 the Geodetic Department of the National Land Survey carried out a number of function and production tests with the aim of:

- getting to know this new instrument
- testing it in normal and precise levelling work
- assessing its possibilities, advantages and disadvantages
- making recommendations

The tests were carried out during a period of three weeks in late autumn 1990 in Gävle and Hofors. Various test sights were used representative of the type of working conditions and terrain types found in Sweden in connection with levelling work. The equipment was tested by using both on foot and motorized levelling technique. Reference heights had been determined by using Ni002 from Zeiss Jena and through repeated precise levelling.

3.1 FUNCTION TESTS

These tests were carried out during one week in Gävle on a short test track at Alderholmen. In total, three NA2000 were tested (no 85790, 85384 and 85636), two of which were always used at the same time, although with different operators, and under the same conditions. Reference heights were levelled each day using Ni002 from Carl Zeiss Jena. In total, 22 tests were carried out as follows:

3.1.1 Determination of collimation error

Repeated determination was done with all three instruments according to Wilds instructions.

The purpose was to check repeatibility (precision), accuracy and stability over time (representativity) of the "Check and Adjust" function. A measuring and computing program for determining the collimation error is inbuilt in the instrument. The program does not take into account the effect of earth curvature and refraction (corr. = 0,0000673 x S^2 mm, where S = sight distance in meters).

The manual recommends distances of 15 and 30 m. At these distances, the error in the calculated angle due to earth curvature is 0,57" and at distances of 20 and 40 m the error is 0,85". This is equivalent to an error of 0,13 and 0,20 mm respectively for a sight distance of 50 m. As the instrument gives results (readings) to 0,1 mm, the effect of earth curvature cannot be completely ignored.

We observed rapid variations over very short periods of time especially at the start when the instrument came from indoors or from a car where the temperature varied considerably. Variations during the course of a day or from day to day were not as great.

Determining the collimation error repeatedly for half an hour gave a distribution of 3,4" and a mean error in one observation of 1,13". During the entire testing period, about 20 double determinations of the collimation error were carried out immediately after each other. Differences varied between 0" and 3,5" with one exception where it was 7"! Using instruments not adjusted to surrounding air temperature, the difference could be as much as 10,1" in only 5 minutes!

Comments: The collimation error that is determined at the start of a day, and which then is used to automatically correct all measurements, is not representative and, in addition, falsifies the day's measurements. The rapid changes indicated can mean a height error of up to 0,2 mm if the backsights and foresights vary by 10 m. This is not satisfactory.

Conclusion: Either something must be done about the instrument (increased stability) or the collimation error will have to be determined several times during a day and weighted corrections applied afterwards when computing. Errors due to earth curvature must be taken into account.

3.1.2 The effect of instrument levelling

The tests were carried out by setting the NA2000s circular level in 5 different ways. The instrument was tilted so that the bubble was shifted outside the middle circle and touched the edge of the casing. The following settings were used:

o-correct in the middle of the circle
a-to the right of the middle circle
b-to the left of the middle circle
c-in front of the middle circle
d-behind the middle circle

The measurements show, relatively speaking, larger errors in the readings taken when the instrument is tilting forwards or backwards. The degree of error varies between 0,3 and 0,5 mm for sight distances of up to 100 m. Incorrect levelling of the instrument in a sideways direction gives errors of half the size.

3.1.3 The effect of varying the focussing

The same height differences were determined using different focussing when sighting the staff: first a sharp setting, then less and less sharp and, finally, sharp again. This experiment was carried out for sight distances of 50 and 75 meters. The staffs were set up permanently with the help of supports during the test. The aim was to find out how important this setting is and what effect it has on accuracy.

The following table no 1 shows the result:

Sight distance:	50 m	75 m
Instr 85790, max error:	0,85 mm	1,25 mm
Instr 85636, max error:	1,20 mm	1,55 mm

3.1.4 The effect of light intensity

Surveying was stopped towards the evening as light intensity was not adequate for the NA2000 to differentiate between the black and white lines of the bar code. This occured - during the autumn - timewise about half an hour before the optical reading, using the NA2000 according to classical levelling, became impossible.

This limitation is not unimportant and can cause loss of production especially during spring and autumn or in densely shaded areas.

3.1.5 The effect of sunlight into the instrument

When the sun is low and the instrument is directed towards the sun, a "blind sector" of about 15 degrees on either side of the line of sight makes measuring impossible. By using a sunshade, this sector could be reduced although not eliminated completely. Measuring was made more difficult when strong sunlight shone into the instruments objective. In Sweden, the sun is often low over the horizon during spring and autumn and this will cause considerable problems when using NA2000.

3.1.6 The effect of staff illumination

Different degrees of illumination or zones on the staff can make measuring more difficult especially if the contrasts are great, as previously mentioned. Even illumination of the whole staff gives the best results.

Comment: During the tests, both in connection with ordinary line levelling and precise levelling, situations occured where measuring was, quite simply, impossible due to shaded zones on the staffs caused by trees. This phenomenon occured daily whenever levelling lines followed roads with forest along the sides and when shadows from trees created line patterns on the staffs. NA2000 was unable to cope with this pattern of dark and light zones and we were forced to shade the whole staff image in order to take measurements. This reduced production capacity considerably.

