4 OPTICAL SPECIFICATIONS

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4.1 GLOSSARY

ATF	approximate transfer factor
DTF	diffraction transfer function
MTF	modulation transfer function
W	wavefront error in units of wavelengths
W_{rms}	root-mean-square wavefront error
t-number	f-number adjusted for lens transmission
ν	normalized spatial frequency

4.2 INTRODUCTION

Setting the specifications for an optical instrument or system is an essential part of engineering, designing, or purchasing an optical system. Since the optics usually serve as a portion of a larger system, the specifications are frequently set by project managers who do not have specific knowledge in the basics of optical systems. This can at times lead to unrealistic requirements being established; this can profoundly affect the probability of success for the system. Properly drafted specifications can make the entire project successful and cost effective. Poorly written specifications can lead to excess cost and ultimately project failure.

One of the difficulties with setting optical specifications is that the ultimate result of a beam of light passing through a complex assembly of components is affected by each of those components, which in turn need to be specified and tolerances placed upon the fabrication and assembly of those components. In the case of an imaging system, the problem is compounded by the need to describe an optical system which passes many bundles of light across a wide field of view. Even in the case of single beam, optical communications components, indirect issues such as scattered light and environmental stability may prove to be major issues.

*Retired.

In the worst case, the specifications may be set so high that the system is not capable of being manufactured. In most cases, the specifications interact with other devices, such as detector arrays, and matching the quality of the optic to the limits of the sensor is required. In this section some of the principles involved in setting the specifications will be discussed, and guidelines provided for carrying out the process of specification setting. The reader will have to extend these principles to the device or system that is being considered. In this chapter, the stress will be placed on imaging systems.

Specifications for optical systems cover a wide range of needs. Functional specifications of the image quality or other optical characteristics are required for the satisfactory operation of a system. These functional specifications serve as the goal for the design and construction of the optical system. In addition, these specifications are a basis for tolerances placed upon the components of the optical system and lead to detailed component specifications used for procurement of the optical elements of the system. Assembly specifications and detailed specifications of optical parts to be produced by a shop can be written based upon these component specifications. The detail and extent of information required is different at each step. Over- or underspecification can contribute significantly to the cost or feasibility of design of an optical system.

Functional specifications are also used to describe the characteristics that an instrument must demonstrate in order to meet the needs of the user. This may include top-level requirements such as size, weight, image scale, image format, power levels, spectral range, and so on. Component specifications are developed after design of the system and describe the optical components, surface, and materials used in the system to the detail necessary to permit fabrication of the components. Assembly specifications are another derivative of the design and system specifications. These include the statement of tolerances upon location of the components, as well as the procedure to be used in assembling and testing the system.

The development and writing of these specifications is important both for initiating and for tracking the course of development of an optical instrument. In a business or legal sense, specifications are used to establish responsibility for a contractor or subcontractor, as well as to define the basis for bidding on the job. Thus the technical specifications can have business importance as well as engineering significance. "Meeting the customer's specifications" is an essential part of any design and fabrication task. Identifying areas where the specifications could be altered with benefit to all parties is an important business and engineering responsibility.

Specifications are usually communicated as a written document following some logical format. Although there are some international standards that may cover the details of drawings of components, there is no established uniform set of standards for stating the specifications on a system or component. The detailed or component specifications are usually added as explanatory notes to drawings of the components to be fabricated. In modern production facilities, the specifications and tolerances are often part of a digital database that is accessed as part of the production of the components of the system.

The detail and the intent of each of these classes of specifications are different. Optical specifications differ from many mechanical or other sets of specifications in that numbers are applied to surfaces and dimensions that control the cumulative effect of errors imposed on a wavefront passing through the total system. Each of the specifications must be verifiable during fabrication, and the overall result must be testable after completion.

