Development of a high precision positioning system (PS) for a large chamber scanning electron microscope (SEM).

by Martin Klein and Thomas Brandt
VISITEC Microtechnik GmbH
Grevesmuehlen, Germany

LARGE CHAMBER SEM

A conventional SEM is equipped with a shoebox-sized vacuum chamber with a multi-axis sample holder inside. The holder is used to position the sample relatively to the electron beam. Due to the design principle the maximum weight of the sample is 1 kg and the maximum diameter is 300mm.

In order to overcome the limitations of the sample dimensions, a Large Chamber SEM is developed (Fig. 1) in a completely new approach.

FIGURE 1. Large Chamber SEM

The electron gun is now part of a positioning system (Fig. 2) that allows to "walk" around the sample and see it from any direction. With a typical sample volume of 1 cubic meter and a weight of up to 300 kg it can be used to analyze large samples like turbine blades, engine blocks or even grinding wheels in a non destructive way [1]. Also the integration of various testing and analyzing devices is possible because of the large vacuum chamber.

The SEM itself is the best measurement instrument to get information about the quality of the positioning system (Fig. 2). A microscopical image (Fig. 3) of a nanometer structure and image acquiring times of up to an hour set the quality level of the positioning system. In addition to these tasks, the positioning system must follow the specific design rules of vacuum compatible components to operate it down to the high vacuum of 10^{-6} torr.

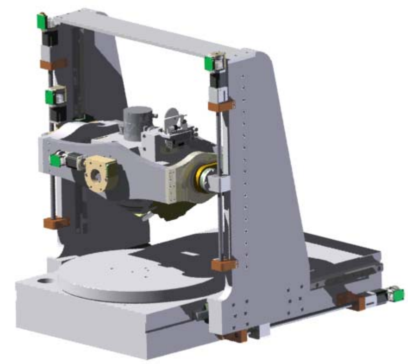

FIGURE 2. Positioning System

To position a body in a space six degrees of freedom are required. The positioning system allows the freely positioning of the electron optics within the chamber. Two translatory axes (X-Axis, Z-Axis) and two rotary axes (A-Axis, B-Axis) are moving the electron optics. In addition a rotating sample table (C-Axis) allows the observation of the specimen from all sides.

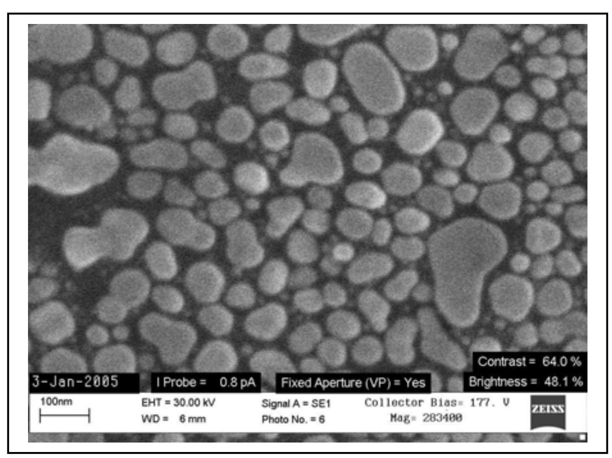

FIGURE 3. Nanometre structure in a SEM image

LINEAR AXES

Linear positioning axes are divided into groups of recirculating and non-recirculating slides. Non-recirculating slides have been chosen here (X and Z) because they are more suitable for operation in vacuum atmosphere. To ensure maximum stiffness the slides designed with crossed rollers are used.

ROTARY AXES

There are two different rotary axes in the positioning system. The A- and B-axes are driven by a combination of a backlash free worm gear which is combined with a Harmonic Drive gear and in the C-axis only the Harmonic Drive is used.

Figure 4 shows the design of the C-axis. The Harmonic Drive gear is made from non-magnetic stainless steel. A special grease is used to ensure that the outgassing behaviour is compatible with the high vacuum atmosphere.

C-axis moves the table which carries the sample. The direct drive of the table with its very high gear ratio of 180:1 is backlash free and a sample mass of 300 kg is permitted.

1 Harmonic Drive 2 Clutch and Motor-Gear
3 Stepping Motor 4 Encoder 5 Brake

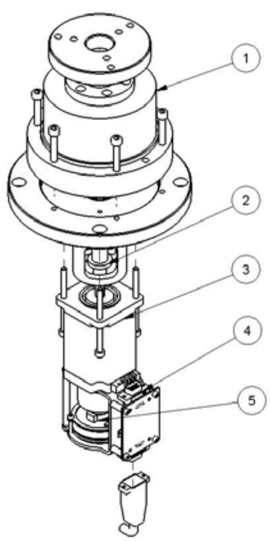

FIGURE 4. Set up of the C-Axis

In contrast to the C-axis the loads and the required stiffness of the A- and B-axes (Fig. 5) is much higher. So a backlash free worm gear with a gear ratio of 44/4 is combined with the Harmonic Drive gear of 180:1 which results in a total gear ratio of 1,845:1.

