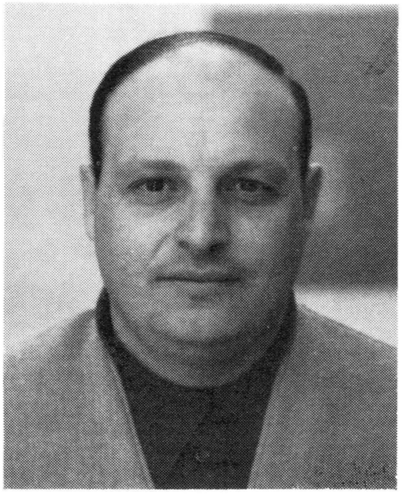


Editorial

John B. DeVelis: An Appreciation

For seven and a half years, it has been difficult to think of *Optical Engineering* without thinking of its outstanding editor, Professor John B. DeVelis. With this issue, Dr. DeVelis is retiring as editor to devote a larger fraction of his time to his distinguished research career.

When he became editor in 1973, John was faced with a journal with low circulation, few contributed papers, and no clear character. Through his untiring efforts, *Optical Engineering* has become one of the most widely read and universally respected journals in optics.

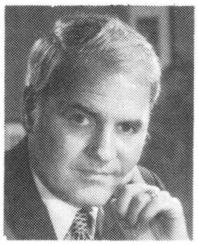
Being editor was only a part of John's career through the 1970s. His research in quantum electronics, coherence, holography, etc., earned him Fellow status in both SPIE and OSA. His work as an educator (teacher and assistant to the Academic Vice President of Merrimack College) earned him the love and respect of his students and colleagues. His work as editor of *Optical Engineering* has earned the respect and admiration of the international optics community.

On their behalf, as well as my own, John, congratulations and best wishes for continued success. Our best wishes go, as well, to John's colleague and associate editor of *Optical Engineering*, Ernest Costello.

H. John Caulfield

H. J. Caulfield
New Editor
June 1, 1979

Instant Photoinstrumentation



William G. Hyzer

Consulting Engineer
P. O. Box 1487
Janesville WI 53545

Instant color-discrimination shadowgraphy

The shadowgraph represents one of the oldest, the simplest and the most elegant of photoinstrumentation techniques. It is still in wide use today as a very practical high-speed photographic method of recording shockwaves associated with explosive and ballistic phenomena. The established applications of this technique are commonly based on black and white films; but color films, particularly large-format, instant-developing materials, are opening up some interesting possibilities of expanding both the usefulness and convenience of this dependable technique into other areas as well.

In its most elemental form, the shadowgraph system consists of a point source of light P which evenly illuminates a film F in a darkened room as diagrammed in Figure 1. A spark or other short-duration flash in the form of a point source is chosen for most high-speed photographic applications. The source P is fired when an object O enters the field between the source and the film, and casts a sharply defined shadow onto the film's surface. The flash duration must be short enough to reduce image blur caused by object motion to a negligible level. Also, the size of the film has to be large enough to record the entire object and the field of interest surrounding it to full scale.

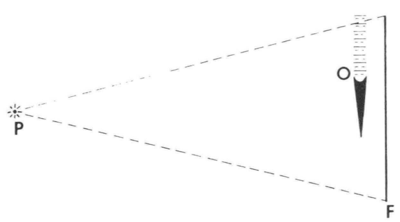


Figure 1. Simple shadowgraph system.

Instant self-developing black and white films suitable for shadowgraphic work were described in an earlier column in this series.[1] Of particular interest are the large-format 3000X and TLX instant radiographic films available from Polaroid. These films are rated at an ASA equivalent speed of 3000, can be developed in 15 seconds in a special motorized processor manufactured by Picker Corporation and provide pictures 10 x 12 inches in size. They are large and fast enough to fulfill most requirements in this field using spark sources.

The velocity of moving objects can be determined from black and white shadowgraphic records by pulsing the same source twice or by firing two separate sources in rapid succession at known intervals of time. The ability to read and interpret the resulting data, however, is often complicated by reduced image contrast and confusing patterns caused by multiple overlapping images of varying shades of grey. It is in this type of application that large-format color film with color-coded images can be put to good advantage.

The color-discrimination shadowgraphic technique is similar in principle to the color-channel camera system invented by Aspden[2,3] in the mid 1940s. The method consists essentially of producing a sequence of colored flashes, each limited to a different spectral bandwidth, and the use of a color film to record the images produced by each of these sources in their respective colors. The processed film contains superimposed images in two or more colors which can either be analyzed directly or interpreted individually by extracting each colored image independently using a suitable color-separation method. For example, two point sources consisting of a red-colored and a blue-colored spark

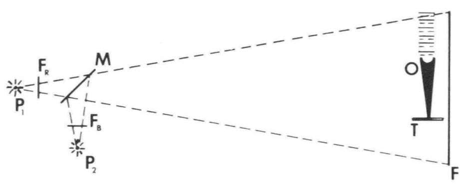


Figure 2. Color-discrimination shadowgraph system showing color film F, object O, target T, semitransparent mirror M, point sources P_1 and P_2 and red and blue filters F_R and F_B.

or strobe are each fired in sequence to produce a double-exposed shadowgraph on color film of a projectile striking a target, Figure 2. Two EG & G Type 549 microflash units with accessory spark-gaps[4] or two GR Strobotacs without reflectors[5] might be chosen for this application. The point sources are typically located 2 to 6 feet away from the film holder. A semitransparent mirror might be mounted as shown in Figure 2 to provide a common origin for both sources, if required to eliminate parallax. This offers the disadvantage of reducing the light from each source by approximately one half. The direction and magnitude of movement of any object recorded by the film can then be determined by measuring the distance from its red image to its corresponding blue image. The color coding of the sources and their corresponding images makes it possible to determine with certainty the direction the individual objects are moving. This is a very important consideration when the object field is cluttered with flying objects of varying sizes, shapes and velocities. Also, by viewing the color shadowgraph separately through either a blue or a red filter, each color image can be studied independently. This capability is very useful for interpreting overlapping images of complex shapes, such as interacting shock waves, liquid sprays and distorting surfaces.

