IMPRESSIONS FROM A VISIT TO THE U.S.

High magnetic field conference at M.I.T.

The conference dealt mainly with the design and construction of magnets which generate magnetic fields in the range from 50 to 250 kgauss and with the cooling systems and power supplies for these magnets.

Water cooled magnets.

This type of magnets has especially been studied by Bitter and coworkers. The old MIT magnet laboratory has several Bitter magnets operating around 100 kgauss. These are all solenoids with inner radii varying from 1" to 4".

For the new MIT National Magnet Laboratory they have tried to push the design of these magnets to the limits of mechanical strength and heat transfer rate. Cooling of the new magnets will be obtained by nucleate boiling. Approximate design parameters are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of cooling passages</td>
<td>1.5 mm</td>
</tr>
<tr>
<td>Water velocity</td>
<td>20 m/sec</td>
</tr>
<tr>
<td>Fraction of water evaporated</td>
<td>0.5</td>
</tr>
<tr>
<td>Heat transfer rate between copper and water</td>
<td>1500 Watt/cm²</td>
</tr>
<tr>
<td>Copper temperature</td>
<td>200°C</td>
</tr>
</tbody>
</table>

A large 250 kgauss DC magnet has been designed for the new magnet laboratory. It consists of three solenoids inside each other, has a 1" bore and is about 30" long. Its DC rating is 14 MW.

The MIT group has found that zirconium copper with 0.15 o/o Zr is twice as strong as copper alone, while its resistivity is only a few o/o higher. Chromium copper has similar properties, but its mechanical strength decreases rapidly at temperatures above 200°C. For both alloys careful heat treatment is necessary to obtain this mechanical strength.

FS/2990
The new magnet laboratory will have 4 DC flywheel generators with a total power of 8 MW continuous, 12 MW during 15 min, 16 MW during 1 min and 32 MW during 5 sec. The stability is 0.015 o/o, the ripple 0.02 o/o. The 4 generators in parallel can give 40000 A continuous and 160000 A during 5 sec.

For flexible high current connections, copper braid surrounded with a rubber hose carrying the cooling water is used.

**Cryogenic magnets.**

Low temperatures can be used either to reduce the input power of large DC magnets or to obtain large pulsed fields with a modest power supply and refrigerator using the heat of evaporation of a large quantity of stored hydrogen.

Calculations for large DC magnets have especially been made by Post and Taylor at Livermore in connection with fusion work. Sodium and aluminium are the most suitable since they can be obtained in very pure form and have the lowest magneto-resistivity. The latter is the dominant contribution to the resistance at low temperatures and in high magnetic fields. The decrease in resistance at low temperatures with respect to room temperature is about $10^3$ x. However, for a given quantity of heat evacuated at $15^\circ$ K, the refrigerator requires about $10^2$ x more power. Therefore the nett power saving would be about a factor 10. Representative design figures are:

<table>
<thead>
<tr>
<th>magnetic field</th>
<th>best operating temperature</th>
<th>power reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>for Al</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kgauss</td>
<td>16$^\circ$ K</td>
<td>25 x</td>
</tr>
<tr>
<td>20 kgauss</td>
<td>17 &quot;</td>
<td>12</td>
</tr>
<tr>
<td>50 &quot;</td>
<td>17 &quot;</td>
<td>10</td>
</tr>
<tr>
<td>100 &quot;</td>
<td>17 &quot;</td>
<td>9</td>
</tr>
<tr>
<td>for Na</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kgauss</td>
<td>6$^\circ$ K</td>
<td>17 x</td>
</tr>
<tr>
<td>20 &quot;</td>
<td>8 &quot;</td>
<td>10</td>
</tr>
<tr>
<td>50 &quot;</td>
<td>8 &quot;</td>
<td>9</td>
</tr>
<tr>
<td>100 &quot;</td>
<td>10</td>
<td>7</td>
</tr>
</tbody>
</table>

The coils would be cooled with He gas.

FS/2990
The capital cost of coil, power supply and the refrigerator are about the same as for a copper coil with its supply, operating at room temperature.

If a coil is placed in a large bath of liquid $H_2$, it can be pulsed to a high field with a small power supply. After all $H_2$ is evaporated the coil will rapidly heat up and the current will decrease to a small value. This has been or will be used for experiments in various places. In Los Alamos is a Cu coil that gives 50 kgauss at 15 kW and 60 kgauss at 25 kW. At NBS Boulder is an Al coil giving 60 kgauss at 2.5 kW. The latent heat of liquid $H_2$ is 32400 J per litre and one litre costs 0.45 dollar at Boulder. In both laboratories the boiled off $H_2$ is vented into the atmosphere, without igniting it through a pipe of modest height. A typical run might consume 500 to 1000 l of liquid $H_2$.