3.1.7 The effect of background

In connection with sights where the staff appears against a light background (e.g. the sky) measuring problems occured (Error 51). NA2000 refused to measure. The same phenomenon was observed over and over again during the production test.

3.1.8 The effect of different sighting of the staffs

As NA2000 needs a section of the staffs bar codes to be visible, we wanted to see how important the sighting of the staff is: a) for the instruments ability to take measurements, and b) for the accuracy of the measurements. This test was carried out in two parts: first checking horizontal and then vertical sighting.

We found that the instruments "window" which vertically covers 2 degrees is exceptionally narrow horizontally. Measuring can only take place when the crosshair is directed at the staff and one must not go outside the graduation of the staff. Sights over 50 and 100 m and sighting the right and left and the middle part of the graduation produced no differences in results.

Comment: For one of the instruments, there was a slight sideways displacement of 1/4 of the width of the staff.

The "vertical" window has, as previously mentioned, an angle of view of 2 degrees. Our investigations showed that it is also possible to carry out measurements with sightings both above and below the staffs bar codes, that is to say also when the horizontal plane formed by the crosshair is outside the staff (up to 2 dm), yet in its vertical plane. (See fig. 2)

This experiment was done using both standard and invar staffs. During testing, 100 m long base lines with height differences of 2,52 m were used for the invar staffs and 3,64 m for standard staffs. Each set consisted of 10 observations of one height difference. The mean value was calculated for each set.

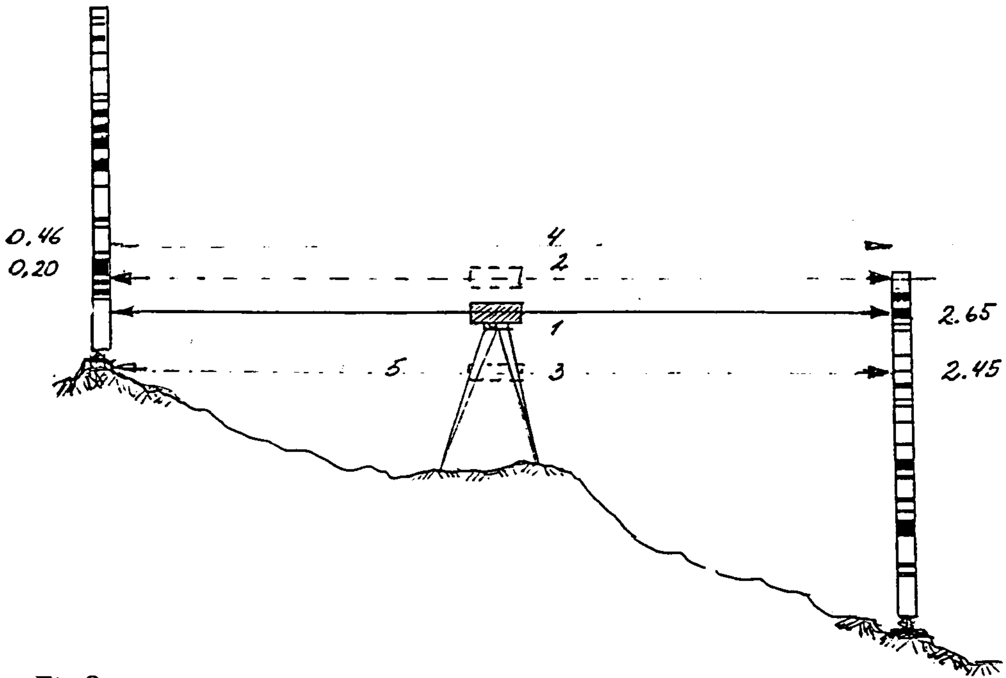

Fig.2

Table no 2 below shows the differences between these mean values and the known, correct height difference. The standard deviation for one observation is given in brackets.

Sighting Backsight	Foresight	Error in height difference Standard staffs	Invar staffs
2,65	below lowest mark	-	-0,18 mm (0,2)
above highest mark	0,20 m	-	-0,24 (0,3)
2,45	below lowest mark	-	0,45 (0,6)
above top of staff	0,46 m	0,45 mm (0,2)	
3,68	below bottom of staff	0,89 (0,3)	

First, we establish that the standard deviation is small which indicates high internal precision (repeatability) and, then, that there is an error in the height difference of up to 1mm per set which indicates low accuracy.

Conclusion: These tests show that one can easily be led to believe that the measurements are good when the instrument is functioning well (no error warning) and especially when the standard deviation is small. This will create problems when levelling is to take place in hilly terrain and the surveying team wishes to minimize the number of set-ups, despite equal distances for backsights and foresights.

These problems and errors cannot occur when using classical levelling instruments. It is, quite simply, impossible to measure.

3.1.9 The effect of staff orientation relative to the instrument

Measurements were taken with the staff rotated sideways to the left and to the right until no further measurement was possible. We found that the staff can be rotated sideways up to almost 80 degrees on both sides before NA2000 refuses to measure. The staff, however, must be vertical. Readings were not affected as long as the instrument was measuring.

