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Progress in binocular design

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ABSTRACT

In this paper a review is given about recent problems in binocular design. In particular the influence of the prism system is discussed, different mounting techniques of prism systems are presented. The effect of antireflection coating of prisms is described. As known since the early forties the rotation of the plane of vibration by total internal reflection at the two roof surfaces causes a loss in resolution and contrast. By a special coating of the roofedge surfaces this effect can be compensated. MTF-measurements give a quantitative analysis of the effect.

1. INTRODUCTION

Beside the progress in lens design, production techniques, producing synthetics, adhesives and lubricants the innovations due to the prisms in a binocular are of interest. By the lens designer the prisms are treated as thick plane parallel plates, which do not have optical power and cannot form images. There is no doubt that the basic features of image quality of a binocular are defined by the objective and the eyepiece. But only in connection with properly dimensioned and manufactured prisms optimum performance can be achieved. For a certain entrance pupil, field of view and a certain type of prism system, ray tracing yields to the optimum prism size, so that the contributions to image quality can be estimated[1]. The amount of longitudinal displacement t' of the image is given by

$$t' = (N-1)\, t/N.$$

t' is the actual thickness of the equivalent plane parallel plate and N is the refractive index of the prism glass. Under the assumption that the prism system is not tilted, no lateral displacement will occur. When used in parallel light a plane parallel plate is free of aberrations.

However, if the plate is inserted in a convergent or divergent beam, it introduces aberrations. The longitudinal image displacement is greater for short wavelengths than for long wavelengths, so that overcorrected chromatic aberration is introduced. The amount of displacement is also greater for rays making large angles with the axis; this means overcorrected spherical aberration. Neglecting production errors and dimensioning errors of the prisms, the lens designer has to consider the contributions to spherical and chromatic aberration, and, if the prism system is tilted, also the contributions to astigmatism, coma and the lateral chromatic aberration.

2. CHARACTERISTICS OF PRISM SYSTEMS

The principal use of prisms in binoculars is as follows[2]:

To fold an optical system into a given shape.
To provide proper image orientation.
To displace the optical axis laterally (Porro prisms).
To provide for optical path length adjustment.

Various aspects have to be considered when one has to decide how to satisfy the tasks mentioned above. The most important criteria for selecting the type of prisms are listed below[3]:

1. Number of reflections.
2. Number of prisms.
3. Number of optical relevant surfaces (total internal reflection, metallized surfaces, glass/air surfaces, cemented surfaces).
4. Number of metallized surfaces (metallized surfaces cause additional loss of transmission and increase in cost).
5. Number of penetration angles of the air-gaps.
6. Length of the path in glass.
7. Displacement of axis between entering and emerging light beam.
8. Length in direction of the optical axis.
9. Type of glass (determining the limiting angle of total internal reflection).
10. Compactness, weight of the binocular.
11. Production costs.

All the formentioned criteria are of different importance. Our conclusions were the following:
Wherever compactness is one of the dominant criteria we found that the Schmidt/Pechan prism system is the best choice. In all the other cases we use Porro prisms. The limiting objective diameter is 42 mm; for this aperture - in our opinion - both types of prism systems give useful designs. Figure 1 shows a Porro prism, Figure 2 a Schmidt/Pechan prism system.

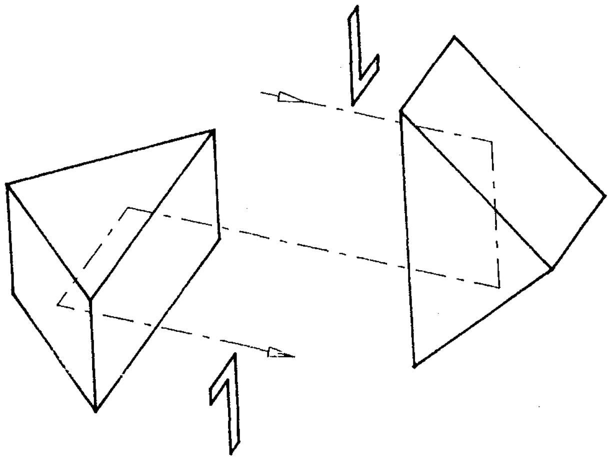

Fig. 1: Porro prism system used for larger apertures.