I have found Polaroid 8 x 10 instant color print film to be ideal for routine work in this field. This is a medium-speed (80 ASA-equivalent) film product, balanced for use in average daylight or with electronic flash. The image area is approximately 7½ x 9½ inches on a super-white base measuring 8½ x 10¾ inches. Its components are the same as other Polacolor 2 "peel-apart" films, consisting of a nonreusable negative sheet and a positive receiving sheet with an integral pod of processing chemicals, except that they are packaged separately. The negative comes in a light-tight protective envelope which is loaded into a special single-sheet film holder under room-light conditions. After the holder is closed, the envelope can be removed. The holder containing the film is mounted at the proper position in front of the point light sources. The room lights are turned off and the darkslide in the holder is pulled out in preparation for the exposure. After the exposure is made, the darkslide can be reinserted and the room lights turned back on. The positive receiving sheet is then slipped into the holder. A simple interlocking tab system aligns the positive with the negative automatically.

At this point the operator merely sets the development timer on the automatic motor-driven film processor, places the film holder into the processor aperture and presses a single button on the processing unit. The processing rollers grab the film tab and draw both positive and negative through, breaking the pod and spreading the processing chemicals evenly between positive and negative. The film assembly is automatically deposited in the unit's processing tray. After one minute (slightly longer at temperatures lower than 75° F), the fully developed 8 x 10 color shadowgraph is ready for inspection. The entire system—film, holder and processor—offers the experimenter absolute control over the finished product without concern for the mechanics of instant film processing. The system completely eliminates the need for darkroom space, plumbing and hardware—or the services of a commercial color lab.

References

1. W. G. Hyzer, Instant films for instrumentation photography, Optical Engineering, **16**, 4 (July/August 1977).
2. R. L. Aspden, Improvements in or relating to photography, British Patent No. 635,365, April 2, 1947.
3. R. L. Aspden, *Electronic Flash Photography*. The Macmillan Company, New York, 1960.
4. H. E. Edgerton, *Electronic Flash/Strobe*, McGraw-Hill Book Company, New York, 1970, p. 133.
5. F. Van Veen, *Handbook of Stroboscopy*, General Radio Company, West Concord, Massachusetts, 1977.

Systems Integration/Optical Design

Gary W. Wilkerson
Consulting Engineer

1250 Lyndell Drive
Kissimmee,
Florida 32741

It is a privilege to have as guest author this issue John Waugh of Martin Marietta Aerospace, Orlando Division. Mr. Waugh is a senior engineer, as well as a consultant, in optics manufacturing. During his 17 years in optics, he has spent five years in lasers and metrology, three years in the manufacturing phase and nine in engineering; he is also experienced in thin film technology. His insight into optics testing and assembly processes is phenomenal. In this article, he provides the definitions (from an optics shop point of view) of concentration error for optical elements, clarifies what happens when a ray traveling along the mechanical axis enters an optical element with centration errors, the relationship of an element's mechanical axis to its optical axis, for testing and various centration errors.

Centration errors in the fabrication and assembly of optical elements

John Waugh
Martin Marietta Aerospace
P. O. Box 5837, Orlando, Florida 32856

Definitions and concepts

Centration of an optical system can be reduced to individual refracting and reflecting elements with three possible centration components:

1. Centering error (angular)
   a. Wedge in the element θ_p
   b. Deviation of the ray
   c. Image runout, twice deviation (FOR)
2. Decentration (linear) of the element
3. Tilt (angular of the element.

Following is a description of the above centration characteristics:

1. Centering error: referencing Figure 1, this defect is expressed as:
   a. Physical angle, θ_p, or wedge between lens surfaces
   b. Deviated ray angle θ_o from the mechanical axis (MA)
   c. Full optical runout (FOR) of the image which is $2(\theta_o)$, occurring during a 360° rotation of the element when it is tested.

   The angle θ_p is the fabrication error of physical wedge within the lens and results in a difference of edge thickness. The angle θ_o is a function of θ_p, radii R_1, R_2 and index of refraction n, (see Figure 1(a)). Centering error in a lens can be described as the angle θ_o a ray is deviated after refraction when the entering ray was directed longitudinally along the center of the barrel or mechanical axis (MA). Centering error is conveniently measured by five methods discussed later.
2. Decentration: a perfectly centered element is shifted laterally in the barrel to form a decentered system (see Figure 1(b)). Decentration is the relationship between the MA and the element's optical axis (OA). The OA is the line joining the two principal points of the element. This relationship can be dimensionally linear (as in Δ_1 and Δ_2) or angular (as in α) as seen in Figure 4 which is discussed later in greater detail. Although the error of decentration is often treated as a different kind of centration problem, and it is, its functional effect is the same as centering error (or wedge); the element's aperture is the physical stop (see Figure 1).
3. Tilt: consider tilting an element which has no centering error. Let the point of pivot be where the OA intersects the MA. A large amount of tilt of a thin biconvex or biconcave lens results in a small amount of decentration, (see Figure 2). The distance (Δ_o) is the error of centration introduced by the tilt component; i.e., the distance the point of focus is moved perpendicular to the mechanical axis. An exceptional case is where the element is rotated about an axis perpendicular to the intersection of the MA and the principal point nearest the image space (see Figure 3). Rotation about this axis will not result in a Δ_o image shift when rays in the object space are parallel. That would be a fortuitous but rare occurrence.

Lens Center is differentiated from *Lens Optical Axis*. By definition "lens center" of a centered element is the intersection of all rays at the OA directed toward the first principal point and emergent appearing to be directed from the second principal point. This type of meridional ray has equal entrance and exit angles.

