probes and good efficiency in generating the field that other magnetic-well coils lack.

In April the first baseball assembly, with a 1-meter diameter, began running. The coil, wound of hollow copper conductor is cooled with liquid nitrogen to reduce resistivity (with conventional water-cooled coils about 30 MW would be required; only one-sixth as much power is needed with liquid-nitrogen cooling).

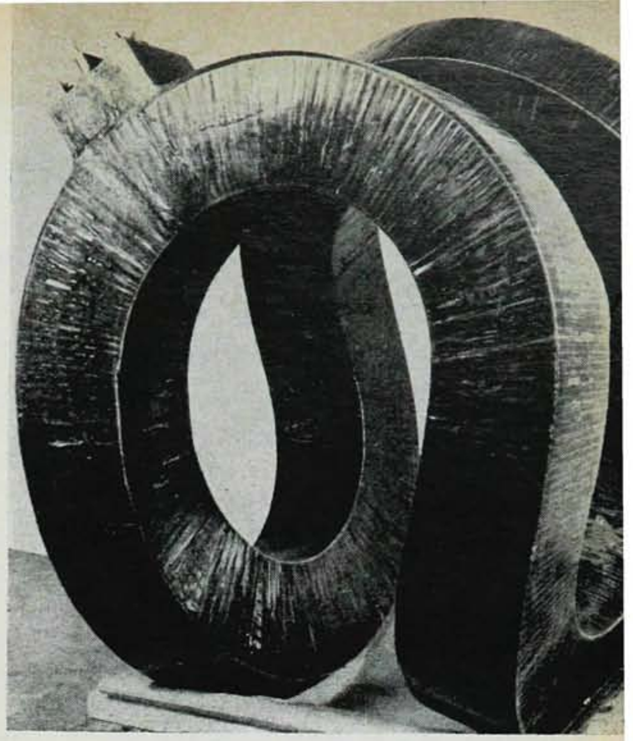
The diagram shows both the curved magnetic-flux lines and the contours of absolute magnetic-field intensity in a central plane of the coil. A central field of 7.2 kG is produced by 2 million ampere-turns. The contours are closed out to about a 30-cm radius, where the field is 20 kG. In this region of closed contours, where plasma containment occurs, the ratio of maximum field to minimum field is about 2.8 : 1. Since the field proportion is short and fat, Post and Damm hope to simplify control of velocity-space instabilities that are expected in open-ended or mirror geometries.

A beam of 15-keV hydrogen atoms is injected to create plasma. Trapping occurs largely from Lorentz-force ($\mathbf{v} \times \mathbf{B}$) ionization of excited atoms; the beam angle is varied to optimize the trapping rate.

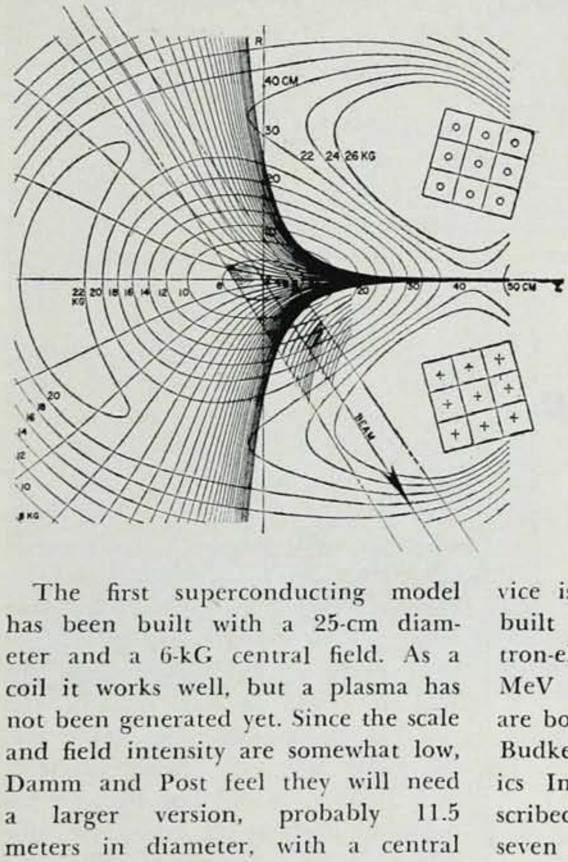
The device is turned on for 5 sec, and in that time the plasma is formed and studied. Coil temperature rises about 100° K, so it is cooled 10 min between pulses. Results are so far very preliminary, Damm says, but plasma has been contained.

In operation the coil is prevented from deforming under the large magnetic forces by an assembly of steel castings and bolts. The entire system is mounted within a 1.5-meter diameter vessel that is evacuated to provide thermal insulation for the coil and the ultrahigh vacuum plasma chamber (also cooled to liquid-nitrogen temperature).

Since plasma buildup time would soon exceed the pulse length achievable with copper, the Livermore physicists had to find a new way of increasing magnetic pulse length. Superconductors seemed to be the best answer, particularly since they want to use stronger fields over larger volumes.



