THE MECHANICS OF THE VEKMAG EXPERIMENT

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Abstract

For the experiments at the synchrotron radiation source BESSY II synchrotron of the Helmholtz-Zentrum Berlin a new end station and a new beamline were developed and are now in user operation. The end station contains a 9-2-1 Tesla vectorial magnet and a cryostat with manipulator for the sample cooling and positioning, a deposition chamber, and a UHV detector chamber. We report here mainly on the technical design of the detector chamber which is placed below the magnet chamber and it is also connected to the deposition chamber. Because of various constrains including the limited available space between the bottom flange of the magnet chamber and the floor level, a sophisticated mechanics had to be developed to provide integrated functionality for both the detector holder and the sample transfer units. The detector unit consists of a tubular holder of 5 cm diameter which travels more than 60 cm vertically and exhibits an unlimited rotation degree of freedom of 360 degrees within the magnet bore. The sample transfer unit consists of a telescopic movement mechanism allowing for the sample holder vertical travel within the detector tubular holder. The functionality challenges and their resolve were addressed in an innovative mechanical design at HZB which was financed and build by the VEKMAG consortium.

INTRODUCTION

Soft x-rays are establishing as the most successful probe for a wide range of disciplines seeking answers of fundamental questions at the nanoscale and for different timescales down to femtosecond resolution[1,2]. In particular the magnetism community has benefited greatly from the element specific sensitivity which allows to disentangle the spin and orbital moments through the theoretical prediction and experimental observation of the XMCD effect [3,4,5,6]. Since then, the instrumentation is being continuously developed for advanced methods providing opportunities for magnetic imaging, spectroscopy, and scattering. To this end the VEKMAG consortium [7] has developed, build and comissioned an endstation installed at a newly build beamline located at segment 7.1 in the BESSY II experimental hall of the Helmholtz Zentrum Berlin.

The VEKMAG endstation includes a magnet chamber which includes a superconducting vector magnet and a cryostat, a detector system mounted below the magnet and a deposition chamber connected to the detector chamber which allows for in-situ growth and transfer of the samples. The magnet provides 9T in the beam direction, 2T perpendicular to the beam direction and in the horizontal plane, and 1T in the vertical direction. The available temperature on the sample ranges between 2.5 K and up to 500 K. A more detailed description of the system and the methods (spectroscopy, scattering and X-FMR) will be described elsewhere. Here we describe the technical design of the mechanics for the detector system and for the magnet chamber support frame.

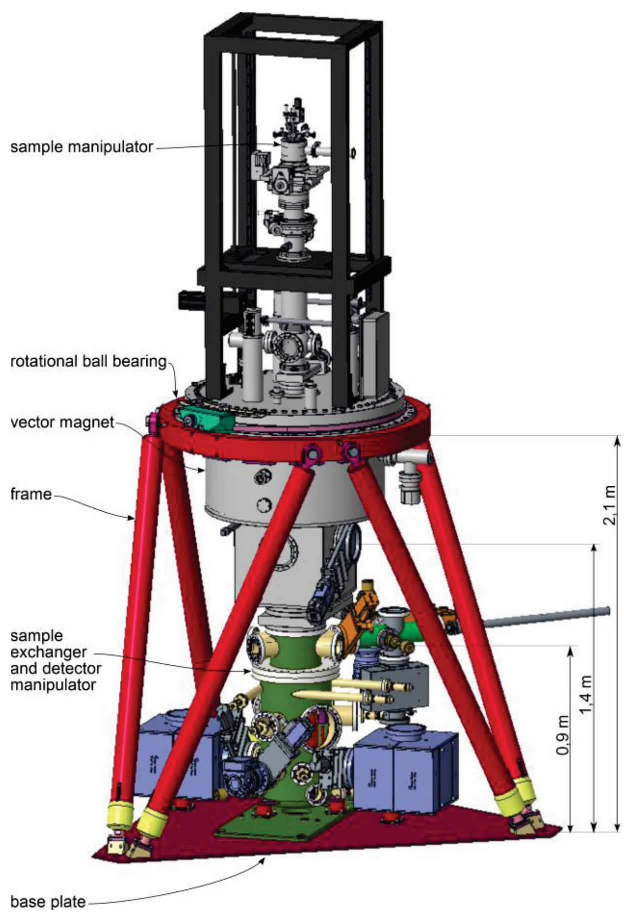

Figure 1: The VEKMAG end-station (the deposition chamber is not shown).

The superconducting vector magnet is accommodated in an individual UHV-chamber which is attached via its upper circular flange of 1 m in diameter to a rotating platform on top of a hexapod frame (s. Figure 1). This rotation is manually driven via a worm gear and a spur belt.