At NASA, Cleveland, which laboratory is near to an airport they use liquid neon, which boils at 27.2°C K, because of safety regulations. They are also installing a He liquefier with a capacity of 100 l/per hour and with a storage capacity of 7000 litres. In future they intend to double both liquefying and storage capacity of He.

There seemed to be a general feeling that these cryogenic coils will lose much of their interest because of the developments in superconductors.

Superconducting magnets.

a) General

Most of the papers on superconductivity were concentrated in the last (in our opinion the most interesting) day of the conference.

Progress is being made in the art of producing superconducting materials and in making small magnets (mostly solenoids). The physical background and some of the experimental phenomena are not yet well understood. It is generally found that, although the critical fields would be sufficiently high for many applications, the critical current densities are too low. It appears that in tightly wound coils the critical current density is considerably lower than in small wire samples, in a way that cannot easily be explained by the stray field of neighbouring wires.
b) Materials

Kunzler (Bell Lab.): The general behaviour of hard superconductors is as follows:

\[ \log i \rightarrow H_{\text{max}} \]

The value of \( H_{\text{max}} \) depends on the material, not on the amount of cold working.

The following values were obtained with samples:

They made a coil of Nb3Sn wire. The characteristics are shown below.

The field is the sum of the field caused by the solenoid and an additional external field.
They also made a piece of Nb₃ Sn wire of 12000 ft long, 32 mil diameter.

For 10 mil Nb-Zr wire (50 at. o/o Zr, made by Wah Chang Corp) he gave the following curves:

![Graph showing magnetic properties of Nb-Zr wire]

A higher percentage of Zr, up to 50 o/o, increases $H_{\text{max}}$, but decreases $I_{\text{max}}$.

Bending the wire with a radius of 1 cm reduces $I_{\text{max}}$ by a factor 10; radius 3 mm gives factor 10 - 100. $H_{\text{max}}$ is not affected by bending.

They also used Mo-Re wire up to 15 kgauss. It behaves in the same way in coils as in short lengths.

Reed (MIT) told about a new material Nb₃ In. They have made this at a pressure of 50 kbar, at 1200° C (specimens of 1/2 cu.in). It is brittle and hard. Transition temperature 9.2° K.

Autler (MIT) gave curves for the 10 mil Nb-Zr wire, made by Wah Chang Corp. (Albany, Oregon).

The composition is 25 at. o/o Zr.
The lower curve is found if the wire is wound in a tight coil. This was confirmed by other speakers. It is not well understood, why. (We heard later from Aron and Hitchcock at Berkeley that they made a coil that quenched always at the same current density, with or without an external field of 70 kgauss. The coil itself produced 4.4 kgauss).

The maximum current in Nb-Zr depends on the rate of rise, according to Autler. The increase should be quite slow. There is also a "training effect". After increasing the current several times (without quenching), \( I_{\text{max}} \) increases.

A small motion of the wire can cause quenching, even at very low field and current. Wire must be fixed very well. He thinks it might be explained by the low heat capacity, if the work done on the wire would be converted into heat. This is not at all sure.

They made a cylinder of massive \( \text{Nb-Sn} \), of \( \frac{1}{2} \)" diam., 1.5" long, with \( \frac{1}{4} \)" hole. At 4.2° K this cylinder when placed in an external field, shields fields up to 25 kgauss. This corresponds to a current density in the cylinder of \( 10^5 \) A/cm². This is much better than the results of Kunzler et al., on arc-melted material. This cylinder was made by first compressing to 95 o/o of the theoretical density, then sintering and heat treatment.

After the field breaks through and is lowered again, 25 kgauss is trapped inside the cylinder. With pulsed fields of 10-20 msec rise time, fields up to 15 kgauss are trapped. Another cylinder of larger diameter (1") trapped less flux.

Susceptibility measurements on wires show that only 1 - 2 o/o of the material is superconducting. However, specific heat data (Kunzler) suggest that most of the section is superconducting.

Hulm (Westinghouse) said that their Nb-Zr wire has exactly the same characteristics as the Wah Chang wire.

