An improved procedure for visual microinterferometry in moderately monochromatic light

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A new procedure is proposed for visual microinterferometry in moderately monochromatic light. It consists in determining optical path difference (δ) from the relation $\delta = c\lambda_{pv}/b_{pv}$, where λ_{pv} is the visual peak wavelength, b_{pv} is the visual interfringe spacing of an interference pattern, and c is the fringe displacement caused by the object under study. All these quantities are simultaneously measured using a single interference system (Biolar PI double refracting interference microscope).

1. Introduction

It has been found [1] that typical interference (metallic-dielectric) filters of IF- and SIF-type introduce errors into an interference measurement of optical-path difference in long- and short-wave regions of the visible spectrum. These errors result from the fact that interfringe spacings observed in a moderately monochromatic light are different from those in highly monochromatic light (e.g., laser light) of the wavelength λ coinciding with the peak wavelength λ_p of the light maximally transmitted by the interference filter. This phenomenon is illustrated in Fig. 1 (taken from [1]) which refers to the birefringent prism no. 2 of Biolar PI double-refracting interference microscope.

Graph 1 in Figure 1 presents the relationship between highly monochromatic light wavelength and interfringe spacing b of the interference field, measured with the aid of a micrometric phase screw PS (Fig. 2) of the interference microscope mentioned above. Graph 2, in turn, illustrates the same dependence, but when a white-light source (e. g., halogen lamp) is used, and is filtered by means of typical interference filters (IF). As can be seen, interfringe spacings b observed in blue and greenish-blue light, are larger than those resulting from graph 1. The reversal divergence occurs in red light. Both the graphs overlap only within the middle region of the visible spectrum, corresponding to the maximal sensitivity of human eye. As a consequence, interfringe spacing b_{mm} observed with the filters (IF), and then measured, slightly differs from the real one b_{hm} which occurs in the highly monochromatic light. It should be pointed out that the values of b_{hm} are in a good agreement with the theoretical data [1].

Deviations of $b_{mm}(\lambda)$ graph from $b_{hm}(\lambda)$ graph are just the source of significant errors in the measurements of optical-path difference in short- and long-wave regions of the visible spectrum [2]. In order to avoid these errors it is necessary to employ miltidielectric interference filters (DIF), as was stated in
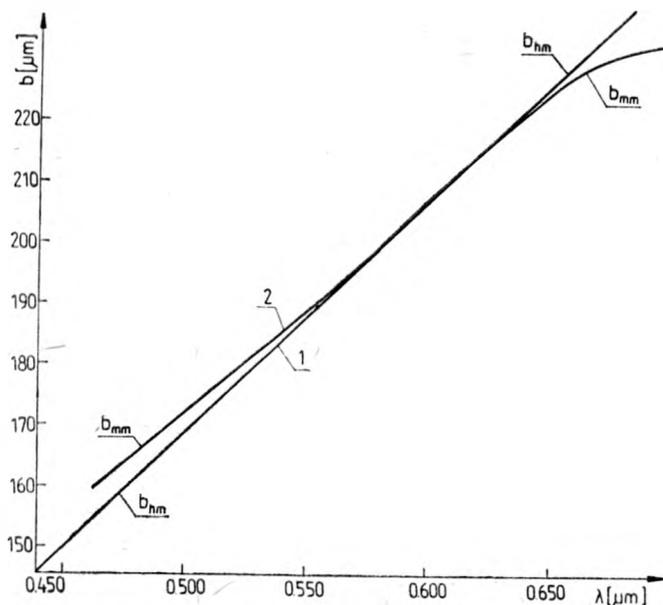
Fig. 1. Relation between the light wavelength (λ) and the interfringe spacing (b) for the birefringent prism no. 2 of Biolar PI double refracting interference microscope. Straight line b_{hm} – for highly monochromatic light (equivalent to theoretical plot), curve b_{mm} – for moderately monochromatic light extracted from a white light source (halogen lamp) by using typical interference filters
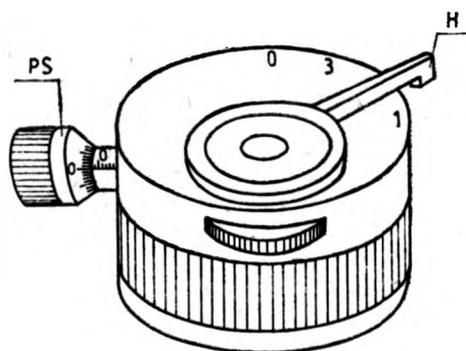

Fig. 2. Double refracting attachment to Biolar PI interference microscope. PS – phase screw (micrometric screw) for measuring interfringe spacing b and fringe displacements c, H – handle for changing birefringent prisms (in position it is shown the prism no. 2 is included into the path of light rays)

[1, 2], which are characterized by a more slender spectral profile of transmittance than that for popular metallic-dielectric interference filters (IF and SIF). It occurs, however, that this requirement may be moderated and replaced by a simple remedical measure, not noticed previously, although it is contained in the theoretical and experimental data given in [1].

