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Associated Universities, Inc.
Upton, New York

CRISP 71-14
ISABELLE PROJECT

STORAGE RING REPORT

PRELIMINARY BASIC PARAMETERS, PROTON STORAGE RING PROJECT

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July 14, 1971

MAS

General

Ring arrangement	Two interlaced racetracks, each consisting of two half circles with a regular lattice structure and two long experimental straight sections. Orbits in the regular lattice separated by 0.2 m in the vertical plane.
Magnet system	Superconducting magnets
Average radius, curved section	220.06 m
Experimental straight section length	284.87 m
Total circumference	1937.07 m ($2.4 \times C_{\text{AGS}}$)
Equiv. proton energy, rest target	100 TeV
Proton energy, each ring	216.56 BeV
Injector	AGS
Injection energy	30 BeV
Acceleration time	120 sec
Stacked protons, each ring	6×10^{14} protons
Luminosity ($\beta_V = 3$ m; $\beta_H = 6$ m), at max. proton energy, unbunched beam	6×10^{32} ($\text{cm}^{-2} \text{sec}^{-1}$)/m

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General Ring Arrangement

Regular Lattice Structure

Cell structure

Separated function, FoDo

Regular lattice, number of cells

52

Cell length

24.4 m

Normal cell structure

$(QHF/2)l(B)s(B)s(B)s(QHD)l(B)s(B)s(B)s(QHF/2)$

Cell components

$LB = 3.2$ m

$LQHF = LQHD = 1.0$ m

Straight sections

$l = 1.0$ m, $s = 0.2$ m

Momentum Function Matching Section, (X_p Section)

Section length

24.63 m

Component length, $LQHF/x$

0.636 m

ll

0.395 m

*Dewar unit length, nominally 40 ft.

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Straight sections	l = 1.0 m, s = 0.2 m

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Dewar unit length, nominally 40 ft.

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Experimental Long Straight Section, Basic Structure*

Section length	284.87 m
Free length, adjacent crossing point, L_f	80.14 m
Free straight, L_{ff}	59.97 m
Inter doublet spacing, l_{FD}	0.26 m
Component length, l_{QHF}	1.0 m
l_{QHD}	1.0 m

Orbit Parameters

Maximum dipole field, $\hat{B}$	41.90 kG
Regular lattice quadrupole gradient, QHF	934.5 kG/m
QHD	932.6 kG/m
Betatron oscillation wave number, ν_x	17.3
ν_y	16.3
- Phase advance per cell, $\Delta\psi_x$	0.28 (2 π) [101°]
$\Delta\psi_y$	0.28 (2 π) [101°]
Phase advance per "in-section"**, $\Delta\psi_{x,ins.}$	1.376 (2 π)
$\Delta\psi_{y,ins.}$	0.833 (2 π)

* Indicating basic β function components only.

** The lattice "insertion" includes the long experimental straight section and adjacent momentum function sections.

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Transition energy, γ_{tr}	17.67
Betatron function and momentum compaction function, regular cell	See Fig. 1
Maximum values, regular cell, $\hat{\beta}_H$	43.1 m
$\hat{\beta}_V$	43.1 m
$\hat{x}_p$ (per $\Delta p/p$)	1.55 m
Bend angle, per cell	0.1109 (rad.)
Bend angle, per momentum compaction section	0.1848 (rad.)
Dipole magnet, magnetic radius, ρ_B	172.9 m
$(B\rho)_{max}$	$7.255 \cdot 10^3$ kG/m
Long straight section quadrupole gradients, QHFs	1205.0 kG/m
QHDS	1196.9 kG/m
Betatron function and momentum compaction function, long straight section	See Fig. 2
Specific values at the crossing point, β_x	6.01 m
β_y	2.64 m
x_p	0 m

Beam Transfer Parameters

Transfer energy	30 BeV
AGS beam intensity	2×10^{13} protons per pulse
AGS* transverse phase space, 30 GeV	$A_{2V} \times A_{2H} = 0.8\pi \times 3.0\pi$ ($\mu\text{rad-m}^2$)
longitudinal phase space, 30 GeV	0.46 eV-sec (per bunch)
momentum spread, $(\Delta p/p)$	$\pm 0.69 \cdot 10^{-3}$
final rf frequency	4.45 MHz

*Parameters prior to beam manipulation for transfer.

Fig. 1, Betatron oscillation functions β_x , β_y ; momentum function X_p , in a regular cell.

Fig. 2, Betatron oscillation functions β_x , β_y ; momentum function X_p , in the lattice insertion.

*Also, symmetry point of insertion.

