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Measurement of Microdensitometer Wobble

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A simple method of measuring the transverse stability of a microdensitometer is presented. The technique is based on a scan parallel to a straight edge using a square aperture such that the aperture partially overlaps the edge over a long distance in the scan direction. As the measured transmittance is linearly related to the width of the overlap of the aperture with the straight edge, it may be used to determine the displacement of the aperture relative to the edge during normal scanning operation. It was found that several commercial microdensitometers did not meet their stated specifications for positional accuracy.

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Introduction

Slight deviations in the position of a microdensitometer aperture can lead to large changes in the measured optical density in regions where the optical density is changing rapidly. Thus, it is desirable for the aperture of a microdensitometer to be positioned accurately for each measurement of a scan. Instability in aperture position can adversely affect measurements of distance that are derived from the digitized image as well as degrade the effective modulation transfer function (MTF) of the digitized image. Manufacturers of microdensitometers often quote high positional accuracy (on the order of a μm or so). However, prudence should be exercised in accepting the results of tests of positional accuracy that are based on unusual scanning conditions or averages of several scan lines or several scans. Each microdensitometer should be be tested periodically to assure that it continues to operate satisfactorily. The following test provides a simple means to determine the positional stability of microdensitometers during normal operation.

Measurement Technique

The technique presented here is based on a scan along a straight edge by the microdensitometer being tested. Referring to Fig. 1, the transmittance through a square aperture that staddles an edge is simply the weighted average of the transmittances on either side of the edge, T_1 and T_2, respectively,

$$T = \frac{\Delta}{w} T_1 + \left(1 - \frac{\Delta}{w}\right) T_2, \tag{1}$$

where w is the aperture width transverse to the scan direction, and Δ is the width of the aperture's overlap with the T_1 side, assumed to lie between 0 and w. The displacement of the aperture Δ is easily found to be

$$\frac{\Delta}{w} = \frac{T - T_2}{T_1 - T_2}. \tag{2}$$

It is seen from Eq. (1) that the measured transmittance varies linearly with the transverse displacement, making the *transition between T_1 and T_2 over the distance of the aperture* width. The technique proposed here is based on the validity of the linearity between transmittance and aperture displacement expressed by this simple formula. Any deficiency in the microdensitometer or the experimental set up that upsets this linearity may adversely affect the usefulness of the proposed technique. Fortunately, approximate linearity can be maintained under a variety of adverse conditions. It is desirable to use a fairly narrow aperture for sensitivity to the displacement. However, to assure linearity, the aperture should not be smaller than several times the expected wobble amplitude. On microdensitometers that directly measure transmittance, instabilities in the transverse displacement are readily observed in a plot of the measured data. Such a plot is easily calibrated since the limiting transmittance values, T_2 and T_1, correspond to displacements of the aperture of 0 and Δ. It is often possible to provide an online display of the transmittance, either as a strip-chart recording, a computer-generated graph, or an oscilloscope trace of the photodetector output. Such a display allows one to observe the amount of microdensitometer wobble present and to determine the effects on this wobble of varying scan conditions.

If the microdensitometer measures optical density, this must be converted to transmittance

$$T = 10^{-D} \tag{3}$$

before using Eq. (2). When T_1 is much greater than T_2 and the overlap with T_1 is small, large changes in optical density are produced by relatively small changes in Δ. Thus, the direct measurement of optical density has the advantage that it may be much more sensitive to small displacements than the direct measurement of transmittance.

It is apparent that microdensitometer wobble will mani-

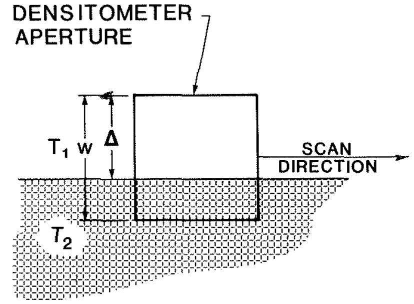

Figure 1. Geometry associated with proposed method to measure the transverse stability of a microdensitometer. When a straight edge is scanned with a square or rectangular aperture, the measured *transmittance is linearly related to the displacement* of the aperture from the edge Δ.

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fest itself in gray-scale displays of the digitized image as a scalloping or jaggedness along high-contrast boundaries that would otherwise be smooth.

Results

The above technique has been applied to several commercial microdensitometers to measure the extent of their wobble. The measurements presented here were made as part of the normal operation of the machines without the benefit of special tuning, except where noted.