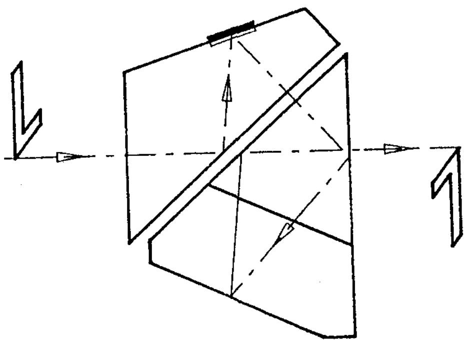

Fig. 2: Schmidt/Pechan prism system for compact binoculars.

3. INFLUENCE OF THE PRISM SYSTEM ON IMAGE QUALITY

Under the assumption that the prisms are properly dimensioned and manufactured within the prescribed tolerances[4] and the refractive index is large enough to guarantee total internal reflection, there are still many other factors that have an influence on image quality.

3.1. Mounting of prisms

The requirements on the mounting of prims in a binocular are manifold. The prism surfaces must not be distorted by the necessary contact pressure. However, the prisms must resist extreme shock, vibrations and thermal effects. In addition, the design must be compatible with the assembling conditions, adjustment, maintenance, size, weight and cost in relation to the entire instrument. Long-term stability of the mount and chemical stability of adhesives must be guaranteed[5]. Our experience has shown, that the two mounting techniques discribed below, should be preferably applied with Porro systems: In our traditional binocular type we fix the prisms with a spring in a prism seat as shown in Figure 3.

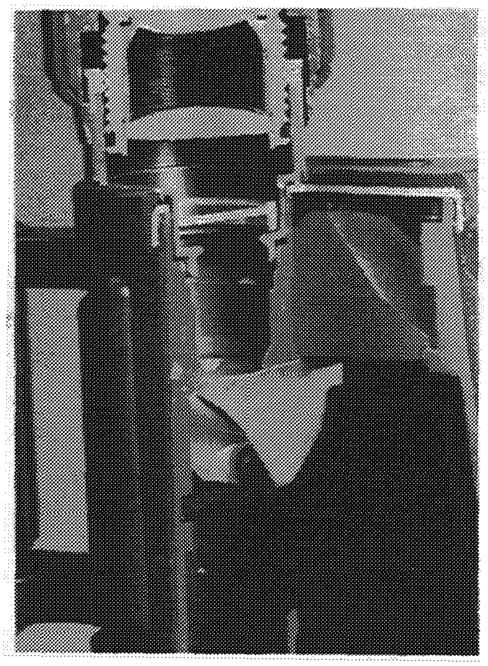

Fig. 3: Clamping a Porro prism system with a spring in a prism seat.

The advantages of this classical method are relatively short assembling times, low costs and good suitability for repair. The second method as shown in Figure 4 - used in our so-called SL binoculars - is able to resist extreme mechanical stress. In the first step the two Porros are cemented together with an UV-adhesive; the second step is to fix a plastic objective and ocular tube on to the Porro prisms. This must be done by using extremely accurate tools. The reflecting surfaces are masked with plastic caps. Finally a silicon compound coats the entire system.

