Collection of manufactured and completely quality-controlled telecentric measuring optics

Fast quality control of lenses in series production

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Despite the importance of imaging optics for the success of quality control in many areas, the statements about the production quality of these lenses are inadequate. The lense manufacturers' fear of time-consuming testing of the imaging quality of their optics is unfounded. OptoMess offers extensive examinations, e.g. white light MTF and asymmetrical distortions which can be done fully automated and recorded within a short time in laboratory and production surroundings. Moreover, on-line corrections to fine tune a lense are possible. Many examinations provide optic designers with information about the offset between optic design and optics production.

In the century of the photon optical techniques increasingly gain importance in dimensional technologies and adjoining disciplines, especially in conjunction with image processing methods. Likewise, the importance of the optics used is increasing as well as the demands on the quality of such systems. In contrast with inspection methods in production becoming more and more ingenious, quality control of the used optics remains at a low level. Only a small number of measurement optics are tested individually and completely before delivery. The number of those delivered with a quality report is even smaller. It is still custom to declare the design data of an imaging optics as the performance data of the produced sample.

For this reason, only a few optics manufacturers have representative data available about the influences of their series production on the long term quality of the optic design. This does not mean that quality control is foreign to optic manufacturers. Occasionally, spot checks are made especially on the basis of the MTF, the optical transfer-function [1-4]. However, the complete scope of the specified performance data is tested by only a few manufacturers, and certainly not 100 percent completely in series production.

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Asymmetrical imaging errors – a characteristic of lense production

It is to be remarked that the norm for the examination of the distortion [5] concentrates on radial distortion. It is normally determined by the optics design, which in term makes concessions to the imaging quality due to the costs of production. Asymmetrical distortions are due to the less than ideal quality of production. No optics can be manufactured completely free from asymmetrical imaging errors since the production always adds tolerances to the system. Since these are not directly calculable but rather assessable only through tolerance simulations, it is a demand on quality control to measure the imaging quality of the produced lenses as completely as possible.

Figure 1. OptoMess measurement bench

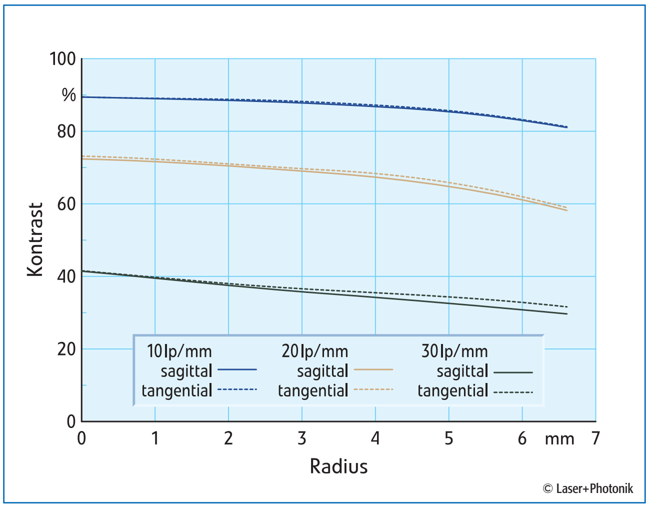


Figure 2. MTF: Modulation vs. picture height for three image frequences

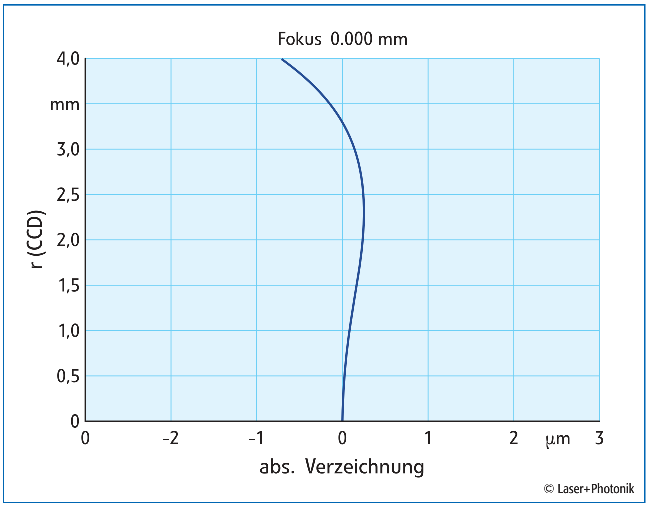


Figure 3. Transfer function in dependence of image frequency

To test the MTF only as a substitute for the specified performance data is the wrong approach since alterations in the MTF and the remaining imaging errors normally have different causes. Conclusions cannot be drawn. Ff the distortion of a sample changes in relations to the standard, its MTF need not change necessarily, and vice versa – in other words, if the distortion of the lenses has been specified for a certain customer, it has to be tested.

