Using the Talbot_Lau_interferometer_parameters Spreadsheet

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Executive Summary

Talbot-Lau interferometers allow incoherent X-ray sources to be used for phase contrast imaging. A spreadsheet for exploring the parameter space of Talbot and Talbot-Lau interferometers has been assembled. This spreadsheet allows the user to examine the consequences of choosing phase grating pitch, source energy, and source location on the overall geometry of a Talbot or Talbot-Lau X-ray interferometer. For the X-ray energies required to penetrate scanned luggage the spacing between gratings is large enough that the mechanical tolerances for amplitude grating positioning are unlikely to be met.

Introduction

In conventional X-ray imaging, contrast is obtained through the difference in absorption cross-section of the parts of the object being imaged. If we are looking for highly absorbing objects imbedded in a weakly absorbing matrix (bones in a body for instance), this works well. If we want to distinguish between two weakly absorbing objects it may be more useful to examine the phase shift experienced by the X-rays as they pass through the objects, that is perform phase contrast imaging.

Up until recently X-ray phase contrast imaging was restricted to monochromatic sources such as synchrotrons or X-ray beams sent through monochrometers. The Talbot effect is now being used as a means of doing phase contrast imaging with low coherence sources such as X-ray tubes. There have been a number of papers detailing the design and implementation of such imaging systems[1][2][3].

There has been interest in the HME detection community in using these techniques. To determine whether these techniques can be used for luggage screening we have taken the basic design equations and implemented them in an excel spreadsheet.

System Parameters

The Talbot-Lau interferometer consists of three gratings as shown in Figure 1.

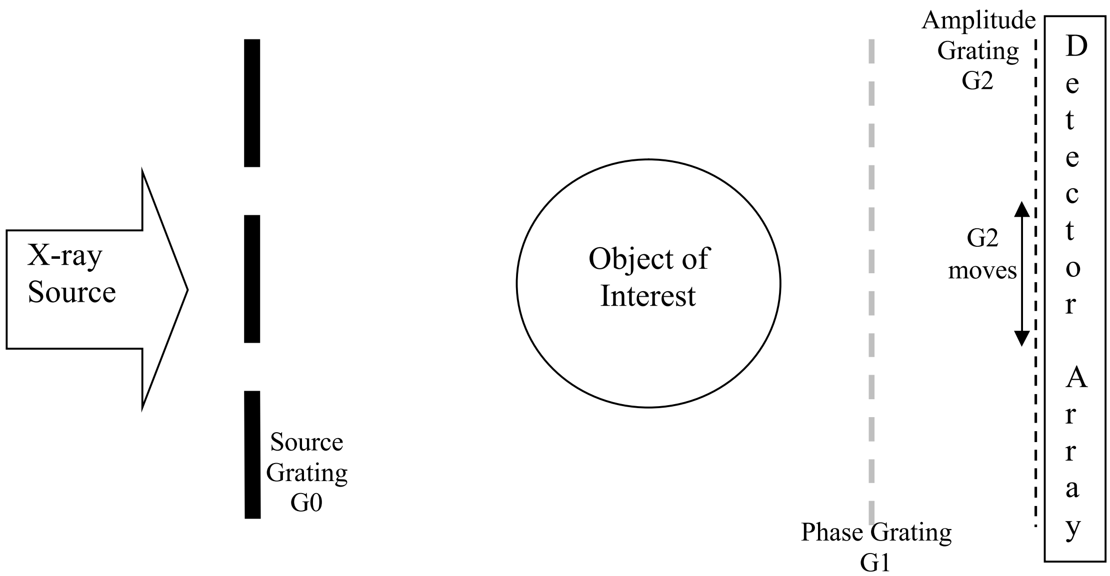

Figure 1. Talbot-Lau interferometer. The X-ray source is divided into effective point sources by grating G0. After transmission through the object of interest, the multiple beams are passed through phase grating G1. After traveling the appropriate number of Talbot distances, the resultant amplitude distribution is sampled by amplitude grating G2. G2 is moved so as to sample the amplitude distribution.

[1] F. Pfeiffer, et. al., "Phase retrieval and differential phase-contrast imaging with low-brilliance X-ray sources," Nature Physics, doi:10.1038/nphys265, March 2006.
[2] T. Weitkamp, et. al., "Tomography with grating interferometers at low-brilliance sources," Proc. SPIE, Vol. 6318, pp. 63180S-1 - 10, 2006.
[3] A. Momose, et. al., "Sensitivity of X-ray Phase Tomography Base on Talbot and Talbot-Lau Interferometer," Proc. SPIE, Vol. 78078, pp. 7807811-1 – 8, 2008.

