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Neutron Imager with Micro Channel Plates (MCP) in Electrostatic Mirror Configuration: First Experimental Test

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Abstract

The idea of a new high transparency device based on Micro Channel Plate (MCP) has been recently presented for monitoring flux and spatial profile of neutron beams. It consists of the assembly of a very thin aluminum (Al) foil with ^{6}Li deposit placed in the beam and a MCP equipped with a phosphor screen readout viewed by a CCD camera. A peculiar feature of this device is that it uses a 90° electrostatic mirror to minimizing the perturbation of the neutron beam, i.e., absorption and scattering. It can be used at existing time-of-flight facilities, in particular at the n_TOF facility at CERN, for monitoring the flux and spatial profile of neutron beams in the thermal and epithermal region. In this contribution the first experimental test carried out by using radioactive sources will be presented and the related results discussed.

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Keywords: neutron detection, beam monitor;

1. Introduction

The Micro Channel Plate (MCP) devices have many advantageous detection features as: fast time response, low dead time, high counting rate, low dark current. In particular they have a very high spatial resolution (J. L. Wiza,

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1979). These features make the MCP very suitable to be used in beam profile monitor devices construction. The MCP radiation detection efficiency depends on the radiation type and energy. For the neutrons, however, they have a very low direct detection efficiency (up to 0.6% for fast neutrons). For that reason, it is necessary of using other than the MCP also a converter material to increase the neutron detection efficiency. In the last years, MCP devices have been largely employed both for detection of ionizing radiation and as image intensifier. It has also been demonstrated that MCPs can be applied in neutron detection and imaging with many advantages (G. W. Fraser and J. F. Pearson, 1990; O. H. W. Siegmund et al., 2001; A. S. Tremsin et al., 2005).

Recently the idea of a new high transparency device based on MCP for monitoring the flux and the spatial profile of a neutron beam has been proposed (V. Variale, 2015). In that reference the device design details are shown and discussed, here, for sake of clarity, the device behavior scheme is shown in fig.1 again. The device consisted of an Aluminum (Al) foil with a ^{6}Li deposit, placed in the beam, and a MCP assembled with a phosphor screen readout viewed by a CCD camera, placed outside the beam. The reaction ^{6}Li(n,α) t used as converter gives to the slow neutrons which hit the ^{6}Li atoms a great chance to produce α and t ions with 2 and 2.7 MeV of energy, respectively. At those energies the α and the t particles have, in Aluminum, a range of 5 μm and 30 μm, respectively. Then, by taking an Al foil with a thickness of 14 μm, all the α would be stopped and all the t transmitted. Furthermore, the tritons would exit from the Al foil and emit Secondary Electrons (SE) which would be accelerated by the nearby grid, and then, reflected at 90°, towards the MCP, by the other grids tilted at 45° (the electrostatic mirror). The SE impinging on the MCP inner channels generate an electron avalanche. Behind the MCP (in chevron configuration) there is the signal read-out system, a phosphor screen followed by a CCD camera where the beam image is collected by a proper lens and recorded.

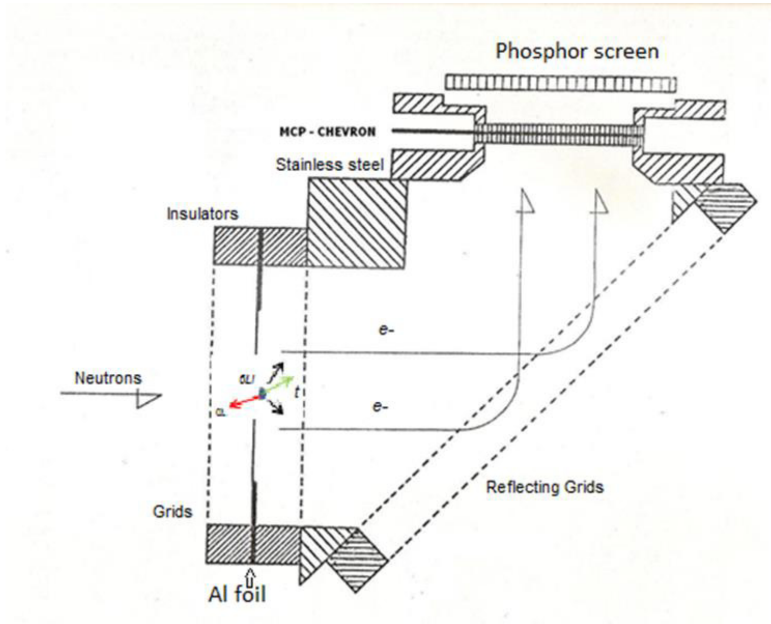


Figure 1. Neutron beam monitor with electrostatic mirror configuration. On the Aluminum foil, the converter material ^{6}Li is deposited. In the figure is shown as a ^{6}Li atom hit by a neutron produces the reaction ^{6}Li(n,α) t.

