

## The New Digital Levels DiNi<sup>®</sup> 10 and DiNi<sup>®</sup> 20

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### 1. Introduction

In 1983, at the FIG Congress in Sofia, Professor F. Deumlich from the Technical University of Dresden gave a lecture in which he reported on an analysis of levelling which he had performed to assess the time requirements and accuracies of the individual operations involved. He also indicated that initial studies were being performed in Dresden to objectify the process of reading the measuring staff and thus to automate levelling.

Extensive investigations were also conducted elsewhere with the same goal in mind. H. Schlemmer has summarized and assessed them in his detailed work /1/, adding his own recommendations.

It was not until in 1990, however, that the first digital level was launched on the world market. The process of objective staff reading in this instrument had been implemented using the principles of image processing. As a result, the opinion prevailed for a long time that the use of an "integral comparative operation" - as quoted in patent /2/ - was the only approach for reading and measuring the coded staff imaged, across a distance in air, on a CCD line installed in the image plane of a telescope.

In the subsequent years, the electronics industry developed new modules such as CCD sensors and computers with improved capabilities (increased line length, higher sensitivity and resolution). These became available at such low prices that they are now the state of the art in technology and permit the implementation of objective staff reading in levelling, even if conventional measuring methods are used. In 1992, R&D engineers at Carl Zeiss successfully used a test setup to visualize on a monitor the signals of the staff image obtained over a considerable distance in air, and found that the familiar technical devices were suitable for the evaluation of these signals. This was the first step in the development of the DiNi 10 and DiNi 20 digital levels which are described in the following.

### 2. DiNi Measuring Method and Determination of the Staff Reading

#### 2.1 Definition of the measuring range

The DiNi operates on the principle of single interval measurement. The staff graduation is imaged through the telescope objective on a CCD line installed in the image plane of the telescope. The staff is divided into 2 cm intervals which form the basis of the measurement on all measuring distances.

According to the intercept theorem, the following formula applies:

$$D \cdot b_i = D \cdot g_i \quad (1)$$

where  $D$  is the distance,  $f$  the focal length,  $g_i$  the distance of a line on the staff from the optical axis of the level and  $b_i$  the distance of the image of this staff line on the sensor from the optical axis.

To permit the resolution of a code element  $g$  at the maximum distance  $D_{\max}$ , the following must apply:

$$g \cdot f \geq D_{\max} \cdot p \cdot OV \quad (2)$$

where  $p$  is the pixel size and  $OV$  the oversampling, i.e. the number of pixels/code element required to ensure the accurate interpolation of the code element position.

The minimum sighting distance is limited by the fact that a sufficient number of code elements  $N$  must be imaged on the sensor to allow the code to be read completely and with the necessary redundancy:

$$N \cdot g \cdot f \leq D_{\min} \cdot p \cdot z \quad (3)$$

Quantity  $z$  is the minimum number of pixels. The possibility of manufacturing a digital level on the basis of single-interval measurement, where the graduation lines are detectable over the entire measuring range from 1.5 m to 100 m, ranges between the inequations (2) and (3). Options for variation are only provided by the type of code used, the minimum bit number of the code being dependent on the size of the code element  $g$ . In the case of pseudostochastic codes, the following applies for the codable staff length  $L$

$$L = (2N - 1) \cdot g \quad (4)$$

The inequations (2) and (3) show that the focal length can be varied in relation to the size of the code element (with due consideration of equation (4)). If (2) and (3) are equated, the following results for the measuring field of the instrument:

$$\text{Measuring field} = \text{pixel size} \cdot \text{distance ratio} \cdot \text{oversampling} \cdot \text{minimum bit number} \quad (5)$$

As a result, the measuring field of the DiNi is larger than the visual field of view. At distances from approx. 15 m onwards, however, the staff section of 30 cm used for measurement is completely visible in the field of view.

Although a pseudostochastic code offers the advantage that reading can be started at each code element, the drawback of this type of code consists in a very uneven distribution of the line widths which is not very suitable for precise height measurement using the method described here. According to [3], the pseudostochastic code is superimposed by a bi-phase code which leads to a change in brightness after each bit, permitting each bit of the code to be used as a measuring interval. Binary ones and binary zeroes are distinguished by the fact that the zero bits include an additional brightness change in the middle of the interval which, according to equation (2), must of course be detected by the instrument even at the greatest measuring distance.