3.1.10 The effect of staff inclination

This test was carried out by giving the staffs spirit level a wrong setting in the same way as the instruments spirit level in a previous test (3.1.2). The results show that when the staff leans so far that the bubble touches the outside edge of the level casing, a reading is given which is about 0,2 mm too great. When the staff leans less, no difference from the correct value can be detected.

3.1.11 The effect of staff movement

This test involved moving the staff fairly sharply in all directions, more or less quickly, but keeping its bubble within the spirit levels outside edge. No errors were found in the results. The only noticeable factor was that the instrument required more time to produce a result.

3.1.12 The effect of staff graduation error

NA2000, in contrast to classical levelling instruments, uses a section on the staff the size of which is dependent on the sight distance. Because the digital process makes use of all graduation marks within the visible section, the effect of individual graduation errors is considerably reduced the longer the sights are. For short distances (under 10m), the effect of errors is greatest.

3.1.13 Errors due to staff construction

The standard staffs consist of three separate elements (sections) which are fitted together. A check of how well this works was done and we noted errors due to incorrect fit of up to 0.5mm.

These errors are treated in the same way as other graduation errors in the computing process if they are within the visible staff section (window). If the visible section is completely within the second or third staff element, the height readings will be totally affected by any errors due to incorrect fit.

One can assume that errors due to incorrect fit of the staff elements will become greater due to wear and tear as well as age. If surveys are carried out in hilly terrain and with short sight lines, this is a source of error that ought to be given some consideration.

3.1.14 The effect of temperature variation

We wish to draw attention to the effect changes in temperature have, especially on the standard staffs. These have a coefficient of expansion of just under 10 ppm per degree Celsius, which is quite high.

The following table, no 3, shows the height errors which occur for various height differences when the temperature varies by 10, 20 and 30 degrees

Height differences in meters.	Height errors due to temperature variation of 0 degrees	10 degrees	20 degrees	30 degrees
1m	0 mm	0,1 mm	0,2 mm	0,3 mm
10 m	0 mm	1,0 mm	2,0 mm	3,0 mm
100 m	0 mm	10,0 mm	20,0 mm	30,0 mm

Surveys are carried out in Sweden in outside temperatures which lie between -10 and +30 degrees. During one day, variations of between 15-20 degrees can occur. Normally, staff calibration is done at 20 degrees. Height differences of around 10 m are very common in daily levelling work. Errors due to temperature variation can easily reach one or more mm if no corrections are applied. For this purpose, however, the temperature of the staff has to be measured and recorded.

3.1.15 The effect of sight distance on accuracy

All measurements were carried out with optimal focussing. The levelling was done using constant sight distances during each test: 30, 40, 50, 75 and 100 m. Backsights and foresights were of equal length so that possible collimation errors would be eliminated. The following table, no 4, shows the results when the values have been re-calculated to represent mean error for 1km of levelling.

Sight distance	Instr:85790	Instr:85636	Instr:85384	Mean value
30 m	0,3 mm	-	0,5 mm	0,4 mm
40 m	1,0 mm	-	0,8 mm	0,9 mm
50 m	1,4 mm	1,0 mm	0,9 mm	1,1 mm
75 m	1,2 mm	1,6 mm	0,9 mm	1,2 mm
100 m	4,0 mm	3,5 mm	8,6 mm	5,3 mm

We established a clear relation between accuracy and sight distance. Fig.3 makes clear the mean errors dependency on sight distance.

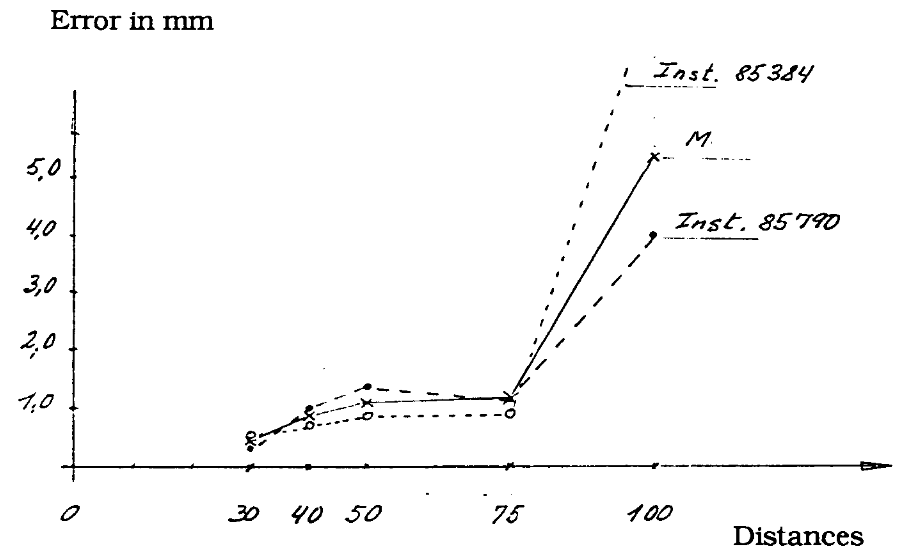

Fig. 3

3.1.16 The effect of an obstructed field of view

According to Wilds recommendations, at least 70% of the total visible section of the staff (a 2 degree window) should be unobstructed in order to carry out so called "sound" measurements. In the following tests, we have examined how different screening affects results.