In this paper the MCP based monitor test measurements carried out with radioactive sources are presented and discussed.

2. The measurement apparatus

Before to test the high transparent beam monitor on a neutron beam two radioactive sources have been used to verify the correct behavior of the electrostatic mirror described above.

In Figure 2, the experimental apparatus scheme used for these test measurements is shown. The MCP assembly flange is mounted on a 4-way cross vacuum chamber up in the vertical direction. The electrostatic mirror is fixed by two aluminum supports to the flange placed on right part of the horizontal direction. In the set up scheme of Fig. 2, the positions where the radioactive sources have been placed for the test measurements are also indicated.

In the first measurement stage we used the neutron source ^{252}Cf, which has a half-life of 2.645 years and an activity of 3.35×10^5 Bq. The neutron energy spectrum of the source is similar to that one of a fission reactor which has the most probable energy at 0.7 MeV and the average energy at 2.1 MeV. The source neutrons, then, had to be moderated before to hit foil converter.

The α particle source used in the second measurement stage was an ^{241}Am source with an activity of *3* kBq. The α particles were emitted isotropically in all directions with a kinetic energy of *5.5* MeV. The source particles have in the *Al* a range of *24.5* μ. Since our *Al* converter foil thickness was about *15* μ (including the ^{6}Li deposit thickness of *1.4* μ on the *Al* foil) we could assume that, practically, all the α source particles that reached the foil converter exited from it and the SE produced in their exit were accelerated towards the MCP by the electrostatic mirror field. This kind of measurement could verify that all the α particles which hit the *Al* foil could be detected by the MCP assembly although it was placed outside the visual angle of the source, owing to the action of the electrostatic mirror on the SE trajectories.

The SE driven by the electrostatic mirror toward the MCP lower face were multiplied and accelerated toward the phosphor screen where they produced light points recorded by CCD camera witch had an exposure time of 1 second. Notice that the light points represented the image of the neutron reactions happened in the converter in one second.

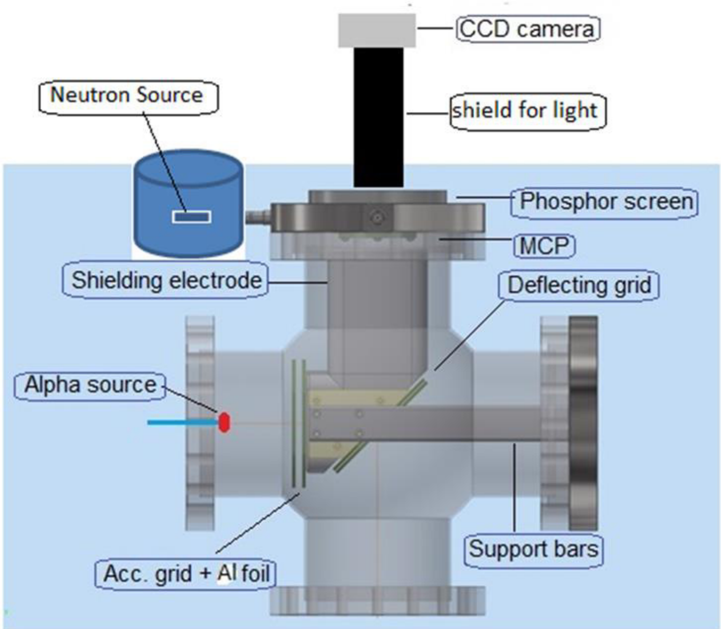


Figure 2. Experimental apparatus scheme: the vacuum chamber with the inside Electrostatic Mirror and the MCP assembly with CCD camera. Notice the radioactive sources positions used for the test measurements.

