Leviathon on the desk-top

Powerful X Rays, which needed kilometer-wide facilities, can now be made on the desk-top, says S.Ananthanarayanan.

X Rays, those ultra high frequency light waves which can pass through bone, concrete and metal, changed the face of the earth in the last century. The first X Ray guns were rudimentary arrangements, barely able to create this marvel radiation. But as X Rays became important for science and technology, to say nothing of medicine, more efficient and sensitive X Ray generators became necessary. High ingenuity and great investment were brought together to generate X Rays of a range of intensities and penetrating capacity.

A problem has been that the arrangements, involving high voltages and currents, were large and unwieldy. Researchers from Imperial College, London, the University of Michigan and Instituto Superior Téchnico, Lisbon report in the journal, ***Nature***, of a new, handy and compact arrangement for producing well directed beams of high energy X Rays.

Rudimentary X Rays

The simple X Ray gun is an electron beam that smashes into a metal target. Electrons are produced by heating a metal coil, and the coil is given a negative charge. As electrons are also negatively charged, they are repelled and can be accelerated towards a positively charged attractor, generally of tungsten, molybdenum or copper. When high voltages are applied, the electrons smash into the metal target at high speeds and expend their energy mainly as heat, but also, about 1%, in the form of radiation.

The radiation has 2 sources. One is that electrons in the atoms of the target material would get knocked to higher energy levels due to the bombardment. When these electrons de-excite, they release energy through radiation, at frequencies characteristic of the material. The other source of X Rays is a property of any charged particle that is accelerated.

Charged particles give off radiation when they accelerate. Even the simple radio waves from the radio station antenna is a case of radiation from the alternating current that flows in the antenna. More dramatic are instances of high energy cosmic ray particles that make sudden turns as they pass heavy atoms in the atmosphere. The change in direction, or speed, is acceleration and the particles give off high energy photons of radiation at very high frequencies. This effect, of radiation when particles are suddenly ‘braked’, is called ***bremstralung***, German for ‘braking radiation’.

In the same way, when the high energy electrons in the X Ray gun come to a rapid stop in the target, they give off radiation because of the sudden turns and the rapid braking. As the voltage of the arrangement is increased, both the maximum speed of the electrons, and hence the hardest X Rays, as well as the frequency at which most of the X Rays are produced inches higher. The voltage applied, as well as the current through the arrangement is thus the tool for controlling the penetrating power and the quantity of X Rays. In practice, there are also filters which can absorb lower frequencies, which help narrow the spatial and the frequency spread of the X Ray beam, for more precise application, both in medicine as well as in industry.

For many years, hence, the X Ray industry was dominated by equipment for generating the high voltages for the X Ray gun, along with arrangements for insulation, and to cool the target when more than a momentary X Ray flash was required. A change was seen only as an offshoot of arrangements in nuclear physics research, where arrangements had to be made accelerate charged atomic particles to the energy of an electron in fields of millions or even trillions of volts. In these arrangements, where the objective was the high energy particle, the generation of X Rays by the speeding particles was seen as a nuisance, which 'bled' the particles of energy and it was only in specialized facilities that X Rays were the main objective.

Accelerators

The earlier of the high energy particle accelerators was the ***Cyclotron***, where charged particles move in circles under the effect of a magnetic field. As a moving charged particle amounts to an electric current, a magnetic field will push the particle in a direction at right angles to its motion. As the particle turns, under this force, the force also changes and the result is motion is a circle, like a satellite. Now, in a cyclotron, the charged particles are contained in a sandwich of two semicircular, oppositely charged disks, with a magnetic field in between. Thanks to the magnetic fields, the particles move in circles, within the sandwich. As the semicircles are charged, there is a voltage difference across the gap and the particles get a short burst of acceleration when they cross over. This makes the particle speed up, but it keeps going in a circle, only a slightly larger one. The charge on the discs is managed so that when the particle comes round to the next gap, the voltages are switched and the particle gets another 'kick', and so on every time it goes halfway round, and the particles gets faster and faster, moving in an expanding spiral – till it gets very fast indeed. The cyclotron at Canada's national laboratory in Vancouver is 18 m in diameter and uses a 4000 tonne magnet!

A problem with the cyclotron is that as the particles get faster, relativistic effects become important and the timing of the revolution begins to vary. The result is that the particles go out of step with the changing charge on the semicircles and the particles cannot get any faster.

This limitation was addressed in the synchrotron, an arrangement where the particles move not in the plane between two semicircular discs, but in a circular tube. The tube contains a series of accelerating electric ‘gaps’ and the magnetic field is not by a single, circular magnet but by several magnetic segments, covering the circular path. With control of the timing of the electric switching and the strength of the magnetic field, the path can be kept within the same circular tube even as the speed of the particles increases. The segmented magnet is a great advantage, as weight is reduced and using a tube in place of the discs allows the path to be much longer. As the control of switching and field can take care of relativistic effects, very high speeds, approaching the speed of light, are possible.

Both these particle accelerators were basically designed for pushing charged particles faster and the emission of X Rays was a bye-product, at best. But in the case of the synchrotron, where the particles are at nearly the speed of light, relativistic effects leads to X Radiation in a narrow and intense beam and the arrangement has good features even as a source of X Rays. There have thus been X Ray synchrotrons, set up mainly for generating very high power X Ray beams, with rings from 100 to 1000 metres long.

Reduction in size

The development by the group at Imperial College, etc amounts to making use of synchrotron-like effect which can be created within ordinary dimensions by flashing intense laser pulses through a small jet of helium plasma. The effects of the laser pulses on helium at the atomic scale create very intense electric fields over short distances and lead to rapid acceleration of electrons, which does the same thing as a synchrotron.

In a helium plasma, the gas has been so energised that the electrons and the nuclei are separated and the gas consists of charged particles. Now, if a laser pulse shoots through, the electrical part of the pulse would push the positive and negative ions in the plasma apart, as it rushes on. The helium nuclei, being heavy, would stay put, but the electrons would get drawn, as a group, apart. As the pulse passes, the group would fall back, overshoot, bounce outward again, etc, creating a wave of charge separation that moves at almost the same speed as the laser pulse!

A charged particle, like an electron, introduced into this ‘moving bubble of charge’ would then be rapidly drawn forward and would experience intense acceleration and wavy motion, leading to high energy X Ray pulses. The technique had become interesting in 2005, with the work of Victor Malka and others at ENSTA, France and has now been developed in a more practical way.

“..Extraordinarily, the inherent properties of our relatively simple system generates, in a few millimetres, a high quality X-ray beam that rivals beams produced from synchrotron sources that are hundreds of metres long. Although our technique will not now directly compete with the few large X-ray sources around the world, for some applications it will enable important measurements which have not been possible until now", says Dr Stefan Kneip, lead author on the study,