2. Principle of procedure

The measurement of optical path difference is performed in the simplest way according to a widely-known rule described by the equation

$$\delta = c\frac{\lambda}{b} \tag{1}$$

where λ – light wavelength, b – interfringe spacing, c – interference-fringe displacement due to the presence of the investigated object, e.g., a thin dielectric strip on a glass substrate (Fig. 3). Biolar PI interference microscope [3, 4] has an important advantage, as it allows us to determine in a real-time not only the parameters c and b, but also the wavelength λ of light forming the inter-
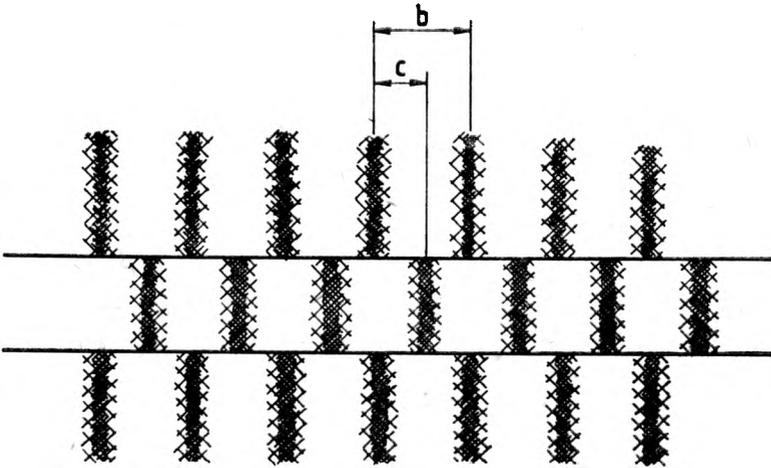

Fig. 3. Illustration of Equation (1)

ference image [1]. The latter measuring possibility results directly from the relation $b(\lambda)$, represented by graph 1 in Fig. 1. This relation is unique and independent of any instrumental and surrounding conditions. Thus, in order to determine optical path difference δ, the real values of λ and b need not be substituted into Eq. (1), but it suffices to substitute the real ratio λ/b which is not charged with errors resulting from the deviation of graph 2 from graph 1 (Fig. 1). For a given light wavelength, the ratio λ/b is a constant (the fundamental feature of the interference system under consideration). This ratio can either be determined accurately once for good, or determined in a real time; thus avoiding the discussed errors [1] of the measurements in moderately monochromatic light.

The suggested procedure is explained in Fig. 4 which illustrates in an enlarged scale the upper (a) and lower (b) parts of the graphs from Fig. 1. Let us first consider Fig. 4a. The red interference filter with peak wavelength of λ_p being included into the white-light ray path makes Biolar PI interference-microscope

field of view have interfringe spacing equal to b_p. Visually, however, we can discern not the spacing b_p, but a smaller one b_{pv} which will be called a visual interfringe spacing. The latter being measured in the visual observation of inter-ference-fringe field. The measurement is carried out with a phase screw PS (Fig. 2), coupled with a transversal move of birefringent prisms of Biolar PI
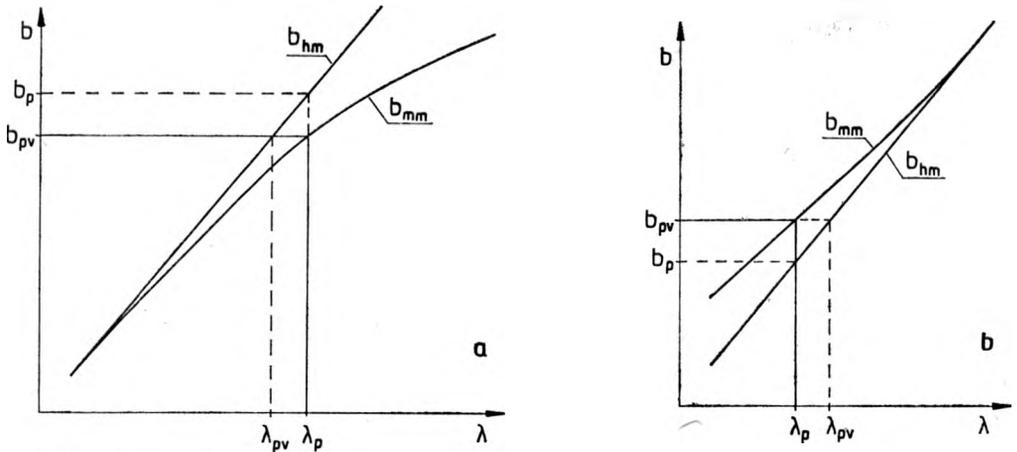