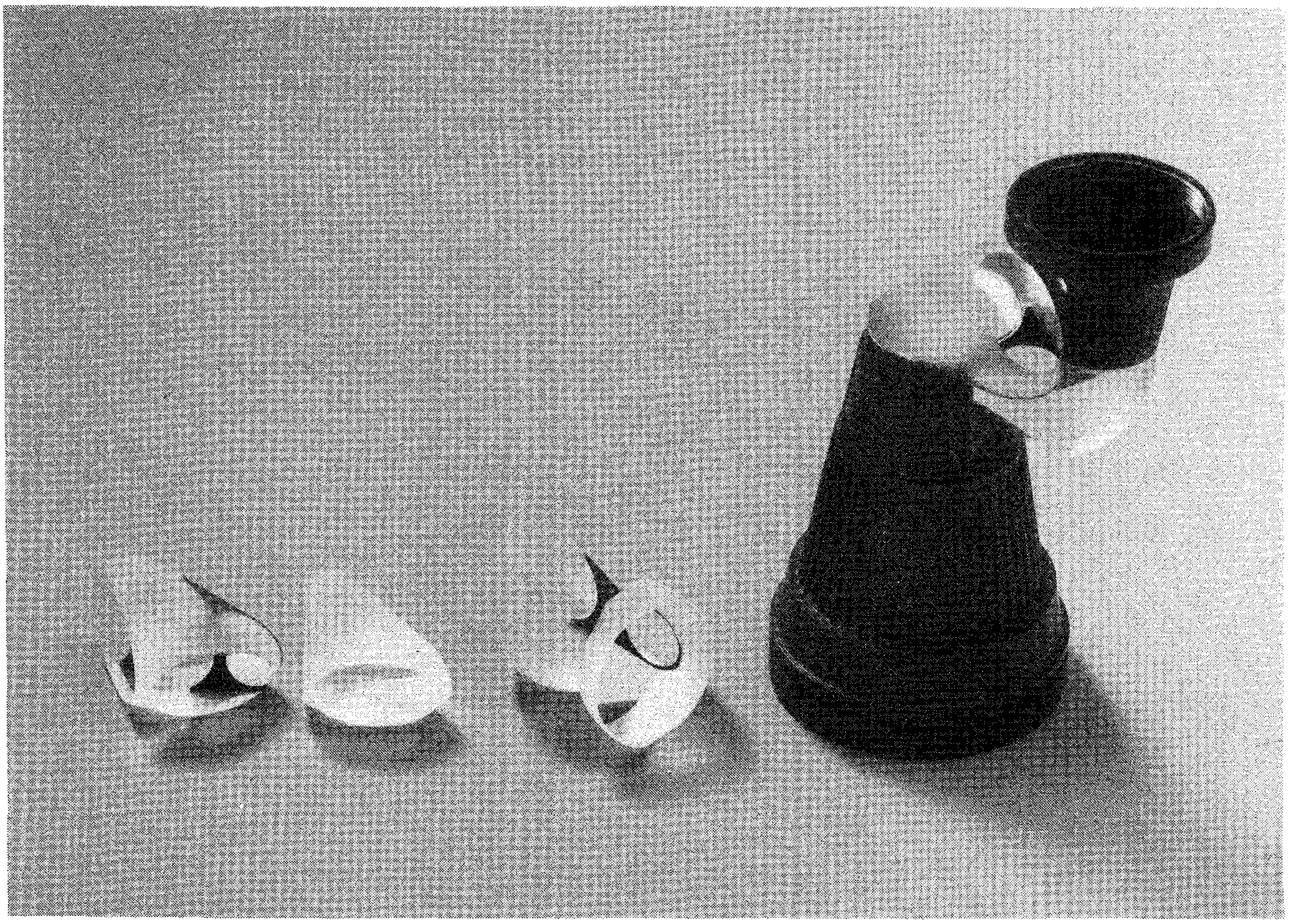

Fig. 4: First steps in production: cementing of the Porro prisms and fixing the objective and ocular tube.

For the compact binocular models with Schmidt/Pechan prisms, we fix the prisms in a prism seat with an UV-adhesive (Fig. 5). The advantages are shorter transit times in production and easier repair.

