

Complex pupil function reconstruction at high NA using the extended Nijboer-Zernike diffraction theory

Joseph Braat[#], Peter Dirksen[&], Augustus J.E.M. Janssen[&], Arthur S. van de Nes[#],

[&] Philips Research Laboratories, Professor Holstlaan 4, 5656 AA Eindhoven,
The Netherlands

[#] Optics Research Group, Faculty of Applied Sciences, Delft University of Technology,
Lorentzweg 1, 2628 CJ Delft, The Netherlands
E-mail: j.j.m.braat@tnw.tudelft.nl

Abstract: We have derived an analytical expression for the field components in the focal region of a high-numerical-aperture imaging system using the so-called extended Nijboer-Zernike diffraction theory. It will be shown that the transmission function of the imaging system and its aberrations can be derived from the through-focus intensity map.

©2004 Optical Society of America

OCIS codes: 000.3860, 050.1960, 070.2580, 110.299

KEY WORDS: Aberrations, high numerical aperture beams, extended Nijboer-Zernike theory

Summary

In a recent publication the authors have presented a formalism that, starting from the complex field in the entrance or exit pupil of the optical system, enables an accurate forward calculation of the field in the focal region produced by a high-numerical aperture beam, including the vectorial aspects. The analysis is a further extension for high NA-values of the extended Nijboer-Zernike theory of aberrations [1] and is capable of representing the field vectors in the focal region of a high-NA objective with the aid of a well-converging series expansion in Bessel functions. For the scalar diffraction case, the starting point is the semi-analytic result for the diffraction integral, yielding the following expression for the complex amplitude in the focal volume,

$$U(r, \varphi, f) = 2V_0^0(r, f) + 2 \sum_{n,m} i^m \beta_n^m V_n^m(r, f) \exp(im\varphi) , \quad (1)$$

and the approximated expression for the intensity according to

$$I(r, \varphi, f) \approx 4 \left| V_0^0(r, f) \right|^2 + 8 \sum_{n,m} \operatorname{Re} \left\{ i^m \beta_n^m V_n^m(r, f) V_0^{0*}(r, f) \exp(im\varphi) \right\} , \quad (2)$$

which is valid when the amplitude variations and aberrations introduced by the optical system are small; r , f , and φ are the cylindrical co-ordinates in the focal region and β_n^m (in general complex-valued) are the Zernike coefficients describing the amplitude and phase distribution of the field in the exit pupil according to $A(\rho, \vartheta) \exp\{ikW(\rho, \vartheta)\} = \sum \beta_n^m R_n^m(\rho) \exp(im\vartheta)$; the V -functions are obtained from the extended Nijboer-Zernike diffraction theory.

In this presentation we will discuss aspects of the inverse problem [2], viz. the reconstruction of the complex field in the exit pupil by collecting a set of through-focus intensity measurements. We also address the extra complications that arise when the fully vectorial situation is treated in the case of high-NA imaging.

References

1. J.J.M. Braat, P. Dirksen, A.J.E.M. Janssen, A.S. van de Nes, "Extended Nijboer-Zernike representation of the vector field in the focal region of an aberrated high-aperture optical system", J. Opt. Soc. Am. A **20**, 2281-2292 (2003)
2. P. Dirksen, J.J.M. Braat, A.J.E.M. Janssen, C. Juffermans, "Aberration retrieval using the extended Nijboer-Zernike approach," J. Microlith. Microfab. Microsyst. **2**, 61-68 (2003).