Ways that designers and fabricators can help each other

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ABSTRACT

We show that, when designers and fabricators understand each other's art, there are ways to combine their techniques to achieve the best results with the minimum difficulty. We share some problems that we have encountered, and sometimes caused ourselves, in hopes of helping the reader avoid the same pitfalls.

1. INTRODUCTION

We previously published a compilation of experience and advice on design for manufacture(1) and a series of three papers on the relationship of cost to tolerances(2,3,4). We expand on these here with a specific example of a wide angle eyepiece design that turned up several problems to be aware of and avoid.

2. APPARITIONS IN AN EYEPIECE

We have recently dealt with an eyepiece design with two difficult requirements. First, the apparent field of view had to be 72 degrees. Second, the image to be viewed by the eyepiece was strongly curved away from the eyepiece. There were also the usual requirements for adequate eye relief, exit pupil diameter, flat visual field, and diffraction limited resolution on axis. Figure 1 shows what we thought at first was a good final design (with certain qualifications). The amount of field curvature to be corrected and the very large field of view drove the details of the design. We also had a firm constraint on the overall diameter. Note that a strong negative "field flattener" lens was needed at the front of the eyepiece on the left. This sent the ray bundle at the edge of the field off at a very large angle. That in turn made the elements become very large and thick. The strong positive lenses in the cemented doublets were a mechanical problem for fabrication. A consultation with our optical shop resulted in the opinion that these could be fabricated with an edge thickness no more than a fine chamfer, because the edges intersected at nearly a right angle (like a prism, without even a roof). Thin edges are generically to be avoided, but here the overall diameter constraint indicated this approach and the shop felt they could oblige us.

That was the good news; now for the bad. It is an easy design trick, used by many of us, to describe a cemented surface to the design program as a simple glass to glass interface ignoring the cement in between. This worked very well for us, or so we thought, until it turned and attacked us. The two glasses of the doublets are both of index of refraction near 1.785, and no total internal reflection (TIR) occurs until almost 90 degrees angle of incidence. However, the optical cements which are available are near 1.56, and none of much higher index can be obtained. We found that the proper substitution of the cement between the surfaces caused TIR to occur well before the edge of the field. In order to solve this apparition, we had to split out much of the positive lens power in the two doublets and form another doublet in the midsection of the design. This resulted in an acceptable design shown in Fig. 2. This is still very demanding on edge thickness, but slightly relaxed from Fig. 1.

Lenses of these high indices have an advantage that a single layer AR gives a photopic reflection less than 0.4%. A normal broad band AR might even risk being higher without more than normal care in production coating. However, the cemented interfaces with index of about 1.52 have higher reflectance of .65% because of the Fresnel reflection at the large index difference between the glass and cement. We have recently submitted a brief letter to the editor (5) describing the "almost obvious" solution of an AR coating for the interface between the glass of 1.785 and the cement of 1.52. This fortuitously works out to be the index of aluminum oxide at about 1.64. Figure 3 shows the comparitive results of various coatings in such a case. We have applied this to these doublets with great success. Let us caution designers, however, not to assume that T + R = 1. Just because reflections are reduced to low levels by AR coatings does not mean that the rest is transmitted. Absorption and scattering can take a toll of more than the residual reflection in many cases of ordinary coatings in commercial practice.

We encountered another unpleasant apparition in this project. The instrument has several prisms in the optical path which account for many centimeters of path length. At one stage of the design, we changed to high index glass in the prisms in hopes of gaining certain advantages. We neglected to notice that the glass selected had significant absorption in the blue and even into the green. This effect devoured most of the instrument transmittance tolerance before we thought to look who was into the cookie jar.

3. HELP FOR THE COMPONENT FABRICATORS

In our previous works (2-4), we discussed what constitutes economical and realistic tolerences for the fabricators and the relative costs versus tolerances. We discussed (1) several ways to help the fabricators in the design process. We would like to add a few more at this time. We have found many cases where the the performance of a design is quite sensitive to the thickness of a cemented doublet. In production, this may be more readily maintained by selecting pairs for each doublet where the thicknesses add to the desired amount. The individual lenses could potentially made be to a much more relaxed tolerance because the position of the cemented interface is not nearly as sensitive as the overall doublet thickness.

The homogeneity of glass can be of great concern where a good transmitted wavefront is required through a prism or thick window. For the glass manufacturer to guarantee that you will get a certain high homogeneity, you usually have to pay quite a bit extra. We have been quite successful in using relatively common, non-special, homogeneity grades of glass for even massive prisms. We allow some extra for the fact that we might have to throw away a few out of a large lot due to inhomogeneities, but the cost is far less that buying one or two grades higher for the "insurance." This has been true for the common types of glass, we cannot say that it would be true for all glasses. However, it has been a practical way to keep fabrication cost down for only a little risk.

4. HELP FOR OPTICAL ASSEMBLERS

A frustrating thing for assembly departments is a lens that is almost equiconvex or equiconcave but not quite. It is difficult to tell which way it is to be oriented just by looking at it. We try hard to alter a design to make the lens have the same radius on both sides. This would reduce the tooling cost also. If this is not practical, it may be possible to make the difference greater to make it more visible to the assembler.