## **2.2 Procedure of a Single Measurement**

What aspects must the instrument take into account in a DiNi measurement? At the beginning of the measuring process and prior to each single measurement, a check is made to ensure that the pendulum is not at its stop.

Since the CCD line is only able to convert a limited brightness range into a signal suitable for evaluation, the exposure time must be adapted to the signal available. This adaptation must be performed rapidly to permit prompt setting of a long exposure time if only a limited amount of light is available (the necessary acting time in such cases increases the measuring time by one second), and it must be sufficiently sensitive to ensure full illumination of the sensor, if possible. As in all cameras, over-exposure must be avoided. Backlight observations with a bright background of the staff graduation may result in underexposure of the actual measuring object, i.e. the staff. Suitable measurements have been implemented to enable the evaluation of the measuring signal even in such conditions, but of course the possibilities are not unlimited.

The averaging of the pendulum oscillations and air turbulence alone necessitates several single measurements which are then averaged to obtain the measured value finally output. The standard measuring time of the DiNi 10 is approx. 4 seconds, the DiNi 20 only requires a measuring time of about 2 seconds if sufficient light is available.

If the brightness changes during the measuring process (the sun begins to shine), single measurements may be overexposed despite the preceding exposure control. In this case, the measurement is automatically restarted. If the measuring beam is interrupted, unsuccessful single measurements are repeated. As a result, the measuring time may be virtually doubled.

The measuring image is available in the DiNi in the form of a list containing amplitudes for all pixels. The light/dark transitions are detected according to the principle described in /4/. The amplitude information is converted into edge positions on the CCD line. Again, various aspects need to be taken into consideration. Which edges belong to the staff? How can interfering structures be identified and marked as being invalid for the measurement? A series of digital filters is used for the successive procedures of detecting the staff, reading the code and identifying the staff section relevant to evaluation.

The DiNi determines all measured values on the basis of a 30-cm staff section positioned symmetrically to the line of sight, as this provides the most accurate measurements. Staff areas beyond the 30-cm section, although recorded, are not used for obtaining the measured values. In a normal setup and in flat terrain, this ensures that staff sections located close to the ground, and therefore more prone to refraction, are not used for evaluation. Due to the high accuracy of edge detection, a larger staff section or a greater number of single measurements is not needed for the determination of the staff reading, even in the case of air turbulences or oscillations of the pendulum.

If it is not possible to obtain a symmetric staff section, for example because part of the measuring field is concealed or measurements are to be performed near the ends of the staff, an asymmetric staff section is selected. Measurements extending by more than approx. 2 cm beyond the upper or lower end of the staff are stopped.

In principle, the DiNi is also able to use a staff section of less than 30 cm for measurement, as long as a sufficient number of code words can be read. The minimum measuring field for the shortest sighting distance of 1.5 m is 10 cm. As a result, a range of approx. 6 cm at the upper and lower ends of the staff cannot be measured if the shortest sighting distance is used. However, this is unlikely to be of any practical significance.

### 2.3 Determination of single measurements

The principle of single interval measurement is illustrated in Fig. 1. The DiNi staff is divided into measuring intervals of the size  $g = 2$  cm which also include coded information.

