Synchrotron Radiation Issues in Future Hadron Colliders

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Any future energy frontier hadron collider, using high field magnets, will produce several W/m of SR power [1]. The recently proposed VLHC in its 2nd stage [2], for example, would produce 5 W/m/beam of SR power, which is ~50 times as much as the current LHC. This power is to be extracted from a cryogenic environment, making total cryogenic power requirements of the collider a top priority issue. We know solutions to this problem: cooled beam screens and/or photon stops. Both solutions have limitations, which will be briefly discussed in the following. A more thorough discussion of the issue can be found in [3] and [4]. The conceptual beam screen and photon stop designs for the recent VLHC proposal are presented in [2] and [5].

Beam screens

One of the results emerging from the recent VLHC study is that a cooled beam screen, much like the LHC beam screen [6] except for larger cooling channels, extracting 10 W/m of SR power can fit into a ~40 mm diameter magnet aperture, leaving a ~20 mm diameter area for the beam, which appears to suffice for beam-stability purposes. An important issue arising in the presence of large SR power is whether one can absorb the SR at an elevated temperature in order to reduce the cryogenic power requirements. We believe, in fact, that minimizing cryopower should take precedence over other issues in the choice of the operational temperature of the beam screen cooling system. The chosen beam screen temperature therefore rises with increased SR heat load, together with the required cryogen flow rate and cooling channel size. The results of calculations of these parameters, which are reported in detail in [3] and [5], are shown in Fig.1. The calculations assume a 20 bar gaseous helium as the cryogen, a 20 K temperature drop and a 1 bar pressure drop over the 135 m cooling loop unit and coefficients of conductive and radiative heat transfer between the screen and the cold bore measured on the LHC beam

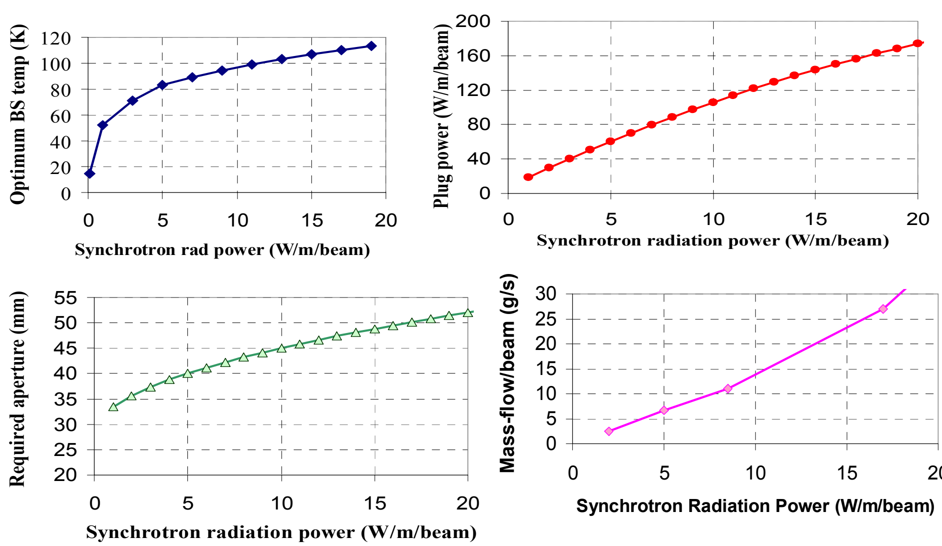

Fig.1 : Optimum beam screen temperature, beam screen plug power requirement (at optimal temperature), magnet aperture to fit beam screen (assuming a 20 mm diameter minimum beam area) and beam screen cryogen mass flow as a function of SR power per beam, per meter.

screen, as well as operation at the optimal temperature. The optimal temperature rises quickly with increased SR load and reaches ~100 K at ~10 W/m before saturating at ~120 K at ~20 W/m. Above, an increase of beam screen temperature is not favored, because the heat transfer from the screen to the 5 K cold mass becomes prohibitively large. The saturation of the optimal temperature is an indication that an additional shield between the beam screen and the cold mass is required, such as in the case of the room temperature (RT) beam screen, which is discussed next. The RT beam screen consists of a water-cooled screen surrounded by an 80 K (helium-cooled) shield. The RT beam screen is not attractive at a SR heat load <5 W/m/beam, because it produces a residual heat load of 3.7 W/m/beam (extracted by the intermediate 80 K shield), independently of the SR load. In terms of power cost it is the better solution above a SR heat load of 5 W/m/beam. However, the RT beam screen requires a larger magnet aperture for the helium shield, which makes it larger than the cooled beam screen up to a 20 W/m of SR. In addition the intermediate shield interferes with the pumping function of the beam screen, causing a yet unsolved problem.