3. The experimental results

The first test experiment has been carried out by using the neutron source previously described. As shown in Fig.2, the neutron has been left in its moderator container and placed externally to the vacuum chamber. In fact, since the monitor uses an Al foil with ^{6}Li deposit, which is a slow neutron converter, the neutrons had to be moderated. A MCNPX (D. B. Pelowitz (ed.), 2011) simulation using the same geometry, but with vacuum chamber walls not considered, has been carried out to evaluate the number of neutrons that could reach the converter and could be seen by CCD camera as light points. That simulation has shown that a very low rate of neutron conversion resulted in ^{6}Li deposit (few tritons per second exited from the Al foil). The light points rate (number/sec) recorded by CCD camera in our first step measurements roughly confirmed the simulation results. In fact, the recorded rate for the background was 1.7 ± 0.1 sec-1 while that one with the ^{252}Cf neutron source was 3.4 ± 0.2 sec^{-1}. In fig. 3 a snapshot of the CCD camera displays of the signal obtained for the background and for the signal in the case with the neutron source measurements are shown.

On the contrary of the first part of measurements carried out with the neutron source, the α source used in the second stage of our experimental test is placed, as shown in Fig.2, inside the vacuum chamber. Notice that the source in this case was relatively close to the Al foil converter. The relatively big solid angle formed by the source on the surface of Al converter foil should guaranty a high number of particles and then a 'big' signal. As previously observed, all the α particles exiting from the Al foil should produce SE that would be accelerated by the electric field present in the region from the foil to the grid, towards the deflecting grid and then on the MCP lower face.

The accelerating and deflecting fields used have been generated by applying a potential of -1 kV to the foil converter and to the external deflecting grid (see fig.2). A MCNPX simulation has been carried out also to evaluate the number of the α particles which should exit from the Al converter foil to produce the SE. Also in this case the geometry used in MCNP simulations does not take into account the vacuum chamber wall. Notice that the distance from the α source (d_α) and the sensitive converter foil surface (S_f) could not be measured with precision inside the vacuum chamber. A rough measurements gave d_α= 5.5 cm and S_f= 14 cm^2 and with those values the foil exiting α rate, in the simulation, was 103 s^{-1}. In order to understand the influence of the d_α value in MCNPX simulation results, we slightly changed the value of d_α with *5.7 cm* and the new simulation results gave a α rate of *130 s^{-1}*. The measurement results shown in fig. 4b) have given a rate of about *120 s^{-1}*.

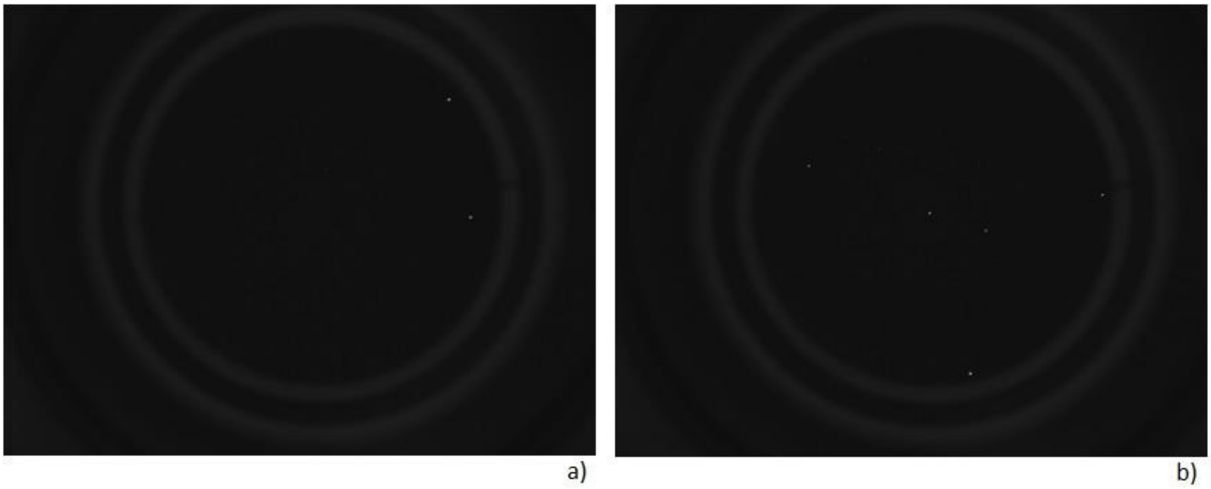
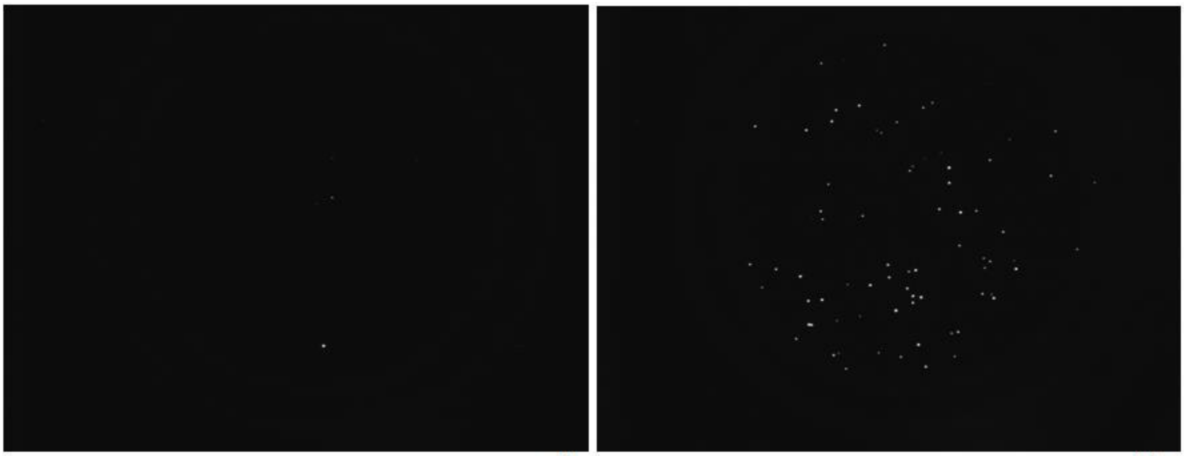


