MACHINE GEOMETRIES FITTING INTO THE ISR TUNNEL

by

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1. **Introduction**

When one wants to put a set of superconducting storage rings (SSR) into the ISR tunnel one must strike a balance between two conflicting requirements:

i) In order to reach as high an energy as possible with a given field in the bending magnets, one must make the radius of curvature in the curved sections large;

ii) in order to accommodate experimental sections with low values of $\beta$ and sufficient free space one needs rather long straight sections in the SSR.

It is of great help in the design of this facility, that intersection regions with low values of $\beta$ and $\alpha_p$, the momentum compaction function, allow a substantial reduction of the crossing angle without the length of the region where beam-beam interactions take place becoming much longer than in the ISR.

This means that the "inner" and "outer" arcs have essentially the same bending angle. Alternatively, one might arrange for the beam crossings to take place in the vertical plane. In this case the two rings are exactly on top of each other.

2. **Ring Geometry**

In the following, we shall adopt the ring geometry shown in Fig. 1. We shall consider machines with $S$ superperiods. Each half superperiod consists of a curved section of radius $R$, and angle $\pi/3$, and a straight section of length $L/2$.

This corresponds exactly to the case of two rings with vertical crossings. We believe that it is also a good approximation to the case where the two rings cross horizontally at a small angle.

We impose the condition that the circumference of the machine is $300 \, \pi \, m$, i.e. the circumference of the ISR. This yields the relation:

$$2\pi R + SL = 300 \, \pi$$

(1)
The width of the ISR tunnel imposes an upper limit on the difference between the maximum and minimum radius of the machine, i.e. on the maximum and minimum distance of the ring from the machine centre. As can be seen from Fig. 1, the minimum radius \( \bar{R} \) is given by

\[
\bar{R} = R + \frac{1}{2} \frac{L}{\tan(\pi/S)}
\]  

(2)

and the maximum radius \( \bar{R} \) is given by

\[
\bar{R} = R + \frac{1}{2} \frac{L}{\sin(\pi/S)}
\]  

(3)

The difference between maximum and minimum radius becomes

\[
\Delta R = \frac{1}{2} L \left( \frac{1}{\sin \pi/S} - \frac{1}{\tan \pi/S} \right)
\]  

(4)

Or, solving for \( L \):

\[
L = 2 \Delta R \cdot \cot \frac{\pi}{2S}
\]  

(5)

Although, in principle, the ISR tunnel is 15m wide, passages along the inner and outer tunnel wall require that \( \Delta R \) is limited to about 10m.

If we assume this, and furthermore assume that the proton momentum is 150 GeV/c, and that 2/3 of the curved sections of the SSR is occupied by bending magnets, we arrive at the parameters shown in Table I.

| Table I. Maximum straight section length \( L \) for \( \Delta R = 10m \), \( p = 150 \text{ GeV/c} \) |
|---|---|---|
| \( S \) | \( L [m] \) | \( R[m] \) | \( B[T] \) |
| 4 | 48.28 | 119.26 | 6.3 |
| 5 | 61.56 | 101.01 | 7.4 |
| 6 | 74.64 | 78.72 | 9.5 |

When studying Table I it should be borne in mind how it was arrived at, and what its purpose is: it shows the maximum straight section lengths which can be accommodated in the ISR tunnel. It is quite obvious that their length increases with their number, \( S \), and that, as a consequence, the bending radius goes down rather quickly, and
the magnetic field goes up rapidly.

A more realistic picture emerges when one keeps the length of the straight sections constant. Table II shows a number of cases with \( L = 50 \text{m} \).

Table II. Machine Configurations for 
\( L = 50 \text{m}, \; p = 150 \text{ GeV/c} \)

<table>
<thead>
<tr>
<th>( s )</th>
<th>( R[\text{m}] )</th>
<th>( B[\text{T}] )</th>
<th>( \Delta R[\text{m}] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>118.17</td>
<td>6.35</td>
<td>10.36</td>
</tr>
<tr>
<td>5</td>
<td>110.21</td>
<td>6.81</td>
<td>8.12</td>
</tr>
<tr>
<td>6</td>
<td>102.25</td>
<td>7.34</td>
<td>6.70</td>
</tr>
<tr>
<td>7</td>
<td>94.30</td>
<td>7.95</td>
<td>5.70</td>
</tr>
<tr>
<td>8</td>
<td>86.34</td>
<td>8.69</td>
<td>4.97</td>
</tr>
</tbody>
</table>

When we assume a straight section length of 50m we imply that a section of 50m length is free of bending magnets. However, this section is likely to contain a certain number of quadrupoles for exciting the low \( \beta \) section and matching the beam to the normal machine lattice. Part of this matching section will reach into the curved parts of the machine; any possible differences in the radius of curvature are neglected at this stage.

3. Conclusions

Superconducting storage rings for protons with momenta in the range of 100 to 150 GeV/c can be housed in the ISR tunnel if superconducting bending magnets of the required quality can be made with fields between 5 and 7 T. In order to reach the upper part of this energy range it is important to keep the number and length of straight intersection regions low.
Fig. 1 \( \frac{1}{2} \) SUPERPERIOD OF THE STORAGE RING.