Quality control need not be expensive

The final argument against complete tests in optics production is, like elsewhere: »Complete quality control is too expensive.« As long as the customer accepts it, this practice can be continued. With the existence of the OptoMess measurement bench the argument is no longer valid. Highly skilled personnel to operate the system is necessary only in the teach-in phase. The actual quality control can be operated by the production personnel, since only predefined measurement and protocol definitions have to be loaded. There is no need for adjustments when changing sample.

This allows a quick and complete recording of production with regard to white light and/or spectrally weighted MTF, distortion, asymmetrical imaging errors, vignetting and further optical characteristics. The costs of quality control can be easily compensated for if the reported results can be used to identify high performance samples of the production and to offer these for a price corresponding to their quality.

Analysis options: classical analysis

MTF: MTF is the main criteria for quality. Starting at the modulation

$$M = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \qquad (1)$$

of a radiation quantity I, the optical transfer function T(R) is attained in dependence of the image frequency R by

$$T(R) = \frac{M_{image}}{M_{object}} \qquad (2)$$

The usual testing approaches for the MTF [2] require incoherent monochromatic illumination. The object area is scanned in a time consuming manner by means of a slit, of which the image is in turn scanned by means of a slit in order to increase precision. Calibration and adjustment procedures as well as the measurement itself require highly skilled personnel.

When using OptoMess however, MTF measurements are taken using the same target as the other examinations, with a one-shot-technology for the entire image field using white light or spectrally filtered light. This makes it possible to make fast measurements, with highly qualified personnel only being needed during the teach-in phase. An exemplary MTF measurement is shown in figure 2. »

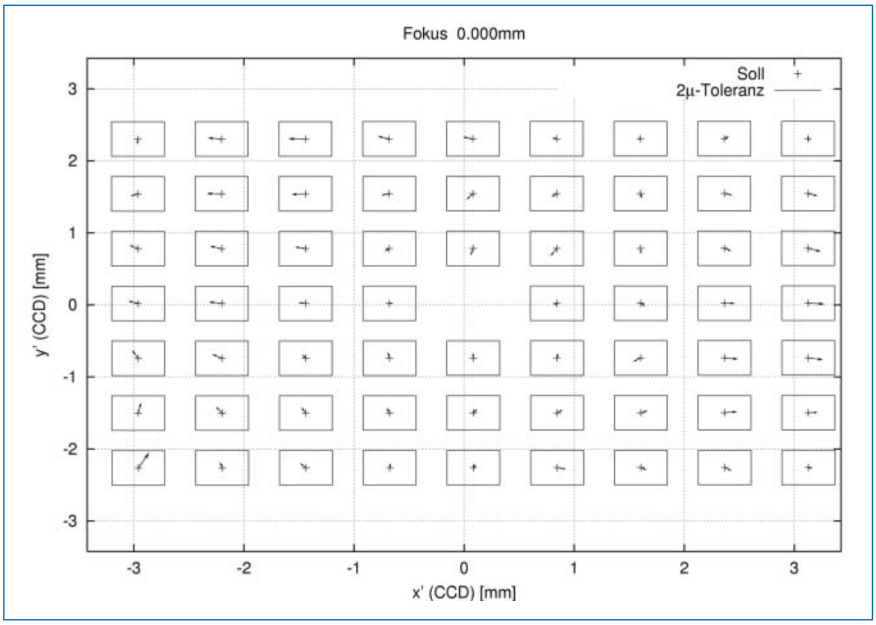


Figure 4. Zoomed illustration of the absolute distortion in the picture area: The arrows correspond to the distortion measured at the target spots with their scaling illustrated by the drawn rectangles which mark ± 2 µm

Distortion: The second classical optical parameter is distortion. An optical image formation is in first approximation described by the paraxial magnification scale ß' connecting object height h and image height h':

$$\beta' = \lim_{h \to 0} \frac{h'}{h} \qquad (3)$$

The distortion describes the effect of a varying magnification scale in the image field - symmetrically because of design limitations and asymmetrically as a result of production tolerances:

$$V_a = h' - \beta' h \qquad (4)$$

The underlying DIN 58187 (on the evaluation of the quality of optical systems [5]) limits itself to a description of the radial symmetrical distortion, scanned at view points within the image field.

