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STREHL RATIO FOR AN ANNULAR APERTURES.

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Abstract:

From optical image evaluation point of view Strehl ratio is an important quality criterion. It has direct relation with the image formation process. Strehl ratio is commonly defined as the ratio of image irradiance at the diffraction focus with apodisation to one without apodisation. For small aberrations, Strehl ratio is an approximate measure of the fraction of the diffracted radiant flux that is concentrated in the central bright core at the image of the point object. The Strehl ratio maximizing means increasing the brightness of the image. Several researchers have investigated and developed various methods to maximize its value. Strehl ratio is not a physically measurable quantity;

Key words: Aberration, Aperture, Hanning pupil and Strehl ratio etc;

1.1 INTRODUCTION:

Theoretically by studying performance of optical system (HOPKINS, 1957). MARECHAL and FRANCON (1960) have developed the aberration balancing method that allows maximizing the Strehl ratio by minimizing the wave-front aberration. Very recently the Strehl ratio expressions are derived and studied for the Gaussian pupil imaging system by YOUNG RAN SONG, MIN HEE LEE and SONG SOO LEE (1998). FRCIMANN and DORBAND (1998) have evaluated the imaging performance via the Strehl ratio on the basis of Marchal criteria. TATIAN (1974) studied the problem of aberration balancing for rotationally symmetric imaging systems. BARAKAT (1962) studied this problem for both circular and slit apertures finding the solutions for Luneberg's, apodisation problem. BARAKAT and LEVIN (1963) have investigated the diffraction pattern of apodised, rotationally symmetric optical systems to have maximum Strehl ratio. BARAKAT and HOUSTON (1965) have investigated the effects of the third and the fifth order spherical aberrations on Strehl ratio for an annular aperture.

1.2 MATHEMATICAL FORMULATION:

In the present case, the aperture is apodised by Hanning amplitude filter. In the presence of defocusing, primary spherical aberration and astigmatism.

$$EE(\delta) = \frac{\int_0^{\delta} \left| G_F(0, Z) \right|^2 Z\, dZ}{\int_0^{\infty} \left| G_F(0, Z) \right|^2 Z\, dZ}$$

Where G_F (0, Z) represents the light amplitude in the receiving plane at point Z units away from the diffraction head and the subscript F indicates that the optical imaging system is apodised with the given filter, the above expression can be written as

$$EE(\delta) = \frac{\int_0^{\delta} \left| G_F(\phi_d, \varphi_s, \Phi_a, Z) \right|^2 Z\, dZ}{\int_0^{\infty} \left| G_F(0, Z) \right|^2 Z\, dZ}$$

The edge-ringing is decreasing gradually as β varies from 0 to 0.5 for all the three filters; however, the rate of fall of ringing is more in the case of Hanning filter as compared that with the shaded aperture and Lanczos filter. When β=0.5 the edge ringing acquired the values 0.0126(for f1), 0.0927(for f3) and 0.1089(for f2) respectively. That is the minimum edge-ringing is obtained when the optical system is partially apodised with the

$$G_F(Y, Y_1, Z) = 2\int_0^1 f(r) \exp\left[-i\left(\frac{1}{2}\phi_d r^2 + \frac{1}{4}\varphi_s r^4 + \frac{1}{2}\ \Phi_a r^2 Cos^2\theta\right)\right] J_0(Zr)\, r\, dr$$

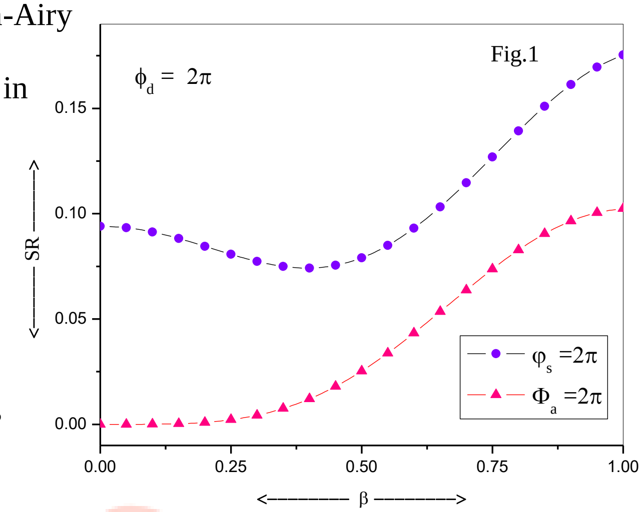
The Strehl ratio describes the effects of wave-front aberrations on the diffraction image formed by optical imaging system. It is, in general defined as the ratio of the image irradiance at the diffraction focus with the non-uniform pupil function, to that with the uniform pupil function (KUSAKAWA and OKUDAIRA, 1972). Thus, in the absence of aberrations,

$$SR = \frac{IMAGE\ \ IRRADIANCE\ \ WITH\ \ APODISATION}{IMAGE\ \ IRRADIANCE\ \ WITHOUT\ \ APODISATION}$$

This can be written as

$$SR = \frac{I_F(0,0)}{I_A(0,0)}$$

where the subscripts A and F stand for Airy and non-Airy pupils respectively. The above equation can be written in terms of amplitude as



$$SR = \frac{|\ G_F\ (0,\ 0)\ |^2}{|\ G_A\ (0,0)\ |^2}$$

Further, the above expression (3.21) can be expressed as

$$SR = 4\left[\int_0^1 f(r) r\, dr\right]^2$$

where r is the normalised radius of aperture and f(r) is the pupil function. In the present study, f(r) is the Hanning amplitude filter given by

$$f(r) = Cos(\pi\ \beta\ r)$$

$$SR = 4\left[\int_0^1 \ \mathrm{Cos}(\pi\beta r)\ r\, dr\right]^2$$

where β is the apodisation parameter, which determines the degree of non-uniformity of transmission of the pupil.