Fig. 4. Top part (a) and bottom part (b) of the graphs given in Fig. 1, in an enlarged scale

microscope. Yet, this measured value of b_{pv} (Fig. 4) should not be attributed to the real peak wavelength (λ_p), but to the visual one (λ_{pv}). It occurs that the ratio λ_{pv}/b_{pv} is practically the same as λ_p/b_p, since, as has been shown in Fig. 1, the graph of b_{hm} is almost an ideal straight line [1]. Similar situation occurs when the red interference filter is replaced by a blue one (Fig. 4b). This time, however, the visual interfringe spacing (b_{pv}) is greater than the real one (b_p) and to this end of the spectrum the wavelength λ_{pv} slightly greater than λ_p resulting from the graph $b_{hm}(\lambda)$ should be ascribed. The graph $b_{hm}(\lambda)$ obviously should be prepared using highly monochromatic light. This is a one-time work if done accurately, its result is valid for good (for a given of Biolar PI microscope).

A validity of the suggested procedure is confirmed by the Table which is the extended version of Table 5 taken from [1]. The extended part thereof consists of the columns 5–9. As can be seen, the values of the ratios λ_{pv}/b_{pv} in short- and long-wave regions of spectrum are the same as those of the real ratios λ_p/b_p (compare columns 7 and 6). The same cannot be said about the ratios λ_p/b_{pv} and λ_{pv}/b_p which differ from each other (compare the column 8 and 9) and deviate significantly from the correct values expressed by λ_p/b_p and λ_{pv}/b_{pv}. In the middle region of the visible spectrum all the four ratios are obviously the same. Their divergence, i.e., the deviation of λ_p/b_{pv} and λ_{pv}/b_p ratios from λ_p/b_p and λ_{pv}/b_{pv} in short- and long-wave regions of the visible spectrum will decrease by employing more monochromatic filters of DIF-type instead of the interference filters of IF- and SIF-type (see the last five rows of the Table).

Numerical data relating to plots 1 and 2 in Fig. 1 (columns 1–4) and illustrating the validity of the procedure (columns 5–9)

| Interference filters | | Interfringe spacing | | Visual peak wavelength (relating to b_{pv}) λ_{pv} [μm] | $\dfrac{\lambda_p}{b_p} \times 10^{-5}$ | $\dfrac{\lambda_{pv}}{b_{pv}} \times 10^{-5}$ | $\dfrac{\lambda_p}{b_{pv}} \times 10^{-5}$ | $\dfrac{\lambda_{pv}}{b_p} \times 10^{-5}$ |
| Type and mark | Peak wavelength λ_p [μm] | Visual b_{pv} [μm] | Real (relating to λ_p) b_p [μm] | | | | | |
1	2	3	4	5	6	7	8	9
IF 450	0.4560	155.1	152.4	0.4635	299.2	298.8	294.0	304.1
IF 466	0.4770	163.0	160.3	0.4845	297.6	297.2	292.6	302.2
IF 475	0.4833	164.9	162.6	0.4895	297.2	296.8	292.9	301.0
IF 491	0.4985	171.6	168.9	0.5070	295.1	295.5	290.5	300.2
IF 500	0.5045	173.4	170.6	0.5115	295.7	295.0	290.9	299.5
IF 525	0.5250	180.6	178.5	0.5305	294.1	293.7	290.7	297.2
IF 546	0.5467	188.1	186.8	0.5525	292.7	292.7	290.6	294.7
IF 550	0.5550	190.0	189.9	0.5555	292.3	292.4	292.1	292.5
IF 575	0.5867	202.0	201.7	0.5875	290.9	290.8	290.4	291.3
IF 578	0.5920	203.8	203.7	0.5925	290.6	290.7	290.5	290.9
IF 589	0.5926	204.0	203.9	0.5930	290.6	290.7	290.5	290.8
IF 600	0.6022	207.7	207.4	0.6025	290.4	290.1	289.9	290.5
IF 616	0.6230	214.6	215.4	0.6210	289.2	289.4	290.3	288.3
IF 625	0.6380	220.9	221.0	0.6380	288.7	288.8	288.8	288.7
IF 650	0.6587	226.3	228.7	0.6525	288.0	288.3	291.1	285.3
IF 675	0.6792	230.7	236.3	0.6640	287.4	287.8	294.4	281.0
SIF 486	0.4890	166.8	164.9	0.4940	296.5	296.2	293.2	299.6
SIF 551	0.5504	188.0	187.5	0.5505	293.5	292.8	292.8	293.6
SIF 589	0.5950	204.9	204.9	0.5950	290.4	290.4	290.4	290.4
SIF 656	0.6560	226.7	227.7	0.6535	288.1	288.3	289.4	287.0
DIF 487	0.4925	168.0	166.2	0.4970	296.3	295.8	293.2	299.0
DIF 546	0.5490	187.2	187.2	0.5485	293.0	293.0	293.3	292.7
DIF 632	0.6375	221.3	220.8	0.6385	288.7	288.5	288.1	289.2
DIF 657	0.6585	228.4	228.6	0.6580	288.1	288.1	288.3	287.8
DIF 695	0.6970	242.4	243.0	0.6960	286.8	287.1	287.5	286.4