Mechanical versus Optical Specifications

There are two types of specifications that are applied to an optical system or assembly. One set of these includes mechanical tolerances on the shape or location of the components that indirectly affect the optical quality of the image produced by the system. Examples of this include the overall size or weight of the system. The other set consists of specialized descriptions that directly affect the image quality. Examples of this latter type of specification are modulation transfer function (MTF), illumination level, and location of the focal plane relative to the system.

System versus Components Specifications

Some specifications have meaning only with respect to the behavior of the entire optical system. Others apply to the individual components, but may affect the ability of the entire system to function.

An example of a system specification is a set of numbers limiting the range of acceptable values of the MTF that are required for the system. Another system specification is the desired total light transmission of the system.

Examples of component specifications are tolerances upon surface irregularity, sphericity, and scattering. The related component specification based upon the system light transmission specification might provide detailed statements about the nature and properties of the antireflective coatings to be applied to the surface of each element.

Image Specifications

The specifications that are applied to the image usually deal with image quality. Examples are modulation transfer function, fraction of scattered light, resolution, or distortion. In some cases, these specifications can be quite general, referring to the ability of the lens to deliver an image suitable for a given purpose, such as the identification of serial numbers on specific products that are to be read by an automated scanner. In other cases, the requirements will be given in a physically meaningful manner, such as "the MTF will be greater than 40 percent at 50 lines per millimeter throughout the field of view."

Other criteria may be used for the image specifications. One example is the energy concentration. This approach specifies the concentration of light from a point object on the image surface. For example, the specification might read "75 percent of the light shall fall within a 25-μm-diameter circle on the image." This quantity is obviously measurable by a photometer with appropriate-size apertures. The function may be computed from the design data by a method of numerical integration similar to that providing the point spread function or modulation transfer function.

Wavefront Specifications

Wavefront specifications describe the extent to which the wavefront leaving the lens or components conforms to the ideal or desired shape. Usually the true requirement for an optical system is the specification of image quality, such as MTF, but there is a relation between the image quality and the wavefront error introduced by the optical system. The wavefront error may be left to be derived from the functional image quality specification, or it may be defined by the intended user of the system.

For example, a wavefront leaving a lens would ideally conform to a sphere centered on the chosen focal location. The departure of the actual wavefront from this ideal, would be expressed either as a matrix or map of departure of the wavefront from the ideal sphere, as a set of functional forms representing the deviation, or as an average [usually root-mean-square (rms)] departure from the ideal surface. By convention, these departures are expressed in units of wavelength, although there is a growing tendency to use micrometers as the unit of measure.

The rms wavefront error is a specific average over the wavefront phase errors in the exit pupil. The basic definition is found by defining the nth power average of the wavefront $W(x, y)$ over the area A of the pupil and then specifically defining W_{rms} or, in words, the rms wavefront error is the square root of the mean square error minus the square of the mean wavefront error:

$$\bar{W}^n = \frac{1}{A}\int W(x,y)^n dx\, dy$$

$$W_{\text{rms}} = \sqrt{[\bar{W}^2] - [\bar{W}]^2}$$

The ability to conveniently obtain a complete specification of image quality by a single number describing the wavefront shape has proven to be questionable in many cases. Addition of a correlation length, sometimes expressed as a phase difference between separated points, has become common. In other cases, the relative magnitude of the error when represented by various orders of Zernike polynomials is used.

There is, of course, a specific relationship between the wavefront error produced by a lens and the resulting image quality. In the lens, this is established by the process of diffraction image formation. In establishing specifications, the image quality can be determined by computation of the modulation transfer function from the known wavefront aberrations. This computation is quite detailed and, while rapidly done using present day computer techniques, is quite complex for general specification setting. An approximation which provides an average MTF or guide to acceptable values relating wavefront error and MTF is of great aid.

A perfect lens is one that produces a wavefront with no aberration, or zero rms wavefront error. By convention, any wavefront with less than 0.07 wave, rms, of aberration is considered to be essentially perfect. It is referred to as *diffraction-limited*, since the image produced by such a lens is deemed to be essentially indistinguishable from a perfect image.

