DIGITAL LEVEL
SDL1X
TECHNOLOGY FRONTLINE

SOKKIA

Introduction

Technical innovation in digital leveling

As electronic versions of traditional optical levels, digital leveling instruments have been in use for many years. A microprocessor is used to automatically measure height while an imaging element (image sensor) is used to read graduations on a staff bearing a printed barcode. The electronics eliminate the need for traditional estimation in leveling by a surveyor. Instead, leveling simply involves aiming the surveying instrument at the staff, focusing, and pressing a button. Measurement expertise is no longer needed to obtain good results. As with other digital surveying instruments, measurement data can be transferred via serial communication, which greatly facilitates data processing.

Our goal: the Formula One of levels

The SDL1X represents the culmination of many years of Sokkia R&D in leveling instrument technology. It was developed to be the world's highest-precision digital level. In an automotive context, this may be likened to developing a top Formula One racecar. The SDL1X is designed not only to offer the highest leveling precision (0.2mm standard deviation for 1km double-run leveling) but also to be even more user-friendly. Simply look through the newly developed view finder to adjust the line of sight, aim the surveying instrument at the staff, and press a button. All steps from focusing to measurement are performed automatically. Since digital levels were first conceived, Sokkia has been known for highly reliable and outdoor-ready levels that offer bidirectional measurement, thanks to our innovative RAB code (**RA**ndom **B**idirectional code). To continue offering a consistent user experience, the same barcode has been used for all levels to date, and our basic stance in design remains unchanged.

This white paper introduces development concepts, product highlights, principles of operation, and other technical information in detail, focusing on new features in the SDL1X.

SDL1X Overview

The SDL1X was developed with two priorities in mind: high precision and stress-free operation.

In precision, measurement with a BIS30A staff yields a standard deviation of 0.2mm for 1km double-run leveling conforming to ISO 17123-2. Several details support this high-precision measurement. The RAB-code level staff has thermal coefficients of expansion that are close to zero making it highly resistant to changes in ambient temperature. The compensator is extremely reliable, and the level's auto focus is designed to provide the sharpest barcode image to the image sensor every time. For easier operation, several new features alleviate the stress of surveying in various ways, which in turn supports high-precision measurement and reduces the need for remeasurement. These features and related user benefits are summarized in the following table.

Table 1. SDL1X features and user benefits

Feature \ User Benefit	Better Usability (Less Stress)	Better Precision (Eliminates Errors)	Better Outdoor Performance	Better Surveying Efficiency (Faster)
External design	◎		○	
Optimized image sensor control		○	◎	○
Auto focus	◎	◎		◎
View finder	◎			◎
Remote trigger	○	○		
Dual-axis tilt alarm	○	○		
Wide range of interfaces, built-in software	○			○
New Super Invar RAB-Code Staff BIS30A		◎	◎	

1. External design

The SDL1X inherits SRX design concepts: outdoor-ready yet refined. The stable, wide body and reassuring control panel support high-precision measurement and are very easy for novice surveyors to use.

2. Compensator

A hallmark of Sokkia levels is the pendulum compensator with a magnetic damping system. This component maintains excellent measurement reproducibility while reducing the control period until the pendulum stops moving, for consistent precision.

3. RAB code and measurement software

Another example of original Sokkia technology in the SDL1X is the highly reliable RAB-code pattern on the staff. We have maintained the same coding system in the RAB-code pattern since our digital levels were first introduced. For this reason, new and old Sokkia staves and levels (which run the built-in measurement software) are intercompatible.

4. Optimized image sensor control

The image sensor functions both in height measurement and auto focusing. We have optimized image sensor control by making significant revisions to the existing technology. This enhances the SDL series' acclaimed stability and measurement while improving outdoor performance and accelerating measurement.

5. Auto Focus

Polished measurement performance, combined with swift focusing motion, affords better usability. Auto focus locks onto the Sokkia RAB-code staff, not other objects, providing the sharpest barcode image to the image sensor for the ultimate in measurement precision. This represents the world's first use of auto focus in this class of digital level.

6. View finder

The "view finder" is a collimation telescope that helps ensure convenient and efficient auto focusing, and fast, accurate collimation.

7. Remote trigger

An IR remote trigger is provided. Use the dedicated DLC1 remote trigger to perform all steps from the start of measurement until recording without touching the level. Touching the level may lead to unintentional movement, and as a result, inaccurate results.

