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MATERIALS INVESTIGATION FOR A TWO-MILE SUPERCONDUCTING ACCELERATOR*

by

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In another paper in these proceedings, Neal[1] gives the reasons for considering an energy of 100 GeV as the goal for a superconducting SLAC accelerator. This energy corresponds to a gradient of 10 MeV per foot, which is greater than has been achieved to date in any superconducting accelerator structure, either traveling-wave or standing-wave. Gradient limitations are related to the properties of the materials used in the accelerator circuits. An examination of the present day materials situation leads to the conclusion that the materials which come closest to the design requirement are the pure metals, lead and niobium. Cavities which have been constructed to date with lead are limited by field emission loading effects to operating at levels below 4 MeV per foot. Niobium cavities in the accelerating mode have shown sharp reductions due to magnetic field penetration at gradients of about 5 MeV per foot. Both the above-quoted gradient are for the traveling-wave mode of operation. For both these materials, sufficiently high Q improvement-factors have been obtained at superconducting temperatures to qualify them for use in low gradient accelerators. Nevertheless, further work is required before a high gradient superconducting machine can be constructed. The purpose of this paper is to discuss some plans for a materials evaluation program at SLAC.

Materials presently used are either type I or type II, and are operated in the region of perfect diamagnetism - that is at magnetic fields below the level at which any flux tube penetration takes place. However, the mechanism of microwave loss in type II superconductors operated in the mixed state, where some flux-tube penetration occurs, is a subject of current study[2,3]. At low frequencies or DC, the current in a conductor flows in such a manner as to minimize resistive losses, but at high frequencies the stored electromagentic energy is minimized and the current tends to flow uniformly through the conducting surfaces. When the level of applied magnetic field is such as to establish a mixed state, there will exist a flux tube lattice which is distributed in a manner determined by its interaction with pinning defects in the material. A fraction of the material will be inside the normal cores of the flux tubes, and this fraction is approximately equal to H_a/H_{c2}, where H_a is the applied magnetic field and H_{c2} is the upper critical magnetic field which corresponds to complete flux penetration. It can be shown that, in the mixed state, even currents at microwave frequencies tend to avoid the cores of normal material and flow in the superconducting regions. However, the flux tubes develop displacement — oscillations about the pinning centers, which cause normal currents to flow in the cores and lead to unacceptable losses. This happens even though no pinning constraints are broken. The "pinning frequencies", which are proportional to the pinning forces, are usually quite low (in the low megacycle region), but it might be possible to prepare surfaces with pinning frequencies in the microwave region. In such a case, the effects of flux penetration might be expected to decrease markedly because the interactions which take place at microwave frequencies are confined close to the surface. However, this is not a very promising approach, because even a very small number of flux tubes having small displacement amplitudes would prevent the achievement of the extremely high Q's desired.

In the above discussion it has been assumed that the flux tubes are established by an externally-applied DC field, and the interaction of a low level probing microwave signal has been considered. If high-level rf magnetic fields (lying between H_{c1} and H_{c2}) are applied to the surface layers of a type II superconductor in the absence of DC magnetic fields, it is not clear how the flux tubes can form because the time of an rf cycle is short compared with the time necessary for a flux tube to become established and to move into the surface. Nevertheless, experimental evidence to date indicates that Q drops sharply as the rf magnetic fields exceed some lower critical field value.[4]

Type II superconductors are thermodynamically reversible and are distinguished from type I superconductors by the value of the Ginsberg — Landau parameter — sometimes called the "disorder parameter", K. The value of K is approximately equal to $\lambda(0)/\xi$ where $\lambda(0)$ is the London penetration depth at absolute zero and ξ is the coherence length. Materials with values of K greater than $1/\sqrt{2}$ are characterized as type II superconductors. An ideal type II superconductor has the type of magnetization curve shown in Fig. 1. The value of H_{c2} increases with the disorder parameter, but even though H_{c2} can reach very large values the thermodynamic critical field H_c stays relatively fixed for a given material. Furthermore, H_{c1} decreases as H_{c2} increases. The Abrikosov theory predicts H_{c1}/H_c values of .82, : 55, .32 and .2 for K values of 1, 2, 5 and 10, respectively. Niobium has a K close to 1 and is a type II superconductor with a relatively high H_c of about 2000 gauss, which means that H_{c1} should be over 1600 gauss. This has been confirmed by DC magnetization measurements and at present much effort is going into the preparation of surfaces which will yield comparable values of H_{c1} at microwave frequencies. To date, values about 25 percent of theoretical have been reported.[4] Most of the work on other type II materials has been directed towards superconducting magnet applications, and the objectives have been both the attainment of high H_{c2} values and the treatment of materials to yield suitable pinning centers for holding the flux tubes carrying the penetrating flux up to very high currents. Materials have been produced with large disorder parameters and correspondingly very large values of upper critical field H_{c2}, but nevertheless total flux exclusion is possible only at very low applied magnetic fields. It is reasonable to ask whether type II materials can be prepared with high values of H_c and low values of K.