Figure 3 shows the absolute distortion in the image field of a high quality lense.

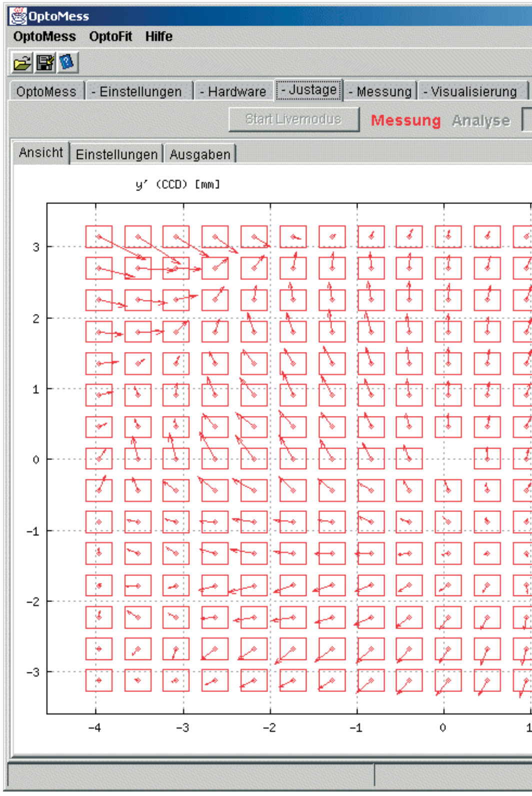
Asymmetrical imaging errors: OptoMess' zoomed illustration of the distortions of individual target spots provides information about asymmetrical errors.

Figure 4 shows in a ›zoom-manner‹ for each measured target spot its individual distortion in direction and amount by means of an arrow: it connects the ideal paraxially defined spot image with the real one generated by the test lense. Rectangles are shown which visualise a chosen tolerance. In the example shown this is 2 µm; i.e., each rectangle represents a tolerance of ± 2 µm, which forms the scale for a fast visual comparison of the measured distortions. Since the target spots can be used for the evaluation of distortion and MTF, special spots can be chosen for the MTF evaluation in order to show asymmetrical effects in the MTF of the test lense. A typical application is the MTF evaluation at the four corner spots, which show misadjustments very sensitively.

Live-analysis: The major challenge in optics manufacture lies in individual error correction. If there are deviations between the measured performance and target specifications for highly priced lenses, these must be corrected. Conventional inspection methods are no option since either the time required for the examination is too long for this procedure to be profitable, or the analysis data is based on inherent rotation symmetry which cannot be used for corrections.

Using the OptoMess method of analysing asymmetrical imaging errors the effect of a correction of the test system can be grasped more quickly then by studying averaged rotation symmetry. Since typical production errors such as the decenter or tilt of lenses evoke asymmetrical errors, the maximum sensitivity required to recognise such errors and the changes due to correction measures can be shown only by a depiction of the asymmetrical errors.

Now a dream has come true for quality testing of optics: errors in the manufacture of optics can be corrected while simultaneously analysing the optical capabilities of the system – challenging optical designers to leave means of corrections in the manufactured optics. This way, a manufactured optical system can be adjusted for maximum performance within a short time.



Closed-loop optic design and control: A step further is the option of evaluating the measurement results of OptoMess by means of the optic design program. Since the design for the tested optics is available, it is possible to reproduce the measurement results through the design program. Such a closed-loop between development and examination makes for an extremely efficient error correction, since the error producing elements are identified and necessary corrections can be de-

