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The User Adjustable Pole-piece: Expanding TEM Functionality Without Compromise

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The transmission electron microscope (TEM) is a widely used and powerful characterization instrument for both physical and life sciences. A modern flagship instrument may well include some combination of; advanced guns and/or monochromator, aberration correctors, fast cameras, one or more sensitive spectrometers and/or a range of in-situ holders. These features along with a new suite to house it, can easily necessitate an infrastructure investment of several million dollars.

However, the specification of objective lens pole-piece gap is crucial in determining the capabilities and performance of the instrument [1]. While a smaller pole-piece gap will result in reduced spherical and chromatic aberrations, and therefore improved resolution, a larger gap offers wider flexibility for sample-tilting, tomography, in-situ experiments, or energy-dispersive x-ray spectroscopy (EDX) collection efficiency. As the former is typically preferred by the high-magnification physical science community, but the latter by the analytical or life-science communities [2], the result is that in order to satisfy both communities, two (or more) columns are often needed. Alternatively, a single intermediate gap may be commissioned but compromises must be made.

As an alternative approach, we propose the design and construction of a User Adjustable Pole-piece (UAP) [3] with a pole gap that can be adjusted by the microscopist to suit a variety of experiments, reducing unneeded duplication of resources. To be of practical use, the proposed implementation must be; operable while maintaining high vacuum (to avoid delays and contamination), must be adjustable without the need to disassemble/remove adjacent lenses/detectors/goniometers, must be mechanically stable with ultra-precise alignment about the optic axis, and must be realignable to a good tuning without a specialist engineer present.

Our proposed adjustable pole-piece design, based around the current JEOL 200/300kV geometry, is shown in Figure 1, both integrated into the existing infrastructure, and separately on its own. In the smallest gap, we naturally expect the lowest aberrations, while in the largest gap we expect full 180-degree rotation for tomography, presenting a solution to the missing wedge problem [4].

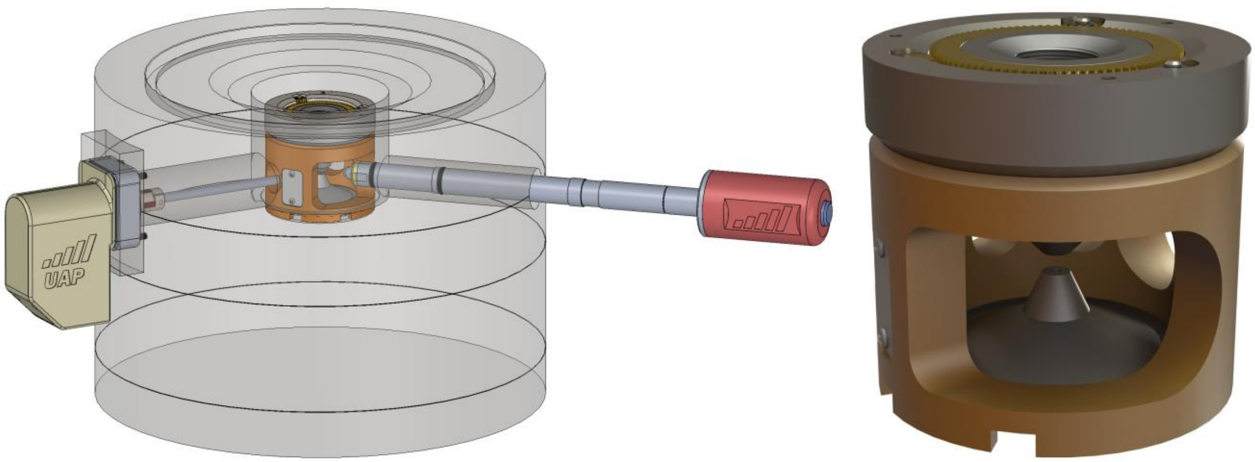

Figure 1. (Left) Integration of the User Adjustable Pole-piece in the existing objective lens module of a JEOL GRAND ARM. Also visible are a custom feedthrough system for adjusting the UAP, and a bespoke sample rod containing an endoscope. (Right) Close up of the UAP, currently positioned at an intermediate pole gap of 4.0 mm.

The existing pole-piece dimensions were recreated digitally and used in multi-physics modelling simulations using the COMSOL™ environment. This allows us to evaluate and compare candidate designs for the UAP and to guide its construction, evaluating geometric predictions for EDX collection solid-angles, the attainable tilt-ranges of a variety of customized holders, and aberration coefficient estimation for the different pole-gaps from magnetic field simulations along the optical axis. An example of one of these customized holders, along with preliminary magnetic field simulations, are visible in Figure 2.

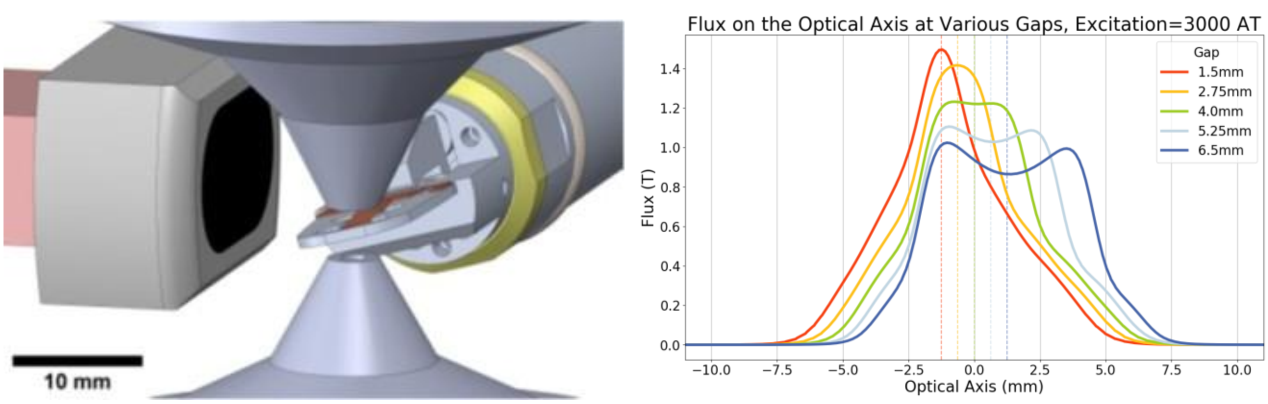

Figure 2. (Left) Insertion of a customized holder tip to measure tilt-range and EDX collection solid-angles for each specified gap of the UAP. (Right) Preliminary computer simulations using COMSOL of the magnetic field along the beam direction for the five UAP pole-gap settings.

In this presentation we will elaborate on our progress in the design and manufacture of the UAP. We will present our preliminary results which confirm that the larger pole gaps yield better tilt/access for experiments, while the smaller gaps yield reduced aberrations. We will discuss calculated contrast transfer functions (CTFs) for the range of gaps and discuss potential applications in low-Cc low-voltage imaging [4].

A TEM column is a significant investment for any research institution due to both the high initial cost, followed by the running and cooling energy costs (leading to non-trivial carbon emissions), support staff costs, and maintenance contracts for perhaps another 15 years. If, to avoid performance compromises, multiple columns must be purchased, then this duplication of both up-front and running costs raises significant sustainability considerations [5].

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