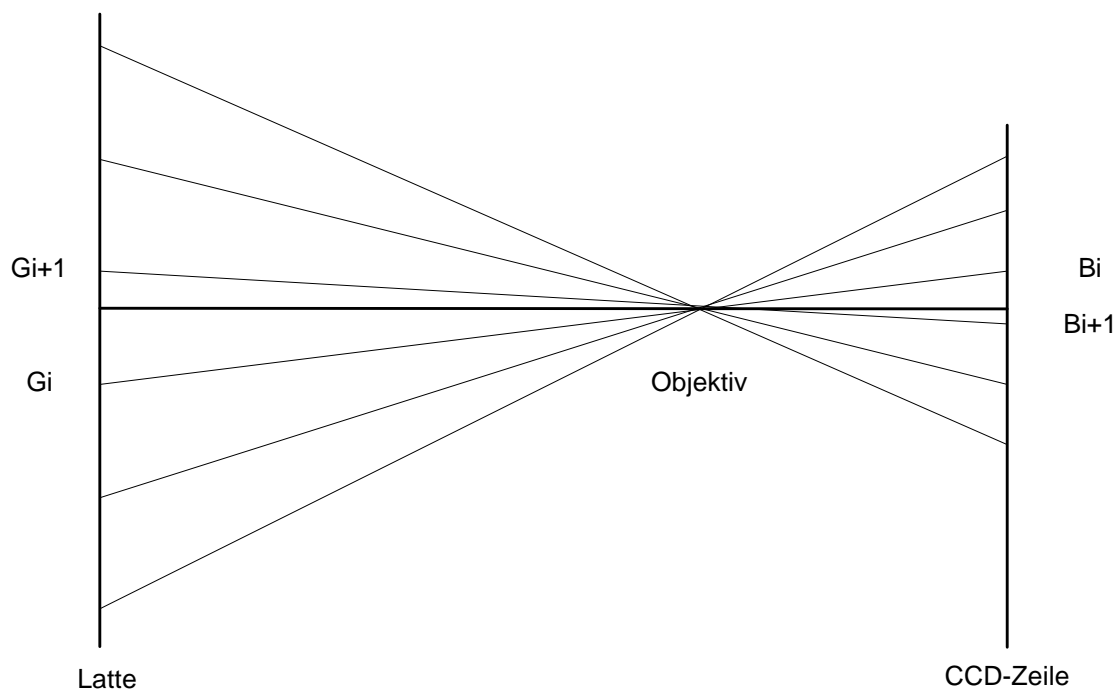


Fig. 1: The staff graduation is imaged through the DiNi objective on the CCD line. The limits of an interval (edges) on the staff are marked  $G_i$  and  $G_{i+1}$ . The corresponding interval limits in the image are  $B_i$  and  $B_{i+1}$ .

First, the image scale  $A$  is determined using the edges at either end of the 30 cm measuring interval:

$$A = g \cdot N / (b_N \cdot b_0) \quad (6)$$

the image scale is then used to compute the distance. The basic principle corresponds to distance measurement based on stadia lines, but with a fixed base at the target point.

The staff reading (height) of a single measurement results from the position of the interval edges  $b_i$  on the CCD line in relation to the optical axis, and from the number  $C_i$  of the code word according to formula (7) belonging to the relevant interval as the mean value of all intervals used for the measurement (usually 15).

$$H = \frac{1}{N} \sum_{i=0}^{N-1} \left( g \cdot (C_i + 1/2) - A \frac{b_{i+1} + b_i}{2} \right) \quad (7)$$

where:

$g \cdot C_i$	height of the beginning of the measuring interval involved
$\frac{1}{2} g$	addition constant as the interpolation value refers to the middle of the interval
$A/2 (b_{i+1} + b_i)$	interpolation value of the interval position relative to the optical axis

The displayed measured value is the mean value of several single measurements, the number of which is dependent on the ambient conditions and the measuring accuracy required.

## 2.4 Where should the user be careful when measuring?

Like any other surveying instrument, the DiNi should be allowed to fully adapt to the ambient temperature before measurement is started. Just as in visual levelling, the staff must be precisely vertical and the staff image must be focussed on the telescope reticle. The usual variations in focussing have only a negligible effect on the measured value. The opinion that a digital level need not be properly focussed /5/ ("it will measure anyway") occasionally voiced is not correct. The alignment status of the level only applies to a staff image precisely focussed on the reticle. This is also the condition for which the measurement algorithm has been optimized with regard to the achievable accuracy.

If extreme backlight situations lead to visible reflections in the telescope, it is advisable - as in any camera - to eliminate these reflections by shading the objective with the hand or the fieldbook. The electronic measurement in the DiNi is performed in the visible wavelength range. In daylight conditions at least, most of the infrared component is filtered out. This means that the situation for the CCD line is exactly the same as it appears to the observer's eyes.