Trefting et al. (Bell Lab) described the effect of heat treatment on Nb-Zr alloys. Two hours at 500 - 700° C improve the current carrying capacity. With 400° C it is somewhat worse at low fields, but much better at 60 kgauss. Subsequent cold-rolling (15 mil \( \rightarrow \) 5 mil) gives much improvement. Flat specimens, not wire, were used. Heat treatment in good vacuum. The cold-rolling may also be done before the heat treatment.
Hart et al. (Gen. El), measured Nb\textsubscript{3}Sn wires in pulsed fields up to 196 kgauss. Pulse was a half sine wave with rise time of 9 msec. Induced voltages cancelled with extra coils; $10^{-4}$ V detectable.

Results:

![Diagram showing Nb and Nb\textsubscript{3}Sn with 4.2 K temperature and field strengths](image)

The wire was heat-treated during 2 h at 1000$^\circ$ K. Measured transition fields depend somewhat on the rate of rise, being higher with slower pulsing.

Saur et al. (Giessen, Germany) described how Nb wires were coated with Nb\textsubscript{3}Sn by diffusion of Sn into Nb in 3 different ways: dipping, evaporating and electroplating. Transition widths of less than 0.05$^\circ$ K near 18$^\circ$ K were measured. No $I_{\text{max}}$ or $H_{\text{max}}$ was measured.

Layers are 0.1 - 0.2 mm thick. Dipping technique is as follows:

- Nb wire is dipped under vacuum into molten tin at 1100$^\circ$ C during 16 minutes. Afterwards, the wire is post-treated at the same temperature during some hours.

It is claimed that rods, sheets, etc., can be coated in this way.

Hanak described results of another coating process, developed by RCA, and called an "irreversible chemical transport technique". How it is done, is secret, as well as what materials are coated. Deposition of 1/2 mil - 2 mil layer on 7 mil ductile wire is possible. Crystallites oriented perpendicular to the surface. Lengths of 300 m have been made. Ribbons 3 mil thick, 20 mil wide, can also be coated. A picture was shown of a ceramic cylinder with coating on it.

PS/2990
Results:

It was said that $I_{\text{max}}$ is proportional to the cross sectional area.

Kneip (Oak Ridge) told about increasing $I_{\text{max}}$ of Nb-Zr by heat treatment + cold working. According to him, 800° C is necessary. Effects of heat treatment and of cold working are additive.

Wernick (Bell Lab) announced they had just found a new alloy, V₃Ga (Vanadium-Gallium). It has a transition temperature of 14.5° K. The critical field was measured as a function of temperature up to 80 kgauss. From extrapolation of this curve, in comparison with the behaviour of other alloys, it is thought that $H_{\text{max}}$ at 0° K might be greater than 500 kgauss.

The current carrying capacity and mechanical properties are similar to those of Nb₃Sn. It is made by melting at 2005° C in an alumina crucible in argon atmosphere.

Taylor told us later (at our visit to Livermore) that the Nat. Research Corp. in Cambridge, Mass. have made thin layers of Sn on 10 mil Nb wire. The layer carries $10^6$ A/cm². He did not know how thick it can be made.

c) Coils

In many laboratories coils (mostly solenoids) have been made. The following were reported:

Kunzler (Bell Lab) reached 67 kgauss in an 8000 turns solenoid wound with Nb₃Sn wire of 3 different cross sections (30, 25 and 20 mil outside diam). The purpose of this is to have smaller current density in the inside turns where the
strey field is strongest. Current was 75 A, limited by power supply. They hope to reach 75 kgauss with this coil eventually. The working space has a diameter of 1/4". The wire has a monel insulation. This makes the time constant long (1 minute). The joints are made outside the field, by indium solder.

Autler et al. (MIT) have made a coil with 1 kilogram Wah Chang Nb-Zr wire (10 mil). It has a hole of 1/2" diam. and 2.1/2" long. Max field 50 kgauss.

They also made another coil with 780 m of 20 mil Nb₃Sn wire from Nat. Research Corp. that gave 28.5 kgauss in a hole of 1/2" diameter. It has a stainless steel coil form and ceramic insulation with Sauereisen cement no. 1 (Nb₃Sn coils must be sintered after winding). They had some superconducting shorts between turns, and think wire for big coils should be insulated better.