According to the results presented above, Eq. (1) can be rewritten as

$$\delta = c\,\frac{\lambda_{pv}}{b_{pv}}.$$ (2)

This equation is practically equivalent to the equation

$$\delta = c\,\frac{\lambda_p}{b_p}.$$ (3)

The latter requires, however, that the wavelength λ_p be known and that inter-fringe spacing b_p, not observed in the interference image in short- and long-wave regions of spectrum be formally ascribed to it. Moreover, Biolar PI microscope cannot be used for measurement of the wavelength λ_p of moderately monochromatic interference filters, and another instrument, e.g., a spectrophotometer, should be applied. This obviously refers only to moderately monochromatic filters (light sources) from short- and long-wave regions of spectrum and to visual measurement of their wavelength. If, however, a photometric measurement was made by means of a photo-receiver of the identical sensitivity within the whole spectral visible region, then the discussed problem would not exist at all.

3. Conclusions

Summing up, it should be stated that the procedure given above allows us to use the moderately monochromatic interference filters (IF or SIF) with Biolar PI double-refracting interference microscope. Then the measurement of optical-path difference is practically not charged with errors resulting from the deviations of the graph $b_{mm}(\lambda)$ from the graph $b_{hm}(\lambda)$. It goes without saying that the wave-length λ_{pv} read from the graph b_{hm} (Fig. 1) must be expressed in the same units as the visual interfringe spacing b_{pv} measured directly with a phase screw FS (Fig. 2), of Biolar PI microscope. It is convenient to express the parameter c in the same units, also measured directly with the aid of the mentioned phase screw. It is the only parameter being permanently measured, since it suffices to determine the ratio λ_{pv}/b_{pv} in a given experiment only once as soon as a given interference filter is employed. Peak wavelength of the interference filters changes, however, with time, thus the ratio λ_{pv}/b_{pv} must be from time to time carefully checked. The plot $b_{hm}(\lambda)$ does not change with time, that is why it should be prepared in an exceptionally careful and exact way, best of all with laser light (He-Ne-, Ar-, Cd-He lasers). In fact, the graph $b_{hm}(\lambda)$ is nothing but a scaling of the interference system. It should be emphasized that this graph agrees with the theory [1] very well.

The suggested procedure is valid not only when the fringe interferometry, but also the uniform one is applied. Taking advantage of [1], the presented procedure, without a separate discussion, can be easily generalized onto the

uniform interferometry in Biolar PI interference-microscope system. This procedure has a universal character and is applicable in a visual interferometry realized by means of any interference system which has a persistently determined relationship between the light wavelength and the interfringe spacing.

References

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Усовершенствованная микроинтерферометрическая процедура в умеренно монохроматическом свете

Предложены новые действия в визуальной микроинтерферометрии в умеренно монохроматическом свете. Они заключаются в определении разности оптического пути (δ) по следующей формуле $\delta = c\lambda_{pv}/b_{pv}$ где λ_{pv} – визуальная вершинная длина световой волны, b_{pv} – отвечающее этой волне межспектральное расстояние интерференционного поля, c – отклонение интерференционных спектров, вызванное исследуемым предметом. Эти все параметры измеряются одновременно с помощью одной интерферометрической системы (интерференционно-поляризационного микроскопа Biolar PI).