The purpose of the source grating, G0, is to make the spatially incoherent X-ray source appear as a set of mutually incoherent spatially coherent sources to the remainder of the system. The parameters of G0 (grating pitch and open fraction) are set by the distance between G0 and G1, the distance between G1 and G2, and the desired fringe visibility for the undisturbed beam. The purpose of the phase grating, G1, is to impose a phase pattern on the X-ray beam. After an odd number of Talbot distances this phase pattern will be replicated in the form of an amplitude pattern. This amplitude pattern is sampled by the amplitude grating G2. G1 and G2 have 50% duty cycles. The Talbot distance is set by the effective X-ray wavelength, the distance between G0 and G1, the pitch of grating G1, and whether G1 shifts the phase by $\pi/2$ or π. The pitch of grating G2 is set by the Talbot distance and the pitch of grating G1.

The order of computation for sketching out the design of a Talbot-Lau interferometer is as follows:

1. Obtain the input parameters
    a. X-ray energy for the source, E
    b. the pitch of the phase grating G1, p_1
    c. the phase shift imposed by grating G1, η (1 if $\pi/2$, 2 if π phase shift)
    d. the Talbot order (should always be odd), n
    e. the distance between the source grating G0 and G1, L
    f. the desired monochromatic visibility, V
2. Compute the X-ray wavelength
$$\lambda = \frac{ch}{E}$$
where λ is the wavelength, c is the speed of light, and h is Planck's constant.
3. Determine the plane wave Talbot distance, D_n
$$D_n = \frac{1}{\eta^2}\frac{np_1^2}{2\lambda}$$
4. Determine the point source Talbot distance, d_n
$$d_n = \frac{LD_n}{L - D_n}$$
5. Determine the amplitude grating pitch, p_2
$$p_2 = \frac{p_1}{\eta}\frac{d_n}{D_n}$$
6. Determine the source grating pitch, p_0
$$p_0 = \frac{L}{d_n}p_2$$
7. Determine the source grating slit width, s
$$s = \frac{\lambda L\sqrt{-\ln V}}{0.94np_2^2}$$

When these equations are implemented in a spreadsheet, the result is shown in Figure 2.

