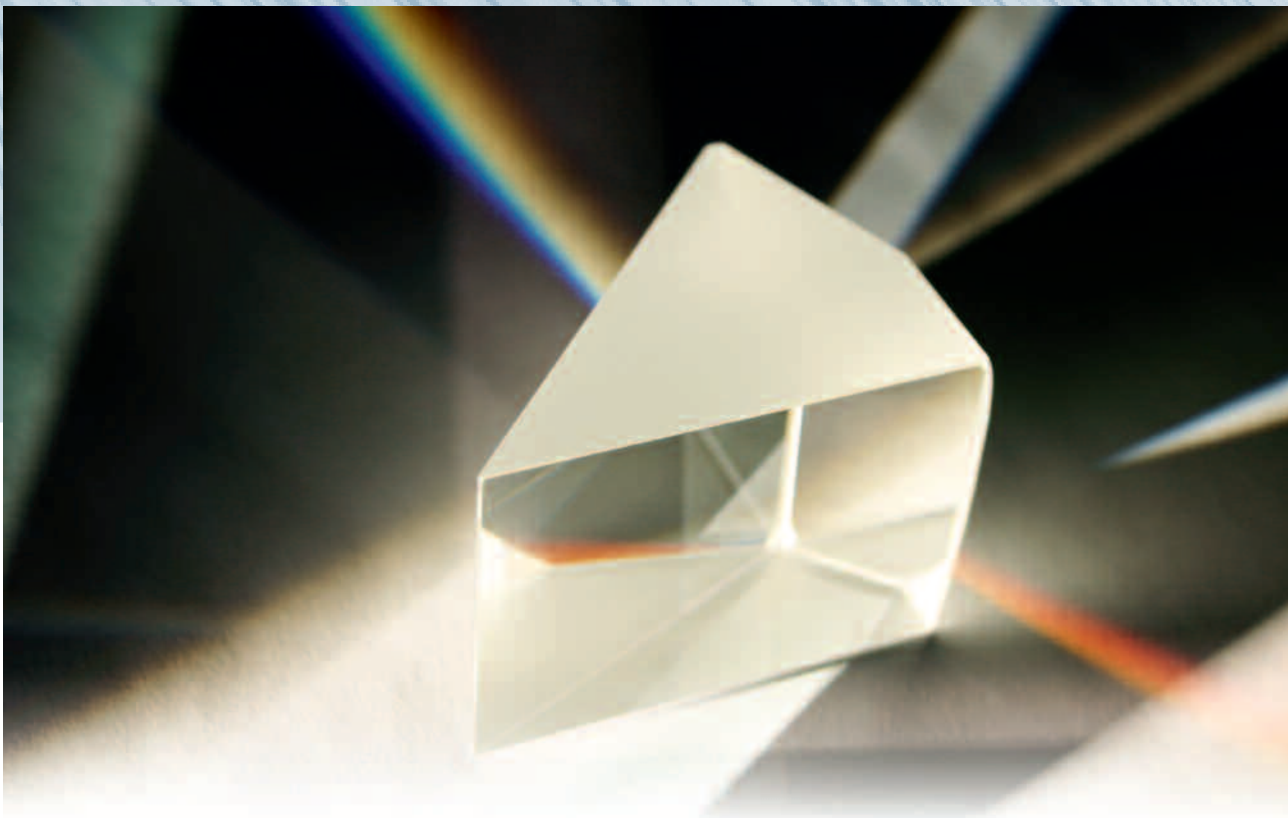
Don't be afraid of ghosts!

RELIABLE AUTOMATIC MEASUREMENT OF ANGLES

on plano-optical components. High precision, automatic and reliable: How automatic goniometers with intelligent measured data analysis and a sophisticated hardware setup are overcoming the traditional difficulties of measuring angles on prisms.



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When constructing high quality optical systems, setting narrow tolerances for the optical components used is a must. This not only applies to coatings, glass types, surface properties and lens parameters, but also to the angular precision of plano-optical components. Because they reverse, fold, reduce, split or join the beam path, deflecting prisms perform hugely important tasks in optical systems, and any faults can have a major impact on the overall optical performance. This is aggravated by the fact that individual faults accumulate through the system. A dependence on off-the-shelf products, perhaps with unacceptable variations in angle, carries the risk of reducing the potential for optimizing the optical system.

