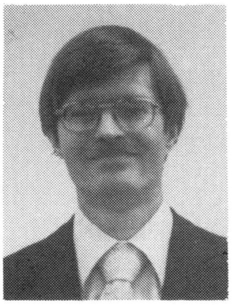

Editorial

H. J. Caulfield, Editor

The Kingslake Award

The Rudolf Kingslake Medal and Prize for the most noteworthy original paper to appear in *Optical Engineering* Volume 19 (1980) has been awarded to G. Ferrano and G. Hausler of the Physikalisches Institut of the Universitat Erlangen, Germany, for their paper, "TV Optical Feedback Systems," which appeared in the July/August 1980 issue, pages 442-451.

The Kingslake Award selection committee (Brian J. Thompson, Albert Macovski, and H. J. Caulfield) was part of the SPIE Awards Committee under Joseph W. Goodman. The committee felt that the Ferrano and Hausler paper represented an important new direction for optoelectronic processing presented in a fashion which is both technically clear and visually attractive.

The award was presented to Ferrano and Hausler by Andrew G. Tescher, President of SPIE, at SPIE's 25th Anniversary Celebration Banquet, August 26, 1981, in San Diego, California. Dr. Tescher cited, "For those in the audience who have never witnessed the astounding psychedelic effects that occur when a TV camera is pointed at its own monitor, you have missed an incredible experience. Ferrano and Hausler have shown us that this phenomenon can be put to good use as a general optoelectronic feedback system, allowing the realization of imaging operational amplifiers, image enhancement systems, and even a large spatial array of bistable flipflops. They have proved that television need not always rot the mind, but can provide a source of technical stimulation and can even perform an occasional useful task."

As Editor of *Optical Engineering*, I want to add my congratulations to those of SPIE and its officers to Ferrano and Hausler.

From left, Joseph W. Goodman, SPIE Awards Committee Chairman; Andrew G. Tescher (back to camera), SPIE President; and G. Hausler and G. Ferrano, recipients of the 1980 Rudolf Kingslake Medal and Prize.

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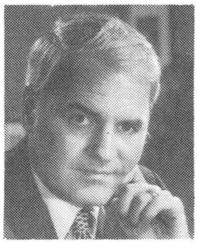
Forum

Instant Photoinstrumentation



W. G. Hyzer, P.E.

Consulting Engineer
136 S. Garfield Ave.
Janesville, WI 53545

High-Speed Videography at 2000+ Frames per Second

A recent advancement in solid-state sensors coupled with two state-of-the-art improvements in magnetic recording are the salient technological achievements behind the development of a newly announced high-speed motion analysis system.[1,2] The brainchild of Spin Physics, Inc. of San Diego, California, an Eastman Technology, Inc. company, the SP-2000 high-speed video system is capable of the remarkable feat of recording up to 2000 full frames and 12,000 split frames per second on 1/2-inch magnetic tape for instant replay and detailed slow-motion analysis, Fig. 1. This represents more than an order-of-magnitude increase in framing rate over the fastest of other existing high-speed video systems.[3] The SP-2000's maximum recording rate of nearly 10^8 pixels/sec at a magnetic tape packing density of 5×10^6 bits/in^2 stands as a new pinnacle of achievement in high-speed video technology.

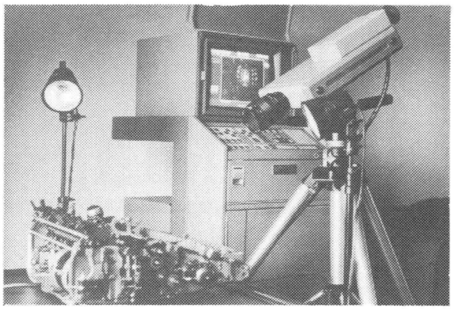


Fig. .1 SP-2000 high-speed video system set up to record the action of a typewriter ball.