The definition of image quality depends upon the intended application for the lens. In general, nearly perfect image quality is produced by lenses with wavefront errors of less than 0.15 wave, rms. Somewhat poorer image quality is found with lenses that have greater than about 0.15 wave of error. The vast majority of imaging systems operate with wavefront errors in the range of 0.1 to 0.25 wave, rms.

There are several different methods that can be used to establish this relationship. The most useful comparison is with the MTF for a lens with varying amounts of aberration. The larger the wavefront error, the lower will be the contrast at specific spatial frequencies. For rms error levels of less than 0.25 or so, the relation is generally monotonic. For larger aberrations, the MTF becomes rather complex, and the relation between rms wavefront error and MTF value can be multiple valued. Nevertheless, an approximate relation between MTF and rms wavefront error would be useful in setting reasonable specifications for a lens.

There are several possible approximate relations, but one useful one is the empirical formula relating root-mean-square wavefront error and MTF given by

$$\text{MTF}(\nu) = \text{DTF}(\nu) \times \text{ATF}(\nu)$$

The functional forms for these values are

$$\text{DTF}(\nu) = \frac{2}{\pi}\left[\arccos(\nu) - \nu\sqrt{1-\nu^2}\,\right]$$

$$\text{ATF}(\nu) = \left[1 - \left(\left(\frac{W_{\text{rms}}}{0.18}\right)^2\right)(1 - 4(\nu - 0.5)^2)\right]$$

$$\nu = \frac{\text{spatial frequency}}{\text{spatial frequency cutoff}} = \frac{N}{\left(\dfrac{1}{\lambda f\text{-number}}\right)}$$

These look quite complicated, but are relatively simple, as is shown in Fig. 1. This is an approximation, however, and it becomes progressively less accurate as the amount of the rms wavefront error W_{rms} exceeds about 0.18 wavelength. The approximation remains reasonably valid for lower spatial frequencies, less than about 25 percent of the diffraction limited cutoff frequency. The majority of imaging systems fall into this category.

Figure 1 shows a plot of several values for the MTF of an optical system using this approximate method of computation. The system designer can use this information to determine the appropriate level of residual rms wavefront error that will be acceptable for the system of interest. It is important to note that this is an empirical attempt to provide a link between the wavefront error and the

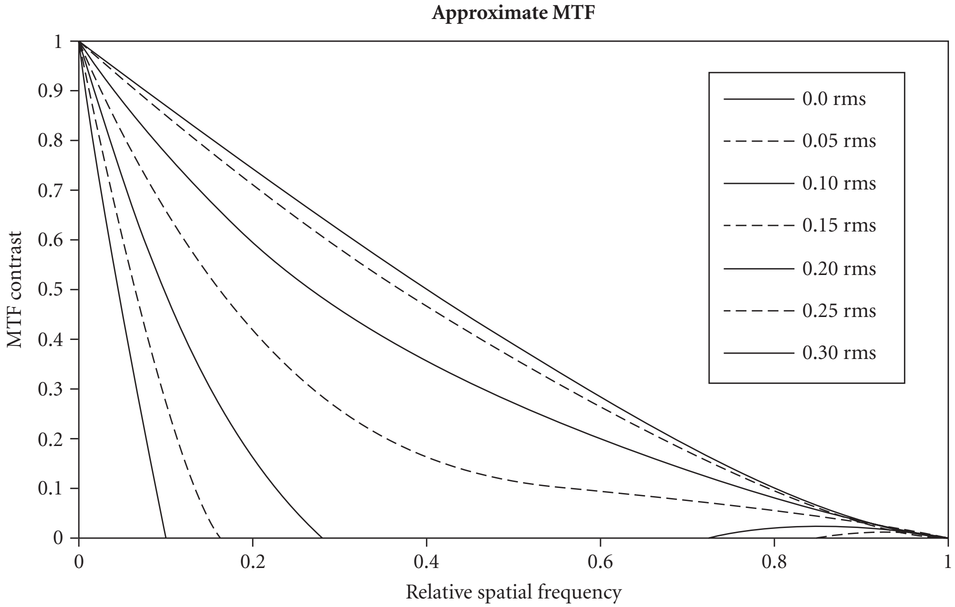

FIGURE 1 Approximate MTF curves from formula.