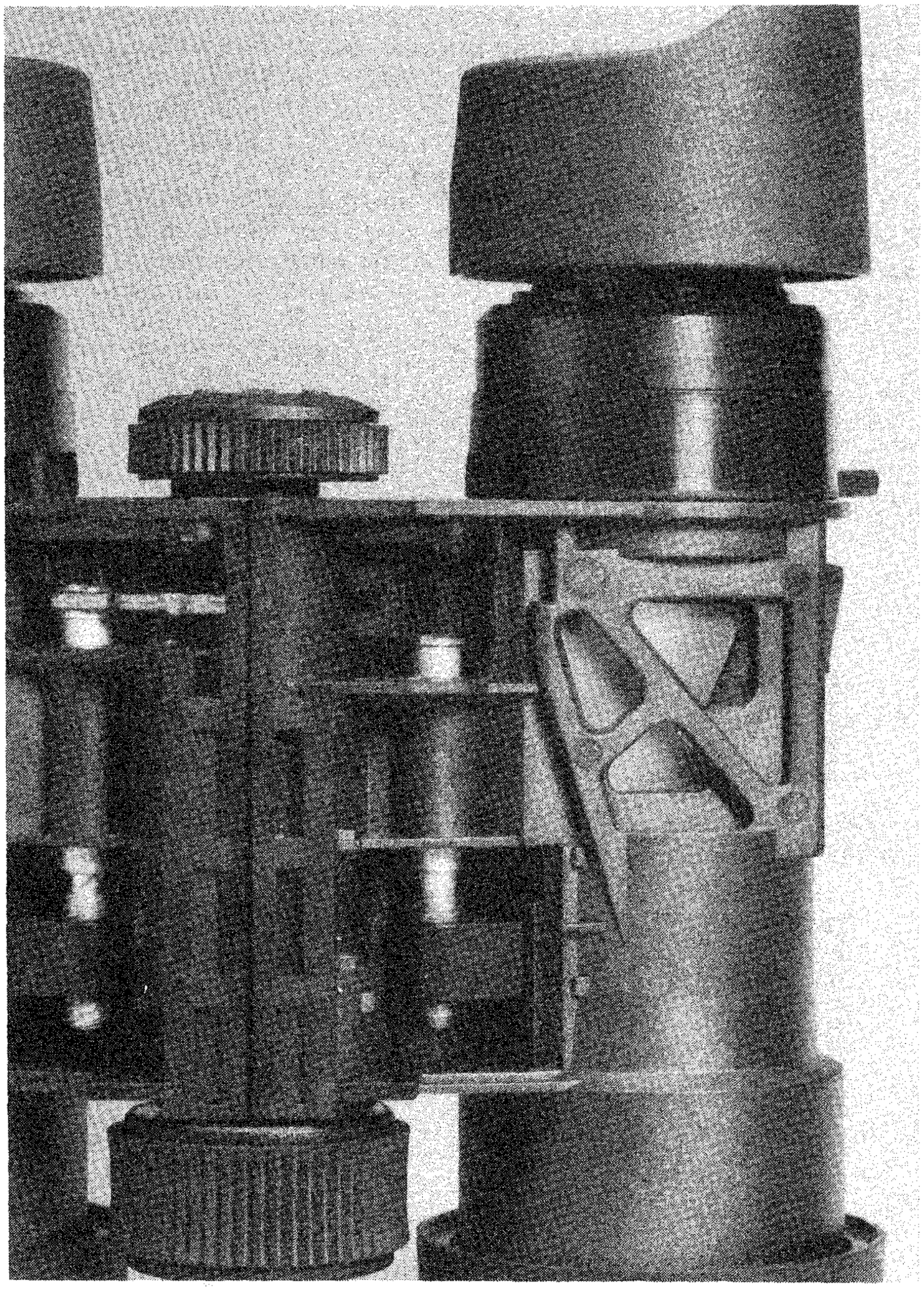

Fig. 5: Schmidt/Pechan prisms fixed in a plastic prism seat.

3.2. Glass quality of prisms

Especially when using large-sized prisms, the influence of the glass on the optical performance is remarkable. Optical homogeneity, striae, stress birefringence, bubbles and inclusions have to be within narrow tolerances. But even when the glass meets the highest precision levels and the surfaces and angles of the prisms are of highest accuracy, we still got varying transmission interferograms for different glass types. (Fig. 6 resp. Fig. 7) A prism as shown in Figure 7 cannot be used in high quality instruments. The tolerances for the single surfaces are better than 1(0,2)-, that means that the regular deviation from the ideal sphere is less than one fringe and the surface irregularity is better than 0,2.

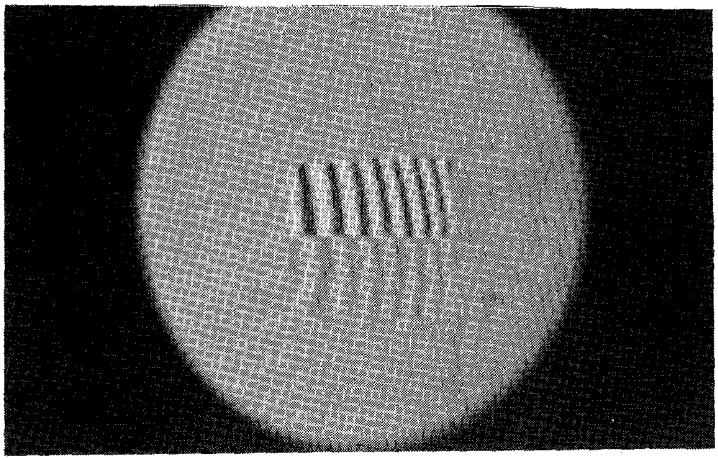

Fig. 6: Glass type A, transmission interferogram, accuracy of the single surfaces better than 1(0,2)-.

