The effect of filters in x-ray phase contrast imaging.

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Phase contrast experiments using a polychromatic, micro-focus x-ray source were conducted on dialysis fibres with and without various filter materials, showing a reduction in phase contrast. The spectrums were measured using multi-channel analyzer and incorporated into computer simulations using Fresnel diffraction. Calculations showed little difference between the filtered and unfiltered cases until source and detector considerations were taken into effect, giving rise to a possible explanation for phase contrast reduction.

1. Introduction

X-ray phase contrast imaging offers potential advantages over traditional absorption radiography such as the ability to image low atomic Z materials that do not appreciably attenuate the beam, with the added advantage that regions of different refractive index are delineated by a diffraction edge providing greater visual acuity. Furthermore the phase component of the complex index of refraction is less dependent on higher photon energies giving rise to the possibility of reduced patient dose in techniques such as mammography[1].

The requirements for phase contrast are an x-ray source with sufficient spatial coherence and sufficient propagation distance between the detector and the sample to allow the transformation of phase information into recordable intensity variations. If polychromatic sources are to be used, often the lower energy x-rays must be filtered from the beam as they have insufficient energy to contribute to useful diagnostic information, and hence add only to sample dose. However, experiments have shown that the use of filters can decrease the phase contrast information considerably and the mechanism for this effect is not clear.

Using a microfocus x-ray tube with a fibre as a suitable phase object, measurements of phase contrast were made with and without various filter materials such as Aluminium, Copper, Nickel and Polymethylmethacrylate(PMMA). The spectrums of each case were also measured and used in a custom Fresnel diffraction program to determine if the reduction in phase contrast were due to the spectrum change alone. Surprisingly it was found not to be the case and other mechanisms in the imaging chain such material dispersion in the target and the finite source size and the scanning of the image plate were found to have significant effects.

2. Experimental

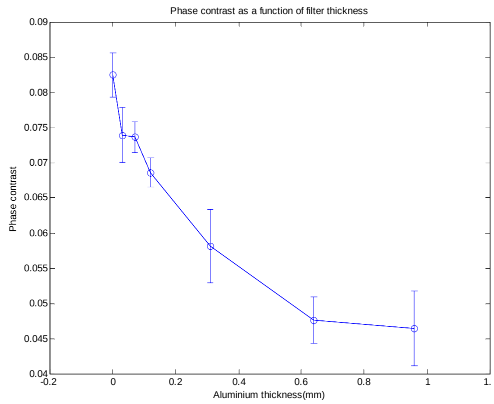
The x-ray source was a Feinfocus microfocus FXE 225-20, located at the CMMT of CSIRO. The source to detector distance was 2 meters, while the object was placed around 20 cm from the source. Detection was via Fujifilm image plates, scanned with a Fujifilm BAS5000 scanner at 25 µm resolution. The phase object was a Cuprophan™ fibre, made from regenerated cellulose with a 200 µm diameter and 8 µm wall thickness. All images were converted into photostimulable luminescent values (psl) format via reference [2].

The images were further software processed to ‘straighten’ the fibres for better phase contrast measurement. Natural deformities could be corrected in this way as well as fibre misalignment with scanner direction, which is important when averaging line profiles for noise reduction. Phase contrast was defined via

$$pc=(max-min)/(max+min). \qquad (1)$$

3. Results

Phase contrast was found to decrease with increasing thickness of Aluminium, Silicon, Copper and PMMA. An example is shown (Fig. 1) for a range of Aluminium thicknesses from 0.03 to 1mm.



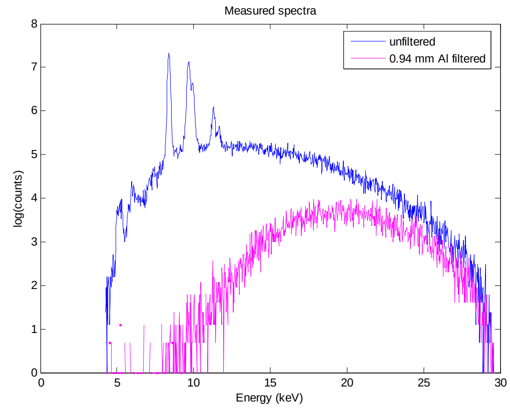
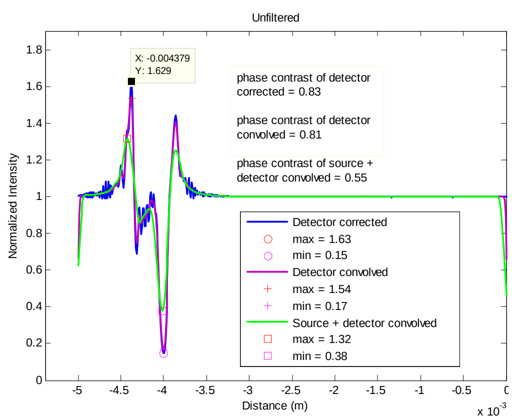


Fig. 1. Phase contrast as a function of aluminium thickness(left) and Fig.2 Measured spectra (right).

