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# Design of a 200 MeV Electron-Positron Storage Ring*

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## I. INTRODUCTION

The increasing interest in storage rings and high intensity accelerators has made these areas of accelerator research extremely useful. A machine in which both colliding beam and high intensity beam phenomena may be studied has been designed and is under construction at the MURA laboratories. This machine is a small electron-positron storage ring. It is hoped that this machine will be in operation early in the summer of 1966.

The projected use of this machine as an accelerator research instrument has led to a design in which accessibility, flexibility, and simplicity are the main considerations. A plan view of the machine is shown in Fig. 1 and parameters describing the machine are given in Table I.

## II. MAGNET AND MAGNET POWER SUPPLIES

The design of the magnet structure was based on several conflicting requirements. These were simplicity and ease of construction, the capability of easily shifting the radial and vertical tunes by at least a half integer and finally, large acceptance in both synchrotron and betatron phase spaces. The structure chosen fills all of these

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requirements reasonably well. It is a separated function, AG structure. In order to simplify construction, an initial decision was made to try for a design in which the edges of the bending magnets were parallel. This resulted in a structure in which the vertical focusing takes place at the edges of the bending magnets and the radial focusing is accomplished through the use of quadrupoles. Thus, shifting the radial tune is simply a matter of changing the quadrupole strength. This also changes the vertical tune. However, by properly choosing the entrance and exit angles of the beam at the bending magnets, the change in quadrupole strength can be made to have relatively little effect on the vertical tune. The vertical tune is shifted through the use of gradient windings on the bending magnets. Again, changing the bending magnet gradient changes the radial tune, but the fact that the bending magnet edges are parallel reduces this effect considerably.

The initial orbit calculations were carried out on a computer using idealized or "hard edge" magnetic fields. As the design of the machine matured, magnet and quadrupole models were constructed and measured fields from these models were used in the orbit calculations. The final bending magnet and quadrupole designs are shown in Figs. 2 and 3. The tune of the machine for various bending magnet gradients and quadrupole strengths is shown in Fig. 4.

As is to be expected, the damping rates for radial and synchrotron motion are dependent on the bending magnet gradient. However, both motions are damped in the tune range $0.5 < \nu_x, \nu_y < 2$.

As will be discussed in the section on injection, the magnet will be operated in a pulsed mode during injection. Therefore, the bending magnets and quadrupoles are laminated. The lamination thickness is 1.5 mm. Since low field operation is not contemplated, the magnet laminations are made of ordinary low carbon steel.

The magnet power supply must be capable of both a pulsed mode and a dc mode of operation. In the pulsed mode, output current will rise from 60 to 280 amperes and then fall to 60 amperes in one-third of a second. The magnet current wave form will be approximately triangular. In the dc mode, the magnet power supply will be required to provide any current between 60 and 400 amperes, constant to better than 0.01%. In addition, shifting from one mode to the other, changing the current during the dc mode and changing the shape of the current wave form during the pulse mode will be required. To meet these requirements, a current-regulated power supply using amplidynes as the power source has been designed. The use of amplidynes in this application considerably simplifies the design of the power supply by virtue of the facts that their response time is considerably shorter than the more common types of dc generators and that they are characterized by enormous power gain. These two characteristics make them particularly suitable as components of a servo system such as this power supply.

## III. INJECTION SYSTEM

The injector for the storage ring is to be the MURA 50 MeV electron synchrotron.[1] This machine is at present equipped with a high efficiency single-turn extraction system.[2] The quality of the extracted beam is extremely good; the emittance being approximately $2 \times 10^{-3}$ cm rad. Since the vertical and radial admittances of the storage ring are $0.04\,\pi$ and $0.08\,\pi$ cm radians respectively, little difficulty in electron injection is expected. At the present operating intensity of the synchrotron electrons may be injected at a rate of 1.5 amperes per second.

The method by which injection is to be accomplished is novel in that it involves no field perturbations in the storage ring. Before injection, the frequency of the storage ring radio-frequency accelerating field will be shifted adiabatically to a value corresponding to an energy 1 MeV lower than the injection energy. Since the momentum acceptance of the machine is somewhat larger than this, the orbit radius of the circulating beam will decrease by about 2 cm with little disturbance to the motion of the particles. This reduction in orbit radius will carry the circulating beam far enough away from the inflector so that its field will have negligible effect on the beam. At the same time that the frequency is shifted, the accelerating voltage will be reduced to a value which just accommodates the energy spread of the circulating beam. The inflector, which has no septum, will then be turned on and the beam injected on the equilibrium orbit. At the end of one revolution the inflector will be turned off, leaving the newly injected beam on the injection equilibrium orbit. The "old" beam will still be 2 cm displaced radially from the equilibrium orbit. The frequency of the accelerating field will then be shifted back to a value corresponding to the injection energy while the low value of accelerating voltage is maintained. This will bring the old and new beams into coincidence radially. Some of the new beam will be lost due to phase displacement, but because the phase area of the old beam is so much smaller than that of the new beam, the loss will be negligible. The accelerating voltage will then be increased at a rate low enough to insure adiabatic capture. The beam will be accelerated from 45 MeV, the injection energy, to 150 MeV and then decelerated back to 45 MeV. In the time required for the acceleration and deceleration, the phase volume of the beam will reduce by a factor greater than $10^3$. The time required for the whole cycle is one-third of a second. At a nominal rate of 0.5 amperes per injection pulse, a fairly sizable circulating beam of electrons may be accumulated in a relatively short period of time.