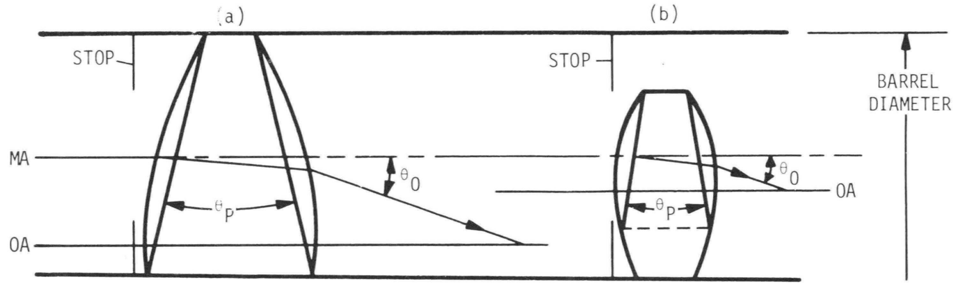


Figure 1.

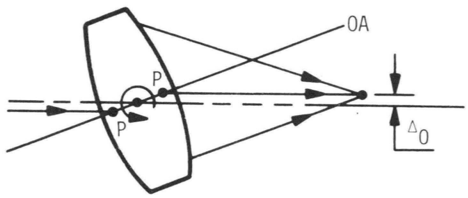


Figure 2.

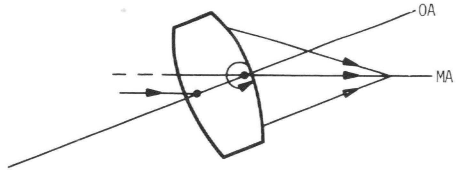


Figure 3.

Relationship of optical axis/mechanical axis

The OA with respect to the MA is a function of radius of curvature and physical angle θ_p. This OA/MA relationship is independent of index of refraction (see Figure 4). For the discussion following, secondary focusing effects are very small and shall be ignored.

1. *Index change* (n), with θ_p and radii at fixed values, will affect the angle of ray deviation θ_o as the point of focus shifts along the optical axis but the relationship between the OA and MA remains constant (see Figure 5).
   For wedge angles up 1.0°, Tan $\theta = \theta$ within accuracy requirements and common centering measurement techniques therefore $\Delta/fp \approx \theta_o \approx \theta_p(n-1)$.
2. For *radii change*, with θ_p and n at fixed values, θ_o remains fixed (see latter part of previous equation) as the point of focus shifts along the angle of θ_o originating from the second principal plane (see Figure 6). The relationship between the OA and MA changes as the radii change. Consider examples of equal and unequal radii (see Figure 4), where:

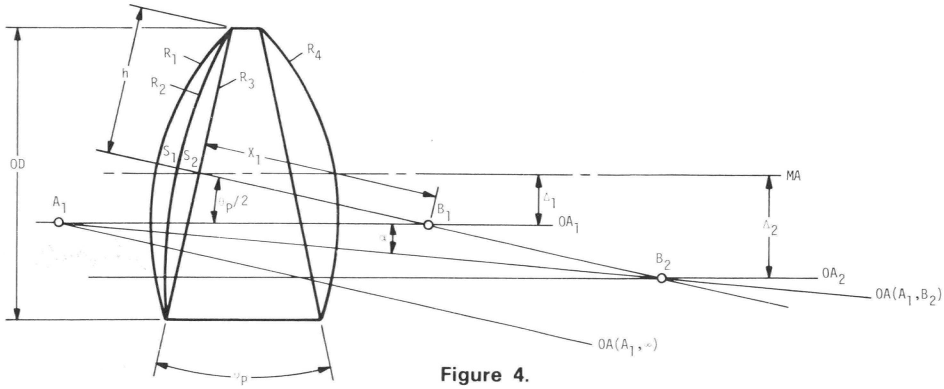


Figure 4.

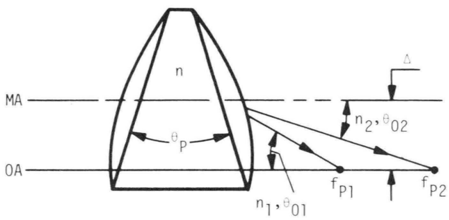


Figure 5.

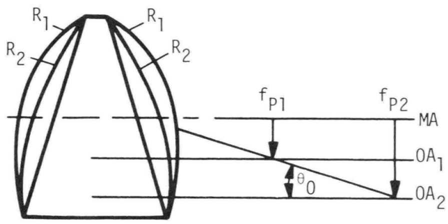


Figure 6.

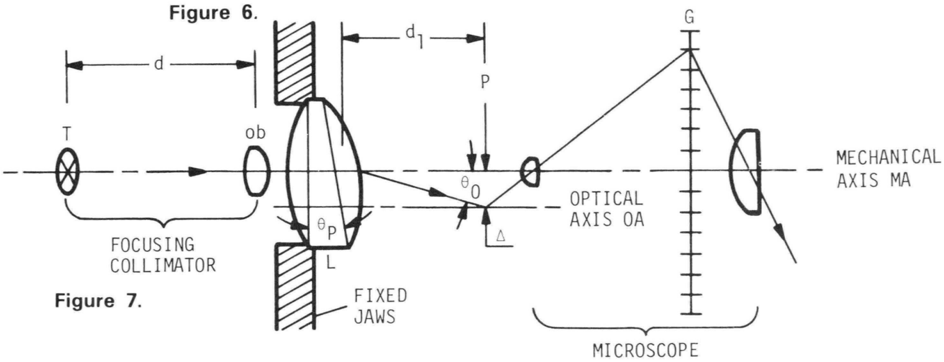


Figure 7.

$R_1 = 3.0"$
$R_2 = 6.0"$
$R_3 = \infty$
$R_4 = 3.0"$
$OD = 2.5"$
$\theta_P = 10$ arc sec
MA = mechanical axis
OA = optical axis
h = semidiameter of optical element
S_1 = sagitta of R_1, h
S_2 = sagitta of R_2, h
n = constant of index of refraction

for OA_1:

$$S_1 = R_1 - \sqrt{R_1^2 - h^2} = 0.2728219713$$

$$X_1 = R_1 - S_1 = 2.727178029$$

$$\Delta_1 = X_1 (\sin \theta_P)/2$$

$$OA_1 = \Delta_1 = 0.0000661086"$$

for OA_2:

$$S_2 = R_2 - \sqrt{R_2^2 - h^2} = 0.131657029$$

$$X_2 = R_2 - S_2 = 5.86834297$$

$$OA_2 = \Delta_2 = X_2 (\sin \theta_P/2)/2$$

$$\Delta_2 = 0.0001422527"$$

For unequal radii OA_1 and OA_2 are not parallel to the MA. If $R_2 = 6.0"$ and $R_4 = 3.0"$, the OA (A_1, B_2) formed by a line through points A_1 and B_2 subtends an angle α to the MA.