MTF as a single-value description of the state of correction of a system. Examination of the curves provides a method of communicating the specification to the system designer and fabricator. More detail on applying the rms wavefront error can be found in Chap.5, "Tolerancing Techniques."

In addition, it must be pointed out that most imaging systems operate over a finite wavelength range. Thus the specification of "wavefront error" can be a bit fuzzy, but is usually meant to mean either the wavefront error at a specified wavelength, or a weighted average over the wavelength band. This should be mentioned when writing the specifications. In either case, the stated wavefront error contains a measure that communicates the extent of perfection required of the optical system performance.

4.3 PREPARATION OF OPTICAL SPECIFICATIONS

Gaussian Parameters

The gaussian parameters determine the basic imaging properties of the lens. They are the starting point for setting the specifications for a lens system. In principle these numbers can be specified precisely as desired. In reality, overly tight specifications can greatly increase the cost of the lens. Some of the important parameters are shown in Table 1.

Table 1 is a sample of reasonable values that may be placed upon a lens. A specific case may vary from these nominal values. The image location, radiometry, and scale are fixed by these numbers. A specific application will require some adjustment of these nominal values. In general, specifications that are tighter than these values will likely result in increased cost and difficulty of manufacture.

There is an interaction between these numbers. For example, the tight specification of magnification and overall conjugate distance will require a very closely held specification upon the focal length. The interaction between these numbers should be considered by the user to avoid accidentally producing an undue difficulty for the fabricator. It may be appropriate to specify a looser tolerance on some of these quantities for the prototype lens, and later design a manufacturing process

TABLE 1 Gaussian Parameters

Parameter	Precision Target	Importance	How Verified
Focal length	1–2%	Determines focal position and image size	Lens bench
f-number	<±5%	Determines irradiance at image plane	Geometrical measurement
Field angle	<±2%	Determines extent of image	Lens bench
Magnification	<±2%	Determines overall conjugate distances	Trial setup of lens
Back focus	±5%	Image location	Lens bench
Wavelength range	As needed; set by detector and source	Describes spectral range covered by lens	Image measurement
Transmission	Usually specified as $>0.98^n$ for n surfaces	Total energy through lens	Imaging test, radiometric test of lens
Vignetting	Usually by requiring transmission to drop by less than 20% or so at the edge of the field	Uniformity of irradiance in the image	Imaging test, radiometric test of lens

to bring the production values within a smaller tolerance. However, it is appropriate that this be investigated fully at the design stage. The designer should be encouraged to consider the possibility of leaving adjustment possibilities in the lens design, so that a final assembly adjustment can bring the Gaussian parameters into the required tolerance range.

4.4 IMAGE SPECIFICATIONS

Image Quality

The rms wavefront error and the MTF for a lens have been discussed earlier as useful items to specify for a lens. Frequently, the user desires to apply a detection criterion to the image. This is always related to the application for the lens.

The most familiar functional specification that is widely used for system image quality is the resolution of the system. This is usually stated as the number of line pairs per millimeter that need to be visually distinguished or recognized by the user of the system. Since this involves both the physics of image formation as well as the psychophysics of vision, this is an interesting goal, but needs to be specified clearly to be of use to a designer. The reading of the resolution by a human observer is subjective, and the values obtained may differ between observers. Therefore, it is necessary to specify the conditions under which the test is to be carried out.

The type of target and its contrast need to be stated. The default standard in this case is the "standard" U.S. Air Force three-bar target, with high contrast, and a 6:1 ratio of bar length to width. This is usually selected as it will give the highest numerical values, certainly politically desirable. However, studies have shown that there is a better correlation between the resolution produced by a low-contrast target, say 2:1 contrast ratio, or 0.33 modulation contrast and the general acceptability of an image.