1 Encoder 2 Controller 3 Stepping Motor
4 Worm Gear 5 Drive Shaft
6 Harmonic Drive Gear 7 Clutch

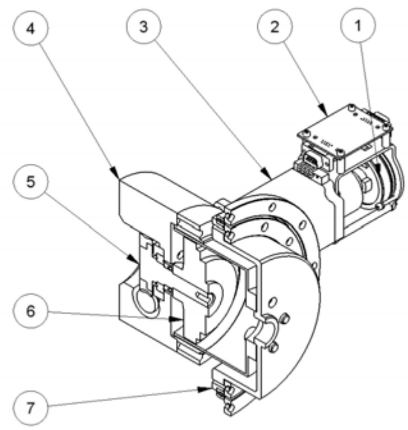

FIGURE 5. Harmonic Drive and Worm Gear

By combining a backlash free worm gear drive with a Harmonic drive the gantry style system can be tilted and cross tilted with an accuracy of less then 1arc minute and a repeatability of +/- 5 arc seconds.

To drive the axes a stepping motor with a feedback system for position detection was chosen. As the stepping motor might “loose” steps during operation due to vibration, the motors were combined with encoders. The motors are driven by microstepping electronics to enhance resolution. A single 360° revolution of the motor is divided into 6,400 microsteps. This is very important during high resolution microscoping because of moving from one point to another without loosing the topographical position on the sample’s surface.

Each axis has its own brake to minimize vibrations after reaching a defined position. A vacuum compatible water cooler is attached to the stepping motor to ensure that the heat which dissipates from the motor will not influence the positioning accuracy due to thermal deformation.

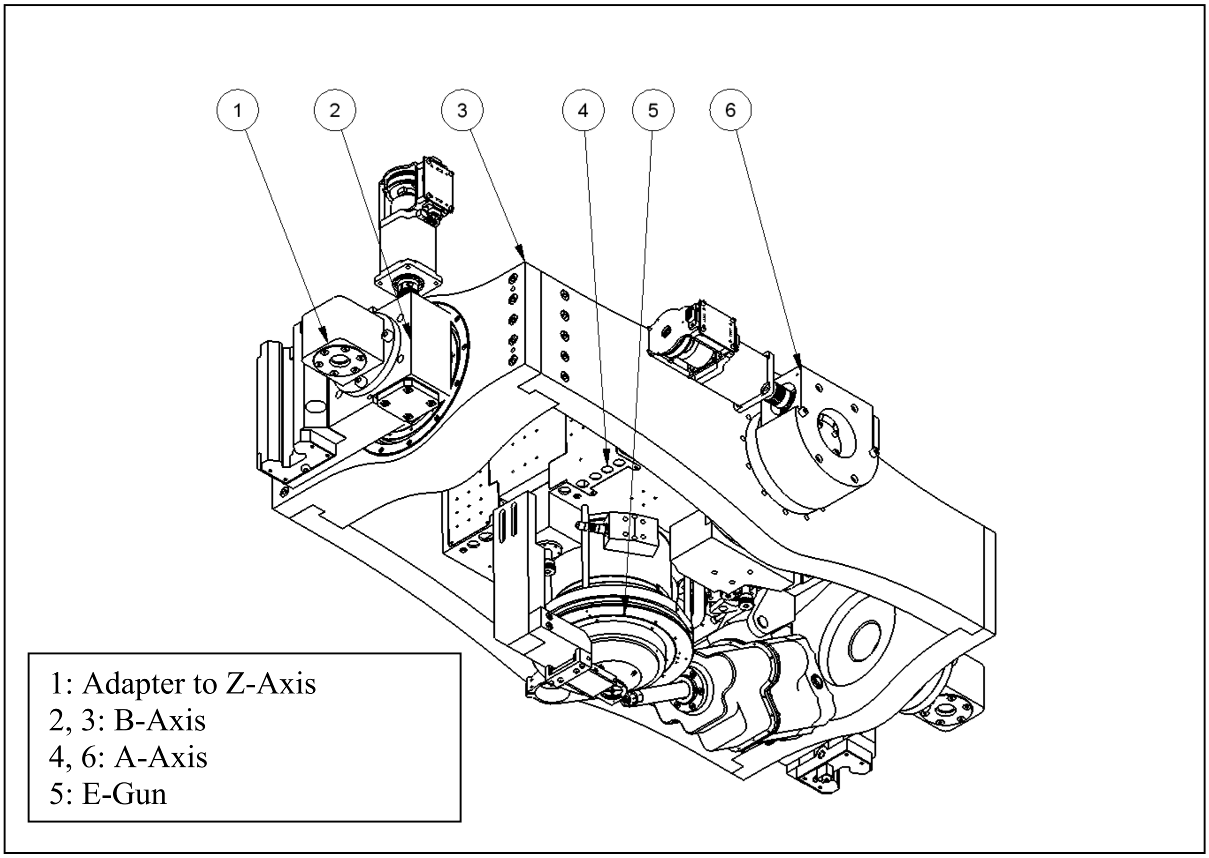

FIGURE 6. A- and B-Axes carrying the Electron Gun

As the weight of the electron optics and the detector is constant, the positioning system can be reliably dimensioned in such a way that fundamental vibrations no longer lead to a relative movement between the electron gun and the object to be investigated. The positioning system has a resonant frequency of 80 Hz. With this set up a magnification of 200,000 times can be obtained which results in a microscopical resolution of below 10 nm.

1. Dekanich, S.J., J.J. Frafjord, D. Carpenter and B. Bolinger, Introduction to the Capabilities and Applications of the World's Largest Chamber Scanning Electron Microscope, Proc. Microscopy and Microanalysis, August 2005