The standard way to ensure the quality of the end product is to employ rigorous component testing. Automatic goniometers are increasingly being used to verify and measure the angles of prisms. The plane angles are determined by autocollimators using a measuring beam reflected by the prism's surfaces. This measurement method delivers excellent precision in the arc-second range.

Classic problem: ghost images

However, one problem with the conventional method is the fact that, in addition to the light bundle reflected directly from the measuring surface, light bundles reflected by other prism surfaces also produce an autocollimation image (known as ghost images, see **Figure 1**). As a result, it is necessary to differentiate between relevant – that is, produced by reflection on the measuring surface – and apparently irrelevant autocollimation images caused by multiple reflection. Making the wrong decision at this point inevitably leads to measurement errors. On prisms produced with very narrow tolerances, the ghost images can also merge. This falsifies the measurement, constraining the measuring accuracy in the very situation

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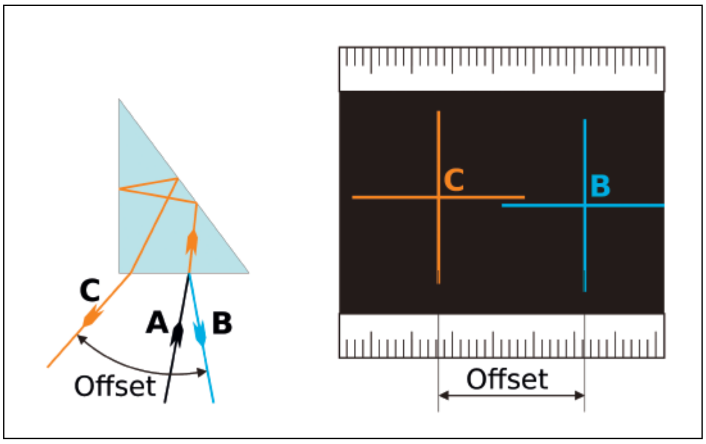
where the requirements are most demanding. The classic solution to this problem is to apply a temporary reflective coating to measuring surfaces or to apply a wax coating, but these steps require significant effort and are thus time consuming.

Trivial approaches are unreliable

If one needs to perform reliable measurements in the shortest possible time, overcoming the ghost image problem that is typical of reflection prisms, one ideally needs a goniometer that supports the user if multiple reflections occur, or that is even capable of differentiating relevant from irrelevant reflections itself. One trivial solution that is widespread in the market is to look at the intensity or distortion of the autocollimation images and to designate the reflection with the highest intensity as the relevant surface reflection by default. However, if the beam path includes total reflections (from roof edges or 90° prisms for example), silvering or anti-reflective coatings, this approach can no longer be used, as irrelevant reflections from other functional surfaces may have a higher intensity in such situations. An automatic goniometer that only utilizes this method will deliver incorrect measured values. In this case, simple blind faith in the reliability of a goniometer means that these grave errors will go unnoticed.

The ›Goniomat‹ series of automatic goniometers produced by Möller-Wedel Optical allows automated high precision angle measurements at high speeds (**Figure 2**). At the same time, their design ensures that none of the product features related to automation can jeopardize the reliability of the measurements.



1 The occurrence of ghost images on non-ideal 90° prism: The incident beam bundle A produces both the directly reflected bundle B and, due to refraction and (total) reflection, also bundle C. This results in two offset images in the autocollimation image (right).

