

ESTIMATION OF THE ENERGY DEPOSITED ON THE CNGS MAGNETIC HORN AND REFLECTOR

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Abstract

In the CNGS (Cern Neutrino to Gran Sasso) installation two magnetic lenses, namely the horn and the reflector, focus the secondary beam generated in the target station. The gap between the horn and reflector is chosen to optimize a wide-band high-energy muon-neutrino beam. These two focusing elements are two coaxial lenses: the outer conductor has a cylindrical shape whereas the inner conductor consists of a sequence of conical shapes to optimize the focusing capacity. The evaluation of the heat load on the support structures is crucial since modifications in the elements around the horn and reflector are under way and the support structures can be adapted to the heat load found. Furthermore, the heat load in the whole horn area has been evaluated to optimize the cooling-ventilation system. The energy deposited on the horn and reflector as well as on their adjacent elements has been estimated using the FLUKA Monte Carlo package and results are presented in this paper. The FLUKA geometry input of the horn and reflector electrical connections has been notably improved in order to accommodate the detailed striplines design to the thermal expansion.

MAIN COMPONENTS OF THE CNGS BEAM

The SPS (Super Proton Synchrotron) proton beam is extracted at 400 GeV and guided over about 840 m to the CNGS target station. The SPS protons collide with the carbon target and produce secondary particles. The positively charged component of the secondary hadron beam is focused by two magnetic lenses (horn and reflector) while the negatively charged particles are de-focused. The positive pions and kaons decay in flight into muon-neutrinos and muons in a 1 km-long evacuated decay tube. Protons not interacting in the target, as well as hadrons which have not decayed, are absorbed in the hadron stopper downstream of the decay tube.

The muon beam from the decays is degraded in the hadron stopper but a high flux of muons still reaches the first muon detector chamber. Only the higher energy muons will reach the second muon detector chamber, separated from the first one by 67 m of rock. The neutrinos are travelling in the direction of Gran Sasso without any interaction.

MONTE CARLO SIMULATIONS OF THE ENERGY DEPOSITION

The energy density deposited by the secondary beam on the horn, reflector and support structure has been simulated with FLUKA [1, 2].

The evaluation of the heat load is needed in order to consider the simulation results in the installation and modification of the structures; measures needed to be taken also to accommodate the design of the striplines in view of possible thermal expansion, due to the energy deposited on this supports. (the striplines are the bus-bars connecting the horn and reflector to the pulse transformers). In addition, the power density in the whole horn area has been evaluated to establish the requirements for the cooling-ventilation system. For this purpose the geometry description of the horn and reflector electrical connections has been notably improved.

Energy deposition calculations have been used as an input for a better optimization of the aircooling system in the horn region. The CFD (Computational Fluid Dynamics) team performed calculations with the Star CD software [3] to verify the efficiency of the ventilation system and determine the temperature map on the horn and its close environment [4]. Helium tank regions, placed downstream each focusing device, have been also implemented in the geometry: each pipes set is equipped with two closing windows, which have been studied to optimize their thickness and shape.

THE MAGNETIC HORN AND REFLECTOR

Layout

The first focusing element, the horn, is placed about 1.2 m downstream of the target station. The inner conductor is shaped so that particles coming from the target, with a given energy but wide angular spread, traverse an integrated magnetic field which will focus them into a parallel beam. Particles of the opposite polarity will be then defocused. The effective focusing range is 20÷50 GeV; particles with an energy in the low part of this interval are over-focused by the horn, while particles with energy close by 50 GeV are under-focused.

The reflector, placed about 40 meters downstream of the target, is nothing but a 'second horn': it has a large aperture to allow the particles which are already well-focused to pass undisturbed, but provides additional focusing for

particles which have been under-focused or over-focused in the horn. In this way the energy band which is focused by the system is broadened, even if beyond the specified interval the reflector cannot compensate the de-focusing of the horn [5].

Energy deposition on the horn

The total energy deposited by the secondary beam on the horn inner and outer conductor is respectively 35.9 kJ and 64.5 kJ per cycle¹; the temperature of the inner conductor will rise by 25°C each cycle [6].

In case of beam displacement (a pure horizontal one has been considered), the neck of the inner conductor will certainly be damaged by the direct beam impact. To protect the horn from this kind of accident a collimator has been placed upstream the target: it has a central opening of 7 mm radius and in case of full impact (12.0 mm displaced beam) its temperature will increase by 800°C.

The energy deposited on the reflector inner and outer conductor is respectively 6.8 kJ and 40.4 kJ per cycle.

The shielding

The shielding around both magnetic lenses, horn and reflector, is a 'sandwich-like' structure made of marble (30 cm), iron (20 cm) and concrete (30 cm). An important issue during the installation, was to grant an effective ventilation system inside this shielding, since it has been seen that, in total, about 42.5 kW of energy was deposited on this structure. Table 1 shows the distribution of the heat on each slice of the 'sandwich'. Fig. 1 shows the power density along the beam direction in the horn region. Results are expressed in Watt considering the nominal beam intensity of $8 \cdot 10^{12} \frac{p}{s}$. CFD calculations showed that the temperature inside the horn chamber could rise up to 1000°C, unless additional gaps in the roof were provided to increase the air flow: further gaps, in fact, can reduce the temperature to 200°C.