8. Dual-axis tilt alarm

Previous digital levels only detect tilt along the collimation axis, but the SDL1X provides a more reliable detection mechanism that also alerts users if the unit is tilted relative to the transverse axis. Audible notification of tilting, in addition to graphical representation of the leveling status, greatly facilitates the process of leveling.

9. Wide range of interfaces, user-friendly built-in software

The level offers many ways to efficiently transfer observation data for post-processing. Save data internally on the SDL1X or on storage media—USB flash drives or SD cards. For connectivity with computers or portable devices, both *Bluetooth*® and RS-232C are available. A critical point of contact with users during operation, the built-in software displays instructions to guide users through the measurement process. An easy-to-use row of soft keys, plentiful configuration functions, and other touches create a user-friendly interface for stress-free operation by any user, regardless of nationality.

## 10. RAB-Code Staff BIS30A (made of New Super Invar)

To date, the Sokkia New Super- Invar Staff GS-1 has boasted outstanding reliability for optical levels. Now updated with RAB-code graduations, the New Super Invar RAB-Code Staff BIS30A has the world's lowest linear expansion coefficient (see below). BIS30A is an ultra high-precision staff that unleashes the full potential of the SDL1X.

$\alpha = \pm 0.1 \times 10^{-6}/°C \ (\pm 0.1 \text{ppm}/°C)$

1 External Design

The subdued SDL1X color scheme, produced with environmentally-conscious water-based paint, follows in the tradition of SRX coloring. The refined shape combines angular contours and graceful, smooth surfaces. At the same time, a wide range of features are packed into the compact body, and design supporting high-precision measurement is evident in many details. Weight is evenly distributed to enhance machine accuracy. Uneven weight distribution would impair machine accuracy, even if perpendicularity of the rotation axis was good. For this reason, balanced weight distribution is ensured, accounting for the weight of each internal module, in a design that brings the center of gravity extremely close to the rotation axis.

The new view finder, housing the optics, is a fresh twist on the familiar telescope of surveying levels. The optics are integrated into the handle with an open space left between eyepiece between eyepiece and objective. Aside from being an original design, this construction places the peep sight in a more convenient position, supports long-range viewing, and keeps the unit more compact.
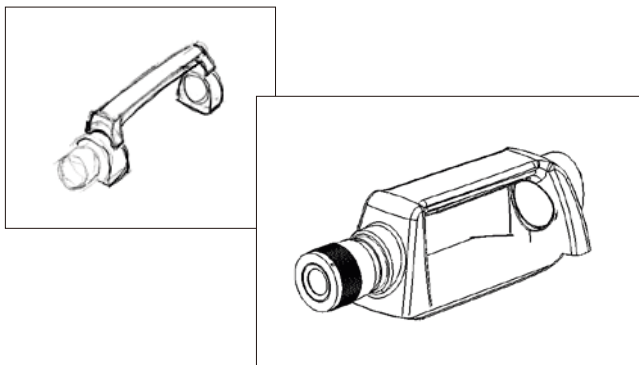
Figure 1. Sketch and CAD drawing of the view finder

Two points were intentionally revised from the previous SDL series. First, fine motion knobs were repositioned from the objective side to the eyepiece side. Because the body is now wider, the knobs were moved closer to the operator for easy access. Additionally, organizing control panel elements at the operator side simplifies operation and enhances surveying efficiency. Second, the focusing knob is now more flush to the body. Given the unit's new auto focus, this design decision makes sense considering how infrequently the knob is are used. Desirable aspects of the previous SDL series were retained, such as the arrangement of the measure key close to the rotation axis and an ample lens hood to prevent ambient light from impairing precision.
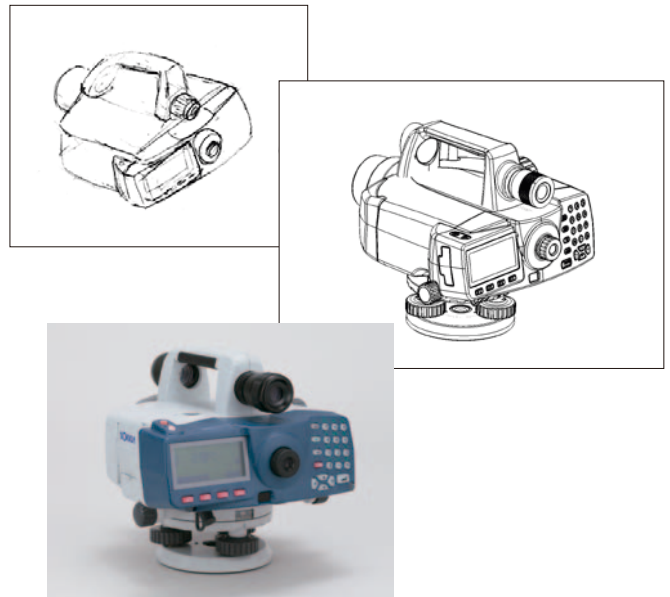
Figure 2. Body design: sketch, CAD drawing, and final design model