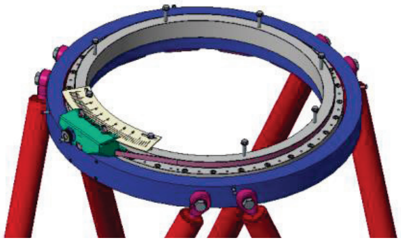

Figure 2: The rotational platform.

The outer frame bears this large ball bearing using six struts in the topology of a W-shape hexapod (Figure 2). The struts have a diameter of 115 mm, a wall thickness of 13.5 mm and are more than 2 m in length. They are attached to a 10 mm thick base plate made of aluminium using ball joints at both ends of the struts. The hexapod frame fulfils best the demanding specifications for highest stability, low vibration amplitudes and precise adjustment of the whole system. It is a result of an optimization process to obtain the stiffest structure combined with a suitable accessibility to the detector chamber. It is actually quite comfortable to work on the experiment chamber. The large top ring of the frame is on an altitude of over 2 m and on the floor it is placed only on a sheet of metal plate. So the scientist can stand direct in front of the chamber and access the rotation unit.

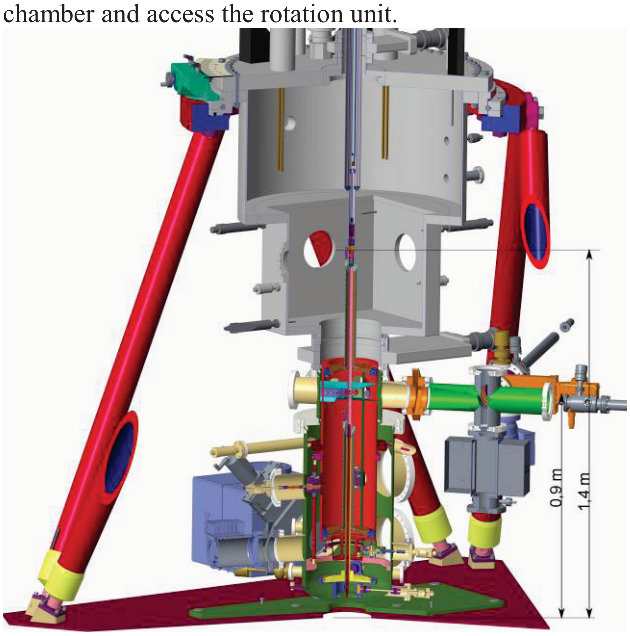

Figure 3: Section view of the end station.

A cryostat is attached to a manipulator on top of the magnet and reaches in to the centre of the magnet at 1.4 m altitude over the floor, at the beam focus location (see Figure 3). The sample exchange level is on an altitude of 0.9 m. The detector chamber is attached to the lower flange of the magnet chamber. It provides mainly two functionalities: vertical sample transfer unit and detector lift which allows for the diode detectors to rotate and translate around the sample within the magnet bore of 60 mm. The samples are brought in to the UHV chamber via a load lock and a magazine which carries nine sample supports were the samples are mounted on (see Figure 4). It is attached rigidly to a long magnetic transfer rod which translates and rotates the magazine manually. The magazine has long blades on the outside, like on Nordic ice skates to allow to slip over the openings of the chamber.

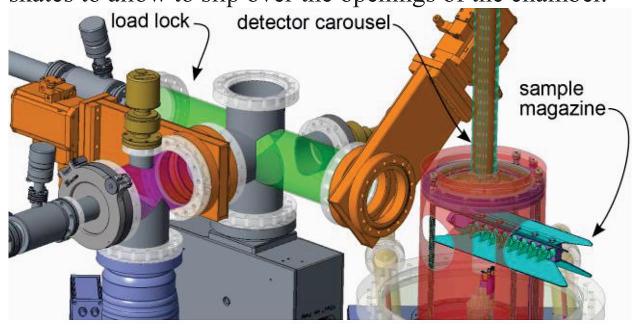

Figure 4: The sample magazine and the transfer system.

Because of the space limitations below the magnet chamber and down to the concrete floor a telescopic mechanism for lifting and screwing the sample in to the cryostat was developed (see Figure 5).

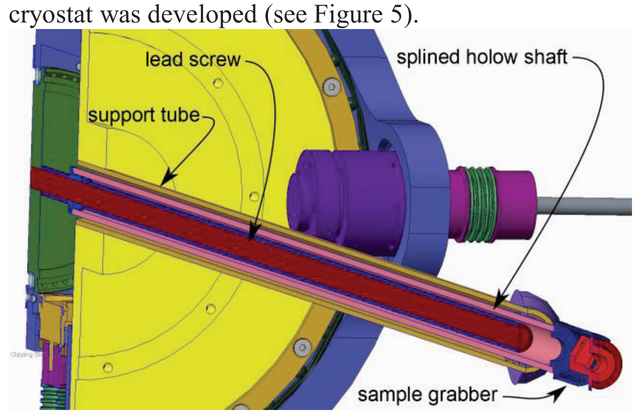

Figure 5: The sample lift.