Donadiou and Rose (MIT) are planning a large solenoid (4 ft long, 8" diam. working space, 28" outer diameter). It should make 25 kgauss (perhaps 40). The weight of wire will be 550 lbs (Nb-Zr). The connections of this wire are said to be easy to make. (Spot-welding or clamping). The radial bursting force can be taken by the wire. The 10 mil wire can stand 200000 psi. Stored energy 300 kJ at 30 kgauss. The energy must be dissipated by metallic shells in case of quenching. They are afraid of an explosion. The helium is therefore carried in separate copper tubes, with gas exhausts. The connecting leads will only carry current during "charging" of the magnet. A thermal switch, shorting the coil, will be built in near the magnet.

The magnet will be supported by 4 ft long stainless steel tubes.

Heat losses:

\[
\begin{align*}
\text{support} & \quad 0.1 \text{ W} \\
\text{leads} & \quad 0.25W \\
\text{radiation} & \quad 0.037W \\
\text{radiation} & \quad 0.25W
\end{align*}
\]

for He

for N₂ shield

The precooling would be done with N₂ first. It would cost 60 l N₂ and 60 l He. For going from zero to top field, 20 l He are required, because of the eddy currents in the stainless steel shells.

Hake et al. (Atomsics International) have reached 59 kgauss in a solenoid with hole 0.5 cm diam. length 5 cm, winding thickness 2.5 cm. They used 10 mil Wah Chang Nb-Zr wire. With earlier coils they had trouble due to high voltages between turns at quenching. Therefore this coil was made with uninsulated wire, with

FS/2990
2 mil copper foils between layers. Time constant 15 - 20 sec. They still heard a bang at quenching. After quenching 3 times the coil was still O.K. They find a hysteresis effect: with decreasing current the field is 2 kgauss higher than with increasing current. They think it is due to trapped field. Their max. current is 19 A.

Betterton et al. (Oak Ridge) made a small hyperco-cored magnet, using both Nb₃Sn and Nb-Zr coils. With either type 25 kgauss was made in a volume of 0.3 x 1.2 x 4.1 cm. Cycling 300 times without current between room temperature and liquid He temperature appears to do no damage, but repeated quenching reduces I_max. They have a theory that the ends of superconducting filaments are heated too much by quenching.

Hulm et al. (Westinghouse) made a coil, using 7.5 mil Nb-Zr wire (25 at o/o Zr). Length 2", central hole, 0.15" diam. Peak field 58 kgauss. Current density 5.10⁴ A/cm². They use a titanium former because this has the same thermal expansion coefficient as Nb-Zr. Joints are made by pressure, outside the field. Stored energy is 100 J. At quenching a bang is observed. They say the decay time is about 100 µsec.

The firm Magnion Inc. (195 Albany Str. Cambridge 39, Mass) distributed catalogues of superconducting magnets, cryostats and power supplies. They claim that they can make 60 kgauss magnets with a hole of 2" diam. The length is 8", the outer diam. 4.62". Critical current 20 A, stored energy 180 kJ. However, it does not seem very probable that they have ever made this. They offer also many smaller types as well as room temperature magnets, d.c. and pulsed, and pulsed power supplies up to 45 kJ.

Homopolar generators.

At NASA, Cleveland a homopolar generator has recently been installed. Maximum voltage is 30 V, maximum current 200,000 A and maximum power 3 MW. The revolution speed is 7200 rpm. It is driven through a gear box. Its price is 250,000 dollars including auxiliaries. The brushes are liquid NaK, its internal resistance 4 micro-ohm. It was built by Allis-Chalmers. The ripple on the output is less than 1 mV. The NaK pumps, storage tanks and coolers are at least as big as the generator set itself.

PS/2990
P. Klaudy in Graz, Austria has done some experiments on homopolar generators with Hg jets as brushes. High velocity Hg jets, with current densities around 50 A/mm² can have a small cross section. This results in much smaller friction losses than in present commercial homopolar generators, which use complete NaK rings as brushes. The Hg is recirculated through a cooler. He has built a small machine for $2 \times 10^4$ A and 14 V at 9000 r.p.m. The circumferential velocity of the rotor is 130 m/sec.

**Miscellaneous**

H.P. Furth from Livermore discussed patterns in fast pulsed coils. If the skin depth is small the flux lines are identical to the equipotentials of the electrostatic analogue with surface charge densities proportional to the skin current density. This well known principle may sometimes help to visualise magnetic field patterns.

W. Bergmann from Munich is building a 7 cm $\phi$ propane bubble chamber operating in a pulsed field of 300 kgauss. The single turn coil, with which the propane is in direct contact is pulsed from a 300 kJcule, 18 kV capacitor bank. He intends to do precession experiments at the CERN FS using the fast kicker magnet to dump the beam on a target in 2 μsec.