For high-precision measurement, a remote trigger is indispensable. This enables users to initiate measurement without touching the level. Because the remote trigger is virtually an extension of the operator's own body, it was designed to be a size and shape that fits in one hand as the operator controls the level. The keys are optimally positioned and a minimum number of keys are used, enabling control without looking. The DLC1 remote trigger combines all of these characteristics for superb usability.

Figure 3. Remote trigger design: sketch, CAD drawing, and final design model

2 Automatic Compensator

The level's compensator can be described as a pendulum system. Gravity brings the pendulum on which a mirror is suspended into horizontal equilibrium. Because magnetism is used to rapidly dampen the pendulum, we refer to this mechanism as magnetic damping. Damping is rapid, but no undue force is applied. The appropriate force for magnetic damping is reflected in the design, for a compensator with superb leveling reproducibility (see Figure 4) and a short damping time after collimation until the pendulum is still (see Figure 5).

The pendulum itself is made of highly antimagnetic material, preventing residual magnetism. As a result, the compensator is not affected by magnetism despite employing magnetic damping.
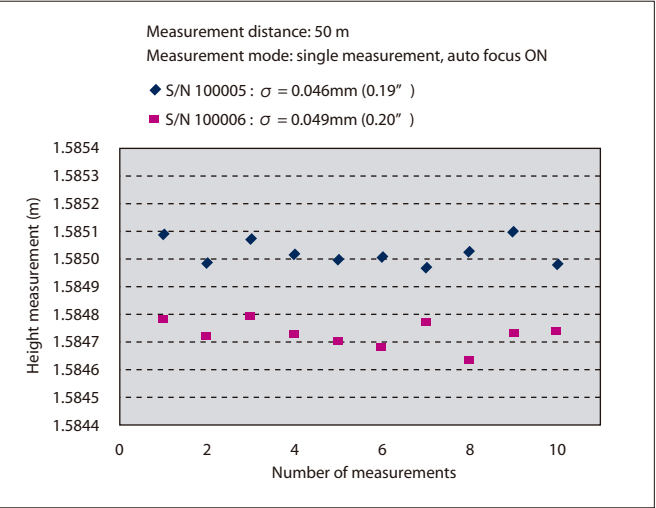

Figure 4. Reproducibility data for height measurement (Rotated 360° horizontally for each measurement)
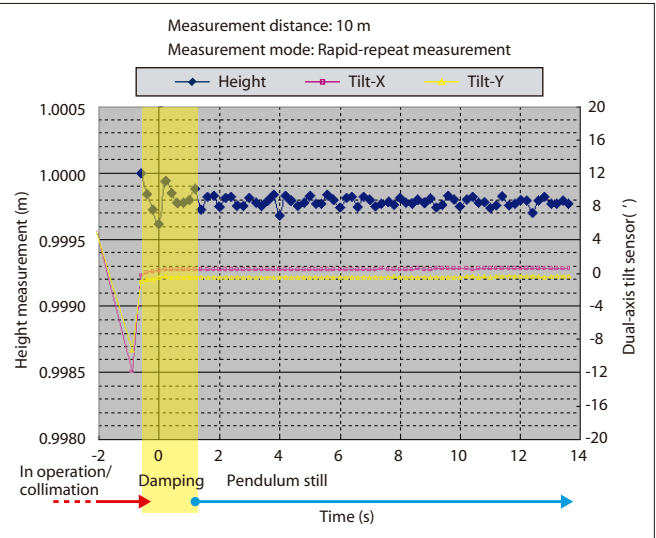

Figure 5. Time after pendulum damping until stillness

3 RAB Code and Measurement Software

Using a built-in image sensor, the digital level reads patterns on the staff. Highly exact values can be calculated for the collimation position (height). The pattern printed on the SDL1X staff is a digital barcode, with the width of each black line representing one element of code (one symbol).

