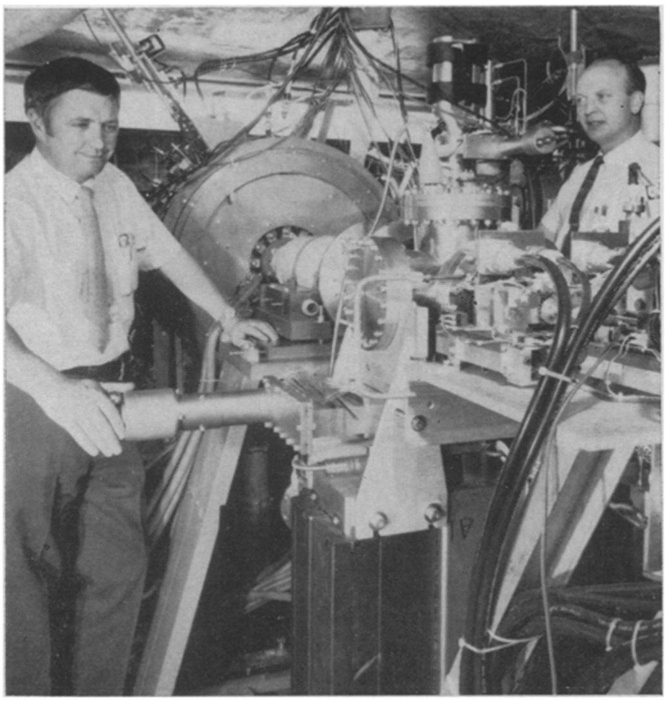
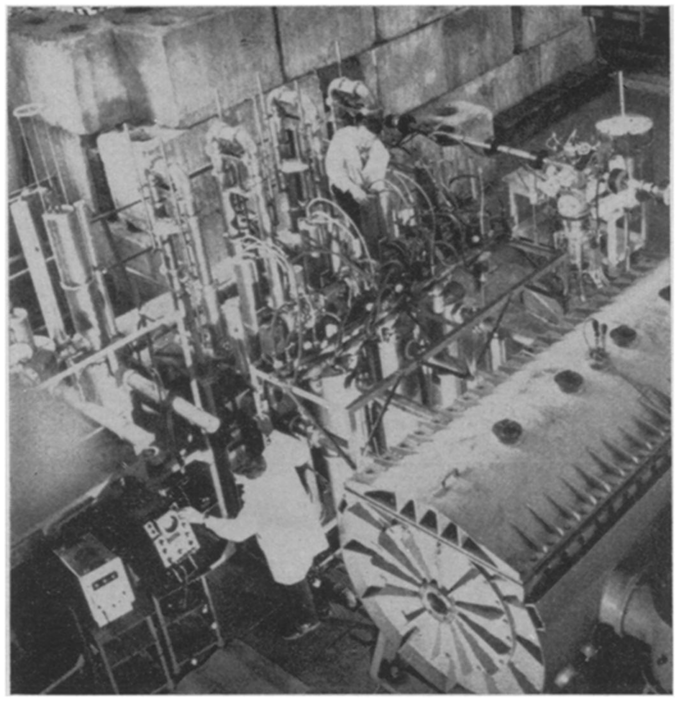


Dennis Keefe, Jack Peterson with ring compressor.



Photos: Lawrence Radiation Laboratory

Workers adjust ERA experimental set-up at Dubna.

PARTICLE PHYSICS

Going along for the ride

Having protons or heavy ions hitch a ride with electrons may lower accelerator costs

by Dietrick E. Thomsen

For 70 years or so physicists studying the microcosm have used accelerated particles to probe structures too small to see and to bring out information about their architecture. The method started with molecules and atoms, progressed to atomic nuclei, and is now being used to elucidate the structure and behavior of subnuclear particles, such as protons and neutrons.

At first physicists used naturally accelerated particles, the alpha, beta and gamma rays that come from naturally radioactive substances. But as the need to study smaller and smaller objects grew, the energy needed by the probe particle went up and artificial means of acceleration had to be developed.

First were linear accelerators that moved electrically charged particles by attracting them from one end of a long vacuum tube to an electrode at the other end and letting them fly out the end when they were up to speed. Then came cyclotrons, which both extended the power and compressed the size of linear accelerators by effectively wrapping them into spirals. Now there are synchrotrons, which use radio waves rather than static electric fields to accelerate particles.