K.E. Wakefield and others from Princeton discussed possible practical designs of "force free" coils. A completely force free coil requires several times more power than a conventional coil, while the accessibility of the volume filled with magnetic field is very bad. In some cases however it may be possible to obtain a significant reduction of the forces with a modest increase in power.
Stellarator C at Princeton

This group consists of 400 people of which about 100 with academic training. The Stellarator C, with only the confining windings on, has been in operation at a 40 kgauss level since last August. The engineering of this machine is impressive and very well done.

There are 3 MG sets. Each of these consists of 4 DC generators for 800 V, 5075 A continuous or 22000 A pulsed during 1 sec, a 96 ton flywheel and a 7000 HP motor, mounted on a common shaft, running at 355 r.p.m. The DC generators are paralleled in pairs to give a top current of 44000 A. Groups of Stellarator coils and pairs of generators are series connected in such a way that the total voltage to ground is a minimum.

The current has a flat top of 1 sec with a 1/2 o/o current regulation. At top current the repetition rate is one pulse per 40 sec. Apart from the large electromagnetic forces, the coil design must take into account the thermal breathing of the conductors due to the sudden heating up during 1 sec and subsequent cooling down. The attractive force between the two U-bends of the Stellarator at full current is about 1200 tons. The stainless steel supports of the Stellarator are enormous.

Allis Chalmers constructed the MG sets and the Stellarator coils. The latter are made of copper, whereas the pipes of the demineralised water system are aluminium. There were no corrosion troubles up to now. We later saw the same arrangement at the AGS in Brookhaven.

The total price of the Stellarator C including buildings is 35 million dollars.

Vacuum is obtained by means of Hg pumps with ultra high vacuum traps. The pressure in the bakeable stainless steel and ceramic Stellarator C vacuum chamber is claimed to be \(10^{-10}\) mm Hg.

K.E. Wakefield has large resistor networks (one with 14000 resistors) which were used to design the confining and stabilising Stellarator coils. He now uses them to design force free coils.

There is a special coil winding shop with about 8 people. Coils are usually insulated with glass tape or sleeve and impregnated with epoxy resin.

PS/2990
In many pulsed circuits ignitrons are used and therefore an extensive igniton testing programme has been carried out for pulse durations in the msec range. The results are described in report MATT-30. G. Bronner has also designed circuits that can "turn off" ignitrons conducting some hundreds amperes within microseconds. This is described in Technical Memo No. 113. They consider the GL 5555 a good tube and often use it. In general they feel that current theories about the igniton and conduction of ignitrons are inadequate, and do not explain the experimental results.

They have found that replacing Hg in the ignitrons by Cs gives a longer life to the ignitrons.

They have also made a 100 kV igniton by dividing the tube in glass and metal rings (five of each). The distance between anode and cathode is 3 cm.

The total number of Coulombs per pulse that can pass through a vacuum gap, a spark gap at atmospheric pressure and an igniton is about 2,6 and 30. However, sparkgaps can hold off higher voltages. In one circuit, where 120 kV capacitors are discharged into a coil, with a ringing frequency of 200 kHz and Q ≈ 30, N.W. Mather uses sparkgaps at atmospheric pressure made by R.C.A. Up to now there is little experience with the sparkgaps but they have burnt out some capacitors. They ascribe this to overvoltages, caused by parasitic high frequency oscillations, due to reflections in the cables. At 40 kV they have successfully triggered parallel sparkgaps 30 cm apart. It seems that Holliday at G.E. in England has made an experimental igniton that holds off 100 kV. In their oscillating circuit they find that the sparkgaps have an effective resistance of 80 m ohm at 50 kHz which decreases to 10 m ohm at 450 kHz. Teflon appears to be a convenient insulating material for use in sparkgaps.

Princeton accelerator.

The accelerator was recently described by Resegotti and nothing has changed since then.

O'Neill gave us some data about his delay line kicker magnets, made for the Stanford colliding beam experiment. These have now been pulsed satisfactorily several million times in vacuum. The pulse duration is 160 nsec, the rise time 20 nsec and the time jitter of the sparkgaps 10–20 nsec. Each storage ring has 2 kicker magnets.
that are pulsed in parallel. The characteristic impedance of each magnet is 11 ohms, the energy is stored in 9 parallel RG9 - U cables, charged to 50 kV.