Figure 2 shows typical results obtained with a PDS-2020 microdensitometer, which was manufactured in 1982 by the Applied Optics Division of the Perkin-Elmer Corporation. A scan was made along the edge of one of the bars of a resolution pattern that was deposited on a 5.08-cm-square glass plate. The slide was obtained from Ealing Corporation (Cat. No. 23-0987). A 30-μm square aperture was used and the distance between samples along the scan line was 10 μm. A spacing of 5 μm between scan lines allows one to observe the transverse wobble for many successive scans. The scan was performed in the edge mode, meaning that the readings were all taken in the same direction of travel. Figure 2(*a*) shows an isometric projection of the measured optical density for 20 successive scan lines. The significance of the observed oscillation becomes apparent when the same data are redisplayed in terms of aperture displacement, Fig. 2(*b*), using Eqs. (2) and (3). One observes a periodic oscillation that has nearly constant displacement amplitude from one scan line to the next but with varying phase angle. At a constant scan speed, a display of the overlap versus sample number shows the lateral displacement as a function of time. Thus, Fig. 2(*b*) indicates a nearly sinusoidal transverse oscillation of the aperture with a period of 0.07 s. When the same edge is scanned at approximately ten times the speed, the result, shown in Fig. 2(*c*), indicates an oscillation with the same temporal period. Figure 3 shows how the above data manifest themselves in a grey-scale display.

Numerous other tests were performed on the PDS-2020 to determine the characteristics of the observed transverse instability and to ultimately eliminate it. Many of these tests were carried out using a strip-chart recorder to plot the measured transmittance immediately following each scan. It was found that no wobble occurred in single-line scans when the microdensitometer was placed at the beginning of the scan line before the scan. Oscillations were produced in one-line scans when the aperture was offset before starting the scan. In multi-line scans, the lateral movement between scan lines apparently provoked oscillations. The conjecture that the oscillations are caused by the lateral positioning servomechanism is supported by the observation that they cease when the lateral positioning motor is turned off.

Similar tests for wobble were performed on two other PDS microdensitometers. A Model PDS-1714, which is constructed similarly to the one discussed above, showed similar oscillations. A PDS-1010, with a different mechanical construction than the larger machines, was somewhat more stable. However, under certain scanning conditions, it also displayed oscillations with peak-to-peak amplitudes of up to 5 μm. The observed instabilities in all the PDS machines were cured with retrofitted nylon drag screws supplied by Perkin-Elmer. Figure 4 demonstrates the reduction of the oscillations as the nylon screw is tightened against the track on which the granite yoke moves. There may be other methods for reducing the lateral oscillations. As the oscillations do not show up when the scanner is first positioned at the beginning of the scan line, it seems that a longer delay between positioning and scanning would reduce the amount of oscillation. In repositioning, the scanners are supposed to turn off the drive motors at a precalculated time before reaching their destination. Perhaps a different ramp-down schedule could be found to damp out the lateral oscillations.

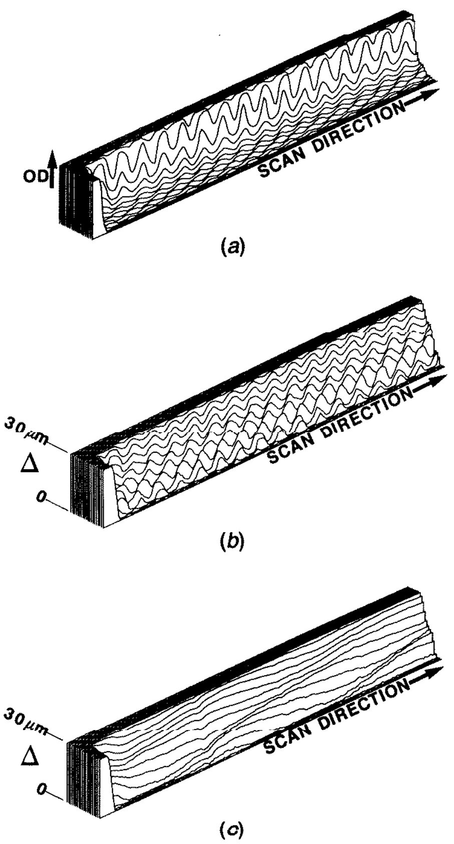

Figure 2. (*a*) Display of the optical density measurements taken in a 20-line scan with 200 samples per line at a scan speed of 1.2 mm/s using a PDS-2020 microdensitometer. A 30-μm square aperture was used with an interline spacing of 5 μm and sample spacing of 10 μm. (*b*) The same data presented in terms of aperture displacement show periodic oscillations with a peak-to-peak amplitude of about 5 μm and a period of 0.07 s. (*c*) The display of aperture displacement derived from a scan taken at 14 mm/s shows similar oscillations with the same temporal period.

Figure 5 shows the results of a test performed on an Optronics Model C4100. Because this scanner can only scan a pliable medium, a contact print of the aforementioned glass slide was made on Kodalith Ortho 3 lithographic film. Numerous small jumps of about 1 μm are observed. However, as most of these fluctuations repeat themselves from one scan line to the next, they are probably caused by imperfections in the edge being scanned and not by the microdensitometer. It is concluded that this particular machine has very little wobble, less than 1 μm, peak-to-peak.