At close range, fewer lines of barcode are read, but the subtle difference in line width is detected. The acquired image is converted to a six-element code. At a greater distance, the opposite applies: more lines are read, but because the resolution is lower, subtle differences in line width are not discernable. Thus, the acquired image is converted to a three-element code. The widths of black lines and corresponding RAB code are shown in Table 2. Because this code system enables identification of the collimation position with as few elements of code as possible (based on conversion in Table 2), correct measurement is possible even when the staff is partially concealed or in the shade, preventing some code from being read. The level automatically distinguishes between staves held right-side-up and those inverted.

Table 2. RAB code conversion table

Black line width (mm)	Six-Element Code (at close range)	Three-Element Code (at a distance)
3	0	0
4	1	
7	2	1
8	3	
11	4	2
12	5	

The black lines are evenly spaced, relative to the middle of each line. This pitch between lines is used in electronic measurement of stadia distance, enabling highly precise measurement of distance to the staff.

Moreover, the measurement software processes each black line separately. This eliminates overall miscalculation if some lines cannot be read and makes it possible to obtain the collimation position from the remaining information.

In this way, both the barcode pattern and measurement software have been developed to make measurement less susceptible to the effects of shading or interference. We have maintained this approach since 1998 when the SDL30 was introduced, and the system is used for staves with all SDL models (SDL30, SDL30i, SDL50, and SDL1X).

Figure 6. RAB-code pattern

4 Optimized Image Sensor Control

Using auto focus under lighting conditions subject to sudden changes requires sophisticated and speedy image sensor control. Control system requirements in both hardware and software were designed to allow optimized image sensor control. The result is superior measurement performance, because the RAB-code pattern is read under optimal conditions whether the staff is viewed in bright settings (such as against the sunset) or under uneven light, as when light filters through branches in a forest. This optimization of image sensor control ensures consistent auto focusing not only in response to environmental factors but also accounting for movement of the focusing lens.

5 Auto Focus

1. Concept

With most traditional digital levels, sighting and focusing on the staff are tasks that depend on visual determination by the operator peering through the eyepiece lens. Focusing therefore involves an elemeny of error. Once measurement results are obtained, however, it cannot be determined whether the effect of this error has been accounted for. Just how much this error can be reduced (at what point is the instrument perfectly focussed) depends on the judgment of the operator.

For this reason, the SDL1X is designed to provide the optimal focal conditions the sharpest barcode image, for the image sensor at all times, eliminating human error in focussing. Moreover, we have also addressed problems of existing auto focus functionality: focus is accidentally set at the wrong point; confusing; time-consuming; stressful for observers. Sokkia's auto focus eliminates these problems to the greatest degree possible, for easy and stress-free operation.

2. Principle

A passive method of auto focusing is employed by the SDL1X, combining electronic stadia measurement and contrast detection. It can be described as passive because, unlike active auto focus involving auxiliary lighting or a distance measurement beam independent of the telescope optics, no such lighting source is used. Instead, images captured by the image sensor are the sole basis for determining focus.

The sequence of auto focus control is shown in Figure 7. When the stadia distance is calculated electronically, the even spacing of RAB code determines whether the object of collimation is a RAB-Code Staff, and the general distance to the staff is calculated.

Next, from the general distance, the lens position for ideal focus is calculated, and a method of detecting contrast near the lens position is employed to determine the optimal focusing position for the image sensor.
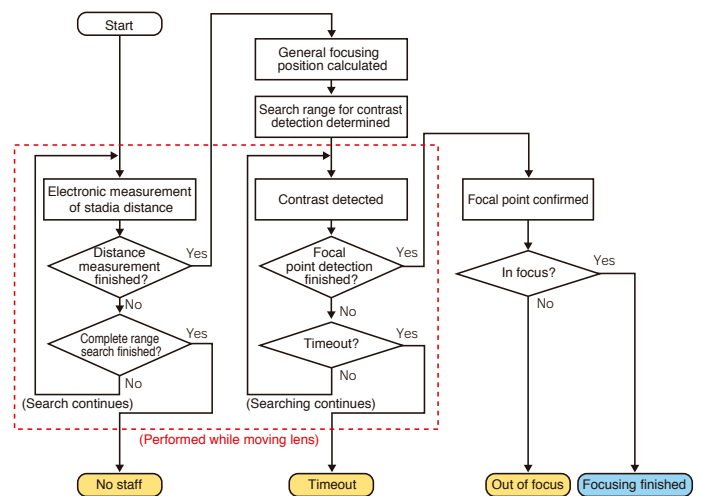