### 3. Design and Special Features of DiNi 10 and DiNi 20

During the last few decades, the improvements implemented in the surveying of heights have centered on two fields of application:

- the medium precision range (engineering surveys)
- the high precision range (precision levelling)

In the field of low-precision height measurement, on the other hand, laser sighting instruments are being increasingly used.

It therefore seemed appropriate to develop two digital levels for the specific requirements of the two above-mentioned fields of application by modifying the previously described measuring technique. The results of our investigation on the capabilities and versatility of the measuring technique and the graded accuracies of the measuring staffs (folding staff and invar staff) proved to be extremely helpful in achieving this goal. This was the basis for the development of the DiNi 20 for the medium accuracy range in levelling using the folding staff and of the DiNi 10 for precision levelling using the invar staff. Needless to say, it is always possible to use the invar staff in combination with the DiNi 20 and the folding staff with the DiNi 10, but optimum performance with regard to measuring accuracy and measuring time is not obtained in this case. Measuring errors, however, will not occur.

To fully meet the requirements of the above-mentioned fields of application in levelling, the DiNi 10 /20 levels offer the following special features:

- high reading accuracy of the measuring staff graduation
- negligible setting error of the tilt compensators
- minimal effect of other instrument errors such as dip of horizon and shaking of the measuring image
- small measuring section on the staff, minimizing the influences of refraction close to the ground
- visual sighting to determine inadequate illumination or glare impairing the sharpness and quality of the staff image
- ease of operation with straightforward user guidance
- multiple measurement with automatic averaging
- automatic evaluation and storage of the measured data
- easy handling and precise, reliable operation during measurement
- on-line measurements via the interface for special applications
- low power consumption (one battery charge lasts for at least one working day)
- low weight and modern styling

These outstanding capabilities of the DiNi 10/20 increase the efficiency in levelling by up to 50 %.

#### **4. Structure and Operating Principle**

The design of the Ni 10/20 is based on that of the familiar classical levels. The horizontal telescope dominates the sturdy base. The control panel with its display and keyboard is the prominent design feature on the eyepiece side of the instrument.

The base comprises

- the tribrach with the footscrews
- the friction clutch for coarse movement of the instrument and
- the adjustable orientation circle with a degree graduation for reading with an accuracy of  $0.1^\circ$ .

The upper structure includes:

- the telescope with the coarse/fine focussing control and the eyepiece
- the circular level for coarse levelling of the instrument
- the continuously adjustable horizontal tangent screw for precision sighting of the staff, for operation on either side
- the tilt compensator for automatic precision levelling of the line of sight
- the CCD sensor line for automatic reading of the staff graduation
- the microprocessor for reading the sensor line and for the determination of the height and distance values using the operation and application programs of the instrument
- the NiMH (nickel-metallic hydride) battery
- the serial interface (V.24) for data transfer and connection of an external PC
- the control panel
- the start key on the right-hand side of the instrument
- the internal RAM for recording of the measuring units, constants and further instrument parameters
- the exchangeable Mem E memory for recording of the measured and computed data.

The measuring staffs are available in the following versions:

- invar staffs of 3 m, 2 m and 1 m length, with the previously mentioned bar-code graduation
- foldable wooden staff, 4 m long, folds to 1 m, with bar-code and E graduations
- foldable wooden staff, 3 m long, folds to 1 m, with bar-code and E graduations

An overview of the optical and mechanical design of the DiNi 10/20 is shown in the sectional views A and B in Fig. 2.