Type II superconductors are usually synthesized as two-or three-phase alloy systems or compounds. A perusal of the literature shows that compounds usually have higher thermodynamic critical magnetic fields than alloys, although the values for alloys do appear to depend quite markedly on the percentage of constituents present. Compounds for magnet technology are normally prepared in polycrystalline form with imperfect stoichiometry. This yields extremely high values of H_{c2}. Compounds of near-perfect stoichiometry and crystal structure might be expected to yield lower values of K which would result in higher values of H_{c1}. Type II superconducting compounds with both high thermodynamic critical field and low intrinsic K might be good candidates for accelerator applications. Large numbers of intermetallic compounds have been prepared and tabulated, and it is possible that some of these have the desired combination of superconducting parameters. Nevertheless, even if type II materials can be prepared with suitable properties they will be useful to us only if they can be economically formed into a high-Q accelerator structure.

At SLAC, a materials research program is being started. Materials and preparation techniques will be studied and rf superconducting properties will be evaluated. It is intended to investigate both niobium and lead with the object of improving surface preparation techniques. For two miles of accelerator structure to be economically feasible it is probable that some deposition techniques on copper or a similar substrate have to be perfected. Niobium test surfaces will be produced by electrodeposition, sputtering, evaporation, and chemical vapor deposition. These surfaces will be further processed in an attempt to obtain consistently the desired properties for use in a high gradient accelerator. We also intend to try coating lead surfaces with thin protective films of other substances.

Following the reasoning outlined in previous paragraphs, a search will be made for intermetallic compounds having suitable rf superconducting properties.

During this summer study, it has been suggested by Autler that technetium may be worth consideration as a practical superconductor. While the values of critical temperature and H_{c1}[5] are intermediate between lead and niobium, it has the advantages over lead that it is a hard, oxidation resistant metal, and the advantage over niobium that it can be electro-plated from an aqueous solution at room temperature.[6] For these reasons, an attempt will be made to build and test a technetium-plated copper cavity.

Equipment for making sensitive measurements of magnetic susceptibilities at low frequencies is in the process of being assembled. These measurements will be made using samples in the form of rods a few inches long and 1/8 to a 1/4 inch in diameter, and will serve as a preliminary selection mechanism in the materials search. Samples will be processed by various techniques such as vacuum annealing, high temperature outgassing etc. It is anticipated that this approach will be economical, because the use of small samples permit many materials to be investigated in a short time. A sketch of the apparatus is shown in Fig. 2. It is hoped that the sensitivity of the experiment will make it possible to detect penetrations of a few flux tubes, which would be enough to reduce the Q values at microwave frequencies.

Materials which show promise will then proceed to tests at microwave frequencies. It is known that surface conditions are critical at these frequencies. For this reason, it is desirable that the test surfaces should be processed in vacuum and transferred in vacuum to an rf test cavity. Additionally, it is preferable that the sample should be relatively small to ameliorate processing and transfering problems. The sample configuration has to be such that it can become part of a resonant cavity in which the field patterns in the resonant mode do not require currents to flow between the sample and the remainder of the cavity. Making the sample the center conductor of a co-axial cavity supporting the TE_{011} mode satisfies all these conditions. The diameter of the center conductor can be chosen so that its losses are of the same order as the losses in the rest of the cavity. A preliminary design sketch of the equipment is shown in Fig. 3. A vacuum chamber is mounted directly over the dewar. It communicates with the cavity at the bottom of the dewar via a tube along the common vertical axis. The tube diameter is large enough to allow the removable center-conductor to slide through it with guides to avoid surface damage. The center conductor is suspended by a stainless steel wire from a winch actuated through a high vacuum coupling. The upper vacuum chamber is equipped to process the center conductor. After processing the sample will be lowered into position in the cavity, which is excited by means of a offset co-axial line in the same way as a simple cylindrical TE_{011} cavity. Besides the complexity of the whole apparatus, the difficulties anticipated are associated with the cooling and possible cold-welding of the center conductor sample. It is probable that adequate conduction cooling can be obtained by machining a conical recess into the bottom of the center conductor and allowing it to sit over a matching protuberance in the end plate of the cavity. This apparatus will allow an investigation of both H_{c1} at rf frequencies and Q improvement-factors as a function of processing. Materials which perform well in this test will then be used to fabricate end-plates or whole rf cavities.

Tests of the most promising materials and surface processing techniques will be continued in cavities resonant in the TM_{010} or similar mode, to investigate the high power limit imposed by field emission losses. Ultimately, tests will be made on prototype accelerator structures.