Figure 7. Auto focus control flow

This combination of electronic stadia measurement with contrast detection prevents the SDL1X from mistakenly focusing on objects other than RAB code, eliminates confusion in operation, and creates optimal focusing conditions for the image sensor. The result: truly ideal auto focusing with no human error during measurement (see Figure 8).
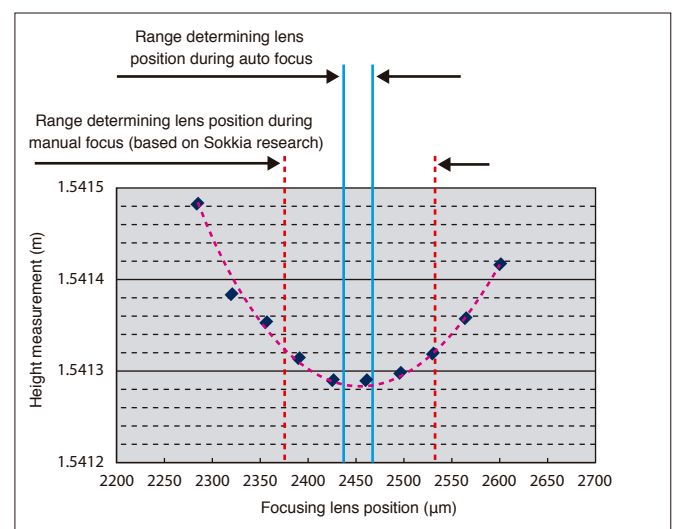

Figure 8. Variation in height measurement results depending on focusing lens position (distance: 30m)

3. Structure

The SDL1X auto focus mechanism is shown in Figure 9. The data acquisition section of the image sensor captures data both for auto focusing and height measurement.

The focusing lens position detection section supports an innovative method for detecting the absolute position of the focusing lens directly (patented). It is carefully constructed to avoid affecting movement by the focusing lens tube.