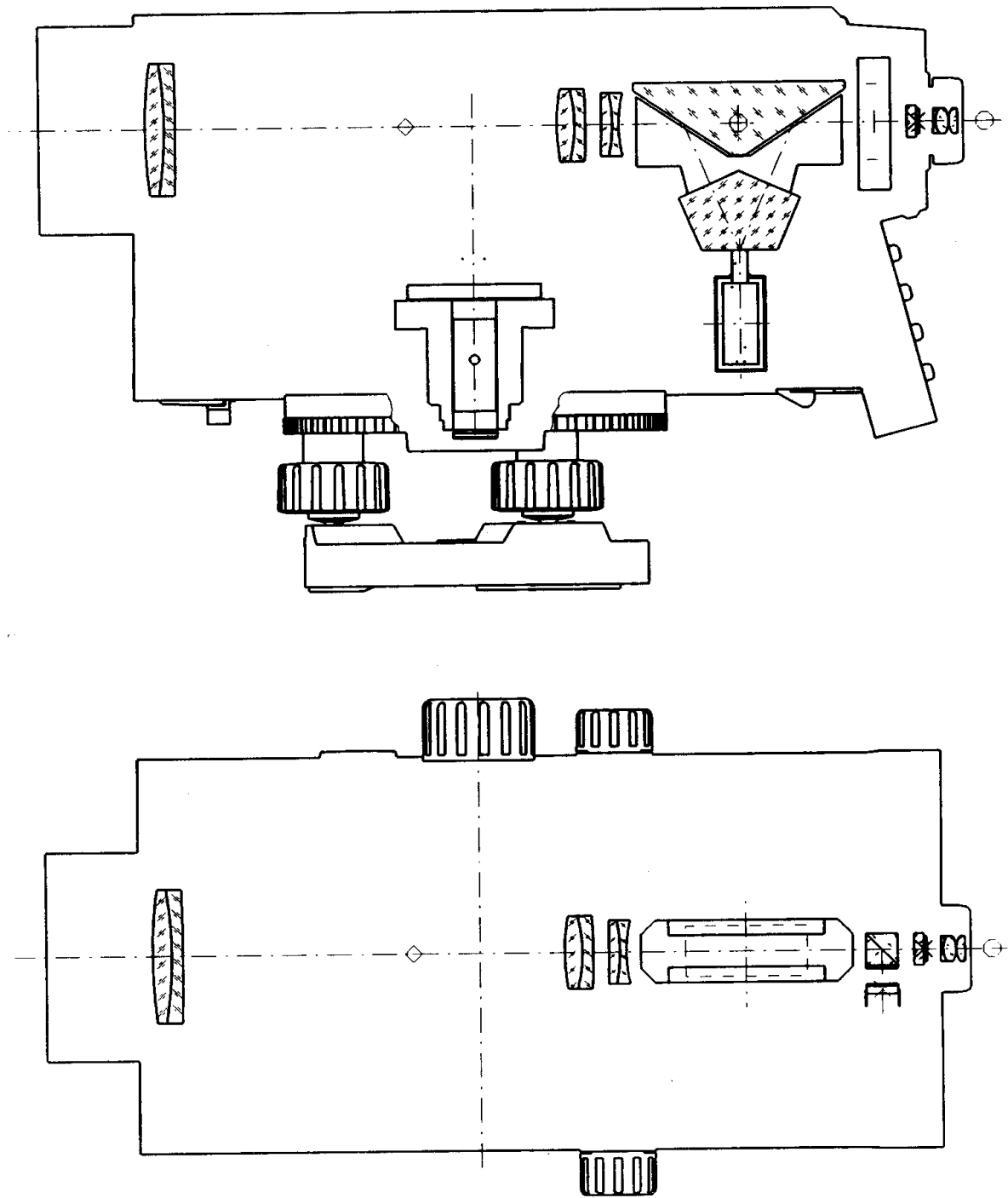


Fig. 2



The sighted section of the measuring staff is imaged by the objective and the focussing lens - via the suspended, oscillating prism, the stationary prism and the beam-splitting prism - both on the reticle and , through the partly transmitting mirror, on the CCD line. The eyepiece permits simultaneous viewing and focussing of the staff image in the reticle plane. This also ensures that the staff image is sharply defined on the CCD line.

This staff image generates dark/light signals in the CCD sensor, which are fed to the input port of a fast A/D converter via the serial analog signal output. The digital values thus generated are read into the RAM of a microcontroller. The digital image of the levelling staff available in this memory is transferred to the image processing software. The computed data then appear in the graphic LC display and can be filed in the Mem E exchangeable data memory, if required.