Costs: Video versus Film Cameras. This combination of high framing speed and high packing density will serve numerous applications where very rapid events of long duration need to be recorded in their entireties. A full minute of action can be recorded at 2000 full frames/sec. If the recorded results are not satisfactory, or after the recorded data have fully served their analytical purposes, the tape may be erased and reused over and over again at essentially no cost for materials. The turn-around times required to record typical events and then view them are of the order of a minute or less. Common turn-around times and operating costs for the closest-comparable film cameras often run prohibitively high. A 2000-foot capacity 16 mm high-speed camera of the rotating-prism type is the largest capacity film camera available today. Operating at 2000 frames/sec, its full load of film is exposed in 40 seconds at a film cost (excluding processing) that normally exceeds \$250 per minute of recording time. Film processing is a time-consuming operation that typically requires from several hours to several days delay. Additional costs for film processing will vary depending upon the specific laboratory services available. A total cost for film and processing of \$350/minute of recording at 2000 fps is a reasonable figure, based on typical conditions in the field.

In applications requiring framing rates of 2000 fps or less, only video offers the advantages of instant replay and long-duration erasable recording. High-speed video hardware, on the other hand, is much more costly than high-speed cameras utilizing photographic film. The author once observed that capital investments for high-speed film cameras ranging in speed from several hundred to several million frames per second increase roughly as the square root of framing rate.[4] The same rough approximation appears to hold true within the high-speed video field as well, where

$$E = K\sqrt{F}\,, \qquad (1)$$

where E = capital expenditure, dollars;

F = framing rate, sec^{-1}; and

K = a constant, having a value of approximately 2500 \$sec$^{1/2}$ for most commercial high-speed video systems.

The capability of reaching higher framing rates requires increased expenditures, but unlike film, increased video costs are limited essentially to *capital equipment* expenditures only.

The Sensor. The solid-state electronic image sensor in the SP-2000 is an MOS photo-capacitor array developed by Kodak Research Laboratories, Rochester, New York. Reminiscent of the architecture in the CCD (charge-coupled device), this unique sensor is comprised of 192×240 charge-accumulation cells, each representing a single picture element or pixel. All of the sensor's 46,080 picture elements are contained within an active surface area of approximately 3/8 inch by 9/32 inch in size. Each cell accumulates a charge proportional to the level of its cumulative exposure to light. These charges are detected as small voltages requiring immediate amplification by circuitry adjacent to the sensor to produce a required output signal level of about 1 V. Individual cells are "wired" on the sensor so that 32 lines of picture information, consisting of 240 cells per line, can be read off simultaneously. There are six 32-line groups or "blocks" on the sensor's surface. A single block is 32 cells wide and 240 cells long. Each of these six blocks is read sequentially, one at a time, starting with block 1 at the top of the sensor and ending with block 6 at the bottom. This unique architecture provides the capability of transferring image data in parallel format rather than in the much slower serial format of conventional video sensors. Cell reading time is very short compared to its charge-accumulation time, so exposure time per frame is equal to the reciprocal of framing rate for all practical purposes. Each cell is completely discharged each time it is read, so "ghosting" is entirely eliminated as an image phenomenon. Exposure to intense light has no deleterious effect on the sensor. The photometric sensitivity of the sensor can be roughly equated to that of a photographic film having an exposure index of 100 ASA. Prototype cameras had a sensitivity equivalent to about 50 ASA, but improvements under way in production models will more than double this value. Light sensitivity is a factory adjustment that cannot be altered in the field.

Recording. Thirty-two parallel tracks of information representing 32 lines of simultaneous picture information are laid down on the 1/2-inch magnetic tape by means of a matched pair of 17-track microgap recording heads along with two additional tracks for timing information and other required data. At the camera's maximum recording rate of 2000 frames per second, one complete picture is recorded on 0.1 inch of tape at a packing density that exceeds 5×10^6 bits/in^2 along each of the tracks. This concentration of recorded information could not be accomplished without the advanced technology that has gone into the design and the precise manufacture of both the magnetic heads and the recording tape.

Playback. To reproduce the recorded information on playback, the parallel channels of information are first converted into serialized form. Then a high-speed analog-to-digital converter transforms the imaging information into binary numbers representing 64 shades of gray and transfers these data to digital buffer memory (DBM) one frame at a time. The digital information describing each frame remains in the DBM until it is updated by the next frame. A digital-to-analog converter transforms the output of the DBM to a composite video signal that is mixed with the synchronization and timing signals required to produce a standard TV picture. It is worth noting that no tape movement is needed to maintain the image once it has been transferred to the DBM. The stored image may be displayed indefinitely until it is replaced by the next image. Tape movement past the reproduction heads is required only when a new frame of information is being transferred into the DBM.