The measured unfiltered and 0.94 mm Al filtered spectra show (Fig. 2) strong L lines in the unfiltered case and a hardening of the beam as expected for the filtered case. It may be surmised that the strong phase contrast can be attributed to these L lines which are absent in the filtered cases, but in calculations based on Fresnel diffraction this proved not to be the case.



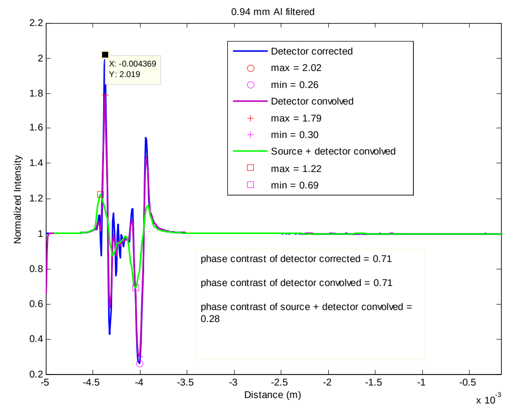


Fig. 3. Raw and convolved Fresnel diffraction pattern for unfiltered (left) and Fig. 4. 0.94 mm Al filtered diffraction pattern (right) respectively.

When a filter is used, the resulting x-ray spectrum is shifted towards the higher energies (Fig.2) and this changes the amount of dispersion in the fibre so that overall pattern due to refraction narrows compared to the unfiltered pattern. Upon convolution (Fig.3 and 4) with the source size and scanner as described in reference [3], these narrower peaks are smoothed out significantly more than the unfiltered peaks, resulting in a decrease of the calculated phase contrast values as observed in experiments. Phase contrast for example is decreased by approximately 50% from 0.55 to 0.28, in the case of a 0.94 mm Aluminium filter. There are discrepancies in the absolute values of the phase contrast but good agreement with the relative changes due to the introduction of certain filters. This not surprising considering the exact shape and size of the source and density of the target material are unknown, and is the subject of further reseach.

Finally, figure 5 shows the effect of the Fresnel based calculations with the measured spectra of different materials. It shows that phase contrast is reduced for higher Z materials as well as thickness by the same mechanism as before with the Aluminium. Also the placement of the filter whether near the source or detector has little effect on phase contrast as does the size of the grain structure showing that the effect is largely due to the bulk and not the internal structure of the material.

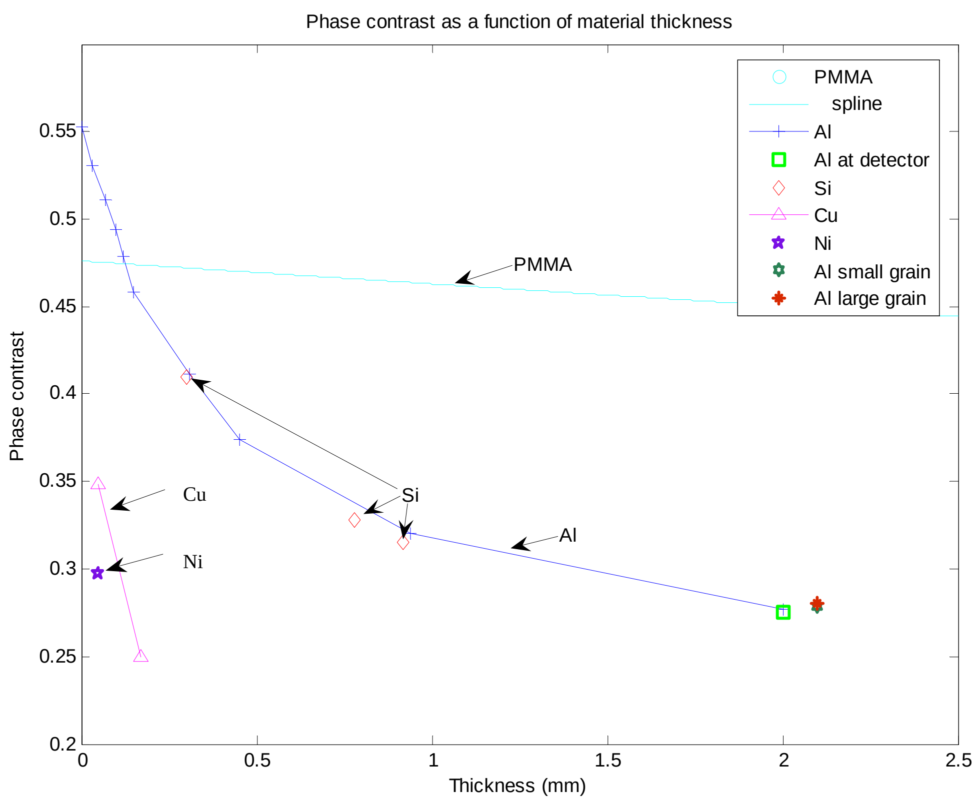


Fig. 5. Phase contrast calculations for various materials and thickness.

Acknowledgments

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References

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