Figure 3. CCD camera snapshots of the light points representing the background radiation in a) (2 light points) and the nuclear reactions induced by the neutrons in the converter in b) (7 light points).

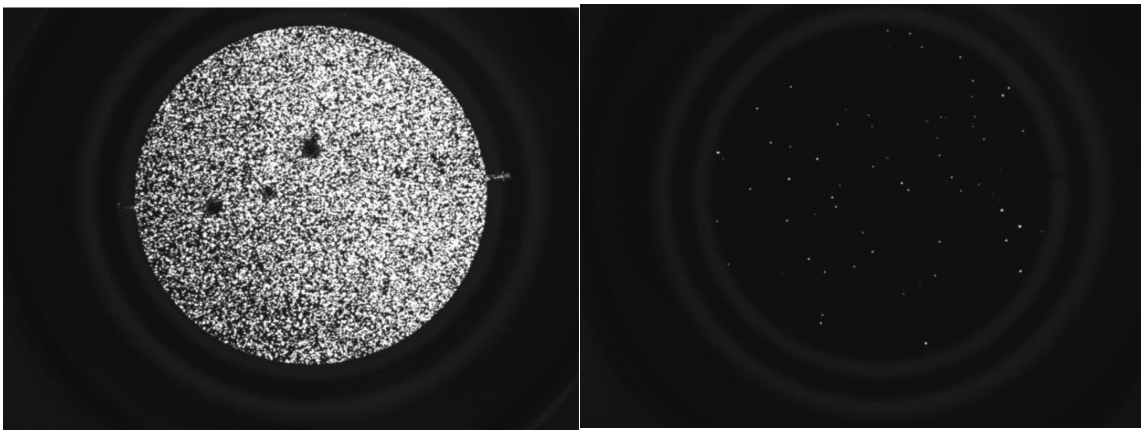
It worth to notice that the applied voltage of *-1 kV* on the foil converter has been chosen because the electrons with a kinetic energy in the range *1 ÷ 2 keV* have a very high detecting efficiency on the MCP (J. L. Wiza, 1979). In order to optimize the values of the applied potentials, further test measurements with higher voltages on foil converter and reflecting grids have been carried out. The results of those measurements have shown that when the voltage was bigger than *-1.5 kV* an increase of the light points on the CCD camera signal was observed. The features of that increase, however, suggest that it should be ascribed to the noise introduced by the ionization of residual gas atoms close the very thin grid wires (there the electric field is very high and Corona effect happened). The electrons coming from the ionization due to the Corona effect, in fact, can be accelerated along with the SE towards the MCP face.



a) b)

Figure 4. CCD camera snapshots for the measurements with the α source. The light points recorded in one sec. by the CCD camera are shown; in a) the CCD background signal, (*4* light points with *2* light points less visible because of the figure size reduction) obtained when the electrostatic mirror was off ($V_{foil}=V_{grid}= 0\ V$); in b) the CCD signal with electrostatic mirror on ($V_{foil}=V_{grid}= -1\ kV$), about *100* light points (also here some light points was less visible and have been lost in the figure reduction).