Positrons will be made by bringing the 45 MeV extracted beam from the synchrotron onto a tungsten radiator. The injection energy for positrons is 40 MeV, hence the radiator is only about 0.1 radiation lengths thick. The actual thickness of the radiator will be chosen to match the emittance of the radiator for 40 MeV positrons to the acceptance of the storage ring. Estimates based on the focal properties of the extracted beam from the synchrotron and the admittance and momentum acceptance of the storage ring give an efficiency of $5 \times 10^{-5}$ for the positron radiator and injection system. Thus we can expect to accumulate positrons at a rate of $2.5 \times 10^{-5}$ amperes per injection pulse. At this rate, about 22 minutes will be required to accumulate a circulating beam of 100 mA. These estimates are fairly conservative, and in practice the filling times may be as low as 10 minutes.

Beyond the radiator, the injection system for positrons will be essentially the same as that for electrons.

## IV. BEAM LIFETIME

At a pressure of $10^{-9}$ mm Hg, gas scattering is not expected to determine beam lifetime in this machine. With a peak accelerating voltage of 50 kV quantum fluctuations should have a negligible effect on beam lifetime. The major factor in beam lifetime will be Touschek effect. For example, at 200 MeV the Touschek lifetime of a 1 ampere beam of 1 mm x 1 mm cross section would be 13 minutes in this machine. This cross section is, of course, far larger than the natural size of the damped beam. Accordingly, provisions are being made to keep the beam cross sections large through a system of rf quadrupoles. These quadrupoles will be excited at frequencies such that the transverse motions of the beams are driven at half integral resonance. The level of the drive will be adjusted so that with radiation damping the beam reaches an equilibrium size which gives an acceptable Touschek lifetime.

Since the damping rates for transverse motions of the beam are comparable with that for synchrotron motion, the gradients of the *rf* quadrupoles will have to be fairly large, on the order of several hundred volts $\mathrm{cm}^{-1}$. It is interesting to note that for really intense beams sizable amounts of power will be required to keep the beam cross-sectional area large.

## V. RF SYSTEM

In order to achieve the filling times for positrons mentioned in Sec. III, it will be necessary that the rf system be capable of accepting a momentum spread of ± 2.5%. This will require a cavity voltage of 60 kV. Since the space available for an rf cavity is severely limited, the cavity must be a high "Q" device if this voltage is to be had without undue power loss. With a high "Q" cavity and an intense beam, it should be possible to observe many of the phenomena of beam cavity interactions that have been studied theoretically[3] recently. To facilitate the study of these effects, fairly sophisticated phase, frequency and amplitude control systems are being designed for use with the accelerating system. In addition, the power amplifier has been designed to provide in excess of 20 kW of drive to the cavity.

## VI. BEAM OBSERVATION, BEAM CLEARING AND BEAM INSTABILITY DAMPING SYSTEMS

This machine will be equipped with a number of beam observation devices. There will be a sapphire window in each bending magnet. Half of these windows will be used for viewing synchrotron radiation from the electrons, the other half being used for the positrons. There will be four sets of radial and vertical beam position monitoring probes. These will be mounted in the quadrupole straight sections. There will also be a set of radial and vertical aperture limiters in each injection straight section.

The storage ring will be equipped with clearing electrodes. These will be located in the bending magnets. The clearing electrodes will serve a number of purposes. Primarily they will be used to clear the beam of ions, but in addition, they will be used to keep the electron and positron beams separated vertically. Since there are eight separate electrodes, and the vertical tune is low, differential excitation is possible. Thus, the average position of the beams as well as the vertical and azimuthal angles of beam intersection will be controllable.