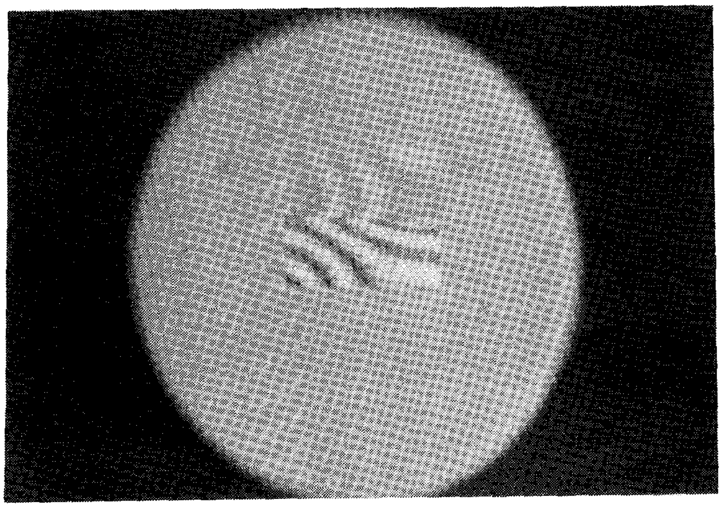

Fig. 7: Glass type B, transmission interferogram, accuracy of the single surfaces better than 1(0,2)-.

Our opinion is that the purity of the chemical elements and faults in production might be an explanation for the varying interferograms. Particles in the glass melt with diameters comparable to the wavelength of light can change the scattering behavior significantly[6].

3.3 Coating of prisms

3.3.1. Antireflection coating

Optimum transmission is one of the most important criteria for a high quality binocular. An uncoated optical surface causes a loss in transmission between 4% and 8%. Typically, in binoculars there are eight to fifteen glass-air transitions, so that multicoating of every surface is essential. The top models have transmissions of approximately 90%. Beside the loss of light coating reduces stray-radiation and therefore increases the contrast of the image. However, from our own observations and from literature[7] we know that antireflection coating can reduce contrast for instance when a Schmidt prism is used. In Figure 8 you can see that two surfaces are reflecting and entrance resp. exit surfaces at the same time.

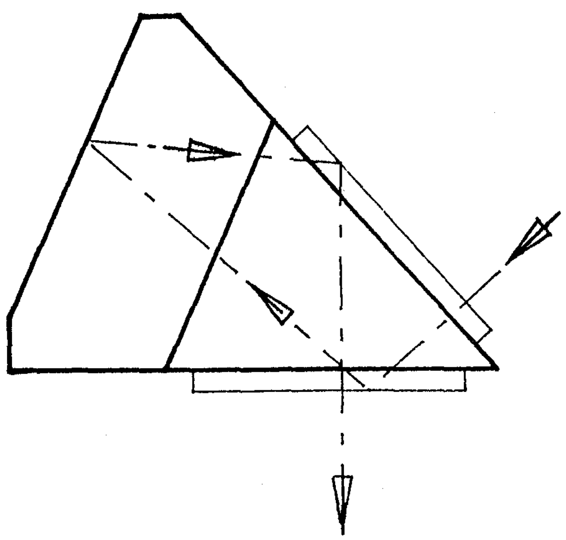

Fig. 8: Schmidt prism. Two surfaces act as reflecting and entrance resp. exit surfaces at the same time.

For the total internal reflection between glass and air an uncoated surface would be desirable; however, this is not desirable for maximum transmission.

You can see that the light has to pass through the antireflection coating six times and in addition, total reflection occurs twice at the film-air surface. To find the best compromise we measured the MTF, for four different types: one, two and three-layer coated prisms and an uncoated prism were measured, using the same objective. The results are shown in Figure 9.