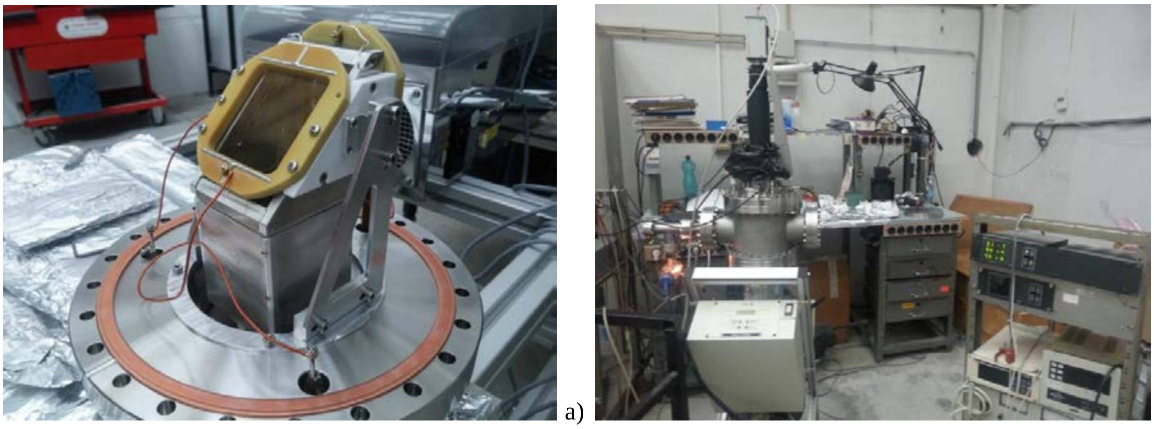
The vacuum chamber pressure measured during all the experimental tests was in the range $3 \div 5\ x10^{-7}\ mb$. No Corona Effect was expected with a such low pressure but, unfortunately, the grid cards are made by glass fiber composite material RF4 not suitable for high vacuum. Atoms desorbed from grid surfaces could have been ionized by the high electric field present close to the grid wires.



a) b)

Figure 4. Possible Corona effect on the grid wires. CCD camera signal with: a) $V_g= -2.8\ kV$, $V_f= 0\ V$; b) $V_f= -2.8\ kV$, $V_g= 0\ V$. The high voltage on the deflecting grid (V_g) gave a very big signal because that grid was placed in front of MCP face. The 3 dark holes that can be noticed in a) are due to defects on the Phosphor coating of the MCP assembly.

Many measurements with voltages higher than *-1.5 kV* applied to the grid and foil electrodes have been carried out and all their results have shown an increase of the background signal. In figure 4, the case where the very high voltage of *-2.8 kV* was applied it is shown. It can be noticed that in 4a), where the voltage was applied to the deflecting grid, the CCD camera signal has a huge number of light points. That could be because the deflecting grid is placed in front of MCP, then, the electrons produced by the 'corona' ionizations have a great chance to hit MCP channels and produce light points on the phosphor screen. In 4b) instead, the high voltage of *-2.8 kV* has been applied on the converter foil which is not in front of the MCP (see Fig. 1). In this case, as expected, the light point number on the CCD camera is much lower than the previous case.



a) b)

Figure 5. Beam monitor assembled on the flange: a) he modified support system on the new larger flange which host also the MCP assembly; b) the new flange closed on the new vacuum chamber and on it the CCD camera is installed.

The beginning of the next year the high transparency neutron monitor will be tested on the neutron beam of the n_TOF facility at CERN. In order to keep the high transparency some modification in the experimental apparatus of fig.2 has been realized. In Figure 2, in fact, the electrostatic mirror support bars were placed on the flange along the beam direction. That solution was adopted to fit the electrostatic mirror on the small vacuum chamber that we had available for the preliminary test. Recently, a new larger vacuum chamber has been acquired and new support bars for the electrostatic mirror have been designed to install the device on the same flange where the MCP assembly has been fixed, as it is shown in Fig. 5a). Notice as in this way the cumbersome support bars on the beam axis have been avoided. In Fig. 5b) it is shown as the monitor flange is mounted on the new vacuum chamber and on it is installed the CCD camera.

4. Conclusion

Before to test the proposed high transparency neutron beam monitor directly on the neutron beam of n_TOF CERN facility, an experimental test on his behavior has been carried out in our laboratory by using radiation sources. The experimental tests have shown that the electrostatic mirror used to convey the neutron image, obtained by the Secondary Electrons, toward the MCP assembly placed off beam axis worked well. Possible corona effects could be observed on CCD camera display when the deflecting grid voltage was higher than *-1.5 kV*. The same effect at a lower level it is visible when the converter foil voltage was higher than *-2 kV*.

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