But as energies have gone up, the accelerators have gotten bigger and more expensive, until now the construction of a sizable one is an undertaking equal to the establishment of a fairly large industrial enterprise. The latest United States project, the 200-400-billion-electron-volt (GeV) National Accelerator Laboratory now under construction, will cost about $250 million.

And more is yet to come. Russian physicists have laid plans for a 1,000-GeV synchrotron (SN: 1/18, p. 63). They don't say how much this would cost, but they do say that it would need a ring-shaped vacuum tube something over five kilometers in diameter and a lake or reservoir for cooling water.

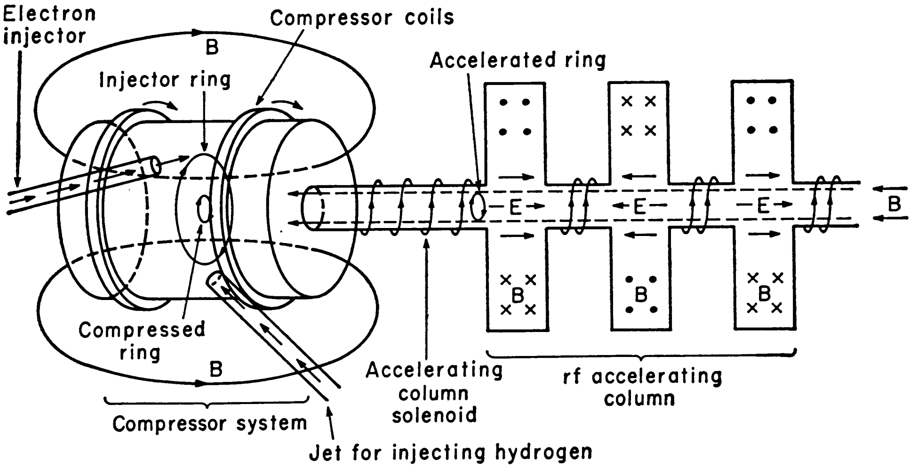
In addition to being cumbersome, these machines are major items in national and international budgets, and many physicists see the budgetary handwriting on the wall: There may be no more money for any accelerators bigger than those now being built.

Thus there is a good deal of interest among physicists in a method of accelerating particles that, if it works, might provide a 1,000-GeV accelerator in a space 1.5 kilometers long. This is only a tenth of the length of the Russian plan, which would have a circumference of 15 kilometers. A 70-GeV machine, about equal to the most energetic synchrotron now operating, could be about 500 meters long and might be built for around $20 million. The current rule of thumb for synchrotrons, $1 million per GeV, would give $70 million or more for a synchrotron that size.

This new type of accelerator would be called an electron ring accelerator (ERA) and is based on an idea that has been mentioned from time to time over the past 20 years, but until now never really pursued.

The idea is basically this: Light particles, such as electrons, can be accelerated to high speeds fairly easily and in short distances. If one accelerated a large cluster of electrons, and if this cluster had trapped within it a few heavy particles, protons or ions, the heavy particles would go along for the ride.

At the end of the trip the heavy particles would have the same velocity as the electrons, but since they are many times heavier than electrons, each of them would have many times the energy of a single electron. A proton, says the current calculation, would have



Electron ring compressor and accelerating column envisioned by LRL.

40 times the energy of an electron in such a case.

The system could work only if the heavy particles were so few compared to the electrons as not to alter the over-all physics of the system very much. A hundred to one is the current estimate. A prototype now under experiment at Dubna in the U.S.S.R. has 10,000 billion electrons to 100 billion protons per pulse. About two-thirds of the energy delivered to the system would stay with the electrons; only a third would go to the heavy particles. But because of the mass advantage, the energy per heavy particle would be large, and this is what counts experimentally.

The first to take up this idea actively was the late Dr. Vladimir I. Veksler of the Joint Institute for Nuclear Research at Dubna, who began experimentation about 1965. His conception started with rings of circulating electrons. In the center of such rings the electric forces would trap and hold heavy positively charged particles that happened to fall there. Once the rings were formed and heavy particles trapped in them, they could be accelerated as a whole.