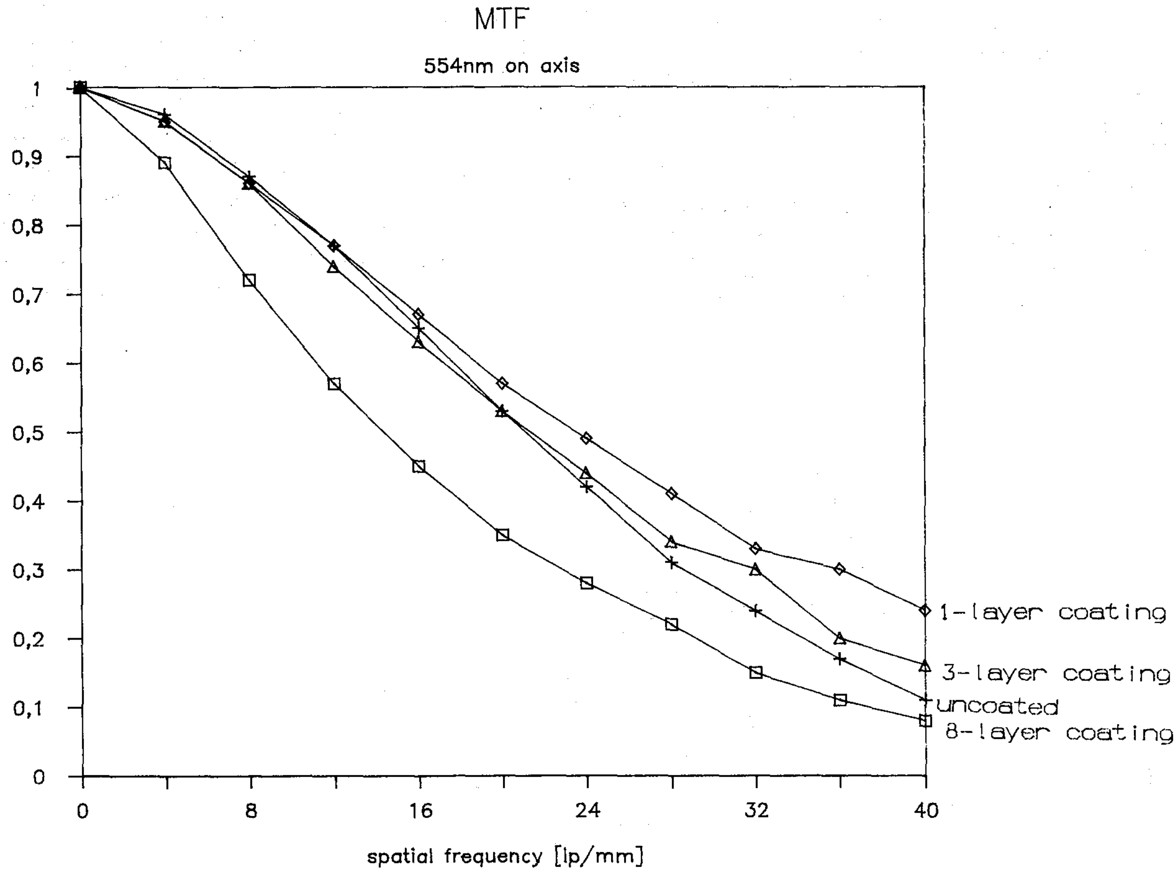

Fig. 9: MTF curves for different coatings.

Our conclusion from the measurements and from our visual observation was that a simple one-layer coating is the best compromise between contrast and transmission.

3.3.2 Phase correction coating for roof surfaces

Already in 1943 G. Joos pointed out that totally reflecting roof surfaces reduce image quality, unless they are coated properly[8]. Even if the surfaces of the prisms and the angles are manufactured extremely accurately, there is still a remarkable loss in contrast and resolution.

When the light wave is totally reflected, not only a change in direction occurs. Light waves vibrating parallel to the entrance plane are shifted in their phase against those vibrating vertically. The result is that the light is polarized elliptically[9]. At the roof prism the incident light is divided into two halves. Both halves are passed in a different sequence and get a different phase shift. By interference the light is partially extinguished and as a consequence of the energy principal this light is focussed beside the optimum geometric image point. The consequence is a reduced resolution and contrast in the direction perpendicular to the roof. The experienced and pretentious user of a binocular can observe the effect especially when viewing a point light source or very bright objects. The manufacturers of high quality binoculars therefore developed a special dielectric multicoating for the roof surfaces to compensate for the phase shift. Figures 10 to 12 compare MTF curves between coated and uncoated roof surfaces. The measurements were done with the same objective but with different orientations of the roof.