The resolution is, of course, related to the value of the MTF in the spatial frequency region of the resolution, as well as the threshold of detection or recognition for the observer viewing the target. If the thresholds are available, the above-described empirical relation between the rms wavefront error and the MTF can be used to estimate the allowable aberration that can be left in the system after design or fabrication.

In the case of a system not intended to produce an image to be viewed by a human, a specific definition of the required image contrast or energy concentration is usually possible. The signal-to-noise ratio of the data transmitted to some electronic device that is to make a decision can be calculated once a model for operation of the detector is assumed. The specification writer can then work backward through the required MTF to establish an acceptable level of image quality. The process is similar to that for the visual system above, except that the threshold is fully calculable.

In some cases, the fractional amount of energy collected by the aperture of the lens from a small angular source, such as a star, falling within the dimensions of a detector of a given size is desired. Such a requirement can be given directly to the designer.

Image Irradiance

The radiometry of the image is usually of importance. With an optical system containing the source, such as a viewer, projector, or printer, the usual specification is of the irradiance of the image in some appropriate units. Specifying the screen irradiance in watts per square centimeter or, more commonly, foot-lamberts, implies a number of optical properties. The radiance of the source, the transmission of the system, and the apertures of the lenses are derived from this requirement.

In the more usual imaging situation, the *f*-number and the transmission of the lens are specified. If the lens covers a reasonable field, the allowable reduction in image irradiance over the field of view must also be specified. This leads directly to the level of vignetting that can be allowed by the designer in carrying out the setup and design of the lens system.

There is an interaction between these irradiance specifications and the image quality that can be obtained. The requirement of a large numerical aperture leads to a more difficult design problem, as the high-order aberration content is increased in lenses of high numerical aperture.

An attempt to separate the geometrical aperture effects from the transmission of the components of the lens is accomplished through the *t*-number specification. Since the relative amount of irradiance falling on the focal plane is inversely proportional to the square of the *f*-number of a lens, the effect of tranmission of the lens can be included by dividing the *f*-number by the transmission of the lens.

$$t\text{-number} = \frac{f\text{-number}}{\sqrt{t}}$$

where t is the transmission factor for the lens. The transmission factor for the lens is the product of the bulk transmission of the glass and the transmission factor for each of the surfaces. When this is specified, the designer must provide a combination of lens transmission and relative aperture that meets or exceeds a stated value.

Depth of Focus

The definition of the depth of focus is usually the result of a tolerance investigation. The allowable focal depth is obtained by determining when an unacceptable level of image quality is obtained. There is an obvious relation between the geometry of the lens numerical aperture and the aberrations that establishes the change of MTF with focal position. This effect can be computed for specific cases, or estimated by recognizing that the relation between rms wavefront error and focus shift is

$$W_{\mathrm{rms}_{\mathrm{def}}} = \frac{\delta l}{8\lambda(f\text{-number})^2}$$

which can be used in the above approximate MTF to provide an estimate of the likely MTF over a focal range.

