DESIGN OF SYNCHROTRON RADIATION INSTRUMENTATION FOR "IN SITU" INVESTIGATION OF EXPLOSION WITH NANOSECOND TIME RESOLUTION

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Abstract

A special instrumentation was developed for the investigation of explosions by synchrotron radiation with 250 ns time resolution. It consists of an explosion chamber, detonation front sensors (wire detectors) and X-ray detectors. The time dependence of the absorption coefficient of the explosive material was measured during the explosion. In the same experiments, the SAXS and the diffraction signal were observed. In the first experiments hexogen–TNT alloy was used to obtain diamond powder as explosion product. In this experiment the SAXS intensity increased sharply for 1500 ns. This is an unusual result, because the theory says that in general chemical transformations finish in about 200 ns. The test experiment has shown that it is possible to receive a time resolution of 20 ns.

1. Introduction

The detonation process so far has been investigated by the most various "in situ" methods. However, till now, usage of X-ray scattering and diffraction methods was impossible. Investigating explosive processes with synchrotron radiation (SR) is planned since a long time, but we could not overcome the following problems: 1) lack of scattered photons in an exposure time of 1 ns; 2) Be windows stability under influence of a shock wave; 3) formation of stable detonation fronts in explosives with a small diameter, which is optimum for scattering and diffraction experiments; 4) rejection of the electrical noise from the detonator.

2. VEPP-3 and wigglers

The storage ring VEPP-3 has the following parameters: E=2 GeV, I=150 mA, revolution period 250 ns, single bunch operation mode, bunch length 30 cm. The three-pole wiggler with a field of 2T was used in explosion experiments, 3T will be used in the nearest future and a 5T multipole permanent magnet wiggler is now proposed.

It is possible to estimate the flux per one bunch on the detector

$$N_\varepsilon[\frac{phot}{bunch}] = \alpha\gamma n_e \frac{\Delta x}{L}\eta(\frac{\varepsilon}{\varepsilon_c})\frac{\Delta\varepsilon}{\varepsilon}A(\varepsilon)D(\varepsilon)$$

where α - fine structure constant, γ - relativistic factor, n_e – the number of electrons in the bunch, Δx- detector size, L - wiggler – sample distance, ε - SR energy, ε_c - critical energy, $\eta(\varepsilon/\varepsilon_c)$ - spectral function, $A(\varepsilon)$ - absorption coefficient in all Be windows and the sample, $D(\varepsilon)$ - detector quantum efficiency. By using the parameters of the experimental conditions at VEPP-3 for white beam: Δx- 2 mm, L – 13 m, ε_c - 5.32 keV, $\Delta\varepsilon/\varepsilon \sim 1$, $\varepsilon \sim 30$ keV, $D(\varepsilon) \sim 0.5$, the flux estimate is $\sim 10^8$ photons/bunch, $\sim 2*10^9$ photons/bunch and $\sim 10^{11}$ photons/bunch for 2T, 3T and 5T wigglers, respectively.

