PRIOR PROTON MICROSCOPE

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Abstract

The new proton radiography facility PRIOR[2] (Proton microscope for FAIR) was developed at SIS-18 accelerator at GSI (Darmstadt, Germany). PRIOR setup is designed for measurement, with high spatial resolution up to 10 μm, of density distribution of static and dynamic objects by using a proton beam with energy up to 4.5 GeV. In the first experiments with static objects with 3.6 Gev proton, was demonstrated a spatial resolution of 30 μm. Dynamic commissioning was performed with target based on underwater electrical wires explosion with electrical pulse with current amplitude of ~200 kA and rise time ~1 μs.

INTRODUCTION

The study of high-energy-density (HED) matter generated by the impact of intense heavy ion beams dense targets is one of the most challenging and interesting topics in modern physics [1]. Measurement of density distribution, with good spatial and temporal resolution, of matter is important task for fundamental understanding of dynamic material properties in extreme states. High-energy proton radiography exceeds X-Ray diagnostic method in many ways, because it has more transmission ability and high spatial and density resolution. The best spatial resolution was obtained by means of high-energy proton microscopy technique [2]. Novel high-energy proton microscope called PRIOR (Proton Microscope for FAIR)[3] will be the key diagnostic instrument for HED research program of HEDgeHOB collaboration at FAIR. (HIHEX and LAPLAS experiments)

EXPERIMENTAL SETUP

The magnetic system of the PRIOR beam-line consists of two sections (fig. 1). The first, matching section, contains electromagnetic-quadruple lenses and provides formation of a proton beam for the objects imaging task (beam size, angular distribution). The second section is a magnification section (K ~4) that consists of four Permanent Magnet Quadruples (PMQ) lenses. Length of the two PMQ lenses 144 mm and 288 mm the other two, magnetic field on pole is 1.83T, aperture 30 mm, magnetic material NdFeB. Tungsten collimators (with elliptical hole), installed at central plane of magnification section, provide regulation of contrast of the proton-radiographic images.

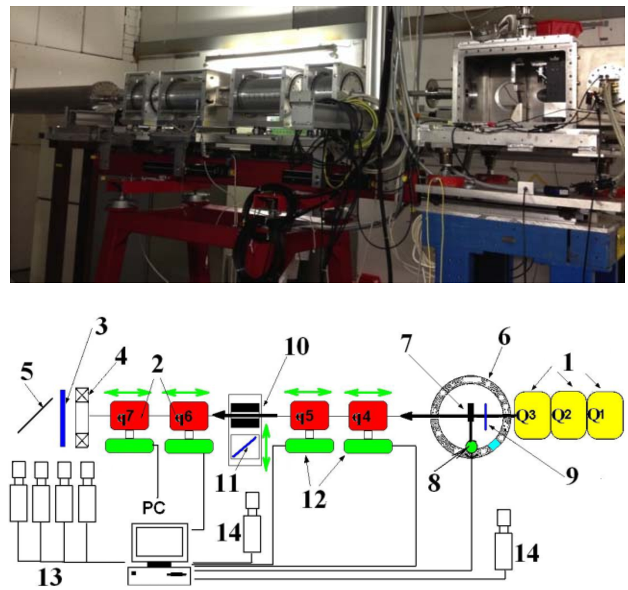

Figure 1: Photo and scheme of PRIOR proton microscope. 1- electromagnetic quadrupoles (matching section), 2- quadrupole lenses on permanent magnets PMQ (magnification section), 3-scintillator, 4- fast current transformer, 5- mylar foil mirror, 6- vacuum or water target chamber, 7- target, 8- target manipulator, 9- beam position/profile monitor (Bicron scintillator), 10- collimators, 11- beam position monitor, 12- linear actuators, 13- fast CCD cameras, 14- CCD cameras for beam tune

Investigated object installed in vacuum chamber between first and second section. The registration system for static experiments consists of CsI scintillator and plastic scintillator (Bicron BC-412) for dynamic one with two types of intensified CCD cameras PCO DiMAX and PCO DicamPro.

STATIC COMISSIONNING

The aim of first experiments at PRIOR was an adjustment of matching and magnification sections of ion optical scheme of setup to achieve best spatial resolution of proton-radiography images. Static objects were used to measure spatial and density resolutions and to estimate chromatic aberration. Primarily the setup was expected to run with 4,5 GeV proton beam. However due to radiation damage of the magnetic material of PMQ lenses (falling gradient and an increase the amplitude of the high-order harmonics of magnetic field) static commissioning of

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facility has been carried out at lower proton energy 3.6 GeV. The object of tungsten, width 20 mm, with polished rolled edge (rounded radius 500 mm) was used to measure the spatial resolution limit. The spatial resolution was measured as a standard deviation of profile approximated function of image of sharp edge of object. The best spatial resolution, according to the preliminary estimates of proton radiography images, is 30 µm. The tantalum step wedge was used to determine contrast sensitivity of facility. Fig. 2 shows the proton radiography image and transmission/areal density diagram of tantalum steps wedge (thickness 0.56, 2, 4, 6, 8 mm), image was obtained by using collimator with acceptance angle of 2 mrad.