ACKNOWLEDGEMENT

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FIGURE CAPTIONS

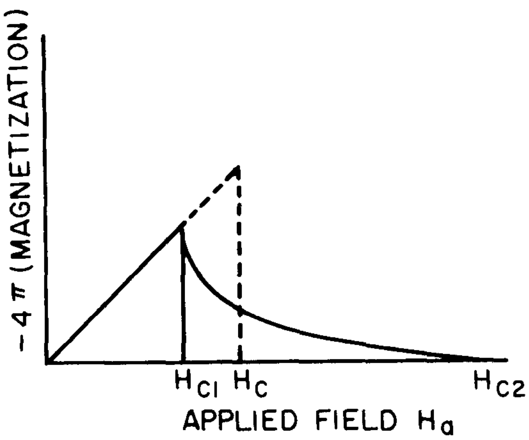

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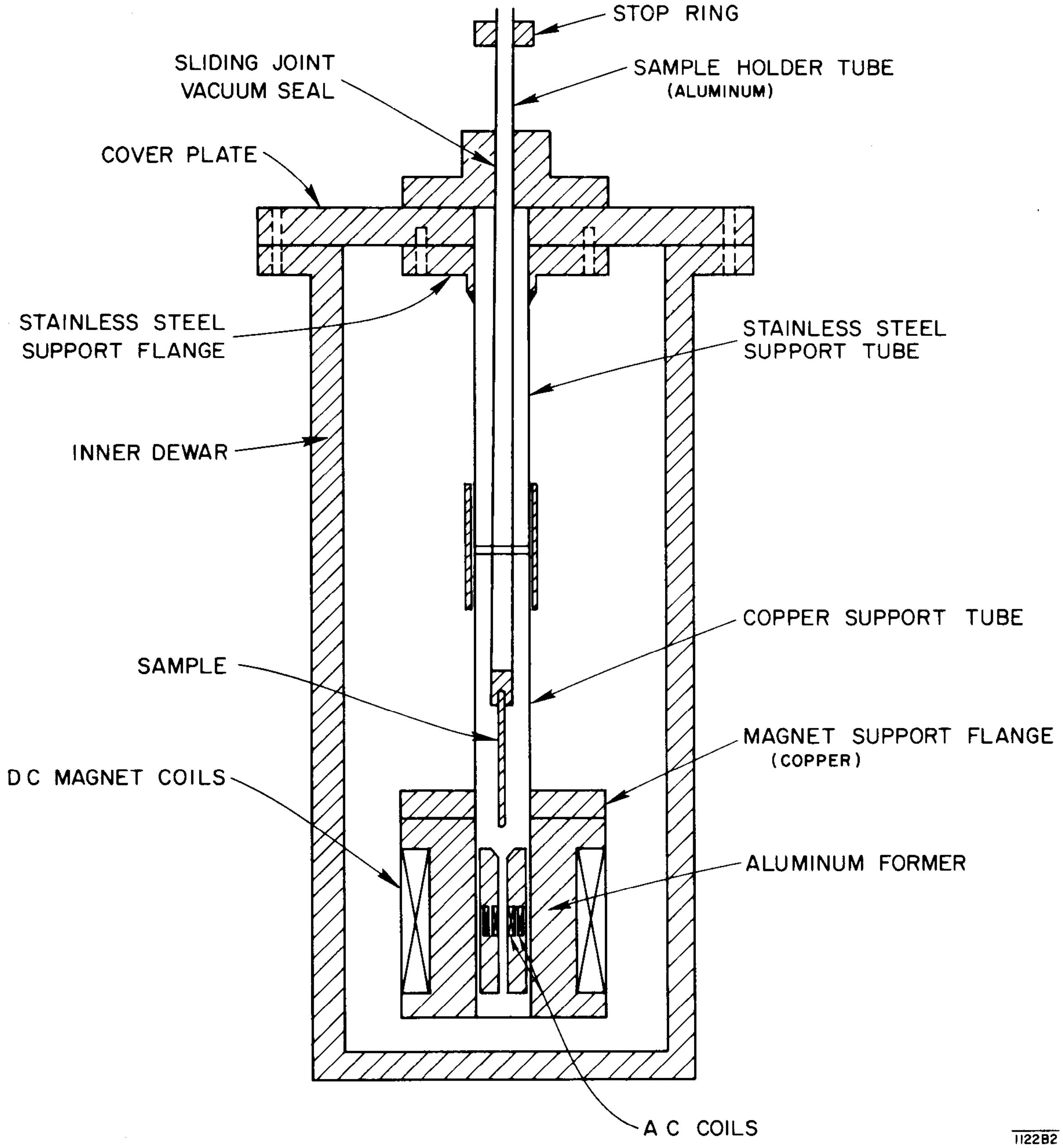
Fig. 1