A unique feature of this system is its built-in capability of measuring the X and Y coordinate positions of any image element by means of cross hairs that can be actuated on the monitor screen and moved independently to address a specific pixel of interest. These coordinate data are reported alphanumerically on the monitor screen in the

Fig. 2. SP-2000 control panel and monitor. Note cross hairs on monitor screen.

Instant Photoinstrumentation Continued on Pg. SR-186

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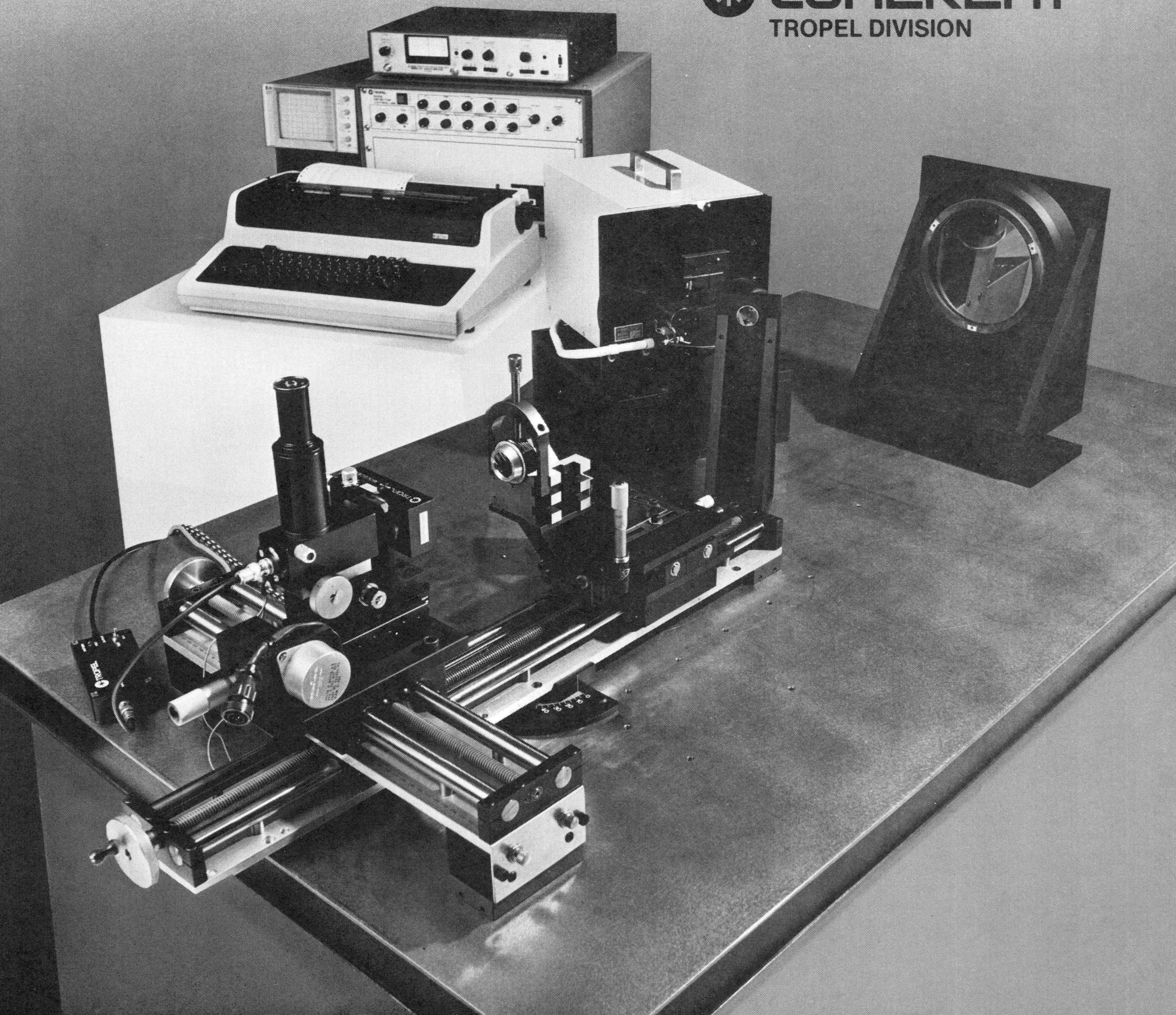