In all these tests, the telescope "window" covered the bar coded part of the staff. The base used for the test was 80 m, sight distances were 40 m and the visible section of the staff was 1,44 m (100%) of which 1,00 m is equivalent to 70%. A series of 10 readings of the height difference were taken for each type of screening (see fig.4).

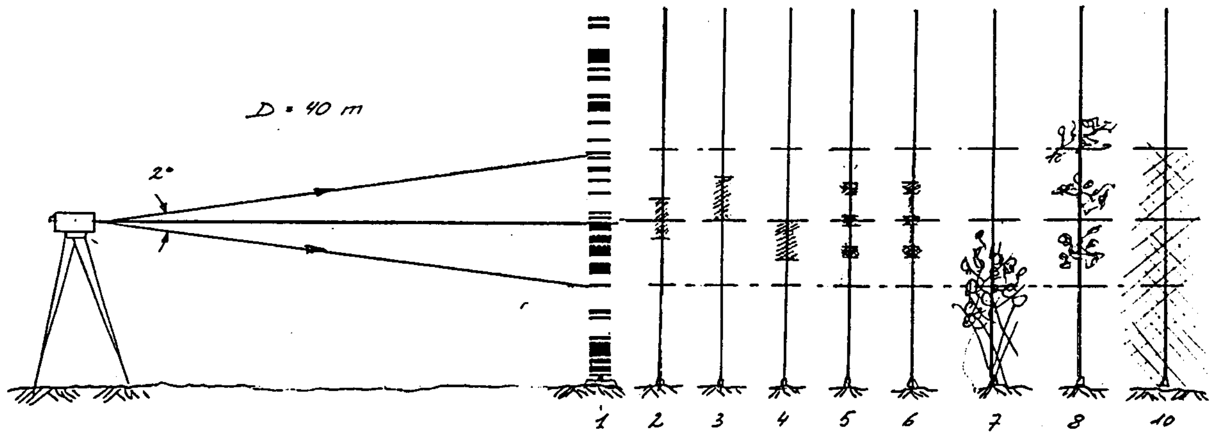

Fig. 4

The following table, no 5, shows the results: on the one hand, the height differences given by the mean values compared to those measured with Ni002 Zeiss Jena, and, on the other hand, the standard deviations for individual height differences.

The effect of different screening on the staff

Type of screening (%)	Instrument 85790 Standard deviation in one reading (mm)	Instrument 85790 Deviation from correct value (mm) I	Instrument 85384 Standard deviation in one reading (mm)	Instrument 85384 Deviation from correct value (mm) II	I-II (mm)
1. None (0%)	0,05	+0,09	0,07	+0,07	+0,02
2. 30% in the middle of the window	0,07	+0,17	0,05	-0,11	+0,28
3. 30% directly above the horizon	0,06	+0,21	0,07	-0,08	+0,29
4. 30% directly below the horizon	0,11	+0,28	0,11	+0,16	+0,12
5. 15% above and 15% below the horizon	0,05	+0,15	0,09	-0,07	+0,22
6. 30% as above + 15% vertically	0,07	+0,19	0,08	-0,12	+0,31
7. approx 30% through bushes & leaves	0,11	+0,06	0,47*	+0,16	-0,10
8. approx 35% thorugh leaves	0,17	+0,25	0,19	+0,27	-0,02
9. approx 30% thorugh moving leaves		+0,1		+0,2	-0,1
10. thorugh a wire fence	0,07	+0,19	0,10	+0,26	-0,97
11. thorugh bars and a hedge (without leaves)	0,07	+0,07	0,10	-0,14	+0,21

We found that a screening of 30% did not greatly affect the result. The standard deviation for one reading is about 0,1 mm, except in one case (0.47mm) where we suspect a blunder. For one of the instruments (no 85790), it seems, however, that the effect systematically receives the same sign.

3.1.17 The effect of vibrations

We achieved this by knocks on the tripod legs. Here, we found that for one series of levelling with 10 measurements and 40 m sight distance, the standard deviation varied between 0,8 and 1,2 mm. We also found considerable height errors. All measured height differences are significantly too large.

3.1.18 The effect of rain

During light and heavy rain, measurements could be taken without difficulty but the reduced light intensity and clarity of the staff's image meant that NA2000 needed more time to produce a result.

3.1.19 The effect of car exhaust fumes

The effect of car exhaust fumes was studied with the help of a car parked in front of one of the staffs (1m). The test was done for 30 m sight distance. Nothing of importance was observed.

3.1.20 The effect of smoke and heat

We created first smoke and then intense heat with the help of a fire close to the line of sight. The results are not much affected except when too much smoke or heat haze made measuring impossible. The standard deviation lies around 2 mm per km. The measuring time rose considerably.