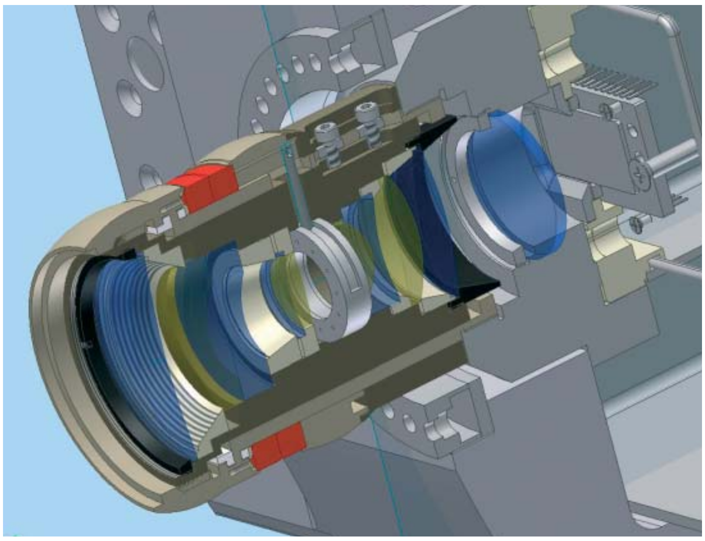


Figure 6. Optical 3D probe with IB/E optics

Figure 7. Wide-angle hybrid optics with diffractive elements for high-dynamic imaging

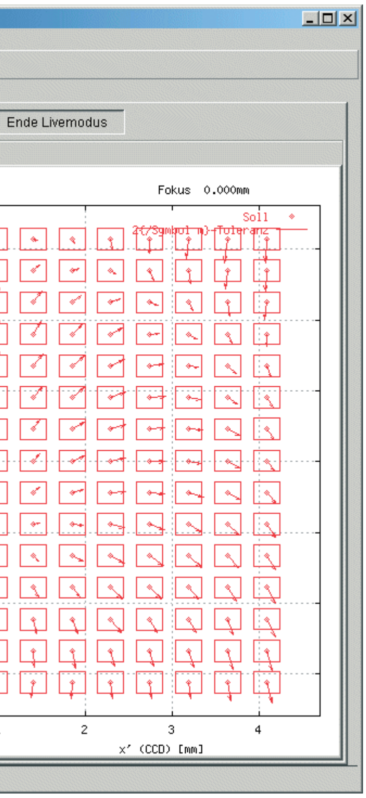


Figure 5. Illustration of an asymmetrical analysis in the live mode of OptoMess

termined. Corrections can be effected in a very short time since there is no need for time consuming trial and error procedures. Of course experience is required to detect the right elements and tolerances as sources of error. But this skill is required only once when setting up this method of analysis.

This procedure is superior to live-evaluation where lenses must be disassembled for error correction. An improved performance using the trial and error method would become very time-consuming due to the additional working steps required when assembling and dissembling.

Application examples

Complete quality control of telecentric measurement optics: We developed the measurement bench OptoMess to enable us to completely protocol our own production of telecentric measurement optics. For us, it was standard procedure to test each manufactured lense with regard to all its specifications. Simultaneously this also enables us to gain very specific data on the ways high quality lense designs are changed by the tolerances involved in the production of series. This experience in conjunction with requests by customers for affordable lenses and an appropriate quality have led to the development of two product-lines at present: telecentric measurement optics with vanishing telecentric errors in standard and in high quality.

Application optical 3D mesurement technology: Geometric measuring procedures that are based on optical imaging place extreme demands on the quality of imaging optics. Where fast computers are working on the evaluation of the image data, symmetrical imaging errors can be corrected easily, but production induced asymmetrical imaging errors cannot. In this area of high priced and high quality optics an exact quality control of production is needed in order to minimise asymmetrical imaging errors. As an example figure 6 shows an optical 3D probe with projection and imaging optics.

Application low priced lenses for automotive area: Lenses for automotive applications are a typical example of the extreme limits on per-piece-expenses with simultaneously high production quantities. A fast quality control system will quickly pay for itself when used in series production. The adapted quality control possible with OptoMess allows fast insertion of the lenses to be tested parallel to the measuring procedure, when the system cannot be integrated directly into the assembly belt. The parallelity of production and quality control timing makes a fully automated 100-percent control of production possible. This way, rejects of samples of substandard quality can be avoided. Figure 7 shows a typical lense developed by IB/E.

Conclusion

A fast quality control of lenses in series production is feasable. Without 100-percent control of production, it is not possible to determine which features of an optical design can be realised within a given production surrounding. OptoMess measurement bench provides full quality control and makes production related optical design possible.

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