With R_4 held constant at 3.0" and R_2 increased to infinity, OA (A_1, ∞) becomes parallel to the line through points B_1 and B_2.

If R_4 is increased to infinity also, then the OA goes to infinity. It should be noted that with R_4 constant at 3.0", as R_1 changes to R_2 then again to R_3 or infinity, point A_1 is the origin for OA_1, $OA(A_1, B_2)$ and $OA(A_1, \infty)$.

Measurement techniques for centering error

A. *Focal collimator technique.* The focal collimator requires an initial calibration of its EFL and target dimensions. From these calibrations, angular units are permanently assigned to target reticle divisions. Concentric circles spaced 0.5 or 1.0 arc minute apart make a convenient measuring pattern. One arc minute spacings in the target pattern will always appear to be the same angle in the image plane of the element under test regardless of the apparent size of the image. The element is rotated a full 360° and a cross line reticle microscope is used to observe the image. A negative test element can be measured for centration by using a microscope with a working distance longer than the negative BFL of the element under test.

B. *Centering microscope technique* (see Figure 7). This method is similar to the focal collimator technique except that no calibrated graticule or collimator BFL is required. Calibration is required on the microscope side of the testing fixture. A focusing collimator for this discussion acts as a variable relay lens. A change in distance (d) from target (T) to objective (ob) does not result in a change of projected angle θ_o, only a change in the apparent size of the projected cross-line juncture as a reference *point* for the element under test.

Distance (d) can be changed to compensate for differences in focal lengths between elements being tested. The measurement (d_1) is from the second principal plane of element (L) to the focal plane (P) of the microscope objective. Failure to know the principal plane of (L) results in a systematic error. At the calibrated distance (d_1), $\theta_o \cong \Delta/d_1, \cong \theta_P(n-1)$ = FOR/2, where FOR is the full optical runout. The element being tested is made to focus at plane (P) by adjusting (d). Graticule (G) is calibrated as a function of (Δ) and (d_1).

C. *Reflection technique.* A third optical testing method for centering error uses a reflected beam from the first surface of an element under test to indicate the runout. This method measures the physical wedge of the element. The reflection angle of full element rotation is four times the physical wedge (θ_P).

D. *Autocollimation technique.* In this case beam deviation is measured from the infinite conjugate side of an element being tested. A projected image of the target at the focal point of the element under test is deviated by θ_o in the image plane of the autocollimator. The useful quantity (FOR) results from a full rotation of the element under test. Autocollimators are generally available and accurately calibrated.

E. *Mechanical indication technique.* The most direct method of centering error measurement is by mechanically indicating the lens surface and reading the wedge θ_P while the lens is under rotation. The lens must be rotated in a fixed jaw chuck or the lens OD nulled in a pretrued rotating chuck. The sensitivity of measurement should be $\geqslant 5 \times 10^{-5}$ inches.

In summary, the measuring techniques described above measure the following centration error characteristics, respectively:

A. Full Optical Runout (FOR), θ_o
B. FOR θ_o
C. θ_P
D. FOR, θ_o
E. Total Indicator Runout, θ_P

The Business Side of Optics

Curt Deckert

Technical and Management Consulting
18061 Darmel Place
Santa Ana, CA 92705

In this issue we will consider some very practical issues in the business side of optics, which will be helpful to the optics user and fabricator. There are many strategies to bidding, but they must be based on substantial information such as this article sets forth. The user also has some responsibilities in the acquisition of optics which can determine the overall success of a program for him and/or for the fabricator. This paper was given at the SPIE Seminar on The Business Side of the Optical Industry IV: Management Engineering and Research, August 1978, San Diego; the complete version appears in the SPIE Proceedings Volume 151.

Successful management of new optical fabrication projects

E. P. Wallerstein

University of California
Lawrence Livermore Laboratory
P. O. Box 5508
Livermore, California 94550

Introduction

In the business of high precision optical components, certain characteristic difficulties are frequently encountered such as misinterpretation of specifications, erratic pricing, late bids, inability to perform, economic losses and, especially, late deliveries. Problems may be expected in state-of-the-art optical fabrication projects but should be reduced through the application of the following management principles:

1) Assessment of relative capabilities within the industry;
2) Clarification of project requirements through discussion with customer prior to submitting proposal;
3) Codified baseline pricing guidelines from which to make pricing decisions;
4) Radical review of project at time of order;
5) Establishment and monitoring of procedures and milestones; and
6) Open, knowledgeable, and objective communication with customer when questions or difficulties arise.

Anyone who is involved in the management of a precision optical organization or anyone who purchases optics is frequently engaged in challenging or state-of-the-art fabrication projects, knows there is a high risk that delivery will not be on time. Sometimes the work could not have been done within the hours estimated, but often the overrun is at least partially due to factors that could have been better controlled.

Depending on the extent to which the project represents the state-of-the-art, there is an element of risk due to the unknown or unfamiliar territory which is being explored. There appear to be, however, characteristic modes of errors in the course of such projects which can be avoided. Avoiding these errors requires that very close attention be paid to the planning and progress of each project. The avoidance of these errors should result in at least minimizing schedule and economic losses.

By ignoring the following six areas of discipline, one permits serious errors to arise, but by carefully attending to these disciplines one will minimize avoidable errors.