The geometry of this can be envisioned by imagining a man blowing smoke rings. First the ring is formed, then the whole ring of particles is accelerated sideways in a bunch. In fact, the device was nicknamed a smokatron, but the term has not caught on.

Making such rings, trapping heavy particles in them and accelerating them sideways are all areas in which past experience offers little guidance. Yet when the Russian physicists began to talk about what they were doing, interest and optimism were aroused in many parts of the world. Russian reports in 1967 stimulated the beginning of an experimental program at Lawrence Radiation Laboratory in Livermore, Calif., and in recent months a German group combining talent from Karlsruhe and Munich Universities has also begun.

The practical difficulties are large. "We are entering with this device a new range of phenomena," says Dr. A. M. Sessler of LRL. "Our intuition and practical experiences will not be adequate—alone—to make a successful accelerator. . . . But . . . it is my opinion that the accelerator can be made to work."

Experimentation divides itself into two stages. The first is designing and building an apparatus that will form the rings, compress them to a size where they will trap protons or ions, and trap the heavy particles in the rings. Formation and compression of rings has been reported in recent months by both the Russian and American groups. Now the experimenters are going on to accelerate the rings.

The proper radius for a ring is about four centimeters, but they cannot be initially made that small. Mutual electrical repulsion among electrons makes it hard to put them in clumps and hold them there. Any such clusters will have a strong tendency to blow themselves apart. The practical technique, therefore, is to make the rings quite large at first, which is easier, and then compress them by means of magnetic fields. Meanwhile hydrogen gas is let into the chamber where the compression is taking place. The circulating electrons ionize the gas, and thus a supply of protons is provided.

When the ring is properly compressed, it will be extracted from the compression chamber into an accelerating column.

The rings, as has been said, have a tendency to expand. If the magnetic fields that hold them are so arranged as to allow them to expand radially as they move sideways, they will gain speed in the sideways direction as they expand. Such an action in itself will give the heavy particles an energy of one billion electron volts per particle, and this alone would be sufficient for many experiments in nuclear chemistry. It can also be combined with electrical methods for higher energies.

Thus, electron ring accelerators, if they can be made to work, will be of use in many experiments in nuclear chemistry, nuclear physics and particle physics. "It is not too often that one comes up with a principle that cross fertilizes other fields like this," says Dr. Dennis Keefe of LRL.

The Russian group, which has been led by Dr. V. P. Sarantsev since Dr. Veksler's death, has managed to extract compressed rings from the compressor. "They can't prove that they have trapped ions in the ring," says Dr. Keefe, but they believe they have. They are now engaged in an experiment by which they hope to show definitely that the extracted rings do have ions trapped in them and that they can be accelerated.

The latest U.S. experiment succeeded in making rings at a radius of 19 centimeters and compressing them to 3.5 centimeters. It showed further that introducing hydrogen gas into the chamber increased the lifetime of the rings beyond the time that the decaying away of the confining magnetic field would have allowed them. This the experimenters interpret as electrical focusing by trapped ions in the middle of the rings, and therefore an indication that ions had indeed been trapped.

The next U.S. effort is scheduled for mid-summer, when the LRL group hopes to extract and accelerate the rings. Dr. Keefe will hazard no guesses as to when a practical ERA might be built. "Until we prove that the principle works, we can't go on to design," he says.

If it does work, it may open new possibilities in particle physics experiments. An ERA pulse will be very short in time and space, about one picosecond (10^{-12} second). It will thus be especially useful for experiments with neutral particles, such as neutrons, neutrinos and neutral K mesons, in which precise measurements of momenta and times of flight are important.

Because the ERA pulse is too short to count more than one event per pulse, a bare ERA will not be able to do the kinds of experiments that depend on the longer pulses of synchrotrons to provide a multitude of events from a single shot. These, however, could be provided for, says Dr. Keefe, by adding a beam stretcher and stacking ring. This would be a chamber with magnetic fields so arranged as to pull the tight little ball of particles slightly apart.

Such a stacking ring for a 70-GeV ERA would cost about $16 million, Dr. Keefe estimates. Adding this to the estimate for the ERA itself makes a figure just under $40 million for the whole installation, still a bargain compared with present synchrotron costs. ◇