Table 1: Total power deposited on horn shielding elements at nominal beam intensity

| Region | Material | Power deposited [W] |
|----------------------------|--------------------------|---------------------|
| Horn shielding | Marble High ² | 24344.73 |
| | Marble Low | 2704.79 |
| | Concrete | 451.30 |
| | Iron [GG20] | 3785.50 |
| Roof of the horn shielding | Iron[GG20] | 11249.20 |

The reflector is placed 30 m downstream the horn. It has been calculated that the total power deposited on the shielding structure is 10 times lower than the horn. For

¹Nominal intensity per cycle is $4.8 \cdot 10^{13} \frac{p}{s}$ but an ultimate intensity of $7 \cdot 10^{13} \frac{p}{s}$ has been considered in these calculations

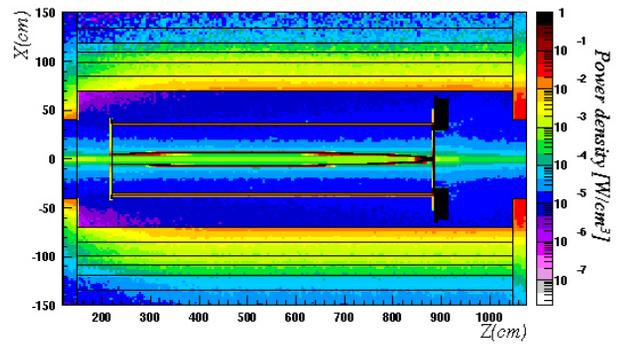


Figure 1: Power density in the horn region. Longitudinal cut.

this reason no further ventilation system is required in the reflector region.

The electrical connections

Eight aluminum alloy plates connect the horn and the reflector to the pulse transformers in the service gallery. The energy deposited by the secondary beam on the plates in direct contact with the horn, could critically rise the temperature causing aluminum mechanical properties to be compromised.

A simplified geometrical description of the electrical connections set was used for preliminary calculations: the total power absorbed was 9.6 kW; replacing the compact configuration with a detailed design, consisting of a layered structure, the absorbed power reduced to 1.6 kW.

In fig.2 is shown the power density distribution on one of the aluminum plates. The peak of energy density deposited on it is $0.1 \frac{W}{cm^3}$ around the beam axis.

These values are not worrying, since the temperature of the aluminum plates stays below 100 °C, and mechanical properties are preserved. The power deposited on the reflector electrical connections is a factor 2 to 3 lower than the horn. More informations about these results can be found in reference [7].

THE HELIUM TANKS WINDOWS

There are two helium tanks set to minimize the interactions of secondary beam particles in their trajectory to the decay tube: the first one is placed between the horn and the reflector, the second between the reflector and the decay tube. Each tank has an entrance and an exit window, 1.0 mm thick in the present calculation³, made of titanium: their thickness and shape optimization was the purpose of calculations.

Energy deposition results from FLUKA simulations have been used as an input for thermo-mechanical stresses evaluation: the final thickness chosen for the construction is a compromise between technical requirements (pressure

³The final design choices are 0.3 mm for the entrance window of the first helium tank and 1 mm for the others.

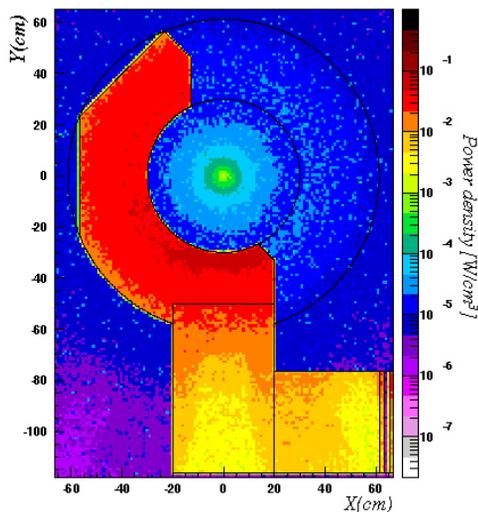


Figure 2: Power density on one of the horn electrical connections.

and temperature maximum load) and production restrictions.

In fig.3 the energy density profile on each window is shown; the heat load on the entrance window of the second helium tank is slightly higher than in the exit window of the first tank: this is due to the focusing effect of the reflector.

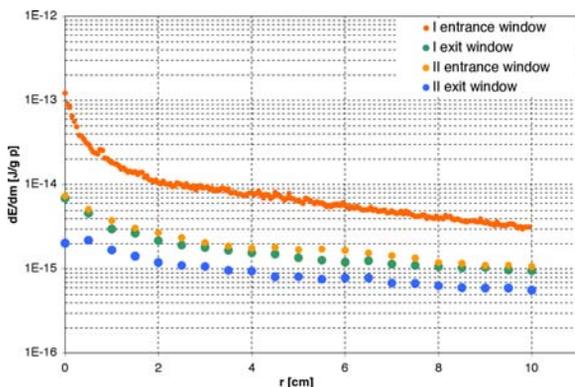


Figure 3: Energy density on the helium tanks windows

CONCLUSIONS

The energy deposited on the horn and reflector regions has been evaluated with FLUKA simulations. Some parts of the geometry have been improved or implemented, to get a complete description of the beam line.

Results show that the temperature in the horn region could rise up to 1000°C without the further ventilation system; with ventilation the temperature is kept below 200°C. Even without ventilation the horn support frame and the

striplines connecting to the pulse transformer are protected. The reflector region does not present any problem, since it is 40 m far from the horn, and the energy deposited by the over/underfocused particles coming from the horn has been absorbed by the upstream shielding walls.

The heat load on the titanium windows closing the helium tanks has been evaluated: the resulting thermo-mechanical stress profile stays below the allowed limits.

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