Virtual tilt table and short focal length

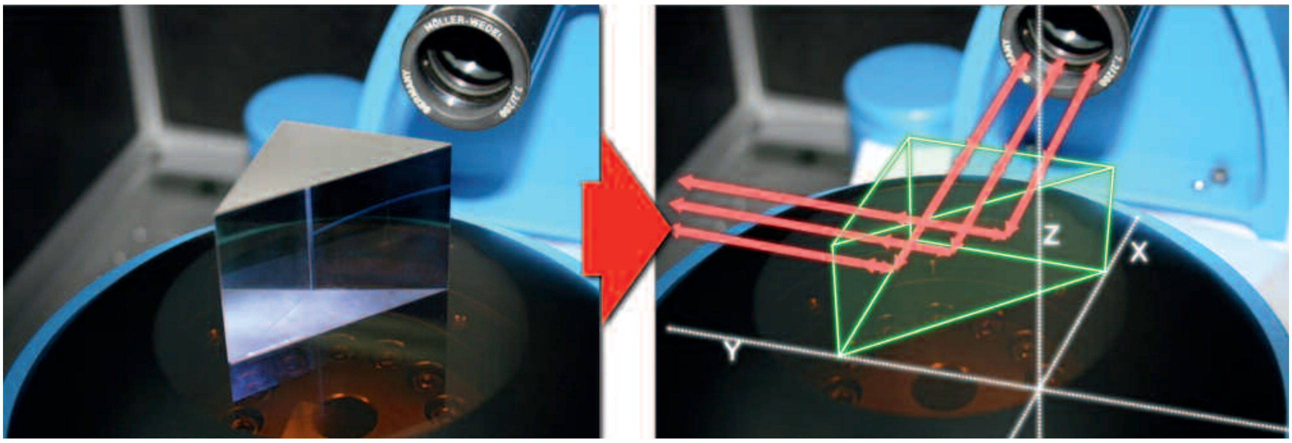
Here, an innovative approach is key in order to properly address the problem. Instead of an adjustable tilt table for holding the specimen, a combination of a fixed measuring table and an autocollimator with short focal length is used. Conventional goniometers use a mechanically adjustable tilt table to adjust the

2 Modern goniometers (shown here: ›Goniomat A‹ from Möller-Wedel Optical) feature short focal length autocollimators and rigid measurement tables.

prism and thus the measuring plane for the angle measurement. The measuring range of the autocollimator on these goniometers is normally small, as a long focal length is needed to meet the accuracy requirements. In many cases, however, the limited measuring range of the autocollimator is insufficient to detect the usual pyramidal variations of specimens. As a result, a mechanical tilt table is essential for these goniometers. If this is adjusted for one specimen, the pyramidal variation for the next series will be different and further adjustment will be needed. For pyramidal angle measurements relative to the basic plane, the table has to be adjusted and recalibrated using an additional tool. By contrast, goniometers from the Goniomat range use autocollimators with short focal lengths, giving them a correspondingly wider measuring range. This eliminates the need for an adjustable tilt table. The manufacturer's expert knowledge in development and production of ultraprecise autocollimators ensures that all accuracy requirements are still met, in spite of the short focal length. The measurement table undergoes a one-off initial calibration in the factory and its fixed configuration then delivers reproducible measurements of pyramidal error. The measuring plane for plano and pyramidal angles can be automatically tilted by the software based on a vector calculation, and can be changed or adjusted to meet the applicable standards even after recording the measured values.

Intelligent data evaluation

Based on the measured data recorded, a sophisticated data evaluation system tackles the problem of ghost images. The measurement and analysis software is equipped with as a ray tracing module, which creates a three-dimensional model of the prism geometry in the system (**Figure 3**). The module produces an accurate physical simulation of the measuring beam, along with its reflection and refraction at the prism surfaces, enabling additional information about the measurement to be obtained. In particular where multiple reflections can occur, the system can reliably differentiate between relevant and irrelevant reflections. The intelligent data analysis system does this by using the information from all of the autocollimation images to arrive at a decision. This includes using ghost images that obviously bare no value for the measurement. This method ultimately smoothes the way to achieving genuinely automatic prism measurements without the need for additional intervention. Even if the ghost images merge, the solution offers an effective way of maintaining the measurement accuracy of the goniometer. The manufacturer's development team is currently evaluating the options with a view to integrating them into future versions of the software. In such cases, the system currently issues a warning message and, unlike most other devices on the market, draws attention to the increased measurement uncertainty.



3 The ray tracing module internally records and simulates the geometry of the specimen and all beam bundles in three dimensions.

Summary

State-of-the-art automatic goniometers allow plano-optical components to be tested and measured much more speedily and efficiently than with conventional goniometers. The innovative method of intelligent data evaluation using computer-based ray tracing is the only way to achieve effective solutions that perform fully automatic measurements with the required level of reliability. ■

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