A trapezoid lead screw made of stainless steel with a nut made of PEEK moves the sample from the magazine up to the cryostat. The rotational definition is featured by a splined shaft made of aluminium on which a hub made of PEEK slides in.

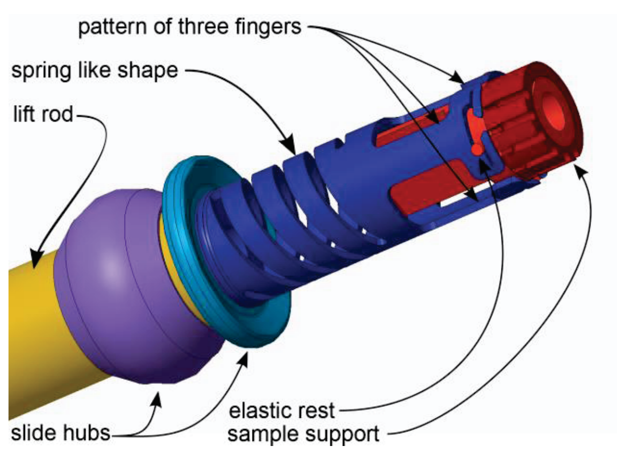

Figure 6: The grabber with a sample holder.

The sample grabber has three holding fingers with elastic clamps to keep the sample holder fixed after it is screwed out of the magazine or of the cryostat head (Fig. 6). The clamping works in both left and right direction. This grabber holds the sample support while it is screwed into the threads. Because there is no axial play for the lead screw or for the cryostat, the grabber has an elastic zone consisting of a compression spring which compensates the axial deviations in the pitch of both screws (Fig. 7).

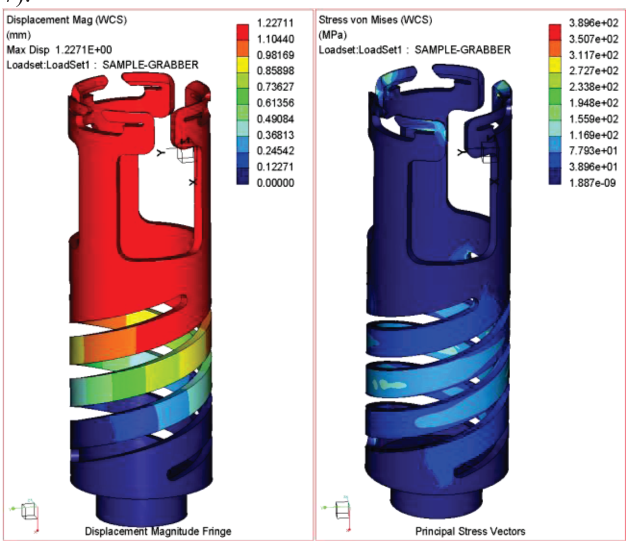

Figure 7: Sample grabber with stress representation in MPa and displacement in mm.

The detector lift and manipulation system are arranged concentric to the sample lift (see Fig. 8). Up to six detector holders can be plugged in to the detector carousel with two electrical contacts for each. A detector holder contains the detector mounted in an electrically isolated slot

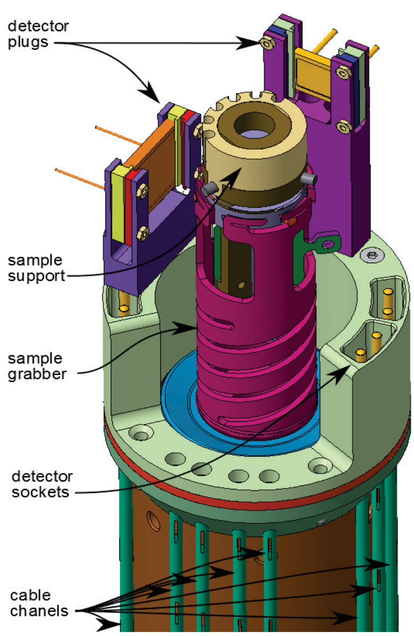

Figure 8: The detector carousel and the sample grabber holding the sample support.

where it can be fixed with screws. In front of the detector a second slot contains an aperture (a pin hole or a slit) and the third slot is used for mounting an electron filter. All three parts can be assembled in the lab and consequently just plugged into the sample carousel.

The top part of the carousel with the sockets is made of PEEK. From there the cables of the contact pins are guided through capillary tubes downwards. At the lower end of the detector lift a spiral shaped tube starts and guides the cables to a fix point from where they connect to the electrical feedthrough.