This detection section feeds back the exact position of the focusing lens to the enabling fast, exact position control of the focusing lens. A valuable feature of this function is that the focusing lens position is not returned to the origin when the level is powered on or when manual focus is used during leveling. Rotation of the focusing knob shaft is converted by the rack-and-pinion mechanism to a reciprocal motion for the focusing lens. The focusing knob is directly attached to the focusing knob shaft allowing the manual focus of previous models. On the other hand, the focusing lens drive section used for auto focus is connected to the focusing knob shaft via a friction clutch. During auto focus, it is through this clutch that the drive section moves the focusing lens. Another advantage, from the point of view of ease-of-use, is that this structure renders a switching operation between manual focus and auto focus unnecessary.
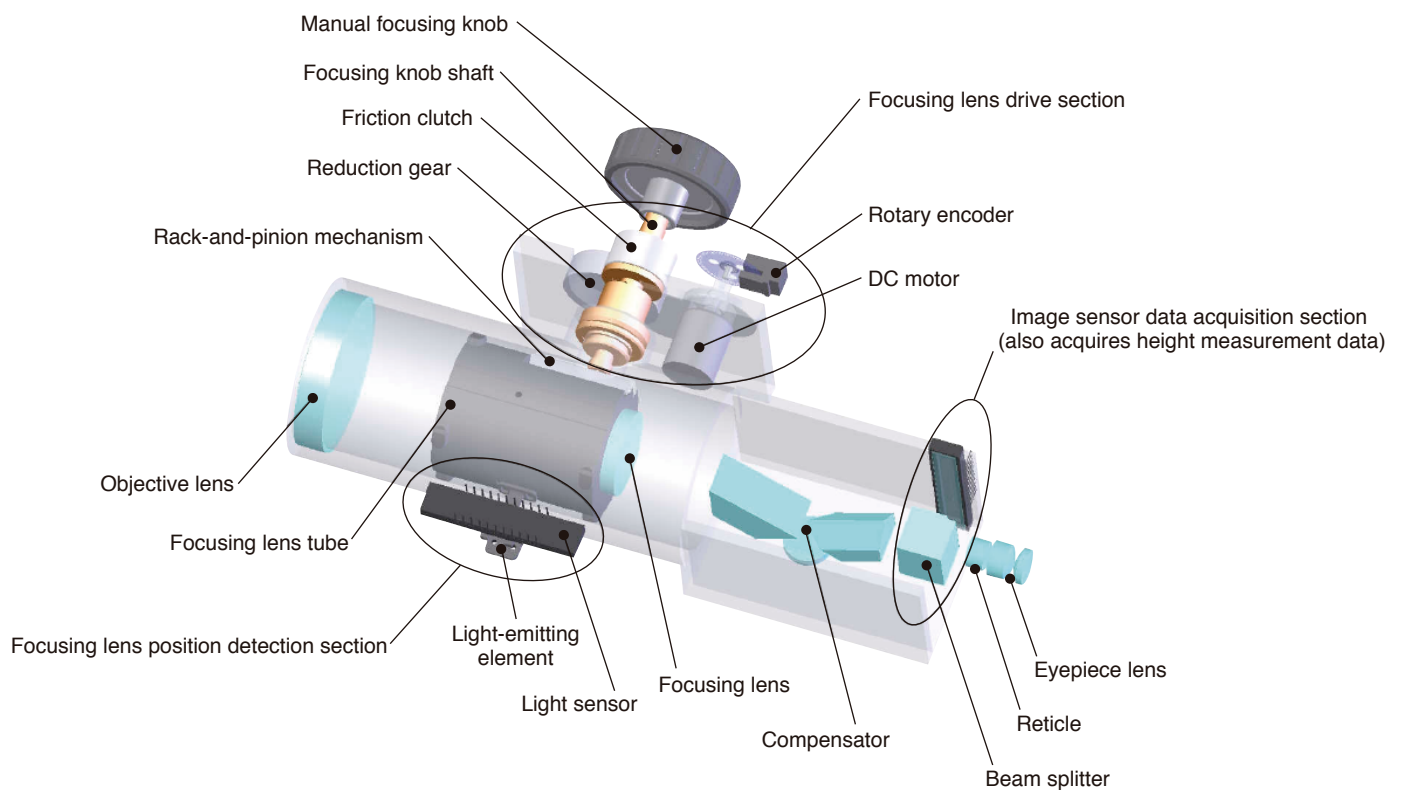
Manual focusing knob
Focusing knob shaft
Friction clutch
Reduction gear
Rack-and-pinion mechanism
Objective lens
Focusing lens tube
Focusing lens position detection section
Light-emitting element
Light sensor
Focusing lens
Focusing lens drive section
Rotary encoder
DC motor
Image sensor data acquisition section (also acquires height measurement data)
Eyepiece lens
Reticle
Beam splitter
Compensator

Figure 9. Auto focus mechanism

6 View finder

The view finder is a small scope (3° field of view, 4.5x magnification) that supports accurate sighting of the staff prior to focusing, allowing smoother operation of the subsequent auto focus and measurement stages as a result. As a fixed-focus scope set at 50m, it requires no focusing. The optical design provides long eye relief, eliminating the need to bring one's eye close to the instrument when sighting, making the view finder easy to use for operators who wear glasses.

These characteristics contribute to a higher magnification, and therefore greater collimation precision, than that of most gun sights (peep sights). What's more, quick sighting of the staff is made easier as the field of vision is wider than that of the level's telescope and there is greater eye relief at the eyepiece.