Photon stops

Photon stops are water-cooled fingers protruding into the beam pipe from one side, placed after every bending magnet, that can be driven toward the magnet axis to intercept the SR emitted by the beam. The advantage of the photon stop is that it extracts the SR at room temperature and thus at optimal Carnot efficiency. Critical issues of the photon stop design are primarily related to the surface power-density and its impedance. Photon-absorbers in light sources operate at surface power rates up to 1 kW/cm^2 [7], exceeding that of any large hadron collider in the near future. Then, there seems to be no reason (except space limitations in the magnet interconnect) why such a photon stop couldn't be shaped like a wedge or taper with a longitudinal extension of up to 1 m to restrict the surface power density. Calculations performed for the recent VLHC study revealed that the impedance of a 3.5×1×1 cm photon stop is small [8]. However, there are also geometrical limits to the applicability of photon-stops. They are only practical in machines with large enough aperture magnets and a large enough arc radius (Fig. 2). The photon stops absorb the radiation emitted by the (1-X)th part of the second magnet up-stream and the |(X-1)|th fraction of the SR from the first magnet up-stream. The maximum possible distance between the photon stop tip and the beam occurs in the case in which X=0, when the photon stops absorbs all the radiation from the second magnet upstream. On the other hand the X=0 case has the most stringent magnet length restrictions. For 0<X<1 the photon stop comes closer to the beam (and reaches the beam at X=1), increasing its impedance as well as the risk of accidental beam impact. Fig. 2 shows the calculated maximum magnet length for different magnet apertures as calculated for X=0 and the distance to the beam, as a function of arc bending radius for different magnet lengths, a fixed physical beam tube aperture (30 mm) and optimal X. It is not clear now what the minimum acceptable distance between photon stop and beam is, but a few mm are certainly required. For the case of small, ultra high field machines a proposal by Talman [9], according to which the magnet is displaced horizontally with respect to the beam orbit, could be extremely useful to provide additional aperture for the photon stop. Another possibility is to share the heat load between photon stops and a beam screen. In the shared regime, however, one cannot fully take advantage of the (modest) reduction in magnet aperture that a solution relying on photon stops exclusively allows for.

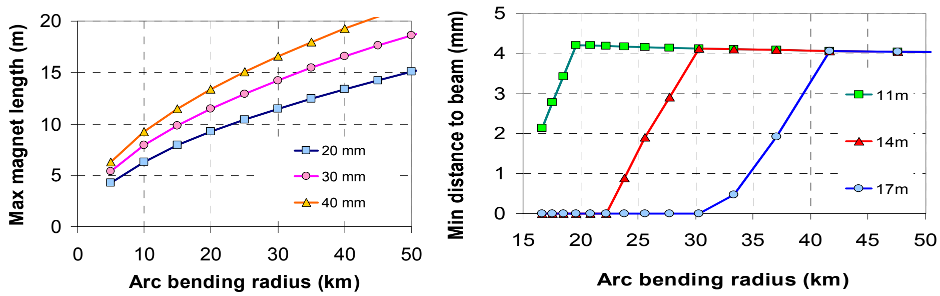

Fig.2: Max. magnet length compatible with photon stops in the X=0 scheme for different apertures. Max. photon stop to beam distance for different magnet lengths at a fixed aperture (30 mm). The calculations assume that the magnets are straight, centered with respect to the beam with 3 m long interconnects.

Summary

Hadron machines mostly use high field superconducting magnets operating at low temperatures. Therefore the issue of extracting a SR power heat load becomes more critical and costly. Conceptual solutions to the problem exist in the form of beam screens and photon stops. Cooled beam screens are more expensive in production and operation than photon stops, but they are, unlike photon stops, routinely used in existing machines. Photon stops are the most economical solution because the heat load is extracted at room temperature. We presently consider it most prudent to work with a combined beam screen and photon stop approach, in which the photon stop absorbs most of the SR power, and the beam screen serves only the vacuum purpose. Provided that the recently launched photon stop R&D [10] supports it, we would like to explore solutions with photon stops only. This would allow to reduce the magnet apertures to a certain extent with respect to those required to accommodate high SR power compliant beam screens and reduce cost. The possibility of magnet designs, which have larger vertical apertures where large cooling capillaries can be housed at no additional cost, would allow to soften this statement somewhat and should therefore be pursued as well.

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