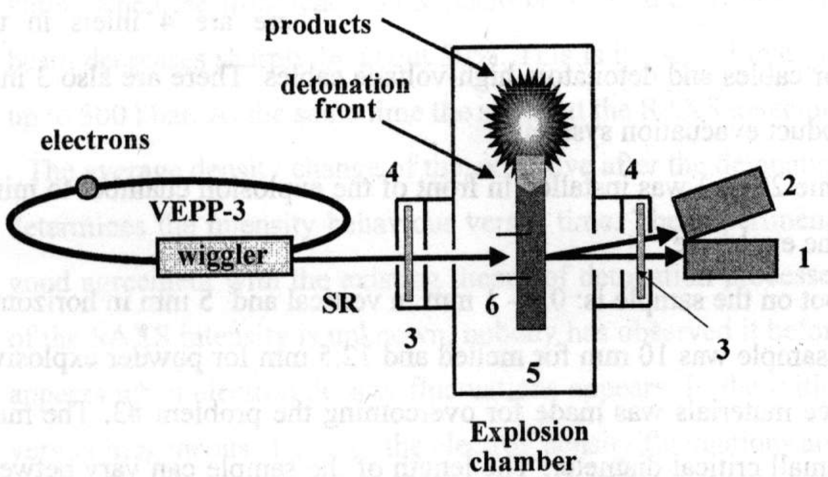

Fig. 1. The scheme of the experiment: 1,2,3 - transmitted beam and SAXS detectors, beryllium window, 4 – shock wave reducers, 5 - explosive material, 6 - wires detectors as a detonation front sensors.

These calculations show that measuring the explosion process is nowadays possible by using white radiation, thereby overcoming problem #1. After installation of the 5T wiggler it will be possible to use monochromatic radiation.

The scheme of the experiment is shown in Fig.1 The synchrotron radiation beam is transported from the wiggler in vacuum tubes to the experimental hall, where the explosive chamber is installed. The radiation is generated in the wiggler every 250 ns, which determines the time resolution of the experiment.

3. Explosion chamber

The explosion chamber is made from 10 mm stainless steel. There are two slits in the chamber, for the primary and scattered beams. The entrance slit has dimensions of 10 mm horizontally

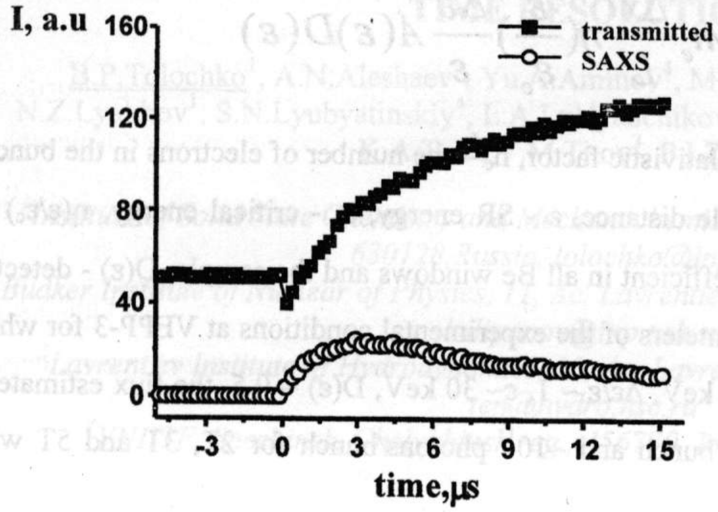

Fig. 2. Experimental results of trotyl detonation. The intensity of the transmitted beam and integral SAXS intensity versus time.

and 3 mm vertically. The exit slit dimensions are 3 mm horizontally and 10 mm vertically. A shock wave reducer (SWR) is installed between the slits and the Be windows. The installation of SWR solves problem #2. The thickness of each Be window is 2 mm. The explosion chamber can operate with an amount of explosive material near 20 g (TNT equivalent).

There are 4 inlets in the chamber body for wire detector cables and detonators high-voltage cables. There are also 3 inlet valves for vacuum, gas and product evacuation systems.

The fast shutter (opening time 20 ms) was installed in front of the explosion chamber to minimise the radiation damage of the explosive.

The size of the irradiated spot on the sample is: 0.1 - 1 mm in vertical and 5 mm in horizontal direction. The diameter of the sample was 10 mm for melted and 12.5 mm for powder explosive. A special selection of explosive materials was made for overcoming the problem #3. The main parameter of selection was a small critical diameter. The length of the sample can vary between 25 and 80 mm. Octogen was used as a buster explosive. The distance between the wire detectors was 20 mm. The distance from detonator to irradiated spot was extended so much to increase the time between detonator explosion and detonation front arrival time to irradiated spot up to 5 µs. This time is enough for reduction of the electric noise from detonator. The problem #4 was solved in this way.