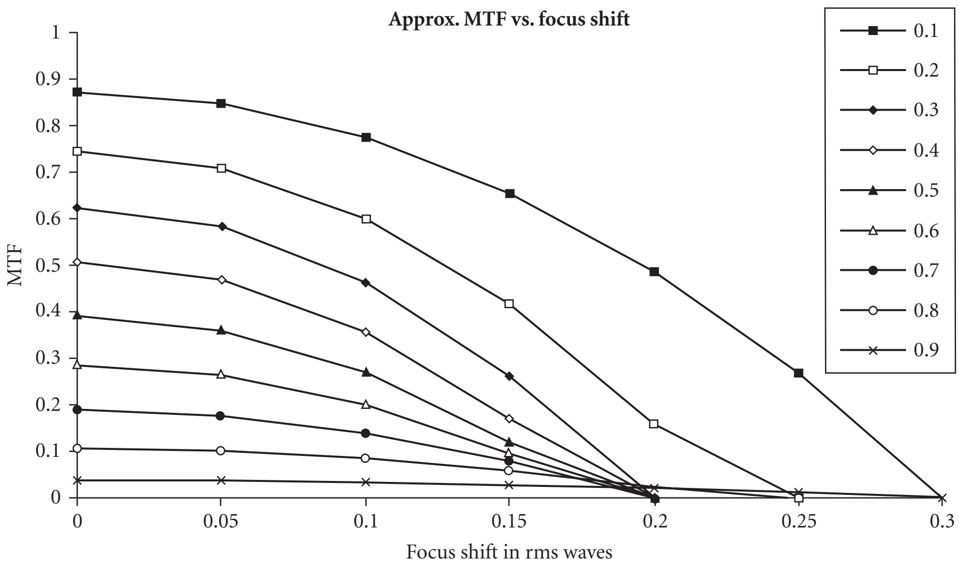

FIGURE 2 Approximate MTF as a function of focal position for various spatial frequencies.

If there is a basic amount of aberration present in the lens, then the approximation is that

$$W_{\mathrm{rms}_{\mathrm{total}}} = \sqrt{W^2_{\mathrm{rms}_{\mathrm{def}}} + W^2_{\mathrm{rms}_{\mathrm{lens}}}}$$

leading to a calculation of the estimated MTF value for the given spatial frequency and focal position. As an example, Fig. 2 provides a plot of the focal position change of the MTF. The interpretation of this curve is straightforward. Each of the curves provides the MTF versus focus for a spatial frequency that is the stated fraction of the cutoff spatial frequency. The defocus is given in units of rms wavelength error, which can be obtained from reference to the appropriate formula. Using this approximate data, a specification writer can determine whether the requirements for image quality, *f*-number, and focal depth are realistic.

An additional consideration regarding depth of focus is that the field of the lens must be considered. The approximate model presented here is used at an individual field point. An actual lens must show the expected depth of field across the entire image surface, which places some limits upon the allowable field curvature. In general, it is the responsibility of the specification writer to establish the goal. It is the responsibility of the optical designer to determine whether the goal is realizable, and to design a system to meet the needs. In a sensible project, there will be some discussion between the designer and the engineer writing the specifications in order to avoid an unrealizable set of goals being set.

4.5 ELEMENT DESCRIPTION

Each element of the lens to be fabricated must be described in detail, usually through a drawing. All of the dimensions will require tolerances, or plus and minus values that, if met, lead to a high probability that the specified image quality goals will be met.

Mechanical Dimensions

The mechanical dimensions are specified to ensure that the element will fit into the cell sufficiently closely that the lens elements are held in alignment. This will be a result of tolerance evaluation, and must include allowances for assembly, thermal changes, and so on.

An important item for any lens is the interface specification, which describes the method of mounting the lens to the optical device used with it. For some items, such as cameras and microscopes, there are standard sizes and screw threads that should be used. In other cases, the specification needs to describe a method for coupling or mounting the optics in which there is a strain-free transfer of load between the lens and the mounting.

Optical Parameters

The optical parameters of the lens element relate to the surfaces that are part of the image-forming process. The radius of curvature of the spherical refracting (or reflecting) surfaces needs to be specified, as well as a plus or minus value providing the allowable tolerances. When tested using a test glass or an interferometer, the important radius specification is usually expressed in terms of fringes of spherical departure from the nominal radius. In addition, the shape of the surface is usually specified in terms of the fringes of irregularity that may be permitted.

When specifying a surface that will be measured on an interferometer, adjustment of focus during the test can be made. In this case, the spherical component of the surface, that is, the fringes of radius error, can be specified independently of the irregularity fringes that are applicable to the surface. When test glasses are to be used, the spherical component must be fabricated to within a small level of error to permit accurate reading of the irregularity component of the surface.