Figure 10. Sighting with the view finder

As shown in the cross-section (Figure 11), the view finder is separated into two sections composing opposite ends of the instrument handle, one unit on the objective side and one unit on the eyepiece side. In front of the objective lens is an adjustment mechanism comprising a pair of glass wedges. These wedges are used to align the view finder's telescope axis with that of the level's telescope, and are adjusted by means of the view finder axis alignment screw on the objective side. The view finder image is brought into focus by means of an view finder eyepiece screw on the eyepiece lens side. In either case, adjustment is easy for users. (patented, design registered)
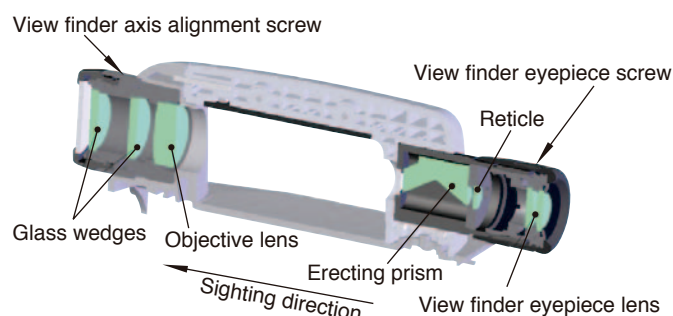
As shown in Figure 12, the view finder reticle image consists of four concentric circles. The outer pattern corresponds to the field of vision of the level telescope (1° 20'). The diameters of the three patterns within this correspond roughly to the width of RAB code bar (22mm) when sighting an invar staff 50m, 25m, and 10m away, outward from the inner circle.
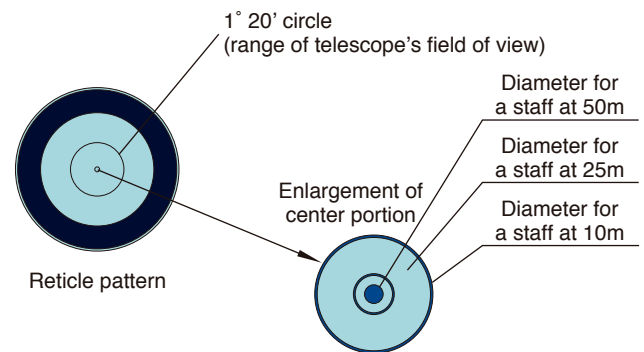

Figure 12. View finder reticle image

Figure 11. View finder cross-section

7 Wide Range of Interfaces and Built-in Software

The SDL1X's software is organized into three menus, as shown in Figure 13: Measurement, Management, and Configuration. Height difference measurement in the Measurement menu enables measurement in accordance with a preset measurement procedure and user-specified tolerance values. Seven measurement procedures are available (BFFB, BBFF, BF, aBFFB, aFBBF, BFBF, and aBF), as are a variety of detailed settings such as maximum/minimum distance limits and upper/lower tolerances on height readings. The step-by-step instructions on the instrument screen and the preset tolerances allow the user to keep track of results at each stage of measurement.

Additionally, a pre-measurement function is available at each instrument position before the actual measurement is begun to confirm that distances to the foresight and backsight are roughly the same. As precise leveling of the instrument is not necessary at this preliminary stage, the tilt warning is temporarily disabled. This pre-measurement enables confirmation of the instrument position, and can save time when relocating to correct an error, thereby promising better working efficiency.

The Route option in the Management menu enables route configuration, deletion, data exporting, and data review. In route settings, up to five configuration patterns (measurement procedures and tolerances) can be pre-set, making it easier to create route settings data under preferred or often-used conditions. Route data can be transferred via the serial port (RS-232C) or via *Bluetooth®*, or saved on a USB flash drive or SD card.
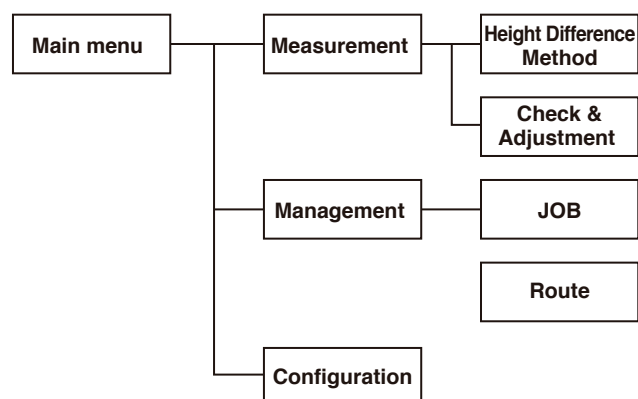

Figure 13. SDL1X application menu structure

8 New Super Invar RAB-Code Staff BIS30A

In measurement with digital levels, a key factor determining measurement precision is the precision of the staff. Attaining a 0.2mm standard deviation for 1km double-run leveling with the SDL1X therefore meant we needed to develop a new staff. This new RAB-Code staff, BIS30A, has highly precise graduations with a coefficient of linear expansion of nearly zero.

