THE MICE DIFFUSER SYSTEM

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Abstract

The Muon Ionization Cooling Experiment (MICE) [1] at the Rutherford Appleton Laboratory [2] will measure the performance of a cooling channel in a variety of configurations of momentum and initial emittance. Coverage in emittance-momentum space relies on the MICE diffuser, a system with five different thickness lead degraders, remotely operated in a high magnetic field. Degrader optimisation for beam matching and technical issues are discussed.

INTRODUCTION

The generation of muons in MICE relies on the interactions of ISIS protons with a titanium blade [3], producing pions that are transported (via a quadrupole triplet and a dipole) towards a superconducting solenoid where they decay in the final particles. Another set of magnets, constituted by a dipole and two quadruple triplets, completes the transport beamline towards the experiment [4]. The emittance from the beamline is determined by the muon production mechanism while MICE requires a variable normalized emittance (up to 10 mm rad) for a variety of beam momenta. The MICE diffuser, an interface between the beamline and the experiment, will ensure the required coverage in the (ϵ_N, P) space while providing a matched configuration with the upstream optics.

DESIGN

Conceptually the diffuser (or degrader) is a layer of material in the beam, whose purpose is inflating the emittance by multiple scattering which locally increases the divergence of the beam. In the case of the MICE experiment care should be observed to fulfill some basic requirements:

- inflate the initial emittance to some desired value,
- cover most of the amplitudes accessible by the tracking devices (and not cut off by the actual aperture of the cooling channel),
- be flexible enough to work for all the beam configurations of MICE ((ϵ_N, P) matrix).

The optimal location for the diffuser has been chosen after careful studies [5] and turns out to be inside the bore of the first tracker solenoid requiring a positioning system whose mechanics and control are being finalized in the Oxford Design Office, Mechanical Workshop and Central Electronics.

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Effect of the Degrader

In addition to inflating emittance, a layer of material will also change the optical functions of a beam. Therefore care must be taken to produce matched values inside the tracker.

Ideally inflation should be uniform over the entire sample of muons, especially at higher amplitudes, requiring a diffuser with a very high radius. The constraints given by the real experiment limit this choice to a maximum possible radius of 15 cm. Also, due to practical limitations, the maximum radius of the interchangeable discs can be only 13 cm, while the remaining 2 cm are covered by an external annulus having a fixed thickness of 1 cm. Details of the disc and annulus can be seen in Fig. 1 where the cross section of the system shows how the movable disc can be positioned on top of the external annulus to form a single piece.

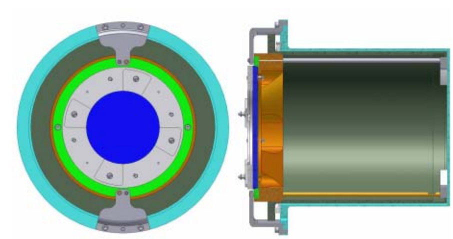

Figure 1: Close view of the disc and annulus system used to degrade the MICE beam. Left: upstream front view, right: cross section. Clearly visible the changeable disc (blue) and the fixed external annulus (green).

Simulations with a gaussian beam of 1.4 mm rad (geometric emittance) and a 10% gaussian momentum spread [6] show how the annulus helps in producing a uniform emittance inflation as illustrated in Fig. 2 where the effect of a bias in the final emittance is shown as a function of a finite size disc, with and without the external annulus. Emittance bias is gradually reduced at any momentum when R_{diff} grows and becomes negligible for $R_{diff} > 15$ cm (solid lines). The use of the annulus favours uniformity also for smaller disc radii (dashed lines), with the benefit of a much easier mechanical construction. The catch with the annulus is in its being a static component whose thickness must be fixed once and for all. The final choice has been therefore a compromise among several possible configurations. It should be stressed that the annulus becomes important only at large emittances, while for low ones it is basically inactive.

The thickness of the lead disc is a function of the beam configuration in terms of emittance, momentum and optics. Conventions on the terms used in this article are shown in

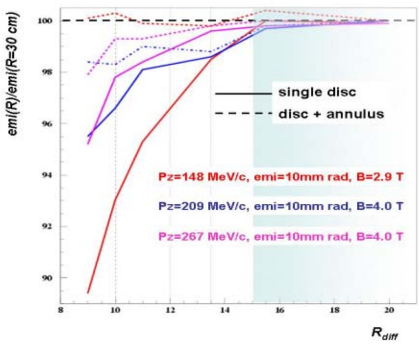

Figure 2: Emittance bias due to a finite size inner lead disc and effect of an external annulus to help uniformity. The maximum available radius is 15 cm (blue area). Results are plotted as the ratio with respect to the emittance calculated for a 30 cm radius disc.