## **5. Operation Concept and Capabilities**

### **5.1 General**

The maximum benefit is achieved for the user if ease of measurement is combined with straightforward, flexible and fast operation of the instrument software. This is the only way of achieving the desired rationalization effects in everyday use.

The prerequisite is an optimum design of the user interface required for the communication between the user and the instrument software. The DiNi user interface offers the following outstanding features:

- display screen with a clear layout and graphic capabilities, comprising four lines with 21 characters each.
- large keyboard with 22 keys divided into function groups and
- conveniently arranged measurement key.

The operation concept is characterized by:

- use of softkeys for user-specific instrument control (the current key assignment is shown in the bottom line of the display, depending on the task involved).
- user guidance as an option for the control of recurring operation cycles,
- graphic support of the processes, i.e. for alignment,
- acoustic and optical warning signals in the case of errors,
- clear messages and system prompts (in the language of the country in question)
- internal checks for plausibility and compliance with specified tolerances

No multiple functions have been assigned to any of the keys. The press of the relevant key on the control panel immediately starts the corresponding function. If input functions are activated, the keyboard automatically switches to the numeric entry mode.

When the instrument is switched on, the measuring program last used is activated. The measurement can be directly continued without the need for any additional operations. All input and computation data required are internally saved during

instrument shutoff and remain available even after the exchange of the instrument battery.

State-of-the-art flash PROMs are used as program memories. This provides the possibility, for example, of loading a new program in the instrument via the interface, without the need to open the instrument and exchange the memory modules.

## **5.2 Measuring programs**

With the basic idea of retaining the familiar methods of height measurement and levelling in the DiNi and of supplementing them with new, specific functions, where appropriate, the following measuring processes are supported in the new instruments:

### Single point measurement

- Determination of a single staff reading and of the staff distance
- Determination of point heights by backsight measurement of a point with a known height
- Setting out point heights by backsight measurement of a point with a known height.

### Line levelling

- Measurement of levelling lines by the BF and BFFB methods (plus BBFF and BFBB in DiNi 10)
- Possibility of interrupting and continuing a line
- Possibility of repeating the last measurement and the complete station
- Independent distance measurement for stationing of the staff
- Intermediate sights and setting out point heights after completion of the backsights or after completion of the measurements at a station

### Collimation alignment

- Näbauer method
- Two further methods provided in DiNi 10

The measurement results and computed data can be recorded immediately after measurement either in the integrated Mem E memory or, in external data storage units via the freely configurable V.24 interface,.

The point numbering system permits the assignment of separate point numbers to single point measurements, change points in the levelling line and to intermediate sights, as well as the incrementing or decrementing of these numbers, if required. 5-digit numeric point codes are used for the identification of measurements. In addition, a maximum of 9 lines is available for the optional storage of additional information comprising up to 21 digits.

If the recording mode is not used, the individual measured values or merely the consecutive height data can be read in the display and noted. Measured lines are continued in the instrument's internal memory, permitting the consecutive height data or the sums of target distances to be called up without any problem even after the instrument has been switched off and on again. If necessary, measurements can also be repeated in this case.

Three lines in the display are available for the measured and computed data. In addition, the right-hand side of the display offers information on the next measurement such as the type of measurement, point number and number of the station within the levelling line.

Backsight 2	Back	1	Z	123.95670	Back	1	Z	123.95670	Back	1	
Rd 2.42210	SNo:	2	h	0.50470	SNo:	2	h	0.50470	SNo:	2	
HD 32.140	CP	2	Da	32.960	CP	2	dR	0.00000	CP	2	
LEnd	IntM	SOut	Rpt	LEnd	IntM	SOut	Rpt	LEnd	IntM	SOut	Rpt

Fig. 3: Display options after completion of a station in the RFFR method

The combination of displayed values can be changed (where possible) using the DISP key. This allows the user to select the set of information in which he is interested and which will be automatically displayed again when the same type of measurement is performed. Together with the preselectable resolution, this permits the user to configure the equipment according to his own specific requirements.

To increase the accuracy, each measurement can be optionally performed in the multiple mode. A preselected number of measurements is then automatically triggered by the instrument, and the mean values and standard deviations are displayed.