1) *Assessment of relative capabilities within the industry.* The situation very seldom exists in precision optics, whether in any of the three major categories of material manufacture, optical finishing, or thin film coating, that a single commercial vendor has an absolute monopoly on being able to solve a particular problem. There is usually a choice on the part of the customer from whom to obtain a particular component. The technologies to do the work are usually common to a few vendors, but often in varying degree, and the relative extent and quality of the capability tends to change radically with time. These challenges can be a major source of error in bidding and managing a project. A reasonably accurate assessment of one's instantaneous position in a particular technology is crucial to the successful bidding and management of a project in that field. In dealing with the opportunity to take advantage of a particular requirement, the supplier must answer the following questions:

(a) Do I have adequate test equipment to determine whether the specifications are met and to demonstrate this to my customer?
(b) Do I have a process that I know will produce the required results?
(c) Does anyone else have these capabilities? If not, how close can they come?
(d) If the answer to (a) and/or (b) is no, what must I do to achieve the required technology?
(e) What is a reasonable estimate of my delivery? What is my scheduling flexibility?
(f) What is a reasonable estimate of the cost of my process, and how does it compare with that of my competition?

From the answers to these questions, the supplier should determine:

(1) If he is in a good position to do the work.
(2) If not, the requirements for getting into a good position.
(3) His approach to his potential customer.

It is incumbent upon the vendor to be able to answer the first set of questions with reasonable accuracy. Doing this, especially for questions (c), (d) and (f), where insight into the competition is required, means a considerable amount of time and effort probing the realities of the outside world. One of the best sources about relative standing in a particular technology can be the customer; this is discussed further in section 2 below.

The negative results from not answering the above questions can be:

(a) Costly effort is expended on bid and proposal time where little or no chance for success exists.
(b) Jobs are won and entered into based on an erroneous assessment of internal capabilities, resulting in late delivery, loss,

and deterioration of customer relationships.

Two examples from the interaction between a single supplier and a single customer illustrate some of these points. In the first instance the vendor was approached about making a difficult set of aspherics, largely because the vendor had a long standing reputation in the field. A substantial contract was negotiated; the parts were delivered over six months late at a loss to the vendor of about 50% of the contract price. In the meantime, the customer's project was delayed and then was filled in partially with substitute parts from another source. As it turned out, both the customer and the supplier had failed to investigate the current state of the art for the type of component in question. The customer subsequently found other suppliers who could do similar work considerably more quickly and cheaply, and the original vendor discovered that his technology was lagging.

In another instance between the same two parties, but requiring a different optical fabrication technology, the vendor accurately assessed the relative state of the technology and approached the customer with a best-efforts fixed price proposal to make some prototypes. The proposal was accepted and subsequently led to a production contract with very satisfactory results to both parties.

Much of the information the supplier requires to help make the right decisions must necessarily come from outside his own organization. The potential customer can be a major source of that outside information, as discussed in the next step.

2) *Clarification of project requirements through discussion with customer prior to submitting proposal.* Even for very simple requests for quotation, such as building a Porro prism to print, it will usually enhance the potential vendor's chances of submitting an intelligent response if he takes the time to discuss the requirement with the customer. This becomes more and more important as the parts become more difficult or as the request is more complex, requiring, say, design as well as fabrication.

All the information the supplier wants is not always available. Some organizations are more accessible than others. In some cases there are policy or even legal restrictions on the data that can be dispensed. It helps the supplier enormously, of course, to know who the actors in a particular organization are, the appropriate executives, technical people and purchasing people. Developing an on-going relationship is important, so the customer knows the supplier's capabilities, and the supplier knows who to talk to. Sometimes large organizations, such as government agencies or laboratories, can appear opaque from the outside, but if the manufacturer knows or suspects that a requirement exists in his field, he should be persistent. Organizations are usually very interested in finding and developing good sources of supply in areas where they have needs. Customers sometimes hold meetings to scope expected requirements or bidder's conferences on known requirements. These are important to attend and vendors can often meet the right people for follow-on conversations. What kind of information does a vendor want? For a wish list, the sky should be the limit; however, the supplier will probably have to settle for less. There are three categories to consider:

(a) Technical
(b) Price
(c) Schedule

These categories interact; the way in which they interact depends on:

(1) The state of the art and complexity of the technical requirements.
(2) The customer's budget.
(3) The type of contract contemplated.
(4) The confidence the customer has in the vendor's capabilities.
(5) The firmness of the requirements.
(6) The expected date of placing an order.
(7) The required delivery date.

The single most usual criterion on which an order is placed is price, although this is by no means always the case. Even when it is, the final competition is frequently among a relatively small group of competitors who have submitted good technical proposals in a two-stage procurement, have demonstrated competence in the field in the past, or have successfully completed a qualifying prototype.

Following is a brief discussion of the informational value of three categories:

Technical. In order to get into the right price range it is important to find out technically what the customer really wants. Sometimes the situation appears to be pretty cut and dried; but more often, especially when the requirements are close to the state of the art, or are based on performance, significant tradeoffs and/or ambiguities may exist in the specifications. It is important, therefore, for the vendor to gain an understanding of the use of the component or system so he can assess these tradeoffs. This understanding should be gained or augmented by direct conversation with a cognizant technical representative of the customer. Depending on the status of the procurement and his relationship with the customer, he can then follow several courses if he feels modification or clarification of specifications might be in order, such as:

(a) Informally discuss possible changes in specification with the customer.
(b) Submit a letter or unsolicited proposal indicating the modified approach on a proprietary basis where practical.
(c) Submit a bid or proposal meeting the letter of the specification with an alternative proposal incorporating alternative (e.g. less expensive) ideas.

One simple frequently recurring example of an opportunity to modify specifications is when surface flatness is specified for optical windows rather than transmitted wavefront. It is often more suitable and less expensive to specify transmitted wavefront and let absolute surface flatness be considerably relaxed or even unspecified. An example of clarifying limits relates to a set of specifications for a fairly simple radiometer for a rocket application. The customer specified that the device should be of the "lightest construction possible." This suggested some fairly expensive approaches, including a beryllium housing. Further investigation revealed that the customer had a certain weight budget, and as long as the weight was within this limit he was satisfied. The winning bid proposed an aluminum housing at much less than beryllium would have cost.