The lowest four rotational motion feedthroughs are for driving the sample grabber up and down and rotate them, and to move the detector carousel up and down and rotate them (see Figure 9).

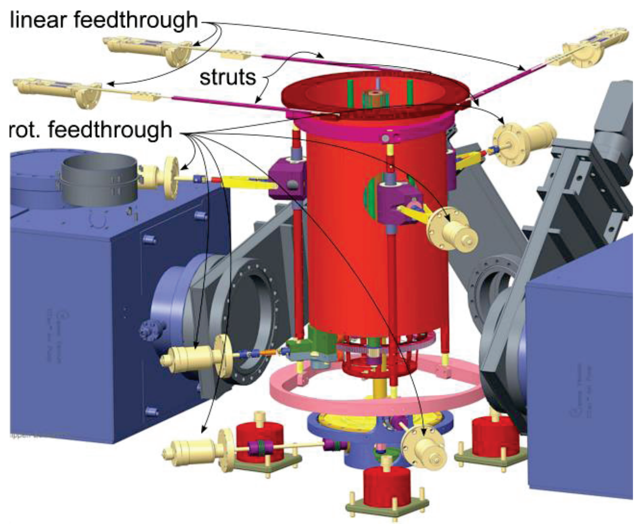

Figure 9: Kinematic structure of the detector carousel.

For the alignment of the detector carousel axis with respect to the sample and to the magnet, a dedicated Cartesian parallel kinematic platform was designed (see Fig. 9) [8], [9]. There are three vertical parallel struts with flexure fibre joints at both ends for supporting the weight of the detector unit and give a guide mechanism for the X and Y translations [10], [11]. This alignment movements are driven by three horizontal arranged linear motion feedthroughs. For one Cartesian direction the two parallel struts are working like a parallelogram and are driven by one single strut through its linear motion feedthrough. For the second translation in the transverse plane two parallel struts have to be actuated through their linear motion feedthroughs by the same travel distance.

The struts are made of aluminium hollow tubes with crimped pieces of stainless steel ropes at both ends. The stainless steel rope is a 7 x 7 cross section design of 6 mm in diameter. These short pieces of steel rope can not only bear strain load. They can also bear axial thrust load without buckling. It is very stiff in axial direction and flexible for bending and twisting in the orthogonal directions. Furthermore, it exhibits high endurance. This design of struts with flexure joints is extensively used for opto-mechanics in different facilities.

The length of the vertical struts can be modified by the three rotational feedthroughs which are attached to these struts (see Fig. 10). There is a worm gear which drives a ferrule with left and right handed thread in a turnbuckle fashion.

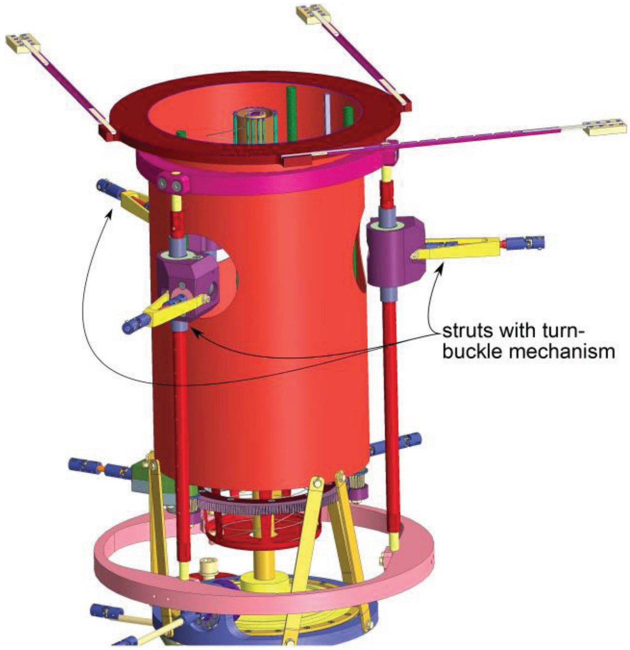

Figure10: Detector lift unit, supported by struts with flexure joints in a Cartesian parallel kinematic topology.

In conclusion, we have described the technical design of the holding frame and of the detector system which is part of the VEKMAG end station installed at the PM2 beamline (BESSY II, HZB). The hexapod frame holding the magnet and the detector chamber provides a large rotational degree of freedom, high vibrational stability through optimised stiffness, and precise adjustment capability within the X-ray beam focus. The detector system was developed to provide two functionalities, telescopic sample transfer and detector motion within a highly constrained geometrical space. The fabrication of these units where accomplished partly at the Ruhr University Bochum and at the University of Regensburg and are now in full operation.

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