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Influence of specification on tolerancing of high-volume optics

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Abstract

Specifications establish tolerances which influence yield of component parts manufacture and tolerances applied to components affect the yield of final assemblies to specific specifications. A simple illustration is presented to demonstrate a technique for evaluating the relationship between specification and component tolerances.

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It is intuitively obvious that specifications imposed on the performance of an optical system impact on the tolerances which can be applied to the components which make up the system. What may not be as obvious is the affect that tolerances have on a high volume production operation as reflected in process, schedule, machine capacity required and cost. The magic word is yield. Specifications establish tolerances which influence yield of component parts and tolerances applied to components affect the yield of final assemblies to specific specifications.

I will review the rationale employed in the application of a relatively simple lens system to illustrate the point.

Let us assume that we are going to use a single meniscus lens to provide optics for a simple box camera and that the constraints imposed on the system are:

1. Fixed Focus
2. Subject range 5' to infinity
3. Format is 28mm x 28mm
4. No factory focus adjustment

A 43mm f/11 lens will satisfy the first three constraints. The impact of the fourth constraint needs to be evaluated.

The essential task of this application is to provide the proper position for the photographic image and to insure that it will be properly located under all conditions of use to provide satisfactory picture quality to the customer.

We will select plastic as the lens material because of its suitability and economic considerations. (Methyl methacrylate has an index of 1.49168 and a V No. of 57.4).

Let us review those things which will influence the image position we wish to control and assume some typical values for sensitivities. Table 1 lists lens contributions to image shift along with typical sensitivities. Table 2 lists mechanical contributions.

Table 1
Lens Contribution to Image Shift

1.	Index	.10mm/.001
2.	Surface Power	.35mm/10 rings
3.	Thickness	.90mm/.20mm
4.	Thermal	.25mm/50°F
5.	Humidity	.10mm/50% R.H.

Table 2
Mechanical Contributions to Image Shift

1.	Assembly Stack Lens Housing Locating Studs Frame	.125mm
2.	Film Plane Variation	.10mm

We wish to determine the tolerance to apply to the focus of the assembled camera relative to the film plane reference. To establish this, we must first make a judgement as to the amount of defocus which will still produce a satisfactory picture for the customer.

We will assume that the customer will accept some degree of defocus in addition to the criteria used to establish a hyperfocal setting for the camera.

The following simple mathematical expression will help to illustrate the relation between specification and error contribution:

$$\text{Specification} = \left[\sum^{i} E_i^2 \right]^{\frac{1}{2}} \quad \text{where E is the error input}$$

Fortunately, manufacturing processes yield gaussian error distribution and their contribution can be evaluated in simple statistical fashion. If we assume fixed error contributions, i.e., those errors which we have no control over or those which represent limits of manufacturing capability, we can use this expression to establish the effect that specification has on the construction parameters of the lens.

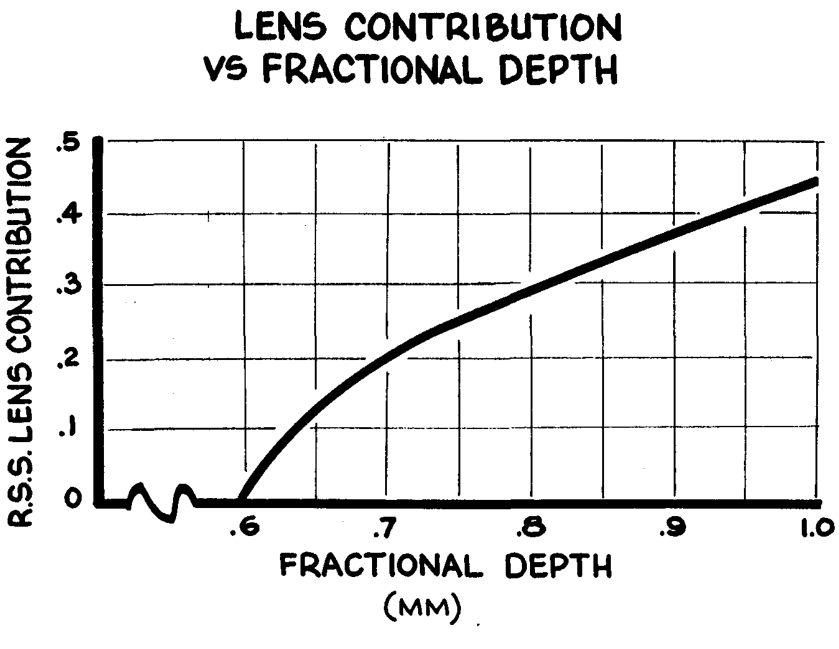
The acceptable blur circle diameter for this format (28mm x 28mm) is .05mm. Therefore, the f/11 system has a single depth of focus of 0.55mm (depth of focus = blur circle diameter x f/No.)