The band on which graduations are printed is made from New Super Invar. This special alloy has a negative linear expansion coefficient. One end of the graduated band is attached to an anchor at the bottom of the staff's aluminum outer frame, and the other is attached to the same frame indirectly, through a coil spring (see Figure 14 below).

The outer frame and coil spring together have a positive coefficient of linear expansion, and offsetting the spring constant and coefficient of negative linear expansion of the band yields a negligible linear expansion coefficient for graduations overall.
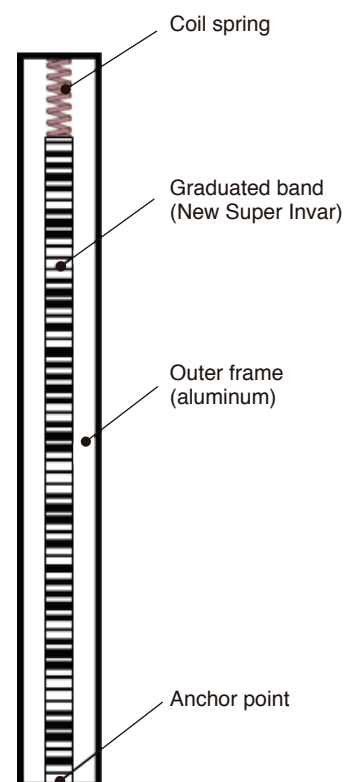

Figure 14. Structural diagram of BIS30A

Specifically, the structure responds to increases in temperature as follows. Because New Super Invar has a negative linear expansion coefficient, the graduated band contracts under higher temperatures. In contrast, the positive linear expansion coefficient of the outer frame causes the frame to expand. The result is that the tension of the aforementioned coil spring increases and stretches the graduated band. The contractive force is balanced by this tension, maintaining a constant length in the graduated band. Because the coil spring tension, and therefore the force exerted on the contracting band, can be adjusted using the spring constant and the total spring length, we have been able to develop a linear expansion coefficient for graduations (α) that conforms to the following equation.

$$\alpha = \pm0.1\times10^{-6}/°C\ (\pm0.1ppm/°C)$$

High graduation precision requires highly precise positioning of the RAB-code pattern in which graduations are printed. The boundary of each black line must be flat on the surface and free of any kinks or distortion. To ensure superior positioning precision when etching on to the band, a length gauge (laser interferometer) is used to compensate for environmental changes in real time when determining the position of each graduation. As a result, the correction value or discrepancy representing positioning precision is within 20μm of graduation design values per meter. Additionally, special coatings and Sokkia laser etching techniques are used to produce RAB-code patterns that are clear and have exact boundaries.

9 World's highest precision: 0.2 mm
(standard deviation for 1 km of double-run leveling)

The technology introduced in this brochure has pushed the boundaries of measurement precision in the SDL1X. The SDL1X inherits the advances made in preceding SDL products while reducing the scope for error further still thanks to the superb leveling reproducibility achieved with the automatic compensator and higher measurement precision achieved with auto focusing.

A combination of superior materials and innovative staff construction has minimized linear expansion, eliminating error derived from ambient temperature fluctuations during measurement. Moreover, exceptional precision in graduation printing translates directly into better measurement precision. Scientific theory and practical experience have enabled us to achieve a satisfying level of precision faced with the error factors mentioned above. We have confirmed an accuracy of within 0.2mm per km (double-run leveling) using both ISO 17123-2 evaluation standards and actual measurement.

Conclusion

In leveling, the level and staff are moved, in turn, to determine relative elevation along a route. The operator needs to concentrate when sighting and focusing on the staff, with extended periods of work leading to fatigue. Such stress can be greatly alleviated by using the level's newly developed view finder and auto focus features, which also improve the measurement precision and produce more consistent results. What's more, auto focus works exclusively on staves with RAB code, eliminating errors in collimation or accidental reading of staves with other barcode. These advances enable more efficient work in the field.

The SDL30i was developed based on the SDL30, a model widely used in measurement work. Like previous models, the SDL1X promises to be a popular instrument not only in surveying but in other measurement applications as well, thanks to its high-precision measurement and the convenience of auto focus. The SDL1X was developed incorporating the best technology used in applications from optical levels to total stations, and it will contribute significantly to higher precision and greater efficiency in leveling.

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