3.1.21 Test of batteries

The capacity of the batteries was found to be adequate and, with a margin, lasted for a whole days work.

3.1.22 Data storage

The storage capacity of the REC module was adequate. The compartment for the recording module is in a protected position under the instrument. It is possible to insert the module incorrectly and, also, it repeatedly comes loose which causes problems.

It was felt that a solely numerical keyboard has certain disadvantages, especially in connection with storage of additional information.

3.2 PRODUCTION TESTS

A number of production tests were carried out after first doing the initial function tests carrying out both normal and precise levelling on our testing grounds in Gävle (Mårtsbo) and Hofors. The equipment has been tested using both on foot (FL) and motorized levelling (ML) techniques during field working conditions.

3.2.1 Normal line levelling

This test has been carried out according to the classical "on foot levelling model" i.e. with an observer and two staffmen. Only standard staffs (4.05m) and conventional Wild foot plates have been used. At each set-up, only one backsight and foresight reading was taken according to the classical model i.e. B-F, B-F, B-..... and so on. The readings were taken automatically and stored in the REC module. In total, 9 sections were double-run which corresponds to a line length of approx. 15 km.

The following table, no 6, shows the results of measurements and calculations and includes the differences between forward and reverse levelling for each section, a) from uncorrected readings, b) after applying various corrections for graduation error, error of curvature and temperature errors, as well as a comparison with the Ni002 results.

Result from normal line levelling on foot (using standard staffs)

Section	Distance in meter (m)	Average sight distance (max) (m)	Height difference in meter (m)	Diff forward-return Uncorr. (mm)	Correction in mm Gradu-ation	Earth curv.	Temp	Total (mm)	Difference forward - return Corr. (mm)	NA2000-Ni002 Uncorr. (mm)	Corr. (mm)
1	784	56	+9,6	-1,3	-0,05	+0,52	-1,21	-0,74	-0,8	+2,6	+1,7
		(94)			+0,18	-0,23	+1,21	+1,16			
2	799	50	+9,6	+1,4	-0,17	+0,04	-1,21	-1,34	+1,4	+1,5	+0,2
		(71)			+0,09	-0,02	+1,21	+1,28			
3	727	52	-4,7	+5,3	+0,41	-0,78	+0,59	+0,22	+4,8	+1,9	+1,4
		(93)			-0,19	-0,10	-0,54	-0,70			
4	735	49	-4,7	+0,5	+0,09	-0,10	+0,59	+0,58	+0,4	-0,6	0
		(66)			-0,10	0	-0,59	-0,69			
5	1005	53	+2,9	+4,7	-0,02	+0,14	-0,36	-0,24	+4,6	+1,9	+1,8
		(91)			+0,25	+0,05	-0,36	+0,06			
6	1028	47	+2,9	+1,2	+0,01	-0,05	-0,36	-0,40	+0,9	-1,5	-1,7
		(63)			-0,26	+0,02	+0,36	+0,08			
7	824	43	+7,0	+3,4	-0,01	-0,11	-1,31	-1,43	+3,5	+4,8	+3,4
		(61)			+0,08	+0,10	+1,21	+1,49			
8	575	36	-26,5	+2,8	+0,44	+0,08	+4,99	+5,51	+2,6	-4,2	+1,4
		(69)			-0,57	-0,14	-4,99	-5,70			
9	927	36	+34,0	-0,7	-0,40	+0,19	-6,40	-6,61	-0,9	+4,2	-2,4
		(71)			+0,14	-0,18	+6,40	-6,36			
Total	7,4 km			+17,3					+16,5		+5,8
Number of setups				81							
Average sight distance				46 m							
Standard error of the mean				+-1,65 mm					+-1,53 mm		

The results show clearly the importance of correcting the readings for temperature and the effect of earth curvature. The size of these errors is considerable when levelling is carried out in hilly terrain and with backsights and foresights of different lengths.

3.2.2 Precise levelling

These tests were done on LMVs test track at Mårtsbo. Tests were carried out using the motorized levelling technique. By making a few simple modifications, the invar staffs and the instrument could be used with existing equipment and cars. One of the instruments had been provided with a rotating eyepiece of a type used on theodolites.

During each set-up we took 4 readings according to the classical model i.e. B,F - F,B. In total, 20 km was levelled although only in relatively flat terrain. The largest height difference was 6,53 m.

Table no 7 shows the results of measurement and calculation in the same way as previously for line levelling using standard staffs.