4. Detectors

A germanium phototransistor with a size of $2x5\ mm^2$, silicon pin-photodiodes with a size of $1x1\ mm^2$ and a Si microstrip detector (100 µm strip steps) were used in the explosion experiments. The first one gives information about scattering of photons with energies between 15 and

30 keV, the second one with energies between 5 and 15 keV.

The ADC 850SK [1] was used for digitising the signal after amplifying The number of memory cells in the ADC was 4096. It corresponds to 512 μs – the full duration of the measurements.

Digital correlated double sampling (DCDS) was used for noise reduction and drift compensation of all electronic components. Two measurements for DCDS was made during one turn of electrons bunch: the fist one when photons reach the detectors, and the second one with 125 ns delay, when no photons were generated.

The recorded flux at the detectors were: 10^4 photons/bunch, 10^3 photons/bunch and 15 photons/bunch for the Si direct beam detector, the Ge SAXS detector and the Si SAXS detectors respectively.

5. Previous experimental results

The sample was detonating in the top part. The velocity of the detonation front was near 7 km/s. When the front reaches the position where the SR beam is, the intensity of the transmitted beam decreases sharply by about 30%. This is the signal that pressure in the explosive increased up to 300 kbar. At the same time the signal at the SAXS detector appears.

The average density change of the explosive after the detonation front in the SR beam trajectory determines the intensity behaviour versus time. The experimental data of our experiments show good agreement with the existing theory of detonation processes in solid explosives. The nature of the SAXS intensity is unknown, nobody has observed it before. But it is obviously, that SAXS appears when electron density fluctuations appears. In the initial explosive the atomic density is very homogeneous. Therefor the electron density fluctuations are small and the SAXS intensity is small too. On the contrary, the atomic density of explosion products are not uniform and the electron density fluctuation is big. These fluctuations will give a high scattering intensity.

When TNT is used as explosive, the SAXS intensity increased in 2.5 μs and then decreased. It is a very interesting and unusual result because the theories of detonation affirms that all chemical reactions finish in 10-100 ns after the detonation front has passed. The behaviour of the SAXS intensity versus time shows that the formation of the products of reactions occurs in a few microseconds.

We have made experiments with a dozen of different explosives and have found a correlation between the amount of free carbon in explosives products (solid products) and the maximum intensity of SAXS– the bigger the amount of solid products, the bigger is the maximum intensity.

The SAXS maximum intensity of those explosives, whose product of reaction contains diamonds (for example TNT-hexogen 50/50 alloy) are much bigger than from other explosives. These experiments give reason to conclude that the nature of the electron density fluctuation is associated with the existence of carbon particles (graphite, diamond) or carbon liquid spray.

6. How to improve time resolution and to receive more information

We plan to use the multibunch operating mode of VEPP-4 for the experiments. The time resolution will be equal to the time interval of 5 ns between the bunches.

The other proposal is to use self scanning properties of detonation processes. This means that the process of detonation develops simultaneously in space and in time and it is therefore possible to make a conversion between time and space by using a photodiode array or a microstrip detector. For this specific detonation we have received time resolutions of 60 ns and have a plan to receive resolution of 20 ns.

After some improvements of the detectors the SAXS/WAXS data versus angle of scattering will be received with the same time resolution. It will allow one to receive the information on phase transformations behind the front of a detonation.

7. Conclusion

We have solved all problems which we had at the beginning stage of the work (see introduction): 1) increased the number of scattering photons with using wide spectrum range of SR; 2) reduced the influence on Be windows with by SWR; 3) used explosive materials which critical diameter is smaller then 10 mm; 4) extended the time interval between detonator explosion and measurement time by using a large spacing and the DCDS method.

References

1. A.M.Batrakov, V.P.Kozak, M.E.Kruglyakov “ADC 850SK ” Preprint of the Institute of Nuclear Physics SB AS USSR, number 88-98, Novosibirsk (1988) p.22.