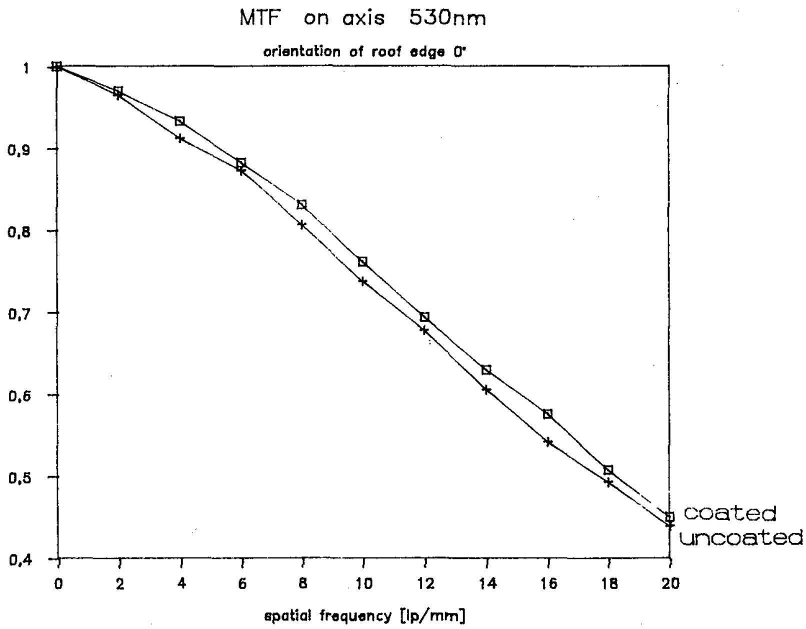

Fig. 10: MTF curves for phase-correction coated and uncoated roof surfaces for 0°.

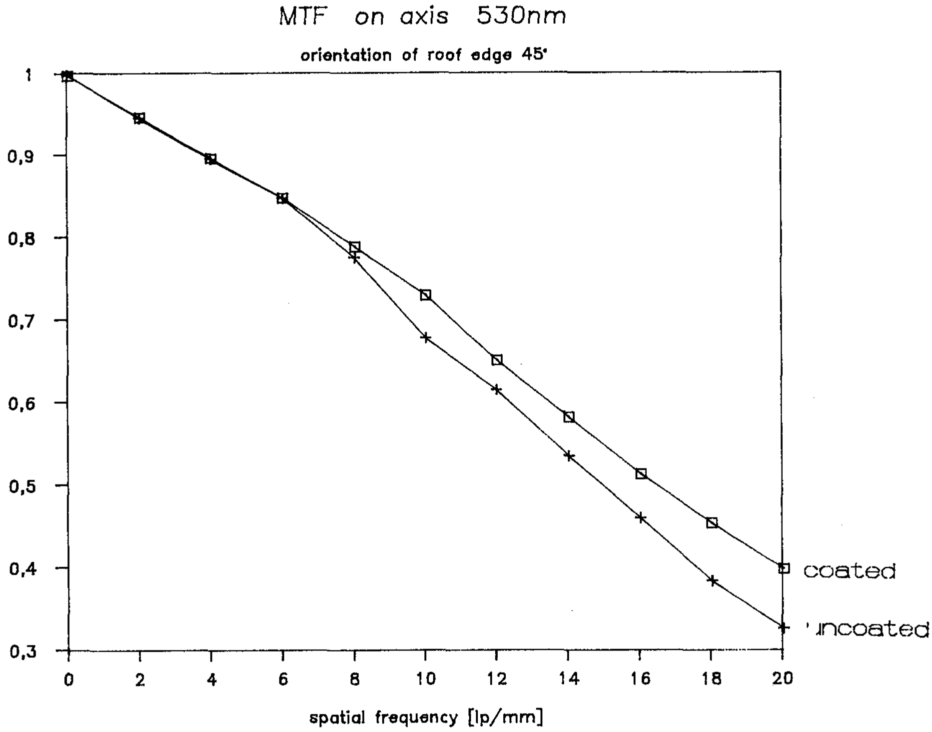

Fig. 11: MTF curves for phase-correction coated and uncoated roof surfaces for 45°.