The cosmetic characteristics of the surface also need to be stated. The specification for this is as yet a bit imperfect, with the use of a scratch-and-dig number. This is actually intended to be a comparison of surface scratches with a visual standard, but is generally accepted to be in terms of a ratio, such as 20:10, which means, more or less, scratches of less than 2-μm width and digs of less than 100-μm diameter. This specification is described in MIL-O-13830, and is referred to a set of standards that are used for visual comparison to the defects on the surface. There have been several attempts to quantify this specification in detail, but no generally accepted standard has yet been achieved. A broader description of these specifications is found in International Standards 10110 and 9211, discussed later in this chapter.

Material Specifications

The usual material for a lens is optical glass, although plastics are becoming more commonly used in optics. The specification of a material requires identification of the type, as, for example, BK7 glass from Schott. Additional data upon the homogeneity class and the birefringence needs to be stated in ordering the glass. The homogeneity is usually specified by class, currently P1 through P4 with the higher number representing the highest homogeneity, or lowest variation of index of refraction throughout the glass. The method of specifying glass varies with the manufacturer, and with the catalog date. It is necessary to refer to a current catalog to ensure that the correct specification is being used.

Similar data should be provided regarding plastics. Additional data about transmission is usually not necessary, as the type of material is selected from a catalog which provides the physical description of the material. Usually, the manufacturer of the plastic will be noted to ensure that the proper material is obtained.

Materials for reflective components similarly have catalog data describing the class and properties of the material. In specifying such materials, it is usually necessary to add a description of the form and the final shape required for the blank from which the components will be made.

Coating Specifications

The thin film coatings that are applied to the optical surfaces require some careful specification writing. In general, the spectral characteristics need to be spelled out, such as passband and maximum reflectivity for an antireflection coating. Requirements for the environmental stability also need to be described, with reference to tests for film adhesion and durability. Generally, the coating supplier will have a set of "in-house" specifications that will guarantee a specific result that can be used as the basis for the coating specification.

4.6 ENVIRONMENTAL SPECIFICATIONS

Temperature and Humidity

Specification setting should also include a description of the temperature range that will be experienced in use or storage. This greatly affects the choice of materials that can be used. The humidity and such militarily favorite specifications as salt spray tests are very important in material selection and design.

Shock and Vibration

The ruggedness of an instrument is determined by the extent to which it survives bad handling. A requirement that the lens shall survive some specified drop test can be used. In other cases, stating the audio frequency power spectrum that is likely to be encountered by the lens is a method of specifying ruggedness in environments such as spacecraft and aircraft. In most cases, the delivery and storage environment is far more stressing than the usage environment. Any specification written in this respect should be careful to state the limits under which the instrument is actually supposed to operate, and the range over which it is merely meant to survive storage.

4.7 PRESENTATION OF SPECIFICATIONS

Published Standards

There are published standards from various sources. The most frequently referred to are those from the U.S. Department of Defense, but a number of standards are being proposed by the International Standards Organization.

Format for Specifications

The format used in conveying specifications for an optical system is sometimes constrained by the governmental or industrial policy of the purchaser. Most often, there is no specific format for expressing the specifications.

The best approach is to precede the specifications with a brief statement as to the goals for the use of the instrument being specified. Following this, the most important optical parameters, such as focal length, *f*-number, and field size (object and image) should be stated. In some cases, magnification and overall object-to-image distance along with object dimension will be the defining quantities.

Following this, the wavelength range, detector specifications, and a statement regarding the required image quality should be given. The transmission of the lens is also important at this stage.

Following the optical specifications, the mechanical and environmental requirements should be stated. The temperature and humidity relations under which the optical system needs to operate as well as a statement of storage environment are needed. Descriptions of the mechanical environment, such as shock and vibration, are also important, even if expressed generally.

Other important pieces of information, such as a desired cost target, can then be included. Any special conditions, such as the need to be exposed to rapid temperature changes or a radiation environment, should be clearly stated. Finally, some statement of the finish quality for the optical system should be given.

In many cases, a list of applicable governmental specifications will be listed. In each case it is appropriate to ensure that these referenced documents are actually available to the individual who has to respond to the specification.