Price. Obtaining budgetary information can be of considerable help in deciding whether or not to bid and what the technical and pricing approaches should be. There are certain basic questions, such as, is it a fixed price or cost type procurement? Competitive or negotiated? Frequently the interaction between potential vendors and the customer will help determine what kind of procurement it will be. Usually the customer has a budget and sometimes he will share that with his suppliers. Sometimes he will ask the vendor for a budgetary price; this is an opportunity for the vendor to get some feedback from him on what the customer thinks is reasonable, and to ask further questions about the type of contract, the expected schedule, etc. Sometimes the supplier can obtain, or it may even be his right to obtain, explicit information on prices bid on recent past procurements for similar items. Budgetary information from the customer will help the supplier decide whether or not to bid; it can focus his attention on a possible underestimate or overestimate of the technical task. If a supplier is convinced he understands the technical task and feels the customer's estimate is much too low, he can attempt to assist the customer in finding an alternative approach and/or reassess his own process. If a supplier thinks his customer's budget is unnecessarily high, it *may* mean he is in favorable competitive position.

Schedule. Any quotation made or contract received will have a delivery date associated with it; in fact, it is not a contract without it. Requests for quotation are more or less explicit about delivery requirements, some request the vendor to state best delivery, some state requirements after receipt of order, and some give specific dates.

From the point of view of long range relationships with his customer, as well as meeting contractual obligations, it is very important for the supplier to quote delivery dates he can meet. Since the quoted delivery date can have the deciding influence on whether or not the job is won, and if the job is won the delivery date will impact the supplier's whole operation, it is very important for him to find out what his customer's real delivery requirements are. The RFO may not be adequate for this purpose; it may be too vague or its delivery requirements may be out of date. So it may be very important to talk to the responsible people in the customer's organization to find out what the real date is, how critical it is, and whether he may quote an alternative before submitting his proposal.

3) *Codified baseline pricing guidelines from which to make pricing decisions.* Maintaining a rational system for the pricing of optical components, and a good record of the results of pricing policy, can be an enormously helpful management tool. With modern data processing equipment, it should be an easy task once the system is set up. Keeping such a system should optimize the accuracy with which a manager can make important decisions on bid prices and help him to determine his relative efficiency and technical standing in a given field.

Such a rational, analytical approach should help reduce loss from overcorrections in pricing policy, which are a frequent occurrence. Two examples of typical overcorrection cycles are as follows:

(a) A bid is made based on previous prices for similar work with the same customer; someone new comes in with, say, a 20% lower price, and the original vendor loses the bid. The customer now requests a quotation on additional parts, which may be similar or quite different. The original vendor now submits a very low bid, say, at half the price of his nearest competitor. Such a wide price spread may be the result of a well-informed decision on the part of the low bidder, based on a new approach, improved technology, or long range strategy, but it is frequently the result of overanxious bidding without the stabilizing influence of proper guidelines, and may result in a serious inadvertent loss.
(b) A vendor has recently experienced a loss on a contract, either due to underbidding or mismanagement or circumstances beyond his control; now he has the opportunity to bid another job in the same category, really loads on safety factors, and discovers himself to be the high bidder by a wide margin.

On the average, a bidder who can develop a more accurate pricing technique should win a larger percentage of the jobs on which he bids, make more money on the ones he wins, and better understand his strengths and weaknesses.

One very helpful device is to develop formulas for pricing various types of components. These can be more or less simple, depending on the variety of work and the complexity of the parts or systems.

A simple case is that of a plano window, where it is necessary to consider, say, the glass blank cost, the optical fabrication cost (generating, grinding, and polishing), and the coating. To first order, the cost of the blank is proportional to the volume, and the cost of fabricating and coating are proportional to the area; there also may be a constant handling charge, independent of size, so the form of the equation might be:

$$P = A + \phi^2 \frac{\pi}{4} (2B + Ct) \tag{1}$$

where P is the unit price, A is the handling charge, ϕ is the part diameter, B is the sum of the cost per unit area for fabrication and coating, C is the cost of material per unit volume (with something added for blank starting size and spare blanks), and t is the thickness.

Various cost components, such as generating, polishing, coating, etc., can all be broken out and expressed separately of course. In addition, the pricing coefficients can be made to vary as functions of quality, size range, quantity, diameter to thickness ratio, etc.

Another equation recently used to estimate fabrication costs of single element coma and spherical corrected aspherics has the form

$$P = A + (2B + CD^{f\#})\, \phi^2 \frac{\pi}{4} \tag{2}$$

where A and ϕ are as above, B is the cost of fabrication per unit area for spherical surfaces, f# is the relative aperture, C is a number quite a bit larger than B, and D is a number smaller than one, so that for fast lenses the term $CD^{f\#}$ is considerably larger than B and the significant influence on the price, and for slow lenses the term $CD^{f\#}$ approaches zero.

The coefficients can be adjusted to current capabilities based on experience, quality or quantities, etc. It is frequently helpful to present the information in graphical form.

It should be possible—with a collection of historical data including actual costs of manufacture, labor rates, overhead, etc., and bid and procurement information—to construct and easily handle (with modern data processing equipment or even an inexpensive programmable desk calculator) these formulas for price estimates for almost any degree of complexity, quantity, or quality level. There are lens design codes which include cost of manufacture in their optimization algorithm. In principle, all the relevant characteristics of an optical component, such as radii, material, quality, etc., along with quantity could be punched into a computer to obtain a baseline price readout. This does not mean that the vendor will necessarily use the prices thus derived in his actual quote, unedited, but it does mean that the manager who is making or approving the quotation, other factors considered, will have a very good baseline for judging what his actual costs will be. This solid base should also save time in the bid process once it is set up, and enhance a company's ability to respond promptly to requests for quotation.

4) *Radical review of project at time or order.* During the bid or proposal process, the person or people assigned to the task of doing the first-line cost estimate, such as the shop foreman, methods engineer, design engineer, etc., arrive at a more or less detailed method for doing the job, presumably including all the required elements such as design, materials, tooling,

fabrication, assembly, test, and so on. Usually, however, many more bids are processed than actually become contracts, and the people assigned to doing the bidding have other jobs to attend to. As a result, the work done during the bid process can tend to be more or less cursory like a feasibility model which indicates one, but not necessarily the best, way of many possible approaches to the tooling, or making the test set up. When the contract comes in it is processed through the system and ends up in the hands of the appropriate department head, project engineer, foreman or technician who is presumably supposed to perform the job within the costs and hours bid using the proposed methods.