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margins of the frame, along with other pertinent information including frame number, elapsed time, real time, framing rate, tape counter reading, and test I.D. number, Fig. 2. The presence of the DBM as a key element in the image reproduction process also makes it conceptually possible to perform enhancement operations on the stored image during playback. The use of pseudocolor to delineate variations in image brightness is foreseen as one probable future development. Another is automatic tracking of target images, in which X and Y coordinate positions would be obtained automatically on the fly as a function of time and plotted out immediately on an external plotter. These and other exciting possibilities are within sight today and are strong indicators of high-speed videography's strong potential for growth in the years just ahead.

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SOME THOUGHTS ON OPTICAL GLASSES AND THEIR PROPERTIES

C. J. Parker
Corning Glass Works
Corning, New York 14831

INTRODUCTION

The optical glass industry is based on an old, established, but ever-changing technology. Originating in the burning lenses of the ancients, it has developed from the spectacles and simple lenses of the Middle Ages to a complex technology today. Today's optical glass chemist uses nearly every element in the periodic table to manipulate the optical properties of glass. The wide range of glass compositions used to obtain these optical properties results in glasses with a great variety of other properties, such as thermal expansion, hardness, chemical stability, and service temperature. This report will touch upon some of these other properties of optical glasses and their relevance to manufacturing and use, after an initial discussion of the terminology of optical glasses.

TERMINOLOGY

As the number of optical glasses and the number of firms increased over the years, there developed a multiplicity of terms to categorize the various glasses and a similar multiplicity of trade or catalog numbers to designate them. This led to a confusing terminology situation which persists today. Figure 1 illustrates some of the confusion, using three glasses as examples.

About 1918 the Sendlinger Optical Works in Germany introduced the familiar six-digit designation showing the index and nu value. This is the most meaningful designation to the optical designer, the optician, and the glass chemist. With this designation the designer has preliminary information on how the glass fits into his lens design, the experimental glass chemist knows the approximate chemistry of the glass, and the experienced optician is aware of the handling, finishing, and serviceability qualities.

Sendingler Designation (also B & L) ($\eta_d - \nu_d$)			
	517642	620603	744448
Schott	BK7 517642	SK16 620603	LaFN2 744448
Corning-Sovirel	BSC B16-64	BCD C20-60	FBS D44-45
Corning AF Series			
Type	BSC52	DBC62	LaF74
Code No.	8260	8286	8296
Chance	BSC517642	DBC620603	SBF744447
Hoya	BSC7	BACD16	LaF2
Standard Corning Line	(8370)	8400	——
$\eta_e - \nu_e$	519640	623601	748445

Fig. 1. Terminology.

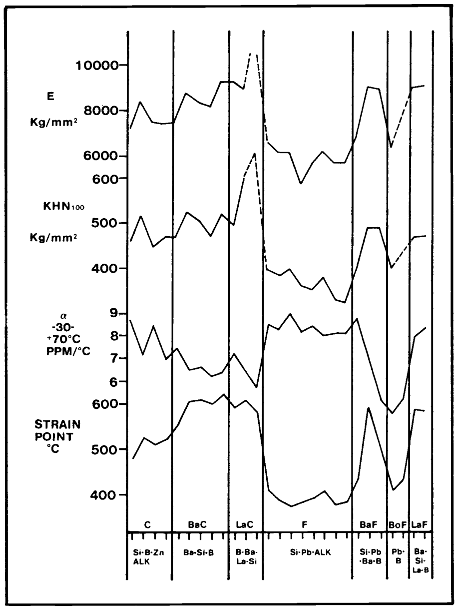

Fig. 2.

The Optical Industry and Systems Directory carries a four-page equivalence chart for glass numbers for eight suppliers. The numbers from only a couple of them give indication of glass type. I would like to point out here that the six-digit system goes far towards meeting the need for a universal designation, although there might still remain the problem of should it be $n_d - \nu_d$ or $n_e - \nu_e$?!

One further problem is that more work would still be needed on uniformity of names even if the six-digit form could be made a standard. This is illustrated in Fig. 1 where 744448 glass is called both lanthanum flint and special barium flint. In fact, considering the composition, the latter name is the more appropriate.