STOP RING
SLIDING JOINT
VACUUM SEAL
SAMPLE HOLDER TUBE
(ALUMINUM)
COVER PLATE
STAINLESS STEEL
SUPPORT FLANGE
STAINLESS STEEL
SUPPORT TUBE
INNER DEWAR
COPPER SUPPORT TUBE
SAMPLE
MAGNET SUPPORT FLANGE
(COPPER)
D C MAGNET COILS
ALUMINUM FORMER
A C COILS
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Fig. 2

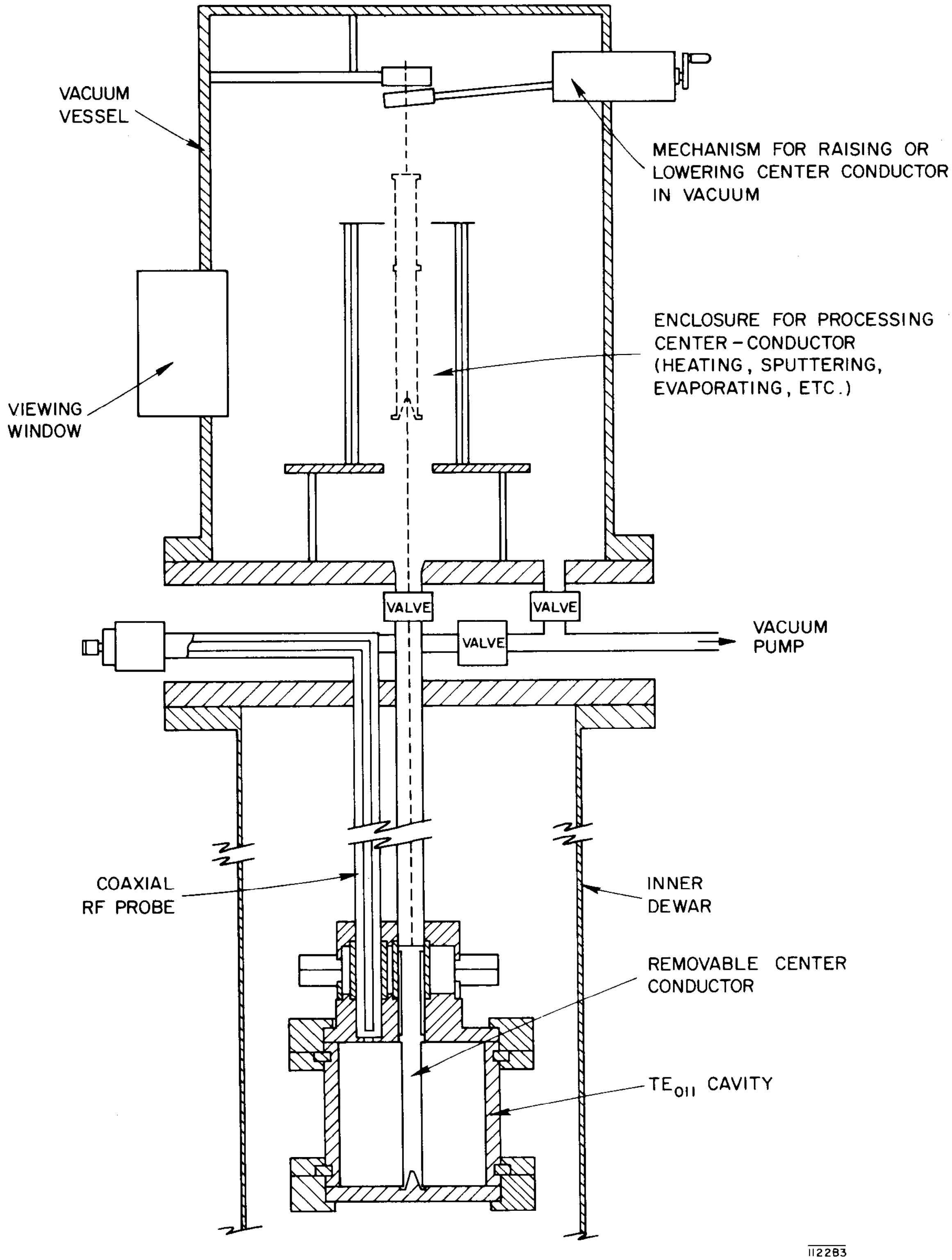
VACUUM
VESSEL
MECHANISM FOR RAISING OR
LOWERING CENTER CONDUCTOR
IN VACUUM
ENCLOSURE FOR PROCESSING
CENTER - CONDUCTOR
(HEATING, SPUTTERING,
EVAPORATING, ETC.)
VIEWING
WINDOW
VALVE
VALVE
VALVE
VACUUM
PUMP
COAXIAL
RF PROBE
INNER
DEWAR
REMOVABLE CENTER
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Fig. 3