Fig. 3 which also illustrates the effect of a material layer on optical functions and emittance. We have considered full and empty hydrogen absorbers for the final configuration of MICE (step VI), with momenta ranging from 140 MeV/c to

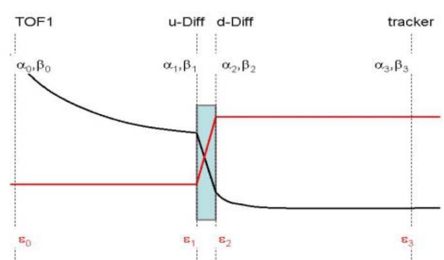

Figure 3: Naming conventions for the quantities used in this study: ϵ, α and β are the emittance (red line) and the optical functions (black line for β) at different positions along the channel (indicated by the subscript). Some relevant z positions (with respect to the central absorber of MICE) are: upstream ($z = -6010$ mm-[diffuser thickness]) and downstream ($z = -6010$ mm) face of the diffuser.

240 MeV/c and final normalized emittances from 2.8 mm rad to 10 mm rad. Nominal momenta are referred to the value reached at the centre of each absorber. The procedure to derive the thickness for each configuration is as follows: we fix the values for ϵ_3, α_3 and β_3 inside the tracker, requiring a matching. Then the optics is transported back to the downstream face of the diffuser (α_2 and β_2); in this transformation emittance is conserved ($\epsilon_2 = \epsilon_3$). The optical functions at the upstream face of the diffuser are then computed using the procedure described in [7]. This also defines the thickness of the diffuser once the upstream emittance ϵ_1 is given. The optical functions upstream of the diffuser are related to the downstream quantities and the thickness of the degrader; this reduces to the solution of a system of three equations (1) in the variables α_1, β_1 and t (diffuser thickness), γ being defined as $(1+\alpha^2)/\beta$:

$$\begin{aligned}\epsilon_2\gamma_2 &= \epsilon_1\gamma_1 + D\cdot t\\ \epsilon_2\beta_2 &= \epsilon_1\beta_1 - 2\epsilon_1\alpha_1 t + \epsilon_1\gamma_1 t^2 + D\cdot t^3/3\\ \epsilon_2\alpha_2 &= \epsilon_1\alpha_1 - \epsilon_1\gamma_1 t - D\cdot t^2/2 \qquad (1)\end{aligned}$$

In the hypothesis of an instantaneous energy loss D is defined as:

$$D = \frac{(13.6)^2 Z^2}{X_0(<P><\beta>)^2} \qquad (2)$$

The average values of P and β depend on the actual energy loss and therefore on the thickness of the degrader. Hence t

Table 1: Downstream emittances and Twiss parameters at the upstream face of the diffuser as a function of the diffuser thickness for empty and full absorber configurations and for different initial upstream momenta

MICE Step VI: empty [full] absorbers				
t (mm)	P (MeV/c)	ϵ_{N2} (mm rad)	α_1	β_1 (cm)
1.5	142 [151]	2.9 [3.0]	0.3 [0.2]	53.9 [55.7]
5.0	148 [156]	6.1 [6.0]	0.7 [0.3]	113.1 [112.7]
10.0	156 [164]	10.8 [10.6]	1.2 [0.6]	200.7 [197.8]
0.0	200 [207]	2.6 [2.7]	0.1 [0.1]	34.3 [36.4]
7.5	211 [218]	6.0 [6.0]	0.2 [0.2]	78.0 [78.2]
15.5	222 [229]	10.1 [10.0]	0.4 [0.4]	131.7 [130.8]
0.0	240 [245]	3.5 [3.5]	0.06 [0.1]	40.8 [41.8]
7.5	250 [256]	6.9 [6.8]	0.14 [0.2]	79.6 [80.6]
15.5	262 [267]	11.0 [10.9]	0.25 [0.3]	128.2 [129.4]

is evaluated through an iterative procedure. Eventually five thicknesses are chosen which produce the required values for the emittances (close to 3, 6 and 10 mm rad). The optical functions α_1 and β_1 are calculated upstream of the diffuser: they represent the reference values the beamline has to provide for a correct matching with the downstream section. Table 1 summarizes the results described so far.