If roof points are to be included in the measurement, the DiNi can be switched to the measurement of inverse staff readings, which are identified by a negative sign.

For extremely critical accuracy requirements, it may be necessary to subject the measurements to specific restrictions - a process supported by the DiNi. Values for the maximum sighting distance or minimum target height (to reduce the influence of refraction) can be entered just like maximum values for the differences between fore- and backsights (station differences), e.g. in the BFFB method.

If these threshold values are exceeded, a message is displayed to the user, and he can decide whether the measurements of this station are to be repeated.

As in conventional levelling, the data measured by the DiNi are influenced by earth curvature and refraction. Therefore, care should also be taken in measurements with a digital level to ensure that identical sighting distances for back- and foresights are used. For stationing the staffs, the distance measuring functions is very convenient.

Generally speaking, the influence of refraction in digital levelling can be minimized by rapid performance of the measurement, by the narrow measuring field of the DiNi and by avoiding low sighting.

In addition, the instrument offers the option of eliminating the influence of the earth's curvature and of refraction on the staff readings by a computation process. Whereas the given earth radius of 6380 km permits a rigorous correction of the former factor, the influence of refraction is subject to changes. Allowance for this aspect can be made by the entry of different refraction coefficients.

The benefits provided by an instrument in practical use are determined not only by the range of pure measuring and computation functions and by its accuracy, but also, to a high degree, by the configuration possibilities. Only if it is easily adaptable to the requirements of the measuring task on hand, will the surveying instrument be an effective aid. For fear of operating errors, however, many users are reluctant to use the often poorly documented setting functions. In the DiNi, a new approach in this instrument category has therefore been pursued. The detailed contents of all setting menus are displayed in the selected language. The settings required can be selected or changed by moving a scroll bar with the cursor or, for experienced users, by direct numeric entries. All modifications are directly visible.

3	SHUT OFF	10 min
↑ 4	SOUND	ON
5	LANGUAGE	E__100
ESC	↑	↓
		MOD

Fig. 4: Menu for setting instrument parameters

### 5.3 The recording concept

The incorporation of the exchangeable Mem E solid-state memory continues the successful recording concept implemented in the total stations of the Rec Elta series. This permits the filing not only of the measured values - optionally supplemented in the DiNi 10 by information on the time of measurement - but also of various computed data. The data file is structured by mode headers, additional information and input data, thus providing an easily understandable documentation of the measurement.

Heights measured by backsights and setting out can be imported from the Mem E to the DiNi, if required. Various search options are provided for this process. Needless to say, the Mem E contents can also be viewed, deleted and, to a certain extent, edited on the DiNi, and can be interchanged with an external computer via the V.24 interface.

Alternatively, the V.24 interface also permits direct recording in an external data memory. The content of the recorded data remains unchanged. However, it is not possible to call up point heights or display and editing functions from the external data memory.

For specific tasks, the DiNi can be used as a pure measuring sensor which is largely controlled via its interface. Appropriate commands are used to call up and set the instrument parameters and to trigger the measuring functions. The results are output automatically via the interface.

Data transmission to the PC uses the data formats familiar from the total stations Rec Elta 13 - 15, with the following characteristics:

- a fixed record length of 122 characters,

- identical record structure as in the data of the total stations,
- 27-digit data field for the point identification or further text information structuring the measurement,
- indication of the measuring unit used and
- clear representation in the printout

## **6. Initial Measurement Results and Experience**

To establish their measuring accuracy, ease of handling and reliability, the first digital levels were subjected to comprehensive laboratory trials under both normal and extreme field conditions, and were also tested in practical use in line levelling under a variety of ambient conditions and influences.

### **6.1 Measuring accuracy achieved:**

The DiNi 10/20 were used for precision levelling in all types of operating conditions including gusts of wind, sunny weather, dense traffic, rapidly changing cloud and covered sky. The average standard deviation achieved under these conditions on one kilometer of double levelling using invar staffs totalled:

- 0.3 mm for DiNi 10
- 0.7 mm for DiNi 20.

