New Glass Puller for Making Better Capillary Optics

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Work has recently begun on fabricating the next generation of glass puller for the custom fabrication of glass capillary optics at CHESS. Over the course of the last several years, the capillary glass puller, DB2, has successfully made excellent single-bounce capillaries for hard x-ray micro-beam applications [1], but the instrument is showing its age and has reached its limit of performance.

The shape of the glass is determined from the mathematical definition of an ellipse that depends on the spot size and divergence of the desired x-ray beam. Figure 1 shows schematically the geometry of the one-bounce capillary. Using the distance from the synchrotron source to the capillary (about 13 meters in the D-line case), a hollow glass tube is drawn to an elliptical shape that the user desires. The actual shape of the glass is determined by the distance from the tip of the capillary to the focus (usually between 25 and 60 mm), the length of the capillary (usually 50 to 100 mm) and the maximum divergence to be obtained in the focused beam (usually 2 to12 milliradians). These values are picked on the experimental requirements and are translated into the “a” and “b” semi-major and semi-minor axes that describe the shape of an ellipse. These are the starting inputs for the puller programs.

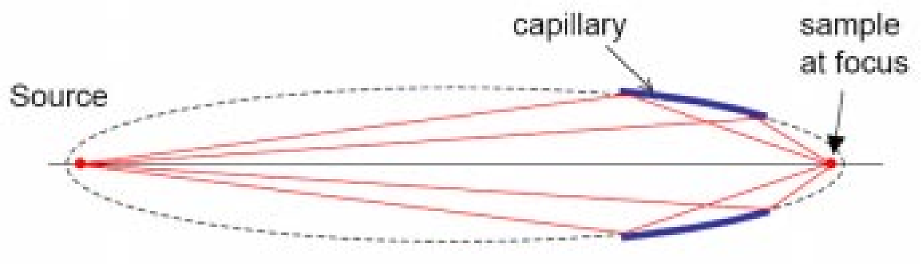

Fig 1: The dotted line represents an ellipse (not drawn to scale) where the synchrotron source is at one focus and the sample is placed at the other focus. A single mirror bounce connects rays from one focus to the other. This can be accomplished efficiently if the angle of reflection on the smooth inner glass surface is kept below the critical angle for the x-rays of interest. For the case of 10 keV x-rays, the critical angle is roughly 3 milliradians or approximately 0.2 degrees. Measured reflectivities from our inner capillary walls are generally greater than 95% so the efficiency of the optics is very high. Usually a “hockey puck” shaped absorber (not shown) is placed at the large base end of the capillary to block the straight through beam.

That particular ellipsoidal shape can then be made in the glass by pulling glass tubing during the drawing process[2,3]. A torque controlled motor keeps the glass under constant tension. An electric furnace softens the borosilicate glass tubing (Figure 2) during pulling.

For elliptically-shaped optics of approximately 100 mm in length and typically employed for high-pressure or protein crystallography x-ray applications, the figure errors of our freely-drawn glass tubes are of order 1 to 2 microns (outside diameter measurements) with slope errors in the range of 60 to 140 microradians. We believe that these values can be further improved by building a new instrument, one that incorporates the knowledge we have obtained over the years as refinements were made to the puller.

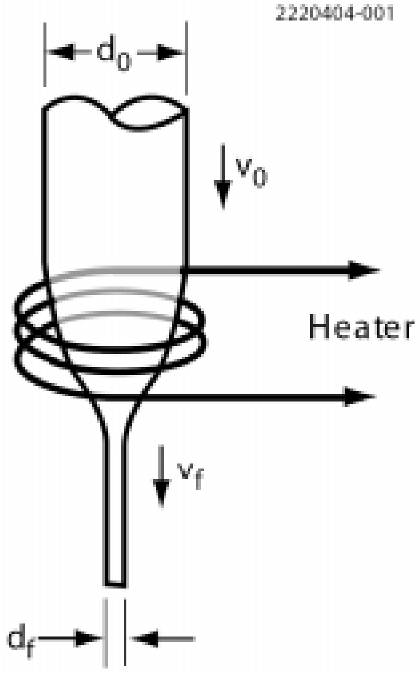

Fig 2: Schematic of glass tube in hot zone of furnace being pulled to smaller diameter and held under constant tension, normally 100 grams. The mass of material entering the heat zone is proportional to $d_o^2 \bullet v_o$. The amount leaving is proportional to $d_f^2 \bullet v_f$. If mass is to neither accumulate nor disappear from the heating zone, these two values must be equal. Hence $d_f = d_o \bullet \mathrm{sqrt}(v_o / v_f)$. This is the control equation of the puller. By controlling the velocities of glass into and out of the furnace, we make the desired diameter vs. length profile. If the furnace is moved quickly in response to a small amount of glass extension, then the initial tubing diameter is reduced a little. If the furnace moves very little in response to a large amount of glass extension, then the diameter is reduced a lot.

The heart of the next-generation puller is a more accurate air bearing that will precisely position the furnace in response to the amount of glass extension during drawing. The new ABTech air bearing (Figure 3) has arrived at CHESS and is undergoing its first movement tests. The bearing should have a sideways runout of order a micron or so and will be able to vertically position the furnace to a resolution of 0.1 micron. This will be a vast improvement over the 100 microns of vertical runout we sometimes experience on the present translation stage.

We are selecting a set of crossed laser micrometers to profile the straightness and diameter of the capillary in two dimensions. This operation, currently done by hand, takes several hours. We hope to reduce this time to minutes and, in the process, to increase the accuracy by a factor of 2 to 5. We expect to similarly improve the tension control during drawing and to better regulate the furnace temperature. We are hoping that construction and the beginning of commissioning will be underway by early fall 2004. This should allow us to make even higher performing capillaries specifically made for particular applications on the various CHESS beamlines in the near future.

Fig 3: New vertical ABTech linear air bearing installed at CHESS on granite base (left) and with new WinXP control computer running Labview. The air bearing is much smoother in operation and can go to a position with 0.1 micron resolution.

References:

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[2] *"Glass Capillary Optics for Making X-ray Beams of 0.1 to 50 microns Diameter"* (invited), D. H. Bilderback & E. Fontes, Synchrotron Radiation Instrumentation: Tenth US National Conference, E. Fontes, editor, AIP Conference Proceedings **417**; 147-155 (1997).

[3] *"A New Computerized Capillary Puller for Hard X-ray Applications"*, D. H. Bilderback, R. Pahl, and R. Freeland, CHESS Newsletter, pages 41-43 (1995).