AGS harmonic number, h	12
orbital frequency	~ 371 KHz
revolution period	2.70 μ sec
bunching factor, $\bar{B}$	0.048
phase width, $\delta\phi$	$\pm 0.192 (\pm 11.0^\circ)$
bunch length	13.9 μ sec or 4.1 m
Transfer mode	Debunch adiabatically 12 AGS bunches, rebunch in AGS to single bunch, fast single turn ejection, "fast", bunched, storage ring injection
Stacking mode**	Fill each storage ring azimuthally, in box car fashion, with 50 AGS "single" bunches.
AGS, longitudinal phase space, single bunch, after beam manipulation	15.69 eV-sec (dilution factor 3.8)
momentum spread, $(\Delta p/p)'$	$\pm 2.5 \cdot 10^{-3}$
final rf frequency, "sawtooth" fundamental	371 KHz
harmonic number, h'	1
phase width, $(\delta\phi)'$	$\pm 0.151 (\pm 8.35^\circ)$
bunch length	125.2 nsec or 37.2 m
Storage ring, rf frequency	4.64 MHz
orbital length ($2.4 C_{\text{AGS}}$)	1937.07 m
orbital frequency	154.5 KHz
harmonic number, h''	30
bunch width, $(\delta\phi)''$	$\pm 1.885 (\pm 104.2^\circ)$
acceleration time	120 sec ($\dot{B} = 0.03 \text{ T/sec}$)
rf voltage	$\hat{V}_{\text{rf}} = 40 \text{ kV}, \sin \varphi_s = 0.25, \varphi_s = 15^\circ$
Beam emittance, after injection, Phase I*	$A_{2V} \times A_{2H} = 3.75\pi \times 1.0\pi (\mu\text{rad-m})^2$
, Phase II	$A_{2V} \times A_{2H} = 1.0\pi \times 3.75\pi (\mu\text{rad-m})^2$
Injection dipole field, B_{inj}	5.96 kG

** It is assumed that (initially) single turn transverse phase space stacking and "single" turn longitudinal phase space stacking will be used only.

* Dilution factor, related to transfer component errors, assumed. Phase I involves transverse phase space interchange in 30 GeV transfer line.

Magnet Aperture Subdivision, Regular Lattice Components

Initially use will be made of transverse phase space interchange in the 30 GeV transfer line in order to "fit" more suitably into the circular aperture of the superconducting dipole magnets. Subsequently, this may be eliminated in order to further increase the luminosity of the intersecting beams for specific crossing modes.

Aperture Subdivision*:

(half aperture values in mm)	Vertical		Horizontal	
Components	B	Q	B	Q
Beam betatron amplitude	11.7(6.0)	12.7(6.6)	6.0(11.7)	6.6(12.7)
Phase oscillation amplitude, $X_p(\Delta p/p)$	--	--	3.6(3.6)	3.9(3.9)
Sagitta	--	--	3.7(3.7)	--
Closed orbit error allowance	5.5(2.8)	6.0(3.0)	7.4(3.7)	8.0(4.0)
Reserve	8.2(16.6)	6.7(15.8)	4.7(2.7)	6.8(4.8)
Half aperture, total (mm)	25.4	25.4	25.4	25.4
Full vacuum chamber aperture, inches	2	2	2	2

Long Straight Section Structure

Emphasis is presently being placed on developing flexible matched long insertions for the experimental crossing region. The result presented in Fig. 2 should therefore be regarded as a typical case only, illustrating the basic possibility of obtaining a long free straight section adjacent to the beam intersection with realizable optical components. For completeness sake the essential parameters of that case are summarized on the next page:

*Numbers in brackets refer to beam transfer without transverse phase space interchange. In this case, it has also been assumed that improvements would result in the reduction of the closed orbit errors by at least a factor of 2.

Pursuing the approach of obtaining extremely long free straight section length adjacent to the beam crossing point, a solution has also been found for the case with $\sim 100 \text{ m}$ free straight section length adjacent to the crossing point. This required the further addition of a horizontally defocusing quadrupole magnet, placed immediately adjacent to the momentum function matching section. This particular case is shown in Fig. 3. As shown, β function values for the beam crossing point as low as $\beta_x = 3.3 \text{ m}$, $\beta_y = 2.8 \text{ m}$, respectively, proved to be still feasible notwithstanding the long drift spaces involved.

Associated with the small beam emittance (at full energy) the extremely large β function values in the insertion special quadrupole magnets do not lead to excessive beam sizes, and realizable quadrupole magnets are involved. Typically, for this case:

Fig. - Betatron oscillation functions β_x , β_y ; momentum function X_p , in the lattice insertion.

Distance along closed orbit (m)

*Also, symmetry point of insertion.

QHD1: $G = 605.0 \text{ kG/m}$, $l = 1.8 \text{ m}$

QHF1: $G = 608.0 \text{ kG/m}$, $l = 1.8 \text{ m}$, full aperture 7 in.^* , pole tip field 55 kG .

QHD2: $G = 604.7 \text{ kG/m}$, $l = 1.8 \text{ m}$, full aperture 4 in.^* , pole tip field 30 kG .

This particular case is presently being studied further, in order to obtain somewhat more modest β function values in QHF1, QHD2, respectively, so that manageable parameters may also be obtained at lower beam energies.

Experimental Intersections, Crossing Angle

Various basic beam intersection options are being studied involving either finite crossing angles of up to 20 mrad or, alternatively, a quasi colinear interaction domain (zero degree intersection). It is not excluded that different interaction arrangements would be used in each of the two long straight sections. Also, more than one interaction region in each, or either one, of the long insertions is being contemplated.