The effects of lens figure irregularities are not as straightforward as we once thought. The simple RSS summation of errors doe not seem to represent what is possible. Here, the fabricator can improve upon what the designer might be entitled to expect. Let us consider a long train of 8 lenses where each may have say 1/2 fringe of irregularity. This is 16 sufaces and the RSS might be expected to be 4x1/2 or 2 fringes effect. If they all were of 1.5 index glass, the wavefront error might be expected to be 1 fringe. However, this may not or need not be the case. The irregularity usually has a simple cylinder as its major component. The orientation of these 16 cylinders is assumed random. The assembler may have the option to orient each of the 8 elements so that some or most of the astigmatism is aligned such that one element compensates the astigmatism of one or more others. This practice is used frequently to reduce the effects of irregularity far below what might be practical by fabrication tolerances alone on the elements.

The areas of overall instrument design and detail have endless opportunities to save or waste effort. We have recently been frustrated by a design (fortunately not our own) which showed spots and spatters on the internal optics after thermal and vibration testing. These were found to be from internal bearing lubricants, excess Loctite, and dessicant system particles. Redesign and modified assembly procedures eliminated these problems. We had a major apparition when an instrument tore apart at its mounting flange under shock test. Upon investigation, it was found that the gain knob of the oscilliscope used to set the shock level was not in the calibrated position. This caused the instrument to undergo a shock of 400 G's instead of the intended 40! The surprise was that the bonded prisms and mirrors and the mounted lenses showed no ill effects.

5. THE BOTTOM LINE

We are operating in a very economically competative world today. The designer of almost any system destined for production has to be very oriented toward minimizing the system cost for the full life of the product from concept to the end of its intended use. We reiterate here Fig. 4 which is taken from Ref. 4. This emphasizes that the detail design phase is THE most critical in the life cycle cost of the product. The designers and fabricators must work closely together or other teams that DO cooperate will not only eat their lunch, but also breakfast and dinner.

6. REFERENCES

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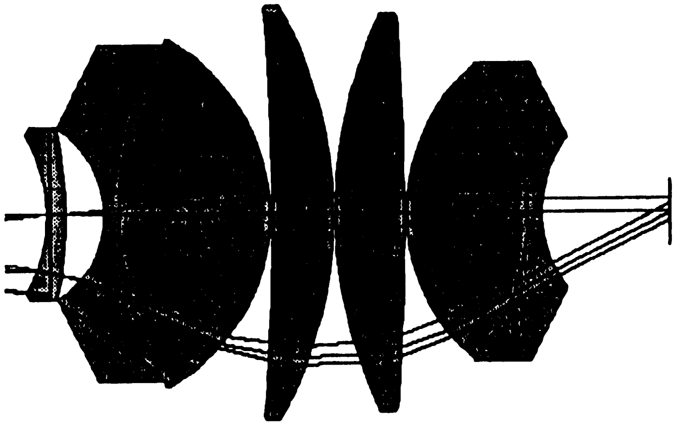

Fig. 1. A good eyepiece design until the effect of cement between the doublets was taken into account. Then TIR occured at the cemented interfaces.

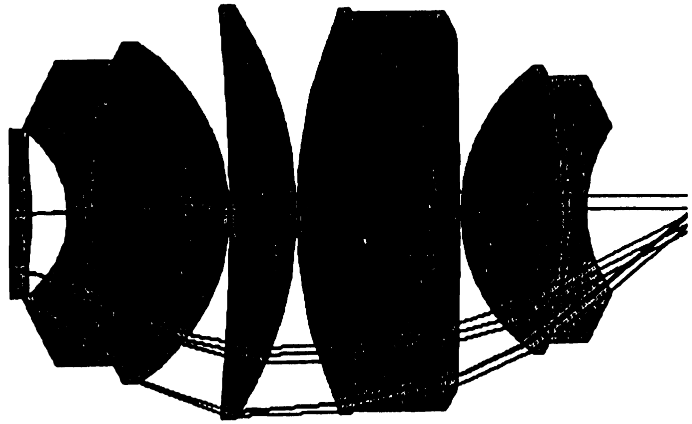

Fig. 2. The corrected design from Fig. 1 where the positive lens powers of the doublets were reduced and the balance put into a third doublet.

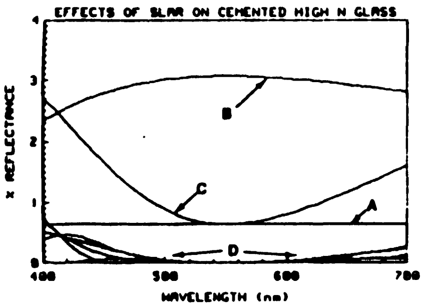

Fig. 3. Curve A, Fresnel reflection at interface between 1.785 glass and 1.52 cement. Curve B, reflection of surface as in Curve A if coated with one QWOT of magnesium fluoride. Curve C, reflection of surface as in Curve A if coated with two(2) QWOT's of magnesium fluoride. Curves D, reflection of two(2) surfaces as in Curve A if each is coated with one QWOT of aluminum oxide (1.64 index) for various thicknesses of optical cement between the coated elements.

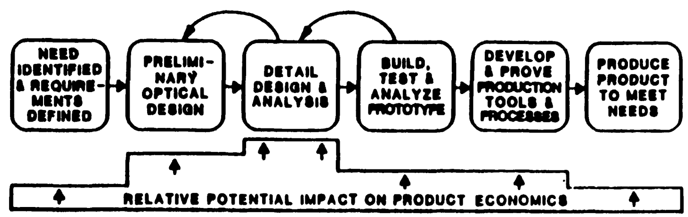

FIGURE 4. OVERALL PROCESS TO DEVELOP AND PRODUCE A NEW OPTICAL PRODUCT