Available online at www.sciencedirect.com
ScienceDirect
Int. J. Miner. Process. 84 (2007) 327 – 336
INTERNATIONAL JOURNAL OF MINERAL PROCESSING
www.elsevier.com/locate/ijminpro

Conceiving a high resolution and fast X-ray CT system for imaging fine multi-phase mineral particles and retrieving mineral liberation spectra

Gianni Schena *, Luca Santoro, Stefano Favretto

Division of Georesources, Faculty of Engineering, University of Trieste, 34127 Trieste, Italy

Received 4 May 2006; received in revised form 9 October 2006; accepted 9 October 2006
Available online 27 November 2006

Abstract

Mineral liberation studies on fine particulate systems require high resolution and fast examination of a (statistically) significant number of particles. Commercial X-ray computed tomography systems allow high resolution on very small samples (say few micrometers on single particles) and only limited resolution on large particulate samples: thus they are unsuitable for fine particle liberation studies. A computed tomography system was conceived that is capable of high resolution (say micrometric or sub-micrometric) and allows imaging at once a large number of particles. It uses a detector design with a fiber optic bundle that allows enlarging the Field of View of a standard high resolution CCD in one direction. The thin particle multi-layer in a straw offers low X-ray attenuation and permits scanning with low current and voltages that in turn allows keeping small the size of X-ray focal spot and the induced geometrical un-sharpness of the projected particles. At low magnification values (i.e., with the sample close to the detector fiber optic input end) the overall resolution is controlled by CCD pixel size and the detector allows to scan more particles. At higher magnification values the detector design allows also improvements in resolutions. The system allows studying directly in 3D those liberation problems that require micrometer-size resolution.

Keywords: Mineral liberation; X-ray computed tomography; Fine particles; Cone beam

1. Motivation

The mineral liberation spectrum of a system of fine composite multi-phase particles gives the fraction of particles in narrow classes of size and composition. The liberation spectrum of a system of particles undergoing processes of size reduction and/or concentration is an important bit of information for plant optimization. This is especially true for streams that are critical for overall plant performance. The information is most valuable if available in short time from sample gathering in order to allow adjustments of the plant operating variables.

In the past, the combined use of SEM measurements of areal grades or linear intercepts on the transects of polished sections of the particles, encapsulated in epoxy resin, and stereological correction methods for converting these low dimensional measurements into volumetric grade distributions have been used. One recent review paper (King and Schneider, 2000) summarizes the state of art of the stereological correction procedures. Indeed, most of the recent scientific literature on

* Corresponding author. Tel.: +39 040 558 3496; fax: +39 040 558 3497.
E-mail addresses: shena@univ.trieste.it, schena@units.it
(G. Schena).

0301-7516/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.minpro.2006.10.002

liberation measurements has been generated at University of Utah by R.P. King and co-workers. The approach they pioneered uses the conditional probability of measuring a lower dimension grade (i.e., apparent grade) on a particle with a given volumetric grade and set out the inversion problem that allows recovering the true grade distribution as an inhomogeneous Fredholm equation of the first kind. R.P. King in the late 70s at the Withwaterstrand University was the first to use the conditional probability idea to tackle the mineral liberation problem. The principle was also used in the same years by M.P. Jones at the Imperial College (London).

Also the authors of the present paper have elaborated from the same idea and developed one stereological correction method for mass-balancing and recovering volumetric grade distributions and the separation efficiency of a mineral separation system from the areal grade distributions of the feed and the two separation products (Schena and Chiaruttini, 2000). However, the acquisition of low dimensional data is a laborious task because it requires the preparation of polished sections of the sample and the subsequent mathematical stereological correction (even if rapid) is not a well accepted procedure yet.

The improvements in resolution of X-ray computed tomography (CT) make it a promising alternative to traditional time consuming and error prone laboratory procedures for mineral liberation analysis based on measurements on polished sections. In principle one CT system specifically designed for this purpose could provide the size-by-size liberation spectra or washability data in tens of minutes after sampling. It helps to study liberation at least in the cases where a resolution of few micrometers is sufficient.

These improvements in resolution were made possible by the micro- and nano-focus technology – that allows the production of clearer radiographic images at high magnification reducing the penumbra (fuzziness) associated with the large spot size of the X-ray tube – and by the decrease in pixel size of the CCD component of the detector.

A number of compact commercial cone beam CT machines with microfocus cooled and sealed X-ray sources and focal spot sizes in the range of 5–20 μm and source energies in the range of 80–160 kVp which claim micrometric spatial resolutions are today available (see www.scanco.ch). Recently (2005) one manufacturer has introduced a nano-tomografic machine in his standard product line (see Skyscan 2011 www.skyscan.be).

The Modulation Transfer Function (MTF) is commonly used to describe the ability of one imaging system to transfer object contrast to the image (www.olympusmicro.com). The detector impulse response in the spatial domain is called point spread function (PSF). The amplitude of the PSF Fourier Transform is the MTF. The overall MTF of one tomographic system is the composition of the MTFs of the individual elements – i.e., of the chain X-ray source, scintillator, CCD. There are, however, several definitions of resolution based on the MTF of the system (see Lubberts and Rossmann,

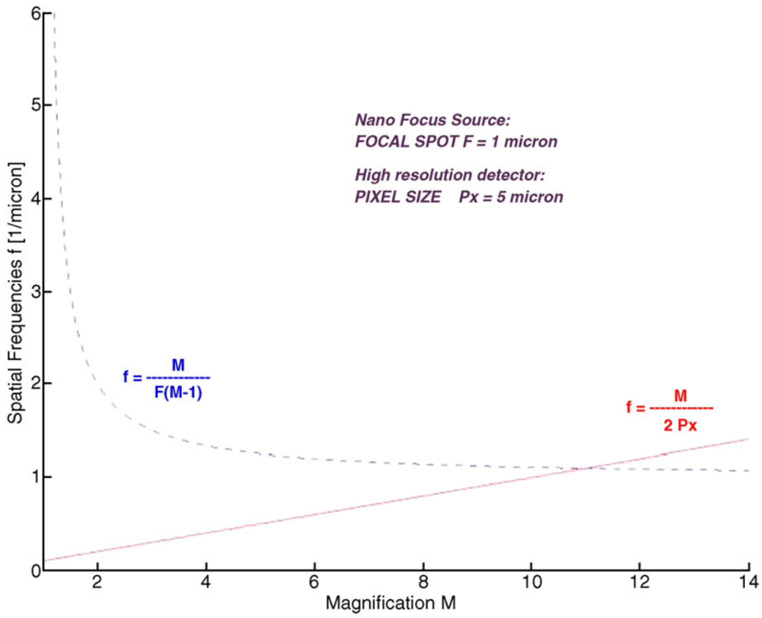

Fig. 1. System cut-off frequency for a given tube focal spot-size and detector pixel-size combination.