BASEBALL-SEAM COILS used at Livermore to produce minimum-*B* field for experiments on plasma containment and stability. Diameter is 1 meter.



FLUX LINES AND CONTOURS of constant field modulus in one plane of coil shaped like seams on baseball. At 2×10^6 ampere-turns central field is 7.2 kG.

The first superconducting model has been built with a 25-cm diameter and a 6-kG central field. As a coil it works well, but a plasma has not been generated yet. Since the scale and field intensity are somewhat low, Damm and Post feel they will need a larger version, probably 11.5 meters in diameter, with a central field of 10 kG or more. Sometime next summer it may be ready for plasma experiments.

Other participants in the baseball coil program are: Archer Futch, James Foote, Angus Hunt, R. W. Moir, K. G. Moses, L. C. Pittenger and Clyde Taylor.

Novosibirsk colliding beams

A new kind of colliding-beam device that stores 25-GeV protons and antiprotons is being built at Academic City, Novosibirsk, USSR. The device is the third storage ring to be built there; a pair of 160-MeV electron-electron-storage rings and a 700-MeV electron-positron storage ring are both operating. Academician G. I. Budker, director of the Nuclear Physics Institute in Academic City, described the devices in talks given at seven US laboratories last September.

The 25-GeV storage ring, making full use of both proton and antiproton energy, will open a new energy range—10^{12}–10^{15} eV—to high-energy physics, according to Budker. A counterpart, being built at CERN, will inject 27-GeV protons from the proton synchrotron into a pair of proton storage rings.

At Novosibirsk, however, Budker will combine both the accelerator and ring into one device. Two semicircles, each of 45-meter radius, will be separated by two straight sections, each

41 meters long. An iron-free synchrotron, with 70–100-kG field, will inject 500–1000 MeV protons into the ring; 10^{14} particles are expected. In a one-minute interval the field will be increased until the protons reach 25 GeV. The proton beam will then strike a target, and a much smaller number of antiprotons will come off -10^7 antiprotons are expected; antiprotons will be stored in a small additional ring. By repeating the process 1000 times Budker expects to obtain 10^{10} antiprotons. Once that intensity is reached the protons and antiprotons will be accelerated and allowed to meet.

The device is expected to cost $8 million. (Budker notes that 1000 GeV from a conventional accelerator would cost more like $1 billion.) Tunnel construction was scheduled for completion in October before the Siberian ground froze.

Meanwhile the 160-MeV electron-electron-storage rings have been used to study elastic scattering at 43, 135 and 160 MeV. Results agree, within experimental error, with theory.

The 700-MeV electron-positron ring, which recently started running, produces a 2-ampere electron current. and 20 milliampere positron current. Characteristic instabilities of the electron and positron beams have been photographed with the synchrotron light produced by the beam itself. The very intense light lasts for many hours. As electrons disappear, the light drops off in steps; at the last step only one electron remains and one can observe with the naked eye, the light from the single electron. The lifetime of this last electron has been as long as 12 hours. So one can leave the electron at night and still see its light the following morning.

When electrons interact with positrons, one can observe elastic scattering or annihilation with formation of two photons, two muons, two pions or two kaons. Right now pion formation at 380 MeV and kaon formation at 510 MeV are being studied. Next year physicists expect to examine photon and muon formation.

Other laboratories are also doing colliding-beam experiments, including a Stanford-Princeton group, operating electron-electron rings at 500 MeV, and a French group, which is expected to start experiments with a 500-MeV electron-positron ring in a few months.—GBL.

PPA beam extracted

After a year of effort physicists at the Princeton-Pennsylvania accelerator have succeeded in extracting the synchrotron's beam. The method of extraction, which is the same as the one used on the electron accelerator at Frascati, employs betatron oscillation to blow up and spill the beam. Specifically the radial betatron resonance, $\nu_r = 2/3$, is excited so that the radial oscillations of the beam build up and move the protons so far from the equilibrium orbit that they find their way into the field of an extraction magnet that bends them out of the accelerator.

Exciting the oscillation requires special magnets. First the synchrotron's magnetic field index n must be raised from the measured value of 0.60 to 0.67 to tune the machine to the 2/3 resonance. [$n = -(R/B_z)(dB_z/dr)$; R is the radius of curvature of the normal trajectory taken in the center of the beam, B_z is the field along this trajectory, and dB_z/dr is the radial derivative of B_z.] In addition, since the resonance is nonlinear, an azimuthal second harmonic in the radial gradient of n must be provided. Extensive digital calculations determined the quadrupole and hexapole field components needed and thereby showed that the existing pole-face windings on the synchrotron magnet could not be used (this had been done at Frascati) because they could not carry enough current.

Therefore four excitation magnets were constructed and placed symmetrically in four short straight sections around the machine. These are current-sheet magnets, 30 cm long, with an aperture of 6 × 18 cm. Their left and right sides are separately powered by modulators capable of delivering 200 amperes at up to 75 volts. The quadrupole component (approximately 85 gauss/cm), which tunes the betatron oscillations to resonance, is given by the sum of the currents in the two halves of the magnet. The