Guest Editorial

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Specifications and Tolerances, Optical Style—A Commentary

Abstract

The optical fabrication industry is troubled on one hand by a lack of standardized specifications and on the other hand by the overzealous application of the few formal specifications which it does have. The article comments on the various philosophies of tolerancing, the difficulties in communicating tolerances, and the pitfalls to the implementation of specifications. The nature, use and abuse of the MIL-0-13830 scratch and dig standards are also considered.

Introduction

Optical Engineering and Fabrication is a growing field with many practitioners, new and old, who are feeling their way in an area which has very few formal guidelines. Their lot can be vastly improved by the use of standard, accepted methods of specifying and communicating their requirements. Ironically enough, on the other hand, the optical fabrication field is saddled with the not-so-hidden costs of gross quantities of perfectly functional optics which are declared "rejects" by the application of standard, accepted government specifications.

Philosophy

The art of tolerancing can be approached from different philosophical viewpoints. The statistical technique of tolerancing[1] is becoming widely accepted and understood, primarily because the costs of 100% assurance are simply staggering, and the savings which result from tolerances relaxed to a level which produces a small but finite failure rate much more than compensate for the cost of the failures. There is, however, a more idealistic attitude which can add another side to the "Does it work?" vs "Does it meet specs?" argument. This highly informal approach looks at print tolerances not as absolute limits, but rather as goals. Assuming that parts are made by techniques which can be expected to hold tolerances, a few will probably fall outside the limits. Under this approach, these are used without much inspection and without much question unless the departures are gross. This bland acceptance of "rejects" can work out nicely in optics because the functional degradation of an optical part as its dimensions depart from nominal is usually a very gradual affair; *there is seldom a sharply delineated point at which the optics suddenly become nonfunctional.* The savings in red tape can be surprising.

Communication

Technological optical manufacturing (as opposed to fabrication as an art or craft) is, in a sense, a small, new field. Our drawings and specifications are far from standardized. Every engineer has his own personal favorite format. Thus it is vital that our specifications be complete and incapable of misinterpretation. Anyone with experience in this field knows this is impossible, but we all try. About the best we can hope for is a good working understanding within our own shops so that we are not inundated by the reams of paper that would be necessary to formalize all the unwritten requirements by which we operate. We make certain that we call out everything of importance. And this works well, until we make the mistake of sending an internal shop print to an outside supplier. Whereupon we discover that what works well in *our* shop doesn't necessarily produce good parts in *their* shop. Some examples which come to mind include a close tolerance lens diameter which is to be blackened; does the tolerance apply before or after painting? The answer seems logical and obvious, but the shop down the road may see it differently. Surface "regularity" or "sphericity" interpretations can spark endless debates. Consider that a couple of decades ago most people simply specified "5 rings," if they bothered to do that. More recently it became "5 regular rings." Currently a typical spec might read "5 rings power, one ring regular." The improvement is obvious, yet the specification is still far from complete, because the type of irregularity and the distribution or steepness of the irregularity are important and can strongly affect function. This sort of evolution is the natural result of the improvement in optical system quality which has occurred in both design and fabrication, and which will probably continue.

Trouble for both buyer and seller can result from "hidden specs." The tight spots on a fabrication print should be clearly highlighted, not buried. An estimator who is pressed for time and price tends to be suicidally optimistic; if, for example, a prism print has angles toleranced in minutes and a deviation specified to seconds, a momentary oversight on the part of the estimator may result in a carload of prism-shaped paperweights on the buyer's doorstep (and a production line littered with empty prism mounting brackets). Some tolerances are just naturally confusing. Concentricity is usually specified as a deviation, and most of us have learned that deviation is not a TIR spec. An equally important factor in the quality of our lens assemblies, namely surface tilt, is largely ignored except by a few groups producing exquisite super-lenses. Pyramid tolerances in prisms are often unclear as to whether they apply to the cause (i.e., the pyramid angle) or the effect (the ray deviation).

Much of this could be alleviated if there were accepted standard specifications for producing optical elements. The German (DIN) standards[2] are an example of what can be done in this direction, and contrast markedly with some of our efforts which have obviously been produced under a contract awarded to the lowest bidder.

Implementation

If, up to this point, I haven't caused anguished cries of "Heresy!" from certain quarters, I suspect that omission is about to be rectified. One of the chief difficulties with our methods of quality control is inherent in the adversary system which government contracts have forced upon us. The Q. C. department often feels that it should be the customer's policeman and that, because it reports to a higher organizational level than does the head of production, it is immune from the necessity to join in the common cause of producing goods. The attitude is often summarized by "How can I find a way to reject this?", rather than "How can I find a way to make these parts work well?" or "How can I find a way to assure that this product will function?"