Result from motorized precise levelling (using invar staffs)

Section	Distance in meter (m)	Sight distance (m)	Height difference in meter (m)	Diff forward-return Uncorr. (mm)	Correction in mm Gradu-ation	Earth curv.	Temp	Total (mm)	Difference forward - return Corr. (mm)	NA2000-N1002 Corrected. (mm)
1	1183	44	+4,40	-3,20	-0,01	+0,20	-0,06	+0,13	-3,07	+0,48
					+0,04	-0,12	+0,08	0,00		
2	1183	43	+4,40	+1,00	+0,03	+0,11	-0,05	-0,09	+0,82	+1,97
					-0,03	-0,30	+0,05	-0,28		
3	1183	44	+4,40	-2,20	0,00	+0,07	-0,05	+0,02	-2,19	+0,88
					-0,11	+0,04	+0,06	-0,01		
4	1002	50	-0,29	-1,10	-0,01	-0,05	+0,01	-0,06	-1,10	+0,79
					+0,05	+0,03	-0,01	+0,07		
5	1002	50	-0,29	-1,85	-0,14	0,00	0,00	-0,14	-1,97	+2,12
					+0,18	-0,15	0,00	+0,02		
6	1002	50	-0,29	+0,75	-0,02	+0,09	0,00	+0,07	+0,62	+0,10
					-0,13	-0,06	0,00	-0,20		
7	570	40	-0,27	-1,05	+0,13	0.00	0,00	+0,13	-0,75	-0,34
					+0,19	-0,01	-0,01	+0,17		
8	570	40	-0,27	-0,10	+0,02	-0,04	+0,06	+0,04	-0,11	-0,29
					0,00	-0,03	0,00	-0,03		
9	570	40	-0,27	-0,15	-0,04	+0,01	0,00	-0,03	-0,21	-0,31
					-0,01	-0,02	0,00	-0,03		
10	1370	49	-4,90	+3,30	-0,07	-0,01	+0,07	-0,01	+3,08	-0,66
					-0,14	0,00	-0,07	-0,21		
11	1370	49	-4,90	+1,80	+0,02	-0,04	+0,06	+0,04	+1,84	-0,17
					+0,11	-0,06	-0,05	0,00		
12	1370	50	-4,90	+0,75	+0,13	+0,08	+0,05	+0,26	+1,09	-1,35
					+0,15	-0,02	-0,05	+0,08		
13	933	46	+2,05	-0,95	+0,04	+0,02	-0,03	+0,03	-0,94	+0,13
					-0,03	-0,04	+0,03	-0,04		
14	933	46	+2,05	+0,40	-0,08	-0,03	-0,02	-0,13	+0,35	+1,57
					+0,08	-0,02	+0,02	+0,08		
15	933	46	+2,05	+0,50	+0,03	+0,03	-0,02	+0,04	+0,60	+1,30
					+o,02	+0,02	+0,02	+0,06		
16	1424	51	-2,91	+2,00	-0,04	-0,01	+0,04	-0,01	+2,10	-1,44
					+0,08	+0,03	-0,04	+0,07		
17	1035	47	+3,22	+0,83	-0,09	0,00	-0,04	-0,13	+0,57	+1,89
					-0,11	-0,03	+0,05	-0,10		
18	608	34	+6,53	-1,12	-0,10	+0,07	+0,08	+0,05	-1,06	-1,45
					+0,03	+0,05	-0,07	+0,01		
Total	18,4 km			-0,84					-0,33	+5,22

Number of setups	390
Average sight distance	47 m
Totalt measuring time	1015 min
Time per setup	2,6 min
Standard error of the mean (corrected)	+-0,7 mm

S = 0,67 mm

We found that precision is very good; the standard error of the mean is low, approx. 0,7 mm for a double-run distance. However, all corrections have been applied.

An analysis of how the number of observations affect the results was done for all precise measurements where we had taken 2 readings, Backsight and Foresight. The following table, no 8, shows that the standard error of the mean was hardly affected. The results are equally good and therefore one can draw the conclusion that one backsight and one foresight is adequate

The effect of the number of observations.

Type of result	ΔH uncorrected	ΔH corrected		
Type of measurement	BFFB	BF	FB	BFFB
Number of measurements	18	18	18	18
Total differences:	1,75 m	0,71 mm	2,82 mm	1,75 mm
Total distance:	18338 mm	18338 m	18338 m	18338 m
Standard error of mean	+-0,72 mm	+-0,73 mm	+-0,74 mm	+-0,70 mm
Standard error of reading:	+-1,02 mm	+-1,03 mm	+-1,05 mm	+-1,00 mm
Time used:	1014 min			
Numer of setups:	390			
Time per setup:	2,6 min			
Average sight distance:	47 m			

4. SUMMARY

In the following chapter we will present the advantages and disadvantages found when using NA2000 in our extensive tests and in comparison with other instruments. (1, 3, 4, 8, 11)

These comparisons are made by considering three different aspects: accuracy, production and ability to stand up to field use.

4.1 ACCURACY

4.1.1 The following advantages were found:

* less dependent on the observer's eye due to NA2000's electronic measuring system which does not require sharp sighting and setting of the crosshair on a line on the staff, something which is of vital importance in obtaining accuracy with all classical instruments.

* no reading errors because this is done automatically

* no writing errors thanks to automatic recording

* less influence caused by individual graduation errors as the instrument deals with a large number of bar codes at the same time and distributes (= adjusts for) individual errors. This is especially true the greater the sight distances are. Large graduation errors can even be filtered out during the actual computation.

* less influence from the effect of negative vertical refraction especially on sights made low over the horizon. Haze and refraction are reduced the higher above the ground sights are taken, i.e. towards the top part of the staff. NA2000 can, because it deals with a whole section visible in the telescope "window", "spread out" the effects of refraction and haze and therefore reduce their influence. It should be noted, however, that in many cases where these errors would not have any effect in classical levelling, the use of NA2000 introduces less of a negative effect due to the "infected" lower part of the visible section.

