COMPUTER SUPPORTED INTERFEROGRAM EVALUATION

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Paper presents a method of phase shift calculation and interpretation of complicated interferograms taken in the cylindrically symmetrical medium. Method is applicable for any finite–width interferogram, incl. those with individual closed interference fringes causes by abrupt changes of the refractive index. Phase shift calculation were performed in the MATLAB computing environment.
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1. INTRODUCTION

Study of plasma characteristics by means of optical interferometry makes possible to exclude the problem of plasma interaction with the phase object. The characteristics under study may be quantities related with or influencing the index of plasma refraction at least to such a degree that the shift related with the plasma refraction changes can be registered in an interferogram.

Interferogram is usually created by a distorted system of originally parallel interference fringes. Knowing the fringe shift and assuming the phase object rotational symmetry the distribution of characteristics under investigation can be calculated. In case of high-ionised plasma the total refractive index change mostly depends on electron concentration and in comparison with electron concentration both the temperature and pressure of neutral particles and ions effects may be neglected.

2. PHASE SHIFT CALCULATION

Phase shift subtraction from the interferogram seems to be a rather difficult process moreover complicated by further factors – taken interferograms may be unfocused due to apparatus vibration or non-stationarity of studied phenomena during the measurement. Fringes may join in points of large phase shifts and, sometimes-new fringes can originate in some regions.

For better interference pattern evaluation a new algorithm has been developed. It is simple and easy to be used also for evaluation of patterns containing complex distorted or closed interference fringes.

For model processing a complex interference pattern (Fig. 1) taken in the Z 150 equipment of Institute of plasma physics and laser microfusion (IPPLM), Warsaw, Poland was used [1].

Before the phase shift subtraction and subsequent evaluation the original interferogram had to be digitally modified. This modification can be described as:

- Limitation of investigated area in such a way that resultant area-rectangle contains maximum of complete interference fringes and therefore the most comprehensive information about the phase setting. Then the matrix of these data was standardized.
- Indistinct lines of the processed image were joined by hand, some parasitic pixels were removed. Resultant interferogram was transferred back into degrees of shade and modified with Gaussian filter of size 3x3. Finally the modified interferogram was reduced into 600x600 pixels. This reduction does not influence final results, it is important for the interference fringe approximation used algorithm only.

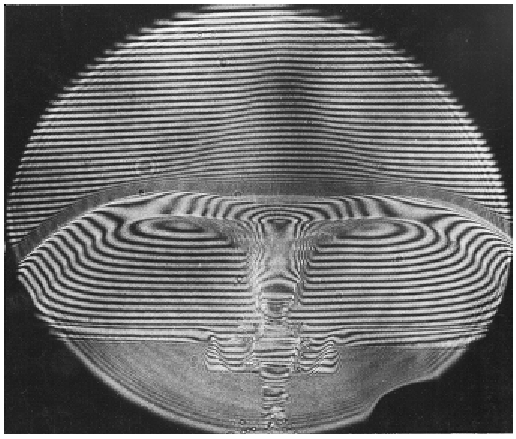

Fig. 1. Interference pattern used for model processing

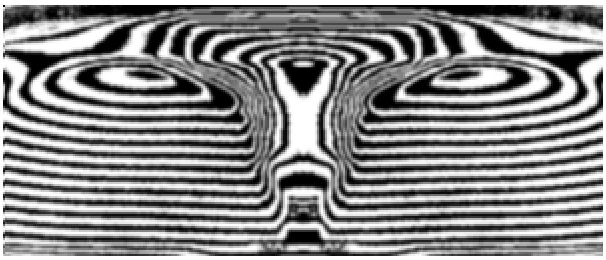

Fig.2. Part of modified interferogram used for calculation

Phase shift calculation had been performed in the MATLAB computing environment.

Evaluation algorithm is as follows: coordinates of a point and relevant phase shift value expressed in multiple of π are entered into the programme. Multiple of π being even means that interfering rays are shifted just a whole wavelength multiple farther in this point and the programme finds all points of maximum intensity along the fringe. For multiple of π being odd the programme searches for points of minimum intensity. Searching algorithm works in two regimes. Be a fringe slope smaller than 45°, the programme shifts in location by one pixel to the left, eventually to the right and checks surrounding pixels placed up and under the current pixel and a new position is relocated into the point of maximum (or minimum) intensity. The algorithm repeats itself until the boundary of the interferogram is reached. For fringesґ or parts of fringesґ slopes greater than 45°, the algorithm moves up, eventually down and locates pixels characterized with extreme intensity value in the left or in the right environs of the current point. During every step the programme saves a predefined value of the phase shift into the matrix on position corresponding to the actual location of the ascertained pixel. The result of the whole process is represented with a sparse matrix. This matrix contains information about the phase shift of lines created by points whose coordinates approximately correspond to the centres of individual interference fringes.

To obtain as much as possible precise and "smooth" information about the phase shift distribution the data are triangulated so that the final phase shift forms dense continuously defined matrix. Points lying outside the area under interpolation, i.e. outside the 1st and the last interference line contain no data. The matrix represents phase shift with introduced space frequency caused by slight decline of interfering rays.