The measurements were performed by different operators in accordance with the rules for double levelling. It was found that, in digital levelling, the careful work of the staffmen and the quality of the stations are of paramount importance for the attainable measuring accuracy, as observer errors have been eliminated and the staff reading accuracy of a digital level is markedly higher than that achievable with classical precision levels. The measuring time is considerably reduced and, thanks to the clear user guidance, familiarization with the instrument presented no problems.

The reduction in measuring time was even more substantial in engineering levelling using the folding staff. Here, the standard deviation on one kilometer of double levelling was:

- 1.0 mm for DiNi 10
- 1.3 mm for DiNi 20.

The standard deviation in distance measurement with sighting distances of up to 20 m totals

$$\sigma_d = 20 \dots 30 \text{ mm.}$$

For sighting distances exceeding this range, the measuring accuracy corresponds to that of optical distance meters.

Special measurements performed for the determination of

- the reading accuracy on the staff graduation
- the setting accuracy of the tilt compensator

- the focussing accuracy for the staff image
- the influence of the staff setup quality

demonstrated that the sum total of these error components is of little significance. A major portion of the height measurement error is caused by ambient influences such as shimmer. Nevertheless, these factors have less effect than in a conventional level.

## **6.2 Alignment stability:**

As described above, the DiNi 10/20 offer various programs for testing and alignment of the collimation line. Irrespective of this, the aim was to achieve maximum stability for the zero position of the collimation line in various ambient conditions. For this, several instruments were subjected to the following tests under conditions conforming to DIN standards:

- shock impact inside and outside the case
- vibrations inside the case in different transport positions
- shaking in a wide frequency range
- temperatures from +50°C to -20°C
- rapid change of temperature from +70°C to -40°C over several days
- warm, humid alternating atmosphere over several weeks
- rain tests using a standardized water quantity and temperature.

The principal alignment parameters were checked after each test. In their entirety, the results provided comprehensive information on the stability of the alignment parameters, functional reliability, the accuracy of the measuring process and the overall quality of the instrument. The tests confirmed the stability, precision and reliability of the measuring process itself and of the behaviour of the measured data. Only a few minor aspects required optimization.

Whereas the above-mentioned checks were made after the exposure tests, measurements were also performed during the tests. For example, instruments were subjected to temperature tests from +20° through +50° to -20° and back to +20° in accessible climatic chambers. The alignment parameters were measured at each stage of the test. At the same time, information was obtained on how these instruments should be operated in such extreme conditions. The change in the collimation line as a result of temperature does not exceed that of conventional levels.

## **7. Using the DINi 10/20 for Measurements on Vibrating Ground and under the Influence of Magnetic Fields**

The measuring process in the DiNi 10/20 is relatively fast, reliable and uncomplicated. Measurements on vibrating ground are possible as long as the excitation amplitude is low. The measuring time may be slightly increased in this case. If the ambient conditions become too harsh, the measuring process is stopped and can be repeated by the operator at any time in improved conditions. This can be judged to a certain degree by the operator when viewing the visual measuring image.

The following can be reported on the first tests of the behaviour of DiNi 10/20 in magnetic fields: No significant influence of the steady magnetic field was detected, i.e. it remained clearly below the detection limit of 0.1 mm/km. This is ensured by the use of aluminium or non-magnetic special materials in the manufacture of all oscillating components of the compensator. The test was performed on the basis of the criteria applicable to the instruments NI 002 A and RENI 002 A. /6/

The compensator deflection detectable in stronger alternating magnetic fields and displaying roughly the same amplitude as in NI 002 A and RENI 002 A is of no importance in practical work due to the quadratic correlation between the deflection and the field strength and the locally restricted occurrence of alternating fields.

## **8. Summary**

As described above, the objective, automatic measuring technique of the DiNi 10/20 for reading the staff graduation completely replaces visual reading by the observer. The measuring process is fast and straightforward, and the resulting measured values are accurate and reliable. The extensive user interface and clear user guidance guarantee easy, reliable operation of the instruments. This was confirmed by the experience gained in the first measurements performed with the DiNi 10/20.

Due to its high efficiency, digital levelling - with the added benefits of the DiNi 10/20 - will rapidly make inroads into surveying and will open up new fields of application.

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