In addition, there is a natural human bias present in all of us. If we are presented with 110 parts to inspect and told that 100 parts are needed to complete the order, the probability is astronomical that we will reject not less than eight nor more than ten pieces out of the lot, regardless of the absolute quality level of the pieces, provided only that judgment, rather than measurement, is involved. These "rejects" will be unquestionably the worst pieces of the batch, and the shipment will go out the door on time, and we will feel quite virtuous for having selected the best 100 pieces to ship, and almost no one will be aware that some of the "rejects" are perfectly good, functional pieces, and that we have just raised the cost of the product by a totally unnecessary five or ten percent. Add to this the understandable tendency for an insecure inspector to "bounce" anything close to the borderline, and you have a sizeable cost factor to contend with. In an environment where the inspector's word is law, it is easy to see why "government" optics cost two or three times as much as their commercial counterparts without any significant gain in *real* quality.

Scratch and Dig

It would be impossible to leave the subject of optical tolerances without at least a passing word for our old friends, Scratch and Dig. There are currently a few attempts underway to establish some sort of measurement of the "functional" effect of scratches and the like. Commendable as they are, these efforts totally overlook the fact that for most systems, scratches and digs have no functional effect at all. If you doubt this, try a simple experiment. Take two identical telescopes and make a grease-pencil mark on the objective of one of them. This mark will be hundreds of times larger than most rejectable scratches, and yet, unless you resort to special tricks, you won't be able to tell the marked scope from the other by looking *through* them. The point is that these are cosmetic defects; they should be treated as such and should be inspected for by means appropriate to their nature.

The method of visual comparison to a set of standard samples as prescribed by MIL-0-13830[3] is a good one. It is, without much question, the most practical and economical way to do the job. In practice it does suffer from two major defects. The first is that the actual physical standards are not what they should be. We need standards which are inexpensive, readily reproducible, durable, easily standardized and calibrated, stable, permanent, and commercially available to any organization that wants them. The standards of MIL-0-13830, available only through the government, meet none of these requirements. In an attempt to improve this situation the specification was recently modified so that the actual measured width of a scratch in microns could be the scratch size number.[4] Unfortunately, this permits a scratch ten or twenty times larger than the previous standard,[5] and the magnitude of the change upset many; I understand that a return to the old system is somewhere in the works, for better or worse.

The second problem is that the surface quality specification number tends to become an "Idiot Number." Inspectors often pour over a few lenses for hours looking for invisible scratches, without the slightest concern for whether the part will actually function in its intended application, or indeed whether it will ever again be seen by the eye of man. The reason for this exaggerated concern for appearance is simply that it is very easy (for anyone, not just inspectors) to become qualified to determine that an 80 scratch is bigger than a 60 scratch; it is often very difficult, even for a highly qualified person, to determine whether the piece will actually work or not. Another aspect of the "Idiot Number" problem belongs squarely on the shoulders of those of us who glibly and almost unthinkingly specify surface quality levels which are not necessary to either function or salability. The 60-40 spec on a lens element buried deep inside a telescope, from which a G.I. wipes road grime with last week's sock, is an extreme case, but a real one.

One way of evaluating your own efforts in establishing specifications is to visualize a scenario consisting of the sequence of events set in motion by your specifications. Imagine how the part will be fabricated and what special techniques and inspections will be required. Then imagine the disposition of borderline cases. Remember that if you use a catchall specification as an insurance policy, someone is going to have to pay the premium. Finally (or perhaps this should be your initial consideration) consider how the product appearance and function will be affected. Consider whether you have specified only those characteristics which you want to control, i.e., those which you really need. If you can do all this on a sound, rational and factual basis, without recourse to cliche or rule of thumb to justify your choices, you are indeed a member of a very select minority—perhaps you should start a committee to standardize optical specification techniques!

References

1. Smith, W. J., "Modern Optical Engineering," McGraw-Hill 1966, pp 423-427.
2. Deutche Industrie Normen (DIN) #3140, Optikeinzelteile (German Industry Standard #3140, Optical Components) available through Beuth-Vertrieb GmbH, Berlin 30.
3. U. S. Government Printing Office, MIL-0-13830A 11 September 1963, "Optical Components for Fire Control Instruments; General Specification Governing the Manufacture, Assembly and Inspection of".
4. U. S. Army Munitions Command Drawing C7641866 describes the comparison standards called out in MIL-0-13830, Section 3.5.1.1. Revision G of C7641866 calls for the old arbitrary standard scratches; Revision H calls for the measured width standards.
5. Hendrix, *Optical Spectra,* Dec. 1974.