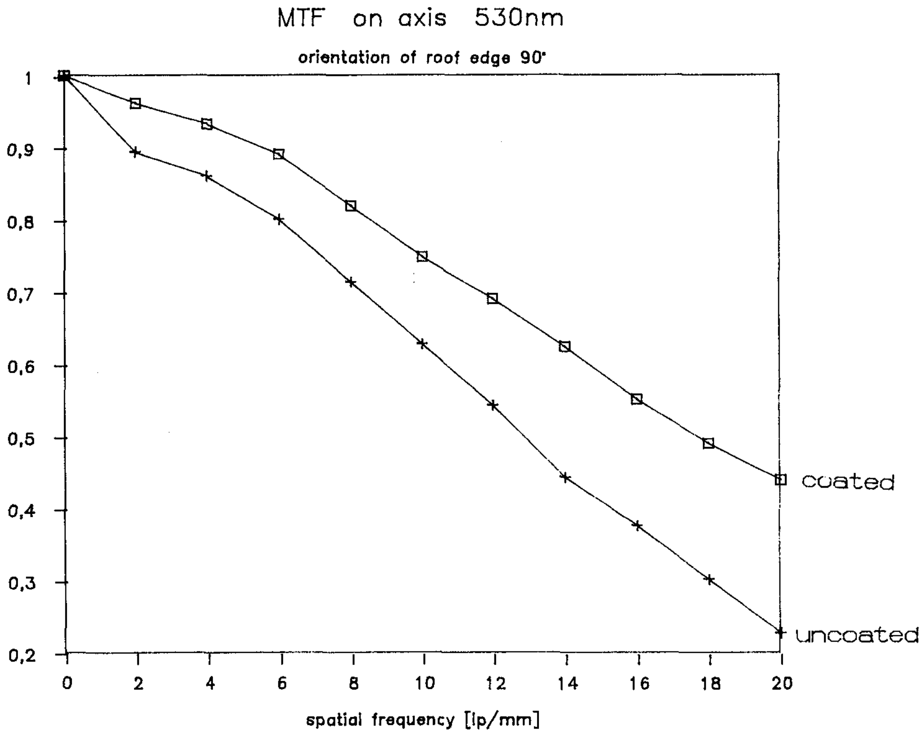

Fig. 12: MTF curves for phase-correction coated and uncoated roof surfaces for 90°.

Figures 13, 14 show interferograms of phase correction coated resp. uncoated roof surfaces. The interferograms are in good correspondence with the MTF curves.

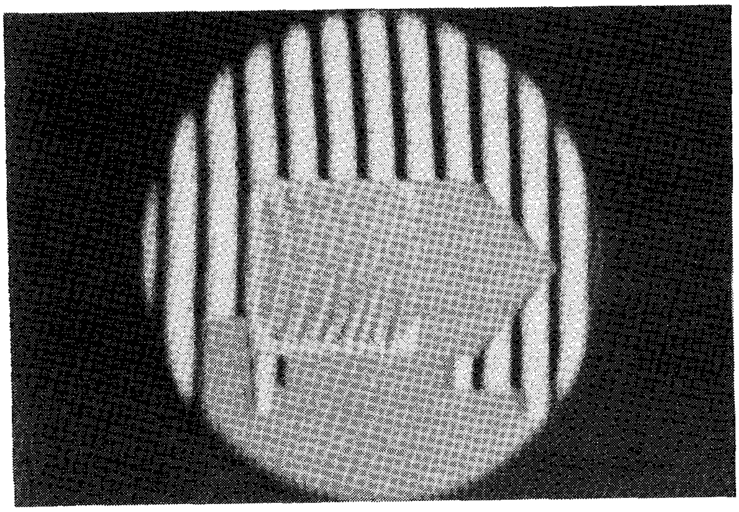

Fig. 13: Interferogram of phase correction coated roof surfaces.

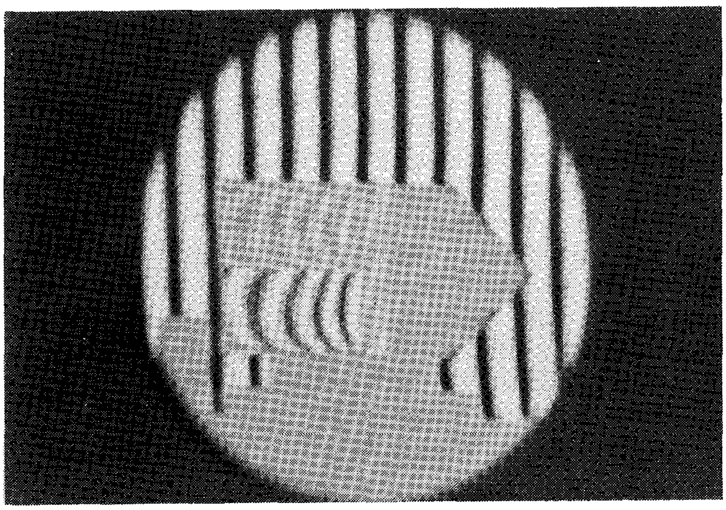

Fig. 14: Interferogram of uncoated roof surfaces.

4. CONCLUSION

The basic conditions to achieve high quality binoculars are an adequate lens design and production of optical and mechanical components within very narrow tolerances. For optimum performance the mounting of prisms and lenses, the quality of the glass and the different coatings of the prisms are essential.

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