The current in each kicker magnet is about 2500 A, the magnetic field 2300 gauss. The terminating resistors are SiC cylinders, with a wall thickness of 6 mm in an oil bath. The magnets get quite hot when they are running for a long time in vacuum, since the repetition rate is 60 cps. The average dissipation is 1200 W.

Brookhaven

So many people have visited Brookhaven by now, that few new comments can be made. It struck us that the services for experimentalists at the AGS are much less developed than at CERN. There is no counting room, no fixed counting cables and no power house for beam transport supplies. Each experimental group has to set up its equipment in some blockhouse in the experimental floor and the rectifiers for the beam transport are placed on top of shielding walls or wherever there is some free space. This will in general require more improvisation on the part of the experimental teams. On the other hand the fact that both at the AGS and Cosmotron the experimenters have access to most parts of the experimental hall makes it much simpler to make small adjustments to a counter set up or to inspect equipment like liquid hydrogen targets without interrupting the operation of the machine.

The neutrino shielding is complete except for the roof over the sparkcounter which is at present being assembled. There is some concern about the AGS magnets near the neutrino shielding which have sagged a few millimeters. If necessary they will be realigned. Full operation of the AGS will be resumed around Nov. 20th.

The results on the 3.3 GeV/c antiproton beam have been written up and will be published in the proceedings of the Brookhaven Conference on Accelerators. The total length of this beam is 85 m and they intend to make also some runs with 2.3 GeV/c K⁻ mesons, for which the intensity should be just sufficient. There are 7 new separator tanks, with crossed electric and magnetic field under construction. Each tank is 5 m long. They are rectangular boxes with large flanges that can be screwed directly against each other to make one long separator of any desired length up to 35 m. The 5 m tanks have no high voltage bushings. These are mounted on separated short service sections, that are screwed in between the tanks. With these tanks a 6 GeV/c separated antiproton beam will be set up, (some time after April 1962).

PS/2990
Laskey is working on a slow ejection system. It consists of an energy loss target, a small septum magnet and a larger ejection magnet. The small deflection magnet has an aperture of 2 x 1 cm and is 200 cm long. The magnetic field is 2000 gauss. It is pulsed with a 6 V, 2000 A flat top pulse. Rise time is 20 msec, the flat top lasts 300 msec. The power supply is a copy of the ones that are used to saturate the ferrite cores in the RF cavities of the AGS. The current is switched with 200 transistors type 2N277. A short model of this septum magnet operates satisfactorily. The large ejection magnet and its power supply will be a copy of the one that is used in the Cosmotron. Both magnets are mounted on hydraulic rams. The small septum magnet moves 9 cm in 0.1 sec and the large ejection magnet moves 5 cm in 0.1 sec.

The Cosmotron ejection magnet has a septum made of 18 turns of square copper conductor with on the outside an iron magnetic shield. The total thickness of septum and magnetic shield is about 25 mm. It is pulsed with a 200 msec flat top from a MG set.

The slow ejection system can be converted into a fast ejection system by replacing the energy loss target with a delay line kicker magnet.

The Cosmotron has a beam intensity somewhat below 10⁸ protons per pulse. This limit is given by space charge instabilities. It is planned to install a 15 MeV linac as injector next year. This should lead to a beam intensity of a few times 10¹² protons per pulse.

There is a very comfortable stock of bending magnets, normal quadrupoles, Panofsky quadrupoles and rectifier power supplies at the AGS. At present at most half of these are in use. The bending magnets are of the poleless picture frame type. The homogeneity is a few parts in 10³ across the whole gap at field as high as 16 kgauss. The coil slots of the quadrupoles are rectangular, with the poles tapered at 45°. Maximum field on the pole tips is 12 kgauss. These designs use more power than our standard magnets, but their field distribution is better.

The stability of the rectifiers for the beam transport magnets is claimed to be appreciably better than one part in 10⁴ (description in reports JGC/EAK/AVS-1 and EAK - 1).

FS/2990
The electron-synchrotron is running with an intensity of a few times $10^9$ electrons per pulse and repetition rate of 1 pulse per second. The magnet can go up to 1.5 GeV but at 1.3 GeV the radiation loss starts to exceed the energy gain from the RF system. The beam intensity fluctuates strongly. The injection tuning is delicate. The injection field is 13 gauss, and the remanent field 30 gauss. Some perturbations are reduced by demagnetising in between pulses. The field is first pulsed to a slightly negative value and the electrons are injected when the rising field passes through 13 gauss. Frequent readjustment of the current in the pole face windings is necessary in order to retune the injection. It is hoped to eliminate these difficulties and to increase the beam intensity by at least an order of magnitude by installing a 10 MeV injector linac next year. They have a flat top operation with a beam spill of 40 msec duration.

