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THE DESIGN OF THE WNR PROTON STORAGE RING LATTICE*

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Introduction

The Weapons Neutron Research Facility, now approaching operational status, is a pulsed neutron time-of-flight facility utilizing bursts of 800 MeV protons from the LAMPF linac. The protons strike a heavy metal target and produce a broad energy spectrum of neutrons via spallation reactions. Ideally the width of the proton pulse should approach a delta function in order to achieve good neutron energy resolution. Practically, the shortest pulse that can be employed in the facility is that produced by a single LAMPF micropulse, which, at design current, contains approximately 5×10^8 protons. With the addition of a storage ring capable of accumulating many micropulses, this intensity can be increased, as can the repetition rate. Moreover, by storing an unbunched beam, a low repetition rate, very intense proton burst can be generated. This latter mode of usage allows neutron time-of-flight studies using large neutron targets, for which pulse lengths of the order of several hundred nanoseconds are suitable. The primary goals of the ring reported on here are: (i) to increase the intensity of the burst to 10^{11} protons while retaining a short pulse length; (ii) to increase the repetition rate of the bursts by at least a factor of six; and, (iii) to store as many particles as possible, uniformly distributed around the ring.

Operational Characteristics

In the mode of operation in which short pulses are accumulated for time-of-flight use, the ring will be filled 120 times per second and will essentially superpose [in six dimensional phase space, employing charge exchange (stripping) injection] 200 LAMPF micropulses.[1,2] The LAMPF H^- pulse structure will be modified for ring injection purposes so that micropulses will be separated by 50 ns instead of the usual 5 ns (during that portion of the LAMPF pulse for which the ring is not being filled, i.e., 440 μs out of 500 μs, the pulse structure will be unchanged). Since the circulation time of the ring is 300 ns, it will contain six circulating bunches, each of which will be separately extracted during the 7.8 ms between filling periods. Thus the pulse repetition frequency of the facility will be increased by a factor of six, while the pulse intensity will be increased by a factor of 200.

In the high current mode of operation, it is expected that the ring will be filled (again employing charge exchange injection) with one or more full LAMPF macropulses (5×10^{13} protons/macropulse). Each macropulse requires that the beam emittance be greater than $1.36\,\pi \times 10^{-5}$ m-rad to contain this current. The repetition rate for this mode is limited by the existing shield at the WNR target which permits 1-2% of LAMPF design intensity to be used.

The Design

The ring lattice was chosen to have a separated function for tune flexibility and simplicity of construction. In order to avoid the negative mass instability for the high current mode it was decided to operate the ring below transition; the particle γ is 1.85, so a design transition gamma of approximately 2 was chosen. This figure in turn indicates that a nominal radial tune, ν_x, of 2.25 would be desirable.

The circumference of the ring was chosen to be compatible with a maximum pulse length generated by single turn extraction of approximately 250 ns. A number of straight sections appropriate to injection, extraction, and beam manipulation, including the possibility of future development of a second extraction section were deemed required. With a tune of 2.25 and a betatron phase advance of approximately $\pi/2$ per period to minimize the betatron functions, an eight-sided figure seemed indicated. An octagonal lattice was in fact chosen to allow placing the injection and extraction functions in separate straight sections within the constraint that the ring must be supplied from and return particles to the WNR beam line. Figure 1 shows the component layout of the ring lattice, while Table I summarizes the lattice parameters and Table II the ring operating characteristics. Figure 2 is a plot of the square root of the radial and vertical betatron functions as well as the off momentum function $\eta \equiv \Delta r/(\Delta p/p)$.

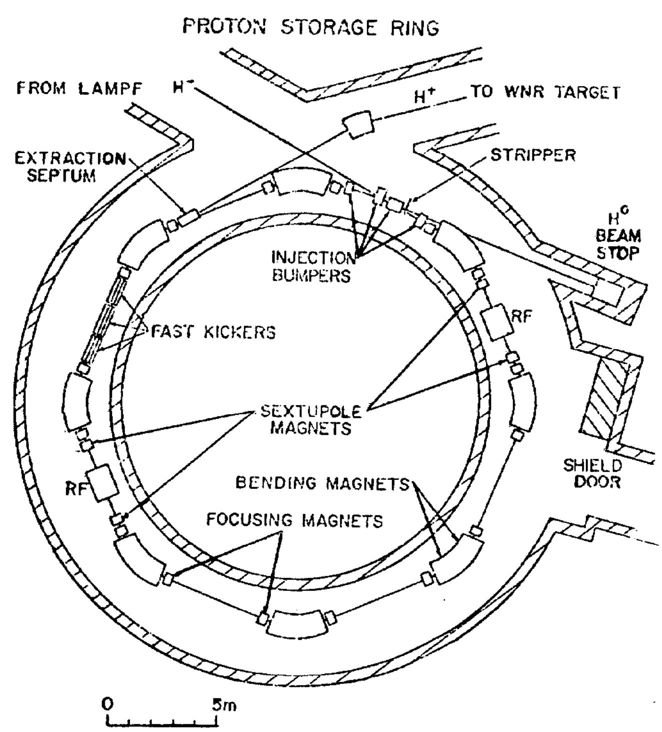

Fig. 1. Plan View of the Ring

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TABLE I

Ring Dimensions

Circumference (length of central orbit)	75.240 m
Mean Radius	11.975 m
Orbit Radius in bending magnets	4.881 m
Length of bending magnets	3.834 m
Gap height	0.080 m
Gap width (useful field)	0.012 m
Length of quadrupole magnets	0.400 m
Bore of quadrupole magnets	0.011 m
Length of straight section	4.171 m