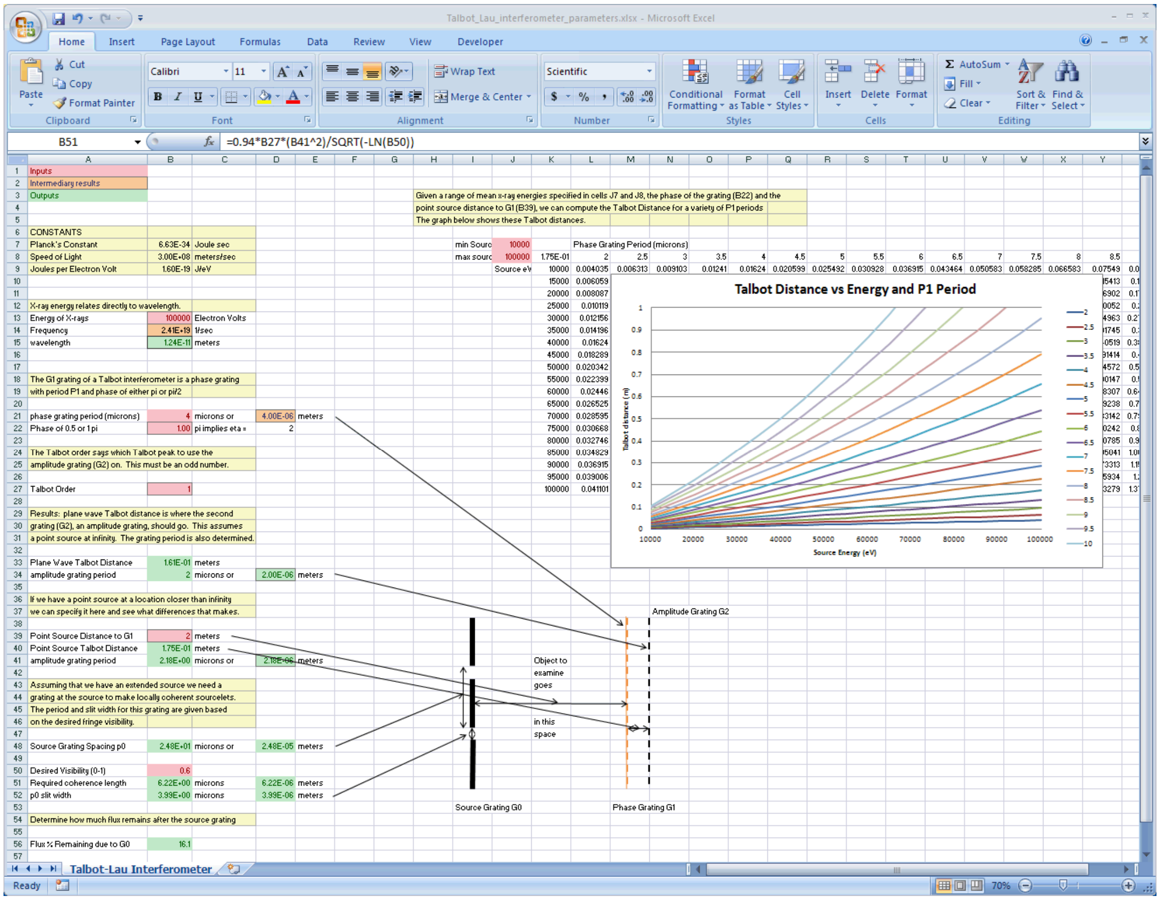

Figure 2. The spreadsheet resulting from implementing the above equations. Red fields are inputs, green fields are outputs, and orange fields are intermediate results.

In using the spreadsheet for the parameters of a typical medical CT scanner (source to detector distance of approximately 2 meter, mean X-ray energy of 90 kV) we find that given a phase grating with a period of 4 microns and a phase shift of p, the point source Talbot distance is 15.6 cm, the amplitude grating period is 2.16 microns, and the source grating period is 27.6 microns with 4.5 micron slits (allowing ~16% of the X-ray flux from the tube to be used in imaging). An image of the numerical part of the spread sheet is shown in Figure 3.

In interrogating the amplitude distribution at the Talbot distance behind the phase grating, the amplitude grating must be moved by small distances. In the example above, the amplitude grating has a pitch of 2.16 microns. To obtain the information needed to extract the phase distribution for one CT projection this grating must be shifted 1 period over the course of at least 2 moves. This means that the mechanisms of the CT system must be precise enough that they can make submicron moves of the amplitude grating held precisely 15.6 cm from the phase grating, all while scanning a piece of luggage. This seems to be a formidable piece of mechanical engineering.

CONSTANTS				
Planck's Constant	6.63E-34	Joule sec		
Speed of Light	3.00E+08	meters/sec		
Joules per Electron Volt	1.60E-19	J/eV		
X-ray energy relates directly to wavelength.				
Energy of X-rays	90000	Electron Volts		
Frequency	2.17E+19	1/sec		
wavelength	1.38E-11	meters		
The G1 grating of a Talbot interferometer is a phase grating				
with period P1 and phase of either pi or pi/2				
phase grating period (microns)	4	microns or	4.00E-06	meters
Phase of 0.5 or 1 pi	1.00	pi implies eta =	2	
The Talbot order says which Talbot peak to use the				
amplitude grating (G2) on. This must be an odd number.				
Talbot Order	1			
Results: plane wave Talbot distance is where the second				
grating (G2), an amplitude grating, should go. This assumes				
a point source at infinity. The grating period is also determined.				
Plane Wave Talbot Distance	1.45E-01	meters		
amplitude grating period	2	microns or	2.00E-06	meters
If we have a point source at a location closer than infinity				
we can specify it here and see what differences that makes.				
Point Source Distance to G1	2	meters		
Point Source Talbot Distance	1.56E-01	meters		
amplitude grating period	2.16E+00	microns or	2.16E-06	meters
Assuming that we have an extended source we need a				
grating at the source to make locally coherent sourcelets.				
The period and slit width for this grating are given based				
on the desired fringe visibility.				
Source Grating Spacing p0	2.76E+01	microns or	2.76E-05	meters
Desired Visibility (0-1)	0.6			
Required coherence length	6.12E+00	microns	6.12E-06	meters
p0 slit width	4.51E+00	microns	4.51E-06	meters
Determine how much flux remains after the source grating				
Flux % Remaining due to G0	16.4			

Figure 3. Example computation to determine Source and Amplitude grating parameters as well as the Talbot distances.

Summary
Talbot-Lau interferometers allow incoherent X-ray sources to be used for phase contrast imaging. A spreadsheet for exploring the parameter space of Talbot and Talbot-Lau interferometers has been assembled. This spreadsheet allows the user to examine the consequences of choosing phase grating pitch, source energy, and source location on the overall geometry of a Talbot or Talbot-Lau X-ray interferometer. For the X-ray energies required to penetrate scanned luggage the spacing between gratings is large enough that the mechanical tolerances for amplitude grating positioning are unlikely to be met.