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The Effects of Thermal Expansion of Gratings in Talbot-Lau Lab-Based X-Ray Phase Contrast Imaging

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Summary: Talbot-Lau based X-ray phase contrast imaging systems utilize a system of three gratings to produce absorption, scatter, and differential phase images. To achieve high-sensitivity measurements, the periods of the gratings must be matched; deviations between the "as-fabricated" and "as-designed" reduces sensitivity. Even with a matched set of gratings, ambient room temperature and thermal radiation from system components, such as the X-ray source and the detector, can cause thermal expansion of the gratings. Thermal expansion of the gratings alters the grating periods, reduces system sensitivity, and causes other undesired effects. We present analysis and effects of thermal expansion of the gratings.

The main components of a lab-based Talbot-Lau based X-ray phase contrast imaging (XPCI) system consist of: an X-ray source; a source grating, denoted as G_0, to create individually spatially coherent, but mutually incoherent sources; two additional gratings, denoted as G_1 and G_2, designed such that the interference between them generates a Moiré pattern; and a detector, [1,2]. The grating periods are a function of the X-ray energy and determine the L and d distances between gratings, which are the distances between G_0 and G_1, and G_1 and G_2, respectively. An XPCI system with high-sensitivity has matched gratings (i.e. manufactured with ideal grating periods) placed at the ideal L and d distances.

Data acquisition of a Talbot-Lau lab-based XPCI system includes measuring reference and sample data sets. During acquisition of the data sets, the G_2 grating steps laterally to the X-ray beam. The signal model for the measured data at a point on the detector is sinusoidal with amplitude A, phase φ, and bias b; the variation of these parameters between the reference and sample data produce the scatter, differential phase, and absorption images, respectively, [3-5]. Noted that the sinusoid also has frequency ω.

The placement of the G_0 grating is very close to the X-ray source and, ideally, the G_2 grating would be co-located with the detector, but instead is reasonably close in front of it. Both the X-ray source and the detector generate a substantial amount of heat and the placement of the G_0 and G_2 gratings, with respect to the source and detector, subject them to the thermal radiation. Given the fine features of the gratings, we hypothesize that an increase of temperature of a few degrees will cause thermal expansion, which will change the grating periods and give rise to undesired effects. For example, one effect of thermal expansion of the periods of the G_0 and G_2 gratings is that the sinusoidal frequency, ω, in the signal model changes [6]. If a frequency difference exists between the reference and sample data acquisitions, then some of the signal model parameters may be estimated incorrectly, which will corrupt the derived image products. As another example, the L and d distances between gratings are very sensitive to the grating periods; grating period changes will decrease the system sensitivity and reduce the contrast of the measurements.

To demonstrate the effect of temperature, consider the following experiment. We attached thermocouples to the X-ray source and the frame of each grating. We left the G_2 grating

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stationary and recorded the projections of the Moiré pattern on the detector every 0.2 seconds as the X-ray source warmed up to thermal equilibrium. Every 50 projections were averaged to give an effective sampling period of 10 seconds. We averaged 21 rows of the detector to obtain a reduced-noise one-dimensional sinusoidal representation of the Moiré pattern across the detector. From this, we estimated the Moiré pattern sinusoidal amplitude, frequency, and phase, and the bias. Figure 1 illustrates the estimated parameters and the measured temperatures versus time. As the temperature increases, the measured sinusoidal parameters change. In our presentation, we will share the results of our analysis, demonstrate some undesired effects of thermal expansion of the gratings, and show the results of mitigating thermal expansion with heat shields.

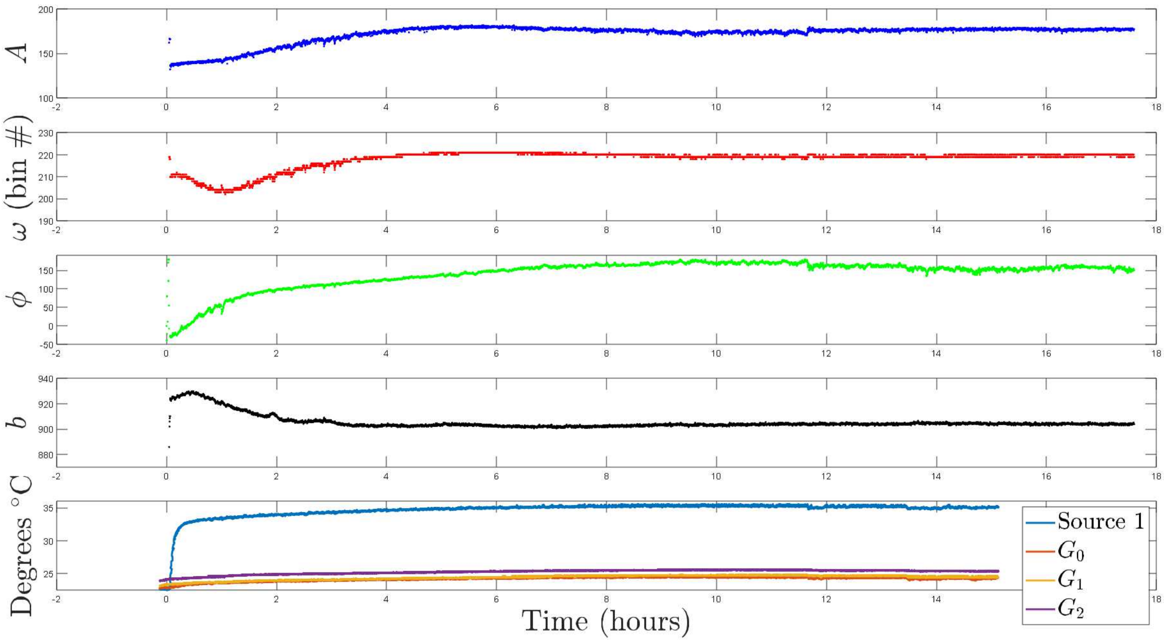

Figure 1: Illustration of the Moiré pattern sinusoidal parameters and temperature of various system components as a function of time. These plots show the sensitivity of the Moiré pattern to temperature.

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