The interference pattern structure in case of the finite width interferogram can be expressed as

$$g(x, y) = a(x, y) + b(x, y) \cdot \cos[2\pi f_0(x, y) + \varphi(x, y)], \quad (1)$$

$a(x, y)$ and $b(x, y)$ are invariables, $\varphi(x, y)$ wanted phase shift and $f_0(x, y)$ introduced undesirable space frequency. To get information about the real phase shift, the subtraction of this space frequency is fundamental.

Before the subtraction it is essential to find a shiftless region within the investigated area. For evaluation reasons these regions were declared as those with the linear phase shift and interpolated with the method of least squares. Knowing the linear phase in these regions the original undisturbed interferogram and original phase shift distribution were restored.

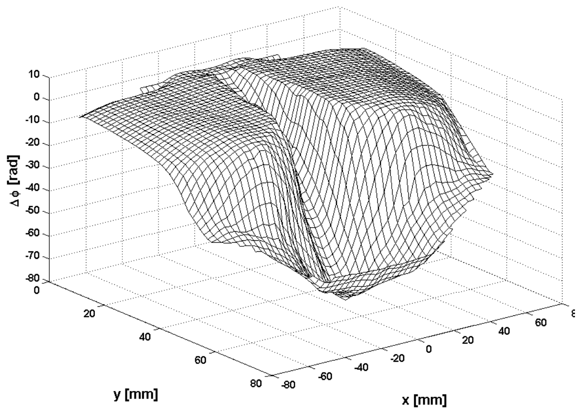

Fig. 3. Resultant phase shift values

Resultant phase shift $\delta\varphi$ values (see eq. 1) for individual points of the interferogram (Fig. 2) are displayed in Fig. 3.

3. CALCULATION OF REFRACTIVE INDEX AND ELECTRON DENSITY

Obtained phase shift distribution must be converted into the refractive index distribution. To get from a two-dimensional interferogram the three-dimensional image of the refractive index distribution, the studied phenomena must show the cylindrical symmetry. Discharge related with studied interference pattern fully satisfied this condition. For calculation of refractive index distribution the discrete Abel transformation was used.

Outside the evaluated region under study the difference between refractive index values and one are very small (of 10^{-7} order) and measurable refractive index changes are of order 10^{-5}. The electron density can be immediately calculated from refractive index changes values.

4. RESULTS

Obtained electron density distribution is presented in Fig. 4. It shows evident increase of electron density

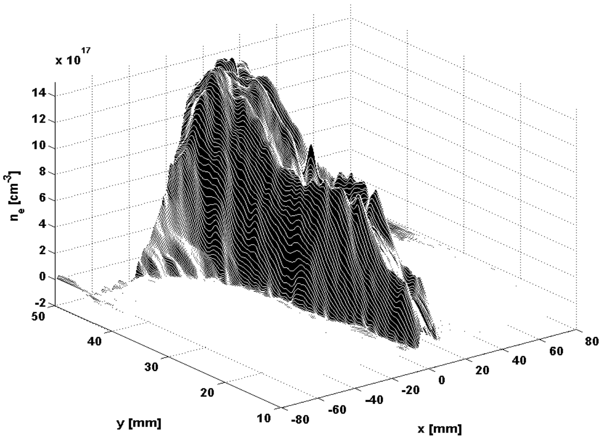

Fig. 4. Distribution of electron density in the discharge channel

values in y–axis direction. Free electron densities values are about (10^{17} ч 10^{18}) cm^{-3}. The calculation of electron density values has been limited into the area with borders determined by zero phase shift values. The accuracy of the calculation decreased with the growth of phase shift values near evaluated region borders (i.e. in the shock wave region).

SUMMARY

Paper presents an algorithm for interference patterns digitalization and phase shift calculation from finite–width interferograms. The algorithm is very simple and easy also to be used for evaluation of interferograms containing complex distorted or closed interference patterns. The algorithm was tested by determination of electron density distribution in the pinch discharge channel at the moment of maximum compression. Final results seem to be in a good agreement with expected values. All calculations were performed in the MATLAB computing environment.

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КОМПЬЮТЕРНАЯ ОБРАБОТКА ИНТЕРФЕРОГРАММ

Я. Олейнишек, Я. Пихал, Я. Блазек, П. Спатенка

Представлен метод вычисления и интерпретации фазового сдвига сложных интерферограмм, взятых в осесимметричном промежутке. Метод применим для любых интерферограмм, включая те, что имеют особенности интерференционных полос, вызванные внезапными изменениями коэффициента преломления. Вычисление фазового сдвига осуществлялось в компьютерной среде MATLAB.

КОМП'ЮТЕРНА ОБРОБКА ІНТЕРФЕРОГРАМ

Я. Олєйнішек, Я. Піхал, Я. Блазєк, П. Спатєнка

Представлено метод обчислення й інтерпретації фазового зсуву складних інтерферограм, взятих в вісесиметричному проміжку. Метод може бути застосовано для будь-яких інтерферограм, включаючи ті, що мають особливості інтерференційних смуг, викликані раптовими змінами коефіцієнта переломлення. Обчислення фазового зсуву здійснювалося в комп'ютерному середовищі MATLAB.