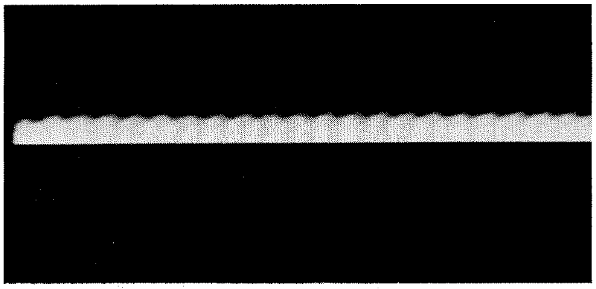

Figure 3. Redisplay of the optical density data shown in Fig. 2(*a*) indicates how microdensitometer wobble may evidence itself in grey-scale displays.

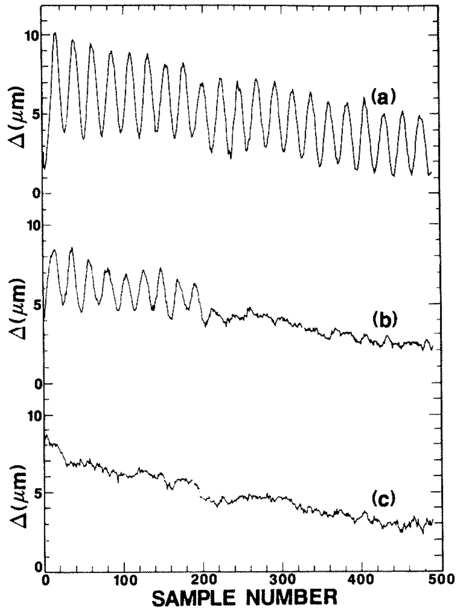

Figure 4. The oscillations observed on a PDS-1714 in a normal scanning situation (*a*) can be reduced by progressively tightening a nylon drag screw (*b*) and (*c*), retrofitted by Perkin-Elmer.

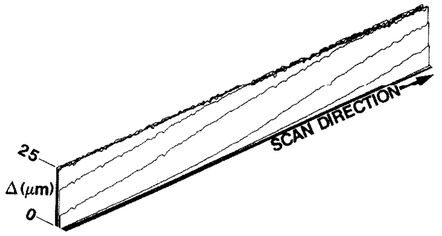

Figure 5. Display of the aperture displacement for 10 consecutive lines, with 300 points per line, of a scan of a straight edge made with an Optronics C4100. A 25-μm square aperture was used with 12.5-μm spacing between lines and between sample points. The recurrence of defects from one line to the next most likely indicates deviations of the edge from a straight line. The wobble in this scan appears to be less than 1 μm, peak-to-peak.

Discussion

The method of measuring transverse stability of microdensitometers presented above enjoys several advantages. The results are insensitive to the orientation of the aperture if it is square. They are also insensitive to the focus of the aperture on the edge, as well as the sharpness of the edge itself, provided such blurring effects occur over a distance that is somewhat less than the aperture width. The calibration of the aperture displacement may be checked either by scanning slowly in a direction perpendicular to the edge or by tilting the edge by a known extent relative to the scan line. In the latter case, the slope of the transmittance curves versus distance along the scan direction, as displayed in Fig. 5, may be related to the known tilt angle. Alternatively, if the distance between successive scan lines is less than the aperture width, it may be used to check the displacement calibration.

This technique relies on the straightness of the edge scanned. The evaporated glass slide used to obtain the results presented here is only marginally satisfactory. The edge produced by a stretched uncoated wire would probably be more reliable. However, if one were to scan the wire directly, one would have to be careful not to allow vibrations in the wire to affect the results. Alternatively, an image of the stretched wire captured on fine-grain photographic film or on an evaporated glass slide could be used.

The principle used here may be extended to check other aspects of positional accuracy that are important for proper microdensitometer operation. For example, the stability of the registration of the illuminating spot relative to the light-collection region may be checked by observing the constancy of the reading as a region of flat optical density is scanned. The positional stability in the scan direction may be checked by scanning a periodic sequence of bars in a direction perpendicular to the bars. If the distance between bars is an integral multiple of the sample spacing, the same transmittance should be measured each time the aperture straddles the edge of a bar.

Conclusions

By scanning a high-contrast straight edge, it is possible to measure the extent of wobble present in a microdensitometer under normal operating conditions. The measured transmittance is directly proportional to the aperture displacement. If optical densities are being measured, the displacement measurement is most sensitive when the aperture is nearly occluded by the dark side of the edge. It has been found that the positional stability of several commercial microdensitometers transverse to their scanning direction is much worse than the manufacturer's specifications indicate. Nearly sinusoidal oscillations have been observed on some microdensitometers with peak-to-peak displacements of 5 μm and greater. The source of this wobble is the positioning servomechanism that is supposed to maintain a constant lateral position. A method to eliminate the observed wobble has been effective on all the machines studied.

It should be emphasized that each user of a microdensitometer must test his own machine to see if its performance meets his needs. It would be folly to rely either on the manufacturer's specifications or on the measured performance of another machine of the same model.

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