The root sum square (RSS) contributions to image shift from all contributors must not exceed the fraction of the single depth we choose as the performance specification. We can determine the RSS allowance for thickness and surface power variations of the lens if we assume as fixed errors: mechanical contribution, film plane variation, index variation, thermal and humidity response.

The RSS image shift caused by these toleranced variations is .329mm or 0.6 the depth of focus. Thus, at this level of specification, there would be no tolerance on lens manufacture.

The RSS image shift allowance for lens variation is shown relative to customer acceptance of defocus as a fraction of the depth of focus in graph #1.

Graph # 1

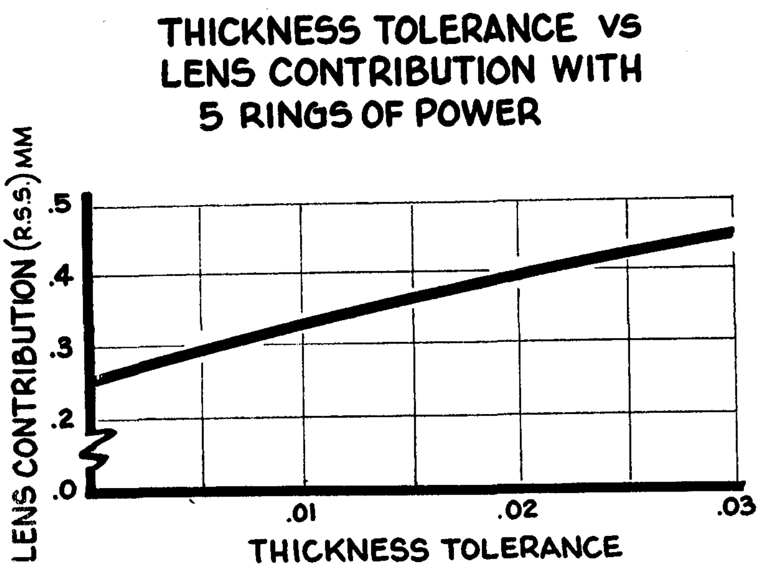


From this graph we also see that the RSS contribution to image shift that the lens may have is .44mm for a defocus equal to a full depth.

If we select five rings of surface power variation as a reasonable tolerance for molding, we find that this amounts to .2475mm RSS image shift corresponding to .75 the depth of focus. This level of performance specification would not allow any thickness tolerance.

The relationship between lens thickness tolerance and the RSS lens contribution with five rings of surface power variation is shown in graph #2.

Graph # 2



A customer acceptance specification of a single depth of focus requires thickness to be controlled to .03mm and power variation to be controlled to five rings. Both these tolerances demand added effort in the area of process control and tooling to maintain acceptable yield.

The RSS lens contribution at this specification is .44mm and the focus tolerance on the assembled camera becomes ± .47mm (.018").

More complicated systems may be evaluated in the same manner and tolerances established for the system components relative to specifications such as: modulation response, field curvature, tilt, resolution, etc.

The procedure which has been presented provides a means of identifying where process development may be required, assessment of the manufacturability of the system, the most important variables to control, and a way to establish meaningful tolerances for product manufacture.