TABLE II

Operating Characteristics

Betatron Oscillations per revolution (nominal)	
radial, ν_x	2.25
vertical, ν_y	2.25
Transition gamma, γ_t	2.07
Bending magnet field strength	1.000 T
Focusing quadrupole gradient	3.116 T/m
Defocusing quadrupole gradient	-3.980 T/m
Bunched operation	
No. of bunches	6
Length of bunch	1 ns
rf frequency	603.75 MHz
harmonic number	180
space charge limit for $\epsilon_x = \epsilon_y = \pi \times 10^{-5}$ m-rad ($\Delta\nu = 0.2$)	1.23×10^{11} p/bunch
Unbunched operation	
space charge limit for $\epsilon_x = \epsilon_y = \pi \times 10^{-5}$ m-rad	3.69×10^{13} p
Chromaticity $\partial\nu/\partial(\Delta p/p)$	
radial	-0.30
vertical	-0.33

Injection is accomplished through a set of pulsed magnets which bring the circulating proton beam and the incoming H^- beam into spatial coincidence at the location of the stripper foil. The magnets are pulsed in order to increase foil lifetime and to control emittance growth effects due to scattering in the foil.[3] A calculation of the space charge limit for the bunched mode of operation for the given lattice shows that the (unnormalized) emittance of the stored beam must be greater than $0.8\ \pi \times 10^{-5}$ m-rad (both planes); since the emittance of the LAMPF linac is approximately $0.1\ \pi \times 10^{-5}$ m-rad, the emittance must be degraded by injecting off the equilibrium orbit.

The rf system to maintain the bunch length of the accumulated micropulses must provide somewhat larger buckets than those in the LAMPF accelerator, due to the fact that the micropulses spread in length in the beam transport system. For a LAMPF $\Delta p/p$ of 0.002 (FWHM), a 450 kV, 603.75 MHz rf bunching system will maintain a 1 ns bunch.[4] This rf voltage may be applied in one or more of the straight sections. Additional rf may be required for synchrotron frequency splitting,[5] or for bunching on the first harmonic to minimize spill during single turn extraction.

The bunches are separately extracted by a set of fast kicker magnets of the parallel plate transmission line type. These kickers must perform their function within 100 ns (twice the time between bunches) and with a 720 Hz repetition rate. These parameters represent the state of the art; further improvements would enhance the capabilities of the WNR facility as a pulsed neutron source. The kickers give an overall

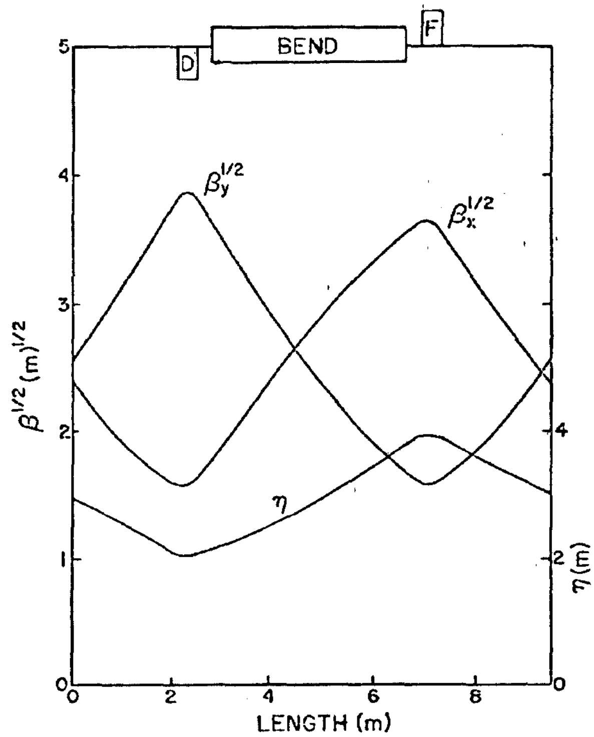

Fig. 2. Beta Functions and Off-Momentum Orbit

kick of 6 mrad; the beam then receives a further kick from the defocusing quadrupole magnet. Upon leaving the following focusing quadrupole, the beam is headed toward the equilibrium orbit but is intercepted by the extraction septum magnet. Figure 3 shows the details of the extraction orbit.

Calculations

A summer study which used a reference lattice similar to that reported on here was held in Los Alamos in August, 1976. The rf bunching requirements were examined, the extraction system was studied, and various instability growth times were calculated. No serious obstacle to successful operation of the ring was discovered. The results of the summer study are summarized in the report cited in Ref. 4.

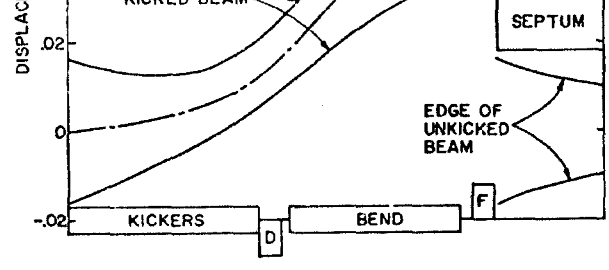

Fig. 3. Extraction Orbit Details

Acknowledgment

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