CONSTRUCTION

The main difficulty in the realisation of this device consists in the limited available space, the need for a remotely controlled instrument and the presence of high magnetic fields (some Tesla) preventing the use of normal electric motors and requiring a careful choice of materials to cope with eddy currents and stress forces in the event of a magnet quench. The location of the degrader inside the first spectrometer solenoid bore requires a specially designed insertion system (Fig. 4). This consists of a revolving

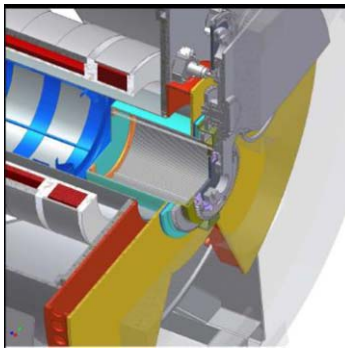

Figure 4: Cross section of the first spectrometer showing the diffuser system in the solenoid bore facing the tracker.

carousel with six fingers hosting five lead discs at different thicknesses and an empty station. After a controlled rotation of the fingers the disc is being unloaded from the carousel, loaded onto a linear stage and positioned inside the bore (Fig. 5).

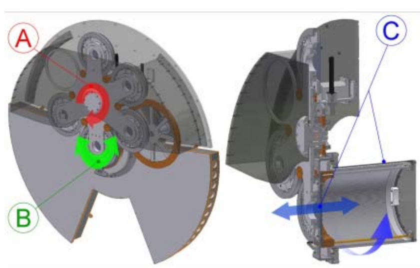

Figure 5: Motions of the diffuser mechanism. Left: (A) rotation of the main carousel, aligning the selected disc with the solenoid axis. (B) motion to unlock a disc from the carousel (15°) and lock it to the catcher unit (15°). Right: (C) threaded cylinder rotation determining the linear motion of the catcher pushing the lead disc inside the solenoid bore.

All the diffuser motions will be controlled locally from an electronics crate by a Xilinx Spartan Field Programmable Gate Array (FPGA) programmed to perform the tasks outlined in the MICE diffuser control sequence. Task selection commands can be made by either a program running on a remote PC situated in the control room (via a fibre optic link), or locally by push buttons mounted on the electronics crate front panel located in a dedicated control rack. The system status will be sent back to the remote PC regardless of which mode of control it is in. This way of controlling the diffuser should ensure a safe termination of a sequence, even in the event of a computer failure or a break in the communication link. A UPS will ensure completion of tasks should a power failure occur. The FPGA firmware will control the steps in each task by monitoring the position encoders and interlock micro switches, and applying a low voltage dc supply (12V) to the solenoid coil of the appropriate air valve of either an air motor or the carousel locking piston. All the air valves will be located in the middle crate of the rack (Fig. 6).

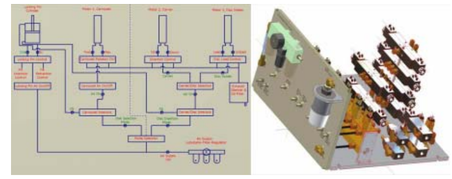

Figure 6: (Left) the air crate front panel, used to display the status of the system. (Right) the air crate with the solenoid valves used to drive the air flow to the diffuser and the back plane hosting gas inlets and air purification and lubrication units.

CONCLUSION

The MICE Diffuser System is presently being assembled in the Oxford Mechanical Workshop (Fig. 7) where it will be checked mechanically. In parallel, control electronics will be completed and tested, which will be eventually merged with the mechanical device for a complete test of the system prior to its installation in the MICE hall at the arrival of the spectrometer solenoid, later this year.

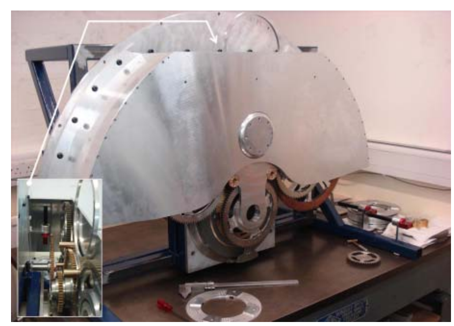

Figure 7: The diffuser system being assembled on the test stand in the Oxford Mechanical Workshop. The inset shows the packed volume hosting gears and motors.

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