PHYSICAL PROPERTIES

The glasses in Fig. 1 labeled Corning AF Series refer to the production by Corning during the 1967–72 period of high-precision blanks in 27 optical glasses, under an Air Force Avionics Lab contract. A wide variety of measurement of optical and other physical and chemical properties was required, and it provides to us an opportunity to examine property differences between glass types and to observe possible correlations among the properties.

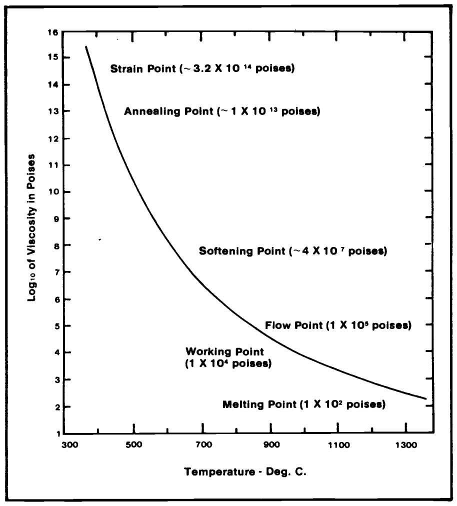

Fig. 3.

Figure 2 shows plots of the indicated properties for the 27 glasses arranged into seven groups. The strain point is a temperature point on the viscosity curve of glass, Fig. 3, and is thus a measure of the melting range of the glasses and an indicator of usable service temperatures.

Thermal expansion coefficient, α, is a prime parameter in consideration of thermal stressing. The high α values for the flints, for example, show in part why care is needed in handling these glasses where high temperatures are involved, as in waxing to a lap.

Knoop Hardness Number (see Fig. 4) is one of various hardness measures. Izumitani and Suzuki of Hoya Glass Works showed in 1973[1] that this is a reasonable estimator for lapping hardness, since both diamond penetration and lapping speed depend eventually on yield stress of the glass. Comparing with the next graph, which depicts

Thoughts on optical glasses Continued on Pg. SR-188

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Young's Modulus E, it is also evident that the KHN depends on E. The elastic modulus, E, is also a critical parameter in thermal and mechanical stress situations.

CHEMICAL PROPERTIES

Turning now to chemical properties, we note from the graphs on Fig. 5 that the several methods for measuring chemical stability generally agree as to the stable and unstable classes of optical glass. The HCl acid-weight-loss test that is used by Corning is also referred to as the "AO" test as it was initially developed by American Optical. It correlates very closely with the Schott catalog acetate staining ratings on these glasses. Looking at chemical compositions it is easily seen that it is the glasses containing large percentages of barium and/or boron oxides that are chemically unstable. Surprisingly, the crowns and flints are the most stable glasses even though they contain major amounts of the alkalis, sodium and potassium.

FORMULA: KNOOP HARDNESS NUMBER

$$\text{K.H.N.} = \frac{L}{Ap} = \frac{L}{1^2 C}$$

L = Load in kilograms on indenter.
Ap = Unrecovered projected area, of indentation (square mm.)
1 = Length of long diagonal (mm.)
C = Constant relating 1 to Ap.

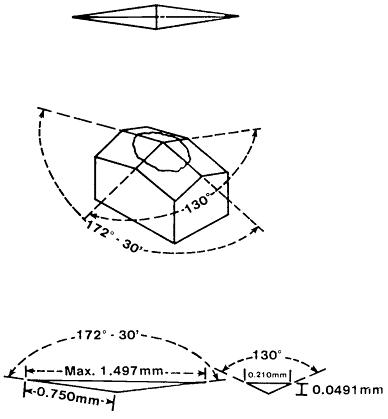

Fig. 4.

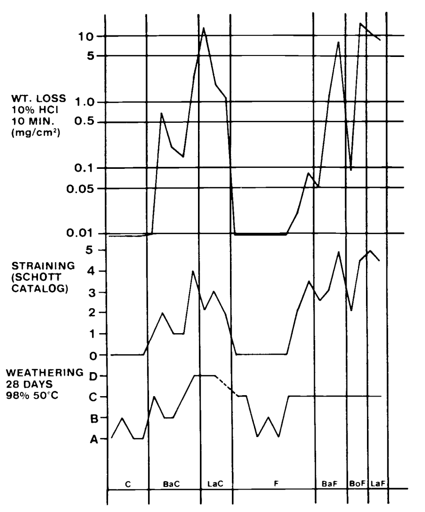

Fig. 5.