The cognizant personnel are usually busy on other projects when a new job comes in, frequently in fact wrestling with unforeseen technical problems, schedule delays and the like; and the new requirement can receive woefully inadequate attention at the beginning. Several things can happen, or not happen, to get it started on the wrong track, such as letting the paper work sit on the shelf until someone gets to it, or ordering the tooling which appears on the bid worksheet before reviewing either the methods or how currently available machinery or personnel fit in with the promised delivery.

What should happen is that a new job should have top priority for review and reassessment from the point of view of:

(a) Specifications
(b) Schedule
(c) Methods
(d) Cost estimate

Depending on the size of the job, and its difficulty, these may require some iteration before an optimum plan evolves. Other work may have come in which is in conflict with the planned use of a particular piece of equipment for the new project; the current delivery date on an item of tooling may be much longer than originally anticipated; a portion of the required labor hours may have been underestimated or omitted in the original costing; a portion of the methods proposed may be suspect or untried, and it may be advisable to run an experiment.

When the plan is evolved at the operations level, it should be presented to management for review and approval. (If you run a small shop, just put on your other hat.) The new plan should be especially careful to point out in very explicit terms any expected problems in meeting delivery or cost goals. The management posture and corporate reward system should put a heavier emphasis on getting things right at this point than in the original bidding process. Otherwise, potential problems with new projects which were glossed over at the very beginning will surface when remedial action to prevent or minimize loss is too late. Careful reassessment of the requirements for performing new jobs when they come in will also have a beneficial feedback to the bid process by sharpening the ability to do original bidding on what must frequently be a fast turnaround basis.

While correct bidding procedures and accuracy in estimating are of crucial importance to a commercial shop, it should be emphasized through all levels of an organization that continuing alertness for, and signaling of, problems at the earliest possible moment is even more important.

One classic example of how *not* to do it occurred when the president of an optical company, concerned by a rash of overruns in the optical shop, made a very large issue of insisting that the shop foreman produce within the estimates he made for bid purposes. A job came in for about $30,000; it was completed at a cost to the company of about $60,000 and was, of course, delivered late. At a later meeting to try to determine what had happened, the foreman stated that he had seen early that his aluminum tooling was not working right and that he should have used glass, but he had already spent $1,000 on the aluminum (which was the tooling estimate on which the bid was based) and the glass would cost $2,000 more. He was so terrorized by the president that he was afraid to point out a $3,000 overrun in the beginning, and so sustained a $30,000 overrun in the end.

5) *Establishment and monitoring of procedures and milestones.* The previous disaster could also have been mitigated by a review of the soundness of the approach taken based on past experience and/or establishment of schedule and cost milestones as checkpoints to monitor the progress of the project.

There are usually identifiable milestones in any process, critical points which must be reached before going on to the next step. These are particularly important to watch when new or untried technology is involved.

In the example in the last section, the foreman, it turned out, was trying a kind of tooling which was new for the purpose intended. Before he found out how to make it work, a lot of unproductive time and labor was spent on a nonconverging process. The kind of problem he ran into was one that could have been discovered on a small scale basis, before committing the production run.

Two other recent examples of inadequate consideration and monitoring of a new process involving larger, more state-of-the-art projects are curiously similar to each other from a management point of view, though they involve two different companies and optical technologies (one is the manufacturer of aspheric surfaces; the other is in the application of multilayer thin film coatings). Both were costly for the suppliers and nearly created serious scheduling problems for the customer.

In both instances, an advanced state-of-the-art technique which had been evolved for prototypes was abandoned when the production order arrived. The substitute techniques appeared to hold out the possibility of considerably higher efficiency (i.e., the parts could be manufactured in less time and at less expense than by the method which had been developed to do them). Now this is a difficult problem; in high technology you do not ever want to turn off someone with a better idea, yet it is very perilous to both the supplier and the customer to start off a production run with an untried process.

Both companies apparently made snap decisions to do the whole program using the untried process, including scheduling people and equipment along these lines, and continued the attempt long after there was schedule slippage and evidence that the process was not working. Ultimately, both went back to the process which had been developed for the prototypes, and which, it should be made clear, was the basis for the production pricing.

A new and untried process should raise a red flag, the risk assessed, and a definitive schedule for determining its efficacy should be set up, along with contingency plans, at the outset of a program. A similar milestone schedule should be available even for the tried and true, so problems can be caught early and corrected.

6) *Open, knowledgeable and objective communication with customer when questions or difficulties arise.* A customer likes suppliers who, in a trouble-free fashion, deliver components to specifications on time. In high technology optics, however, it often happens that difficulties arise which impact the ability to meet specifications, and even more frequently to meet the schedule.

No one likes to be the bearer of bad news. There are the stories of ancient kings who used to behead messengers with news of losses in battles. But the ability to identify potential problems early and bring them to the attention of those who need to know is one of the primary characteristics of the good manager. The supplier should think of reporting difficulties early as good management, because his customer will think of it as such since a problem caught early enough may not turn out to be a problem at all.

Again, the three areas of concern are: specifications, schedule, and cost (depending on the type of contract and extent of the problem). Frequent communications with the customer to ask questions, report progress, and realistically assess problem areas can be of enormous benefit to both parties and to their ongoing relationship. Asking questions and identifying problems as soon as they arise can benefit both parties in several ways:

(a) A specification may be ambiguous or misinterpreted; clarifying it will make the supplier better able to satisfy his customer's needs.
(b) There may be specification tradeoffs simplifying the design or manufacture at no loss to performance.
(c) The emphasis placed on the schedule or delivery date may change with time. If the customer is notified of a delivery problem early enough, he may be able to work around it; or conversely, he may really need the parts, which will help the supplier make the decision to change internal priorities and/or bring more resources to bear on the problem.
(d) The customer may be able to help the supplier solve his problem, whether by providing technical assistance, equipment, pressure on subcontractors, or even money.
(e) The customer will have a positive perception of the vendor's concern for his program, and a higher regard for his management capabilities.