At present, the design option of vertically stacked, independent, magnetic components in a single dewar envelope, for the regular lattice structure, is being pursued. The two orbits would be vertically separated by 0.20 m . The two primary beams could be kept in a vertical plane arrangement, for vertical crossing (or colinear) interaction regions, or alternatively, be "manipulated" for horizontal beam crossings only. Schematically, a few examples are illustrated in Fig. 4. Actually, by means of four dipole units, "movable" along the direction of the incoming proton beams, various crossing options are available, with only minor effect on the primary beam properties. This, is indicated, schematically again, in Fig. 5.

* Beam filling (at full energy) approximately 50%.

I)

quasi colinear crossing

possibility of $X_p = 0$ for both orbits, alternatively $X_p = \text{pos.}$ for one orbit, $X_p = \text{negative}$ for the second orbit. Net result: C of M energy the same, independent of inherent $(\Delta p/p)$.

II)

Fig. 4, Beam intersection options, schematically.

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II)

Fig. 4, Beam intersection options, schematically.

Fig. 5, Beam "crossing" options, making use of four dipole units, "movable" along the direction of the incoming beams.

In order to maintain maximum flexibility for secondary beams and associated detectors, room temperature (yoke) dipole magnets have been assumed ($\hat{B} = 18$ kG) typically, with an aperture exceeding the basic beam separation.

Luminosity

Luminosity values are calculated using (somewhat over-) simplified formulae, applicable for two intersecting beams, each of a cross section $2a$ (full horizontal beam width) by $2b$ (full vertical beam height), and homogeneous particle density distribution within the beam cross section. Also, here, only debunched beams will be taken into account. For completeness sake a few of these well known expressions are given here:

The luminosity of the intersecting beams is defined by the expression for the interaction rate for a particular nuclear event, with cross section σ_{event} ,

$$N_{\text{IR}} = L \sigma_{\text{event}} \quad \text{The luminosity is given by}$$

$$L = \frac{c}{2b \tan \alpha/2} \left(\frac{N_{\text{st}}}{C} \right)^2 \quad \text{where } (N_{\text{st}}/C) \text{ is the line current density}$$

in each ring, C = circumference, c the velocity of light and α the crossing angle. From simple geometric consideration it follows for the interaction length

$$l_1 = \frac{2a}{\sin(\alpha/2)} \quad \text{and the interaction}$$

volume V_i :

$$V_i = \frac{(2a)^2 (2b)}{\sin \alpha} \quad .$$

For a (quasi) colinear crossing region (zero degree crossing) it is more relevant to use the expression for specific luminosity given by

$$L' = \frac{L}{l_1} = \frac{c}{(2a)(2b)} \left(\frac{N_{\text{st}}}{C} \right)^2 \quad .$$

Relevant parameters of the intersecting beams and luminosity values,
at full beam energy, are:

finite angle crossing

beam energy, T	216.56 BeV
crossing angle, α	20 mrad
crossing point parameters	$\beta_x = 6 \text{ m}, \beta_y = 3 \text{ m}$ $X_p = 0, \alpha_x = \alpha_y = 0$
beam emittance, $A_{2V} \times A_{2H}$	$0.52 \pi \times 0.14 \pi (\mu\text{rad-m})^2$
beam size, half amplitudes	$b = 1.2 \text{ mm}; a = 0.9 \text{ mm}$
angular spread, half amplitude	$\Delta y' = 0.43 \text{ mrad}; \Delta x' = 0.16 \text{ mrad}$
stacked protons, each ring	6×10^{14} protons
average current	14.8 amps
luminosity, unbunched beam, L	$1.0 \cdot 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$
bunched beam parameters:	
momentum spread, $(\Delta p/p)$	$0.5 \cdot 10^{-3}$
bunch length	24 m (30 bunches in 1937.07 m)
peak current	40 amps

colinear crossing

Except for crossing angle α , all parameters, as indicated for finite crossing angle. Further in a first approach, slowly varying β values are assumed over the colinear interaction region of interest.

Luminosity, unbunched beam, $L' = (L/l_i)$ $5.8 \cdot 10^{32} \text{ (cm}^{-2} \text{ sec}^{-1})/\text{m.}$

Assuming $\beta_x = \beta_o$, $\beta_y = \beta_o$ at $s = 0$ (crossing point) and further, in the domain $|s| < 5 \beta_o$, $\beta_x \cong \beta_y$ then $L' = K(1 + t^2)^{-1}$ where $t = (s/\beta_o)$, consequently:

$$\text{Total luminosity, unbunched beam, } L_{\text{tot}} (\alpha = 0) = \int_{-\infty}^{+\infty} L' ds \quad 1.8 \cdot 10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$$

Note: For the energy range of interest, L scales with $\gamma^{\frac{1}{2}}$, whereas L' [or $L_{\text{tot}} (\alpha = 0)$] scales with γ , where $\gamma = (E/E_o)$.

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