Strehl ratio gives the efficiency of non-Airy pupil function. It is unity for perfect systems without aberrations. The efficiency of the optical imaging systems will be considered as high when Strehl ratio is high. This is an important factor in determining the image degrading effects due to aberrations in coherent systems. For this case, GOODMAN (1968) has given a definition for the Strehl ratio as the ratio of the light intensity at the maximum of the PSF to the maximum of the same instrument in the absence of aberrations. It is sensitive to apodisation, abscuration, defocusing image motion and wave front error. Strehl ratio is also known as Strehl definition or Strehl intensity or Strehl criterion.

1.3 RESULTS AND DISCUSSION:

SR decreases with defocus for clear aperture; but there is an increase in its value for highly apodised aperture when the defocused plane is at $\phi_d = \pi/2$. when the optical system is under the combined influence of astigmatism and primary spherical aberration with $\varphi_s = \Phi_a = 2\pi$. In this case the influence of optical filter in increasing the SR of the optical system is seen. Almost an increase of about 86 percent in the value of SR is observed from 0.0940 to 0.1754 when the value of β is incremented from 0 to 1. The Strehl ratio curves when the optical system is suffering from primary spherical aberration for various defocused planes. One can observes that the SR decreases with defect-of-focus for Airy aperture and slightly increases with defect of focus for extreme apodisation. Fig.1 present the situation where the optical system is under the effect of astigmatism. From the above curves it is clear that the value of SR increases for highly apodised apertures and it is more when the defocused plane is at $\phi_d = \pi/2$. The SR curves for $\varphi_s = \Phi_a = 2\pi$ with $\theta = \pi/2$ is presented in Fig.1. the values of SR when $\varphi_s = 2\pi$. The value of SR decreases with β initially and then increases for higher values for all defocused planes. The value of SR attains high value when $\beta = 1$ and $\phi_d = \pi$. values of SR when the optical system is under the influence of astigmatism with $\Phi_a = 2\pi$ and $\theta = 0$. In this situation, the SR increases for high apodisation for all defocused planes. values of SR when $\varphi_s = \Phi_a = 2\pi$ with $\theta = \pi/2$. For the defocused plane $\phi_d = \pi$ there in an increase in the value of SR for extreme apodisation. Fig.1 presents the SR curves when the optical system is under the influence of primary spherical aberration for different defocused planes. values of SR for different degrees of primary spherical aberration when $\phi_d = 2\pi$. Fig.1 shows the contrast between astigmatism and primary spherical aberration when the optical system is at defocused plane $\phi_d = 2\pi$ in terms of the SR values with apodisation. In case of astigmatism the SR increases with apodisation where as with primary spherical aberration, it first decreases and then increases to a value higher than in the case of clear aperture. The variation of edge shifting with apodisation parameter β for given value of dϕ . For all values of dϕ , the edge shift is increasing as β varies from 0 to 1. The shift is the maximum at β=0 for dϕ =2π i.e., 1.4175 and is the minimum at β=0 for dϕ =0 i.e., 0.6675. In general the edge shift is increasing with defocus parameter but in this case it decreases for dϕ =2π with β. However it is maximum for β=0 i.e., 1.4175 at dϕ =2π and decreases to a value 1.3950 at β=1. It is found that there is a reduction in ringing along with edge shift and there is a perceptible improvement in edge gradient for β=1 at dϕ =2π.

1.4 CONCLUSIONS: The important conclusions of the investigations on the effect of apodisation by three different filters on the images of straight edge objects formed by coherent optical systems are summarized as:

i. For unapodised and apodised pupil functions, the degree of edge ringing and edge shifting are found to increase with defocus parameter. However, this feature is dominant for unapodised optical systems than that of the apodised ones.

ii. With the apodisation, the unwanted edge-ringing has been reduced at the cost of increase in edge shift and lowering of the edge gradient. The same trend repeated for all defocused planes. For the Hanning filter, the edge-ringing decreases with β from0 to 0.5. However it is increasing for β=0.75 and 1. Hence this filter is suitable for partial apodisation

iii. The unwanted edge ringing effects are found to reduce even in the presence of defocus with apodisation. However this can be achieved only at the expense of increase of edge shifting and a decrease of edge gradient.

iv. At dϕ =π the shift is relatively smaller compared to other defocus planes. For the value of β≥0.7, the edge shift shows decreasing trend at all defocused planes. It means the edge shift can be minimized with high degree of apodisation using Hanning amplitude filter.

v. For the Lanczos filter edge-ringing is decreasing with β, from 0 to 1. That is, this filter is optimum for full apodisation. The edge ringing attains the minimum values at β=1 for all values of dϕ

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