All experiments are done with a $\gamma$-ray beam falling on an external target. Two experiments are in progress to measure the angular distribution of the $\pi^+$ and $\pi^0$ produced in this way down to small angles. Another experiment tries to measure the relative $K^+\Lambda$ parity from the reaction $\gamma + p \rightarrow K^+ + \Lambda$. There are some 25 counters forming a range telescope to detect the $K^+$ and to register the decay proton of the $\Lambda$. If an event satisfies certain electronic selection criteria, the pulse heights of all 25 counters are stored and punched out on paper tape in between synchrotron pulses. The paper tape can be fed directly into the computer.

Peterson has a 5 kV, 40 kJ capacitor bank, that he uses to pulse various types of magnets. One interesting example is a 60 kgauss, 90° analysing magnet for $K^+$ with momenta below 300 MeV/c. The radius of curvature is 17 cm because of the short decay length of the $K^+$. The frequency of the discharge is 1 kHz. There are saturable chokes in series with the ignitrons in order to extinguish them after half a cycle, which leaves the capacitors charged with opposite polarity. By pulsing once more a low loss coil with a second set of ignitrons 50 o/o to 75 o/o of the charge is recovered with the correct polarity. In this way the size of the charging supply is reduced.

PS/2990
We received technical note BeV - 626 that summarizes all presently available beam transport equipment.

The most interesting type of magnet is a high field C - magnet with both sides of the coil in the gap (pole less construction) and the end turns bent up to leave a passage for the particles. The gap height and width are 20 cm and 40 cm, the length is 90 cm. At 18.5 kgauss the power is 300 kW and $\int B_z \, dy$ taken along a straight line in the direction of the particle trajectories decreases by about 2 c/o from the coil edge near the yoke to the coil edge at the open side of the gap. The variation is rather linear, so that at least half of it can be corrected with a quadrupole.

All new power supplies are rectifiers which cost 100 dollars per kW against 200 dollars per kW for the rotating machines.

For current measurements Windsor has developed DC transformers instead of shunts. These are linear over a current range of at least 50 : 1 and have a stability better than 1 in 10$^4$. Their construction is such, that they are insensitive to stray magnetic fields up to 50 gauss. The carrier frequency is 60 Hz, but the frequency response extends beyond 10 kHz, (report UCRL - 9464).

There is only one Panofsky quadrupole in use at Berkeley and at most two more might be ordered.

The components for the Bevatron ejection system are under construction. By far the most impressive part of it is a quadrupole and a large septum magnet that have together with their supporting structure a total weight of 7000 pounds. This ensemble is mounted on a large hydraulic ram that brings them into position during the second half of the acceleration cycle. The total horizontal motion is 75 cm in 0.5 sec. We saw the test setup in operation and a reproducibility of positioning of 1 mil was demonstrated to us. All this will be installed during the long shutdown that starts in May 1962.

The complete ejection system consists of 2 Panofsky type quadrupoles and 2 septum magnets, all of different size. These 4 magnets will be pulsed in such a way that their magnetic fields track the Bevatron guide field with a precision of 0.1 c/o both during the rising part and the flat top of the magnet cycle. The quadrupoles focus
the beam in both planes, at the point where it passes through the stray field, in order to minimize its effect. Current is supplied by a roughly programmed rectifier through a series reactance. Accurate current control is obtained with about 400 shunt transistors in parallel with the magnet. The transistors are rated at 10 o/o of the peak magnet power requirement. The largest magnet is rated at 42 V, 4500 A. The rectifiers are of the standard type used for beam transport.

They now have two electrostatic separators with crossed E and B of 6 m length. The plate width is 25 cm and the plate spacing is 5 cm. The cathode is sodium lime glass, heated to about 100°C. The maximum gradient at which the separators can be run is 90 kV/cm. The anode is at +250 kV, the cathode at -200 kV. In a similar separator with stainless steel cathode a gradient of 70 kV/cm could be reached. Best results are obtained in the glass cathode separator if some argon gas with a pressure of about 10⁻³ mm Hg is let into it. It is always necessary to bring the electrostatic field to its full value before switching on the magnetic field in order to avoid breakdowns. They will use HV cables with an inner conductor of semiconducting plastic material, serving as damping resistor. There are 3 screens between inner and outer conductor, connected to intermediate potentials that are available from the Cockcroft-Wilton sets they use. These intermediate screens also provide the voltage supply for intermediate conductors in the feedthrough insulators.