Although attempts are continually being made to improve chemical properties, the required optical properties place severe limitations on what can be accomplished in these programs.

OPTICAL PROPERTIES

For completeness, the n_d and ν_d values are plotted in Fig. 6, although optical properties are not a main topic for this report. Fig. 6 does reveal a little of why the so-called rare-earth (i.e., lanthanum) glasses are useful—lower dispersions occur at the higher index levels than in conventional flint glasses.

Also shown in Fig. 6 is the stress-optical coefficient, which is the proportionality constant between stress in the glass, whether applied or residual, and the resulting birefringence or double-refraction. It is a quaint custom in the optical industry to specify certain low, viz., 5 or 10 nm/cm, values of stress-induced optical path retardance, usually in the belief that this is specifying residual stress. (The presence of the latter can give the optician figuring problems, and the residual stress level is also a partial indicator of optical homogeneity). However, as shown in Fig. 6 and emphasized in Fig. 7, it is possible for flint glasses to have low or even zero indication of stress in a photoelastic measurement. Of course, where double refraction itself can degrade optical performance, it is good to know this. It is also good to know that glasses can be selected to minimize stress birefringence.

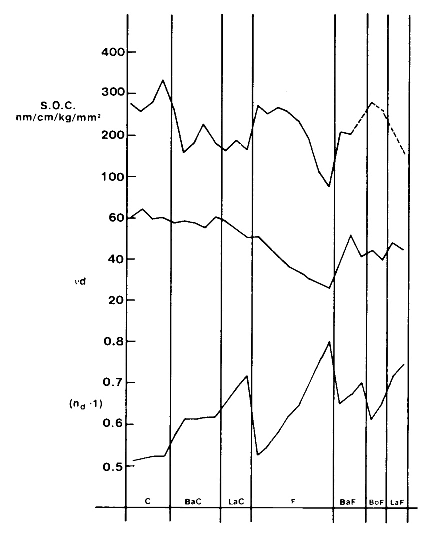

Fig. 6.

STRENGTH OF GLASS

It is well known that the fracture strength of glass is strongly dependent on its surface finish. In fact, in a study conducted some 10–12 years ago at the Perkin-Elmer Corporation—Paul Forman was a prime participant in that study—it was shown that the strength of fused silica glass can be significantly increased by a new controlled grinding schedule.[2] The philosophy is that each finishing step should be continued to remove a thickness of stock equivalent to about three times the particle size of the previous abrasive, thereby erasing the damage effects of the previous step. This idea has been applied to all fused silica Space Shuttle orbiter windows made by Corning. Figure 8 shows the current finishing sequence, modified from the original P.-E. specifications. The bottom line is the proof of the pudding. This is an idea that works, and that affords every optician a means for making his product stronger, where and as needed.

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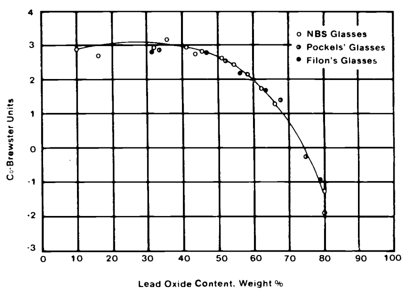

Variation of the Stress-Optical Coefficient with Lead Oxide Content in Flint Glasses

Fig. 7.

Sequence No.	Operation	Grit Diam.	Removal Per Side
1	60 Grit Grind	0.0098"	0.072" min.
2	180 Grit Grind	0.0033	0.034" min.
3	Acid Treat	——	0.007"
4	320 Grit Grind	0.0017	0.010"
5	W-1 Lap	——	0.006"-0.008"
6	W-5 Lap	——	"
7	W-10 Lap	——	"
8	Polish	——	"

Modulus of Rupture, Conventional Finish: 8-10 KPSI
Modulus of Rupture, Controlled Finish: 15-18 KPSI

Fig. 8. Space shuttle windows finishing procedure. Fused silica, Code 7940.