At present, it is planned to damp the coherent transverse instabilities through the use of feedback systems.[4] The aspect ratio of the vacuum chamber is only 2:1 and it is possible that the instability will occur both vertically and radially. Therefore two instability damping systems are being provided. Since nominally both tunes of the machine are near quarter integral, the pickup and driving electrodes for a damping system can be located adjacent to one another, if the delay through the amplifiers is equal to the revolution period or an odd multiple of it. The pickup and drive electrodes for the damping systems will be located in the injection straight sections. This choice of location has the advantage of allowing the damping systems to "see" and act on the two beams separately since they traverse these straight sections on alternate half cycles of the accelerating field. The band widths of the systems will have to be fairly large so that transients caused by one beam can decay before the other beam arrives. A system of about the required band pass has been built and has operated on the MURA 50 MeV electron synchrotron.[5] Thus, no difficulties in building damping systems of the required band pass for this machine are anticipated. Of more concern is the rejection of the large common mode signal when both electrons and positrons are circulating in the machine. An experimental system, similar in operation to the AVC system in a radio receiver, to suppress the common mode signal has been built and tested on the ZGS.[6] The results have been encouraging.

## VII. VACUUM SYSTEM

The vacuum system will be constructed of stainless steel. The interior surfaces of the system will be electro polished. The cross section of the vacuum chamber will be a 5 x 10 cm ellipse except at three of the four long straight sections. In these straight sections rectangular boxes will be installed. This will provide adequate space for the inflectors and vacuum pump attachments. The box in the interaction straight section can be modified in the future to accommodate cryogenic pumping equipment. A schematic view of the vacuum system appears in Fig. 5.

The pumping equipment at present consists of four 100 liter $\sec^{-1}$ getter ion pumps. There will be one of these at each long straight section. In addition, there will be one getter ion pump on each of the beam transport pipes. Isolation between the storage ring and synchrotron vacuum systems will be provided by a thin titanium window in the extracted beam transport pipe. This window will be located just upstream from the switching magnet that sends the electron beam either directly to the storage ring or to the positron radiator.

During pulsed operation of the magnet, a certain amount of eddy current loss occurs in the vacuum chamber. To remove this heat and the heat generated by synchrotron radiation, cooling tubes are welded on the inner and outer radii of the vacuum chamber.

# TABLE I

## PARAMETERS FOR 200 MEV STORAGE RING

| | |
|---|---|
| **Magnet** | |
| Focusing Type | AG, Separated Function |
| Focusing Order | 0/2, D, B, D, f, D, B, D, 0/2 |
| Field Index in Bending Magnets | Variable, $-0.34 \leq n \leq 0.34$ |
| Field Gradient in Quadrupoles | Variable, 1.6 kG $cm^{-1}$ max |
| Field at Injection for $e^{\pm}$ | 2.36 ~~2.4~~ kG |
| Field at Maximum Energy | 12.3 kG |
| Bending Radius | 0.635 ~~0.54~~ meters |
| Average Radius | 1.50 ~~1.53~~ meters |
| Tune | Variable, $0.5 < \nu_x, \nu_y < 2.0$ |
| **Injection System** | |
| Type | 50 MeV FFAG Electron Synchrotron |
| Injection Energy $e^-$ | 45 MeV |
| $e^+$ | 40 MeV |
| Injection Current $e^-$<br>(per pulse) | 0.5 amperes |
| $e^+$ | 25 μamperes |
| Injection Energy Spread $e^-$<br>(total) | 500 kV |
| $e^+$ | 2 MeV |
| Inflector | Delay Line, No Septum |
| **RF System** | |
| Frequency | 31.9 ~~35~~ Mc |
| Harmonic Number | 1 |
| Number of Cavities | 1 |
| Maximum Volts per Turn | 50 kV |
| Maximum Power Available to Cavity and Beam | 20 kW |

# FIGURE CAPTIONS

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|---|---|
| Fig. 1. | Storage Ring Plan View. |
| Fig. 2. | Bending Magnet. |
| Fig. 3. | Quadrupole. |
| Fig. 4. | Radial and Vertical Tunes as functions of quadrupole strength and Bending Magnet Gradient. |
| Fig. 5. | Vacuum System Schematic. |

# REFERENCES

1. The MURA Staff, Rev. Sci. Instr. 35, 1393 (1964).
2. F. E. Mills, G. M. Lee, H. K. Meier, J. E. O'Meara, C. H. Pruett, E. M. Rowe, C. A. Radmer, M. F. Shea, D. A. Swenson, D. E. Young, Proceedings of the International Conference on High Energy Accelerators (Dubna, USSR 1963), p. 723.
3. See, for example, V. K. Neil and A. M. Sessler, Rev. Sci. Instr. 32, 256 (1961); C. H. M. Turner, Nuc. Instr. & Meth. 32, 245 (1965); F. J. Kriegler, K. R. Symon, and E. M. Rowe, Bull. Am. Phys. Soc. 10, 457 (1965).
4. C. H. Pruett, F. E. Mills, and R. A. Otte, Bull. Am. Phys. So., 10, 458 (1965).
5. F. E. Mills, MURA, private communication.