Using these two separators Ticho has made an excellent separated K⁻ beam. The maximum momentum is 1.85 GeV/c, the momentum bite 6 o/o. The total enrichment factor is about 30'000 x and at least 3 particles out of 4 entering the 72” bubble chamber is a K⁻. A sketch of the beam optics is shown on page 20. The target is located in one of the quadrants of the Bevatron. K⁻ produced in the forward direction, are deflected outward by the Bevatron magnetic field and emerge through a hole in the yoke. Particles with different momenta are deflected through different angles. If b is the virtual target in the horizontal plane for the central momentum a and c are the virtual targets for particles with too high and too low momentum respectively. The quadrupoles Q 1,2 make in the horizontal plane an image of the target on BM 1,2 and in the vertical plane a parallel beam, that passes through the first separator. The magnets BM 1,2 are shimmed in such a way, that their focal length for vertical focusing depends on the lateral position with the result that all momenta are brought to a perfect vertical image at S1. There are 2 bending magnets BM 1 and BM 2 because one magnet was not
strong enough. Rough shimming is done with steel shims, fine trimming with pole face windings. Q3 is a single horizontally focusing quadrupole that images BM 1,2 on BM 3,4. It has no effect vertically since its centre coincides with S1. The second stage is identical to the first stage in the reverse order. BM 1,2 deflect in a direction opposite to the Bevatron field, BM 3,4 in the same direction. The target is 100 mil high. With a demagnification of 0.6 the width of the image between points of half intensity at S1 is 90 mil and at S 2 it is 80 mil. The separation is 150 mil. They use magnetised steel slits.

The Bevatron has a rapid beam ejector. This is a multiturn coil, located in one of the straight sections. It is pulsed from a 180 μF, 15 kV capacitor bank. Maximum current is 6000 A, with a rise time of 700 μsec.

Methods of magnetic measurements were discussed with several persons and are very similar to ours. Future magnetic measurements on the Bevatron will use a commercial voltage to frequency converter. Its linearity is 0.02 c/o, the drift equivalent to an input voltage of a few μV. The frequency is 100 kc for a 1 V input voltage. This apparatus can be obtained from Hewlett Packard or from Vidar Corp, both at Palo Alto, Cal.

A quick visit was made to the 88⁰ cyclotron. This machine is scheduled for operation in a few months. It has an electrostatic beam extractor and 60 MeV, 1 mA deuteron beam is expected.

Livermore

Furth showed us several pulsed magnets he had made, among which some force free coils made for testing the principle. One of these had been damaged because an instability developed. His power supply is a capacitor bank of 150 kJ, 18 kV. Switching is done by two 5555 ignitrons, whereas 4 are used as crowbar. The peak current is 50 kA, the frequency 1 kc/s.

Taylor is building a cryogenic coil with windings made of stainless steel tubing of square cross section filled with Na. Tube wall 0.25 mm thick. The coil must be well supported because the shear strength of Na at 8⁰K is only 0.1 kg/mm². The Na is purified by distilling under vacuum several times. It is heated and slowly cast into the coil. When cooling, it shrinks, about 1.5 c/o from freezing point to room temperature.

PS/2990
Schematic beam optics of 1.85 GeV/c separated K⁻ beam.
and another 1.5 c/o from room temp. to 8° K. The advantage of Na over Al is that it is cheap, because easy to distill. Pure Al is expensive and only available in small quantities.

The coil will be cooled by helium and can be operated for about 1 minute. It will make a field of 100 kg in a cyl. volume of 20 cm diam., 30 cm long. Power: 3 kW.

They also have two large 75 kgauss coils for a mirror experiment, cooled with N₂, in order to save investment in power supply.

Van Ness told us they have good experience with ignitrons type WX 4681, made by Westinghouse. This tube combines the good properties of the 5553 and 5555 types. Its anode is baked out at 2130° C. Cost $275. - Delivery time perhaps 2 - 3 months.

S. van der Meer
E. de Raad

Distribution (open)

Scientific staff of N.F.A.
Director-General
Dr. M.G.N. Hine.

FS/2990