Acknowledgement

Work performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore Laboratory under contract number W-7405-ENG-48.

Calendar

JULY 1979

9-13. 4th Inter. Conf. of System Safety Society, San Francisco. Carrol Burtner, System Safety Soc., Box 731, Cupertino CA 95014.

9-13. Course, Fundamentals & Applications of Lasers, Montreal. Laser Inst. of America, P. O. Box 9000, Waco TX 76710.

15-18. Summer Conf. & Expo, OCR in Action—the Second Decade, Boston. OCR Users Assoc., 10 Banta Pl., Hackensack NJ 07601.

17-20. 2nd Joint INTERMAG-Magnetism & Magnetic Materials Conf., New York. P. W. Shumate, Bell Labs, 2D-343, 600 Mt. Ave., Murray Hill NJ 07974.

23-27. Photographic Science Course, Rochester. Inst. of Technology, 1 Lomb Memorial Dr., Rochester NY 14623.

23-27. Semiconductor Electronics & Integrated Circuits Course, U. of Mich. Eng. Summer Confs., 800 Chrysler Ctr. N. Campus, U. of Mich., Ann Arbor MI 48109.

23-27. Detection of Infrared Radiation Course, U. of Calif., Dept. of Sci. & Mgt., U. of Calif. Ext., Santa Barbara CA 93106.

23-27. 30th Ann. Fisk Inst. Course: Interpretation of Infrared & Raman Spectra; Gas-Liquid Chromatography; Pollution Evaluation Meeting EPA & OSHA Standards through IR & GC Techniques, Fisk U. N. Fuson, Fisk Inst., Box 8, Fisk U., Nashville TN 37203.

30-Aug. 3. Microwave Semiconductor Electronics Course. U. of Mich., Eng. Summer Confs., 800 Chrysler Ctr., N. Campus, U. of Mich., Ann Arbor MI 48109.

31-Aug. 2. Conf. on Improving Radiographic Nondestructive Testing, Asheville NC. Karen Long, Conf. Mgr., ASNT, 3200 Riverside Dr., P.O. Box 5642, Columbus OH 43221.

AUGUST 1979

1-3. OSA Topical Mtg. Photoacoustic Spectroscopy, Ames. OSA, 2000 L St. NW, Suite 620, Washington, D. C. 20036.

6-8. IEEE Computer Soc. Conf., Pattern Recognition & Image Processing, Chicago. PR1P79, P. O. Box 639, Silver Spring MD 20901.

6-17. Design & Analysis of Eng. Experiments Course, U. of Mich. Eng. Summer Confs., 800 Chrysler Ctr., N. Campus, U. of Mich., Ann Arbor MI 48109.

7-9. Waves & Stabilities in Space Plasmas, Denver. W. W. Havens, Jr., 335 E. 45th St., New York NY 10017.

12-24. Joint Cryogenic Eng. & Inter. Cryogenic Materials Conf., Madison. D. Belsher, NBS, Boulder CO 80303.

19-31. NATO Advanced Study Inst. Summer School on Lasers in Biology & Medicine, Camaiore, Lucca. F. T. Arecchi, CISE, P. O. Box 3986, Milan, Italy.

20-26. Inter. Cong. of Photographic Science, Rochester. Robert Wood, SPSE, 1411 K St. NW, Washington, D. C. 20005.

20-22. 4th Inter. Conf. on Ellipsometry, Berkeley. R. H. Muller, Mater. & Mol. Res. Div., Lawrence Berkeley Lab., U. of Calif., Berkeley CA 94720.

22-24. Electrical, Magnetic & Optical Properties in Glasses, Troy. W. W. Havens, Jr., 335 E. 45th St., New York NY 10017.

27-31. Amorphous & Liquid Semiconductors 8th Inter. Conf., Harvard. Conf. Secretariat, 20 Garden St., Cambridge MA 02138.

27-30. SPIE 23rd Ann. Tech. Symp. & Instrument Display, San Diego. SPIE, Box 10, Bellingham, WA 98225. 206/676-3290. 17 Seminars:

- **Multiplex and/or High-Throughput Spectroscopy**
- **Interferometry**
- **Optical Systems Engineering**
- **Applications of Optical Coherence**
- **Atmospheric Effects on Radiative Transfer**
- **Measurements of Optical Radiations**
- **Modern Utilization of Infrared Technology V**
- **Laser Applications in Materials Processing**
- **Advances in Display Technology**
- **Laser Recording & Information Handling**
- **Optical Pattern Recognition**
- **Active Optical Devices**
- **Recent Advances in TV Sensors & Systems**
- **Physical Properties of Optical Materials**
- **Image Understanding Systems II**
- **Recent & Future Developments in Medical Imaging II**
- **Applications of Digital Image Processing III**

29-Sept. 4. 11th Inter. Conf. Physics of Electronic & Atomic Collision, Kyoto. K. Takayanagi, Inst. of Space & Aeronautical Sci., U. of Tokyo, Komaba 4-6-1, Meguro-ku, Tokyo 153, Japan.

SEPTEMBER 1979

3-5. Europhysics Conf. on Lasers in Photo-Medicine & Photobiology, Italy. Prof. R. Pratesi, Laboratorio di Elettronica Quantistica, Via Panciatichi 56/30, Firenze, Italy.

5-7. Fiber Optics & Communications Eposition, Chicago. M. O'Bryant, Information Gatekeepers, 167 Corey Rd., Brookline MA 02146.

6-7. Conf. Lasers in Bio-Medicine, Italy. Prof. R. Pratesi, Laboratorio di Elettronica Quantistica, Via Panciatichi 56/30, Firenze, Italy.

10-14. Inter. Conf. Atomic Spectroscopy, Tucson. J. O. Stoner, Jr., Phys. Dept., U. of Arizona, Tucson AZ 85721.

11-13. Mtg. on Excimer Lasers, Charleston. OSA Excimer Laser Mtg., 2000 L St. NW, Washington, D. C. 20036.

12-13. Sira Inst. & Warren Spring Lab Seminar—How will Tomorrow's Microprocessor-