* less dependency on the staff standing still. NA2000 can record continuously without difficulty.

* NA2000 produces a good degree of accuracy even for long sights of up to 75 m. This is difficult when using other instruments especially when it is necessary for the human eye to cope with exact sightings of one single line mark (see fig.3).

* When determination of the collimation error and subsequent readings are dealt with in the "correct" way, the accuracy of NA2000 could be greater.

4.1.2 The following factors have a negative effect on accuracy:

* The expansion of standard staffs due to variations in temperature is significant; 10 ppm per degree and metre height difference. In hilly terrain, where height differences vary considerably, ommission of this correction causes large, unacceptable errors. While carrying out the classical checks on results, where comparison of forward and reverse levelling is recommended, this error was never detected when surveying conditions (temperatures) were the same. The results "agree" but differ from the "true value". If surveys are carried out in different seasons; spring, summer, autumn or winter, there is a substancial risk that real problems will be encountered. This can be illustrated by two examples: Firstly, when line levelling between two known national vertical control points

in hilly terrain, NA2000's result will not "fit in" and the higher order network will be suspected. Secondly, when surveying sinkage of buildings, roads etc using NA2000, effects such as these will occur in the results. These are, quite simply, none other than "the effects of variations of temperature".

If the difference in temperature between going out and return levelling is great, it will be difficult to keep to the permissable standard deviation (tolerance) and can also lead to "unnecessary" re-levelling.

* The amount of unobstructed staff graduation is of great importance where precision is concerned. It should be 70% of the "part of graduation visible in the telescope" if precision is not to be reduced. Placement as well as the distribution of the usable section on the staff is also of importance. If the largest part is at the bottom of the staff the results are affected by refraction.

* Sighting "above" and/or "below" the bar code graduation produces incorrect results of up to 1 mm per set-up despite good repeatability. This can be especially dangerous when levelling in hilly terrain.

* Joining the staff units introduces errors which in some cases can be "spread out" (visible section covers several staff units) but in other cases (visible section covers only the second or third unit), produces false results because of a "stepping effect" which has crept in.

* Readings should be given to 0,01 mm as a tenth of a millimetre is not acceptable for precise measurements.

* Instability of the collimation error and the present method used for determining and using the correction values reduces accuracy unnecessarily. Correction for earth curvature is missing.

4.2 PRODUCTION

By this we mean the production that it is possible to achieve either daily or during a season and under changing measuring conditions.

4.2.1 The production capacity of the instrument increases considerably due to the following:

* Simplicity, speed and automation: only set-up, sighting and then the push of a button.

* Only one sighting in each direction (foresight, backsight) which means no staffs with double graduation.

* No use of stadia lines in order to determine the sight distance.

* No entries in field book; automatic storage in REC module.

* No manual calculations.

* Less follow up work at the office.

4.2.2 On the other hand, there are also a number of factors which disturb or limit production capacity, for example:

* As the instrument requires an unobstructed graduation of approximately 70% of the visible section in order to maintain a high degree of accuracy, the maximum height-difference per set-up which can actually be measured is very

much reduced. A sight distance of 50-m using 3 meter invar staffs where graduation starts at 0,3 m means a loss of 25% (70 cm of 270cm). This loss increases with increased sight distance and corresponds to over 50% for 100 metre sight distances. By using standard staffs, loss of production is less (17% and 34% respectively) although still noticeable in comparison with levelling carried out using classical instruments (fig.5). This is a very limiting factor where production capacity is concerned, especially in hilly terrain.

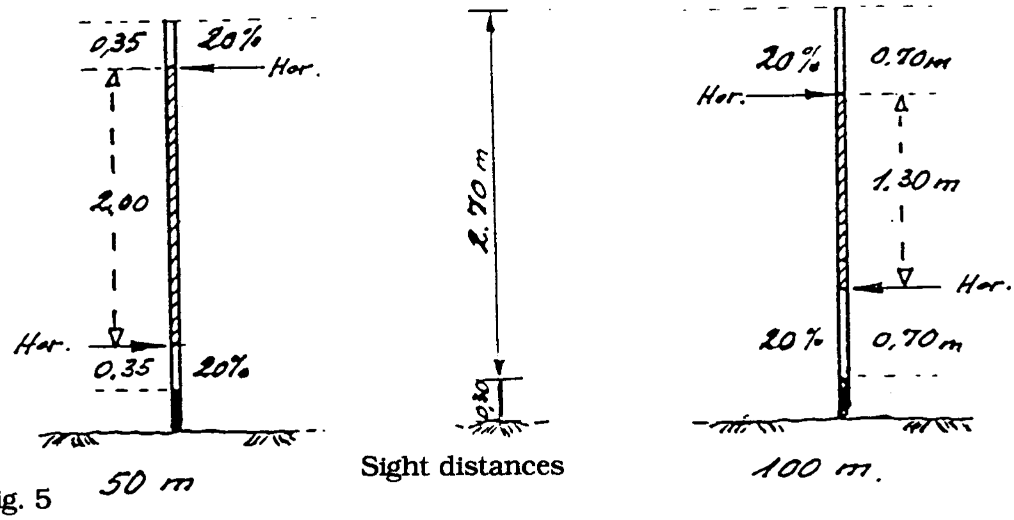

Fig. 5

* The need to have an unobstructed section of 70% is troublesome in general and in particular when levelling is carried out in overgrown terrain (tall grass) or in connection with making bench mark ties to control points. Sights must be cleared if possible or another location found for the set-up. This takes time and reduces production. In some cases, (in towns or industrial areas) it can even make it impossible to take measurements.