Use of International Standards

An important tool in writing specifications is the ability to refer to an established set of standards that may be applicable to the system being designed. In some cases, the development of specifications is simplified by the specification writer being able to refer to a set of codified statements about the environment or other characteristics the system must meet. In other cases, the established standards can be used as a reference to interpret parts of the specifications being written. For example, there may be a set of standards regarding interpretation of items included in a drawing.

Standards are an aid, not an end to specification. If the instrument must be interchangeable with parts from other sources, then the standards must be adhered to carefully. In other cases, the standards can serve as an indicator of accepted good practice in design or fabrication. It is the responsibility of the specification writer to ensure that the standard is applicable and meaningful in any particular situation.

At the present time there is growing activity in the preparation of standards for drawings, interfaces and dimensions, MTF, and other properties of optical and electro-optical systems. The efforts in this direction are coordinated by the International Standards Organization, but there are a number of individual standards published by national standards organizations in Germany, England, Japan, and the United States. The first major publications are ISO 10110, detailing preparation of drawings for optical elements and systems and ISO 9211, on optical coatings. Other standards on optical testing and environmental requirements are in draft form.

The ISO standards are expected to provide significant detail on various standards issues, and should become the principal guiding documents. At present, the standards documents that are most used in the United States are the various military specifications, or MIL-SPEC documents, that cover many different aspects of optical systems.

Information on published standards is available from the American National Standards Institute (ANSI), 11 West 42d Street, New York, NY 11036, or may be downloaded at *www.webstore.ansi.org*. A recent (2008) review of this website showed over 350 individual documents dealing with these issues, the majority of which deal with issues regarding fiber optical systems. Information on U.S. Department of Defense standards can be searched for through the National Search Engine for Standards at *www.nssn.org*. Additional information about worldwide standards is available at *www.worldwidestandards.com*.

4.8 PROBLEMS WITH SPECIFICATION WRITING

Underspecification

Failure to specify all of the conditions leaves the user vulnerable to having an instrument that will not operate properly in the real world. In many cases, the designer may not be aware of situations that may arise in operation that may affect the proper choice of design methods. Therefore, the design may not meet the actual needs.

The engineer developing a specification should examine all aspects of the problem to be solved, and carefully set the boundaries for the requirements on an optical system to meet the needs. All of the pertinent information about the image quality, environment, and relation to other systems that may interact with the lens being specified should be considered. The specifying engineer should also review the physical limits on the image quality and ensure that these are translated into realistic values.

Overspecification

Specifying image quality and focal position requirements too tightly can lead to problems. Overspecification would seem to ensure that the needs will be met, but difficulties in meeting these requirements can lead to designs that are difficult and expensive to build. Achieving the goals can be costly and may fail. In such cases, the penalty for not quite meeting very tight specifications can be serious, both economically and technically.

Boundary-Limit Specification

In most cases, the statement of goals or boundaries within which a lens must operate is better than stating specific values. This leaves the designer with some room to maneuver to find an economic solution to the design. Obviously, some fixed values are needed, such as focal length, *f*-number, and field angle. However, too-tight specifications upon such items as weight, space, and materials can force the design engineer into a corner where a less desirable solution is achieved.

Negotiation of Specifications

Finally it is important to note that unless there is an existing closely defined set of established specifications for an specific optical device (such as a fiber optics coupler, for example) each specification is the product of a single individual or group and reflects the experience and understanding of that individual. The procuring official should be prepared in some cases to act as a negotiator between the engineer and the supplier to ensure that a reasonable and successful set of verifiable specifications has been stated.

4.9 REFERENCES

There are many useful references on optical specifications that deal with specific topics not directly covered by the general discussion in this chapter. The most useful suggestion is that the users having the task of setting specifications on a specific product or system use the massive capabilities of Internet search engines to look for specific data applicable to that task. A general Google search on "Optical Specifications" provided 360,000 hits, of which probably less than 10 will be applicable to any specific problem.