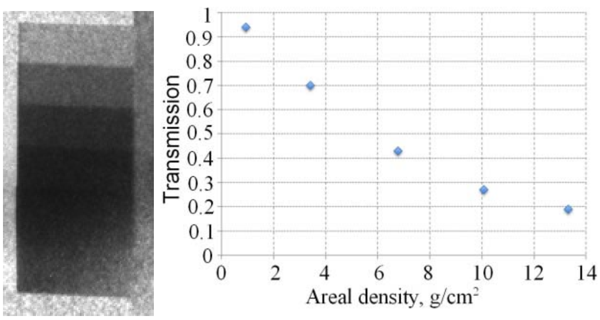

Figure 2: Proton radiography image of tantalum steps wedge and transmission/areal density diagram.

Fig. 3 shows a photo of static object (quartz watch) and its proton radiography image. One can see the main parts of the mechanism, such as a battery, a stepping mechanism, and hands.

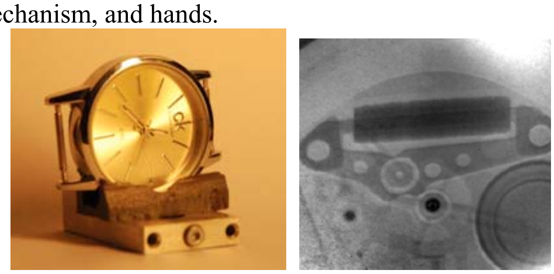

Figure 3: Photo and proton radiography image of quartz watch.

DYNAMIC COMISSIONNING

One of the proposed experiments for PRIOR facility is studying of time- and space-resolved density distribution of different underwater exploding wires (UEWE). First dynamic experiments with UEWE has been carried out using compact high-current generator (fig. 4) producing ~200kA electrical pulse with rise time of ~1µs. The external 10 µF capacitor unit with charge voltage of up to 50 kV controlled by Marx trigger generator is used to generate electrical pulse. Charging of capacitor unit and trigger generator is performed by two high-voltage generator TDK-Lambda 402-50.

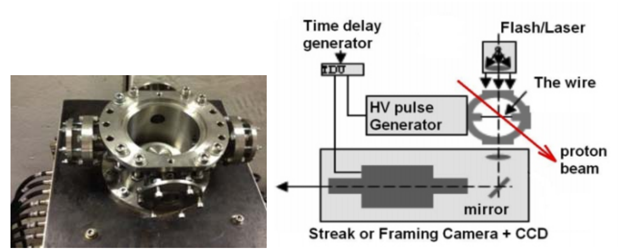

Figure 4: Photo and scheme of underwater electrical wire explosion target.

Fig. 5 shows the photo and proton radiography image of tantalum wire in water with diameter of 0.8 mm. Right part of fig. 5 shows dymanic image of wire which was obtained with electrical pulse of 36 kV voltage.

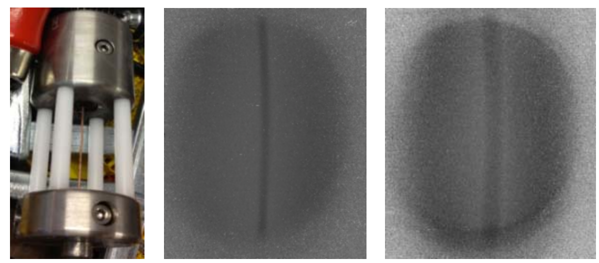

Figure 5: Photo and proton radiography images of tantalum wire.

Fig. 6 shows lineout through the 0.8 mm diameter Ta wire showing that there is sufficient sensitivity and resolution to measure the areal density of the wire.

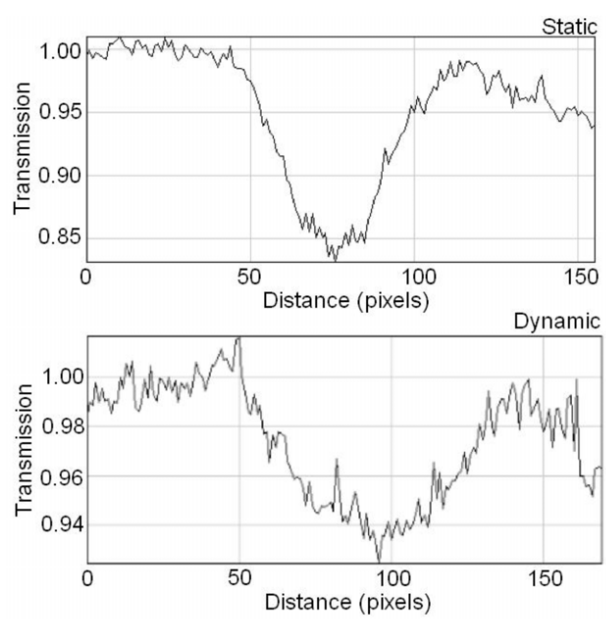

Figure 6: Profile of static and dynamic images of Ta wire.

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