* Direct light (e.g. sunlight) into the instrument; the "blind" sector of about 15 degrees is extremely troublesome and reduces production considerably. Problems occur when making bench mark ties. These problems are difficult to overcome as the sighting opportunities are minimal.

* Illumination of the staff with shadowed or light zones, lack of contrast between black and white bar codes, or the sky as a background, complicates the measuring process. In addition, extra attention must be paid and more effort made whereupon more time is needed and production is reduced.

* Low light intensity makes measuring impossible, which can mean a significant loss of production; about 2 km per day for every hour lost. This is most noticeable during the winter and also on other very dull days.

* Distribution of the work among different people who are part of an NA2000 survey team means that the observer is also the "recorder". This is an advantage when carrying out levelling on foot. However, when using the motorized levelling technique, it is a disadvantage because the number of people in the team cannot be further reduced. At the same time, it burdens the observer with the duties normally carried out by the recorder. The balance in the distribution of work among the members of the team is upset.

* To summarise, it can be said that the advantages, which are greatest when levelling is carried out on foot, are wiped out by the many disturbing and limiting production factors. The amount of time needed per set-up using motorized levelling in relatively flat terrain is greater than when using Ni002 from Zeiss Jena (2,6 mins instead of 2,0). In addition, we noted a general increase (between 5% and 20%) in the number of set-ups.

4.3 FIELD USE

Here we describe the factors which either improve or make worse levelling work when the NA2000 system is used.

4.3.1 The advantages of using NA2000 are as follows:

* The instrument and staffs are extremely light. The combined weight was about 7 kg which was very much appreciated especially when levelling on foot.
* The instrument is easy to use.
* The screws are, with regard to ergonomics, well-positioned and easy to reach.
* The REC Module has a good storage capacity, at least enough for one day's work.
* Battery capacity is sufficient.
* One pleasant surprise is that the staffs can be used in either an "up" or "down" position; the instrument copes without problem. This can have advantages especially within the building industry.
* The inbuilt software gives a greater flexibility when carrying out different work operations. It is also easier to follow the work being done.
* Fewer people are needed for precise levelling on foot.

4.3.2 The factors which prove to be a disadvantage are as follows:

* The need for an unobstructed visible sector of 70% which causes difficulties.
* Problems concerning direct light, lighting conditions etc.
* The numerical keyboard is out of date and a handicap.
* The red measuring key is wrongly positioned and creates difficulties in particular during the winter months when the operator is wearing gloves.
* For motorized levelling, a rotating eyepiece giving a true image, similar to that on NI002 from Zeiss Jena, is lacking.

Moreover, in the assessment of how well NA2000 stands up to field use, it was judged to be good although there are a number of shortcomings which unfortunately cast a shadow over this picture.

5. CONCLUSIONS AND SUGGESTIONS FOR IMPROVEMENT

The appearance of NA2000 marks an important stage in the automation of the levelling process. It is the first instrument to be completely digital, which indicates the possibilities and limitations of this technical solution has.

Automation of readings, recording and computation, the high precision and the fact that it is easy to use are the most positive features of NA2000. Inconveniences and limitations because of the need for a visible sector instead of a line of sight, and also the effect of temperature variation and lighting conditions were felt to be a handicap and very troublesome.

We feel, however, that NA2000 is an interesting attempt to automate the levelling process which also can and should be improved on with the help of the following measures:

* construct a sunshade for the objective, perhaps with a filter

* move the "red measuring key" to a central position so that pressure is directed onto the axis of rotation instead of affecting the direction

* change from a numerical to an alpha-numerical keyboard

* move the data port to the stationary tribrach

* introduce a warning signal (red light as in cameras) to avoid measurements being based on inadequate visible sector

* improve the way the REC Module is attached

* make possible reading and displaying to the nearest 0,01 mm

* introduce a rotating eyepiece (true image)

* improve the way the staff units fit together

* remove the bar codes on the lower part of the staff (approx. 0.3m)

* include a temperature gauge on the staffs

* provide instructions for staff calibration

* introduce new routines for determining the collimation error (times) and also for correction

* provide clear instructions on correct surveying procedure in order to avoid obtaining incorrect results

The greater number of these suggestions can be dealt with immediately, others require larger modifications. However, this should be easy for one of the world's largest producers of survey instruments.

We await with interest the next innovation in levelling technology, perhaps the result of the ongoing development project RPLS (Rapid Precise Levelling System) in which LEICA WILD is participating.

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