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SUMMARY

We report the study of a toroidal coil for a spectrometer to be located in a manned space station in orbit around the earth. Huge acceptances, of the order of 10^2 $m^2 \times sr$, can be obtained using toroidal coil configurations whose weight and complexity are compatible with techniques presently available to transport the spectrometer from the earth to the space.

1. INTRODUCTION

Future cosmic-ray programs are centered /1/ on a superconducting magnet facility to be installed and operated on a manned space station in orbit around the earth. This remarkable research instrument foreseen to be operative by the middle nineties, would make realistic the feasibility of apparata assembled in orbit serviced at the space station itself. The investigation of energetic cosmic ray antiprotons, positrons and electrons in addition to the study of the isotopic abundances of hydrogen, helium and heavier nuclei at high energies are some exciting physics items of these programs /2/. It would also allow the quest for cosmic ray antinuclei.

Space station experiments could improve the acceptance and the corresponding counting rate for these investigations with respect of those performed by balloons, satellites and shuttle flights by several orders of magnitude. The most relevant limitations to assemble in orbit apparata is due to the space transportation system between the earth and the space station implying volume and weight restrictions besides technical difficulties and costs.

One of the most striking features of a space station based experiment is the time dilatation of operation (of the order of years) when compared to the present possibilities (of the order of hours or days). As a consequence, the possibility of measuring very low fluxes as low as $\sim 10^{-10}$ of the primary proton flux will open the access to experiments which are far beyond the present capabilities of conventional balloon and satellite instrumentation.

2. OUTLINE FOR A SUPERCONDUCTING SPACE SPECTROMETER

The general scheme for a multipurpose spectrometer in space is based on a system of coils producing in the environments a strong magnetic field in which lay one or more detecting telescopes. The number and design of such telescopes depend critically on the adopted system of coils which affect their two main performing parameters i.e. acceptance and bending power.

In this paper the design of the system of coils for such a spectrometer is investigated.

Among the possible magnet configurations which could fit the physics goals for the space station, the toroidal structure (Fig. 1) is to be considered the most efficient because it has the optimal exploitation of the bending power of the field. In fact, while a telescope in a toroidal field takes advantage of the entire field strength for bending particles, telescopes near a circular coil can benefit partially of the field because its component parallel to the particle direction is large and it does not work. Furthermore, in a toroidal structure the current loops can be closed far away from the symmetry axis. In this way a remarkably high acceptance can be reached and the range of the covered bending power is made very large with a modest increase of the weight of the coil.

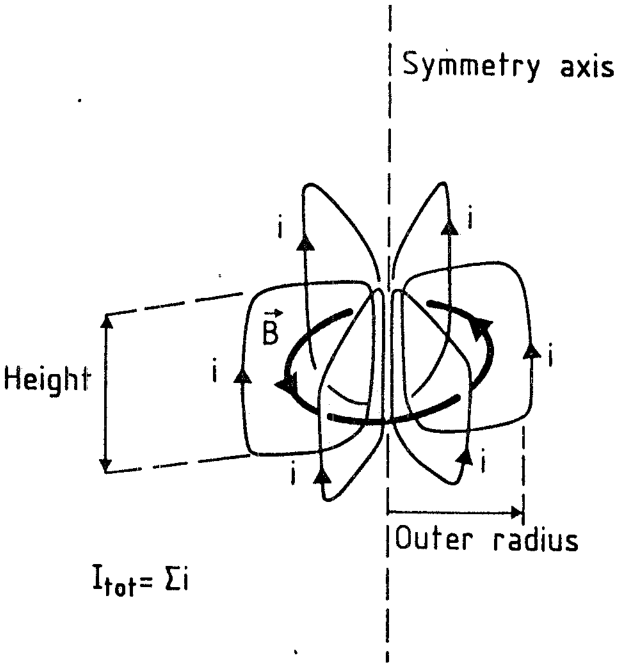

FIG.1 - Layout of the system of six turns producing a toroidal field.

If the outer radius of the coil is very large the bending powers span over several orders of magnitude. From Table I it is apparent

TABLE I - Magnetic field bending powers and cross surfaces as a function of outer radius for total current $I_{tot} = 5$ MA and height of the coil (4 m).

Radius m	B tesla	Bending power tesla x m	Annular cross surface of the coil m^2
0.2	5.0	20	
0.5	2.0	8	0.7
1.0	1.0	4	2.4
2.0	0.5	2	9.4
5.0	0.2	0.8	66.0
10.0	0.1	0.4	235.6

how fields, relatively low, but still giving bending powers in the range of several Kgauss x m cover very large surface acceptance.

We can classify toroidal coils for a space spectrometer in two main classes:

(a) arrangements which could be directly shipped by the transportation system in the space as a unique block;

(b) arrangements of larger dimensions which require to be assembled in the space.

The case (a) is one of the possible solutions envisaged for the superconducting magnet facility by the SCMF definition team /1/ specifically constituted by NASA. Typical acceptance and average bending power for this case are in the range of 2 m^2 x sr and 2 Tesla x m.

In order to increase the acceptance (case (b)) it is necessary to overcome the restrictions due to the transportation system. One attractive possibility is to transfer in the space the package of the turns and opening them as a "fan" as shown in Fig. 2. Under the constraint of occupying only two pallets* of the shuttle transportation system, we

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* A pallet of the shuttle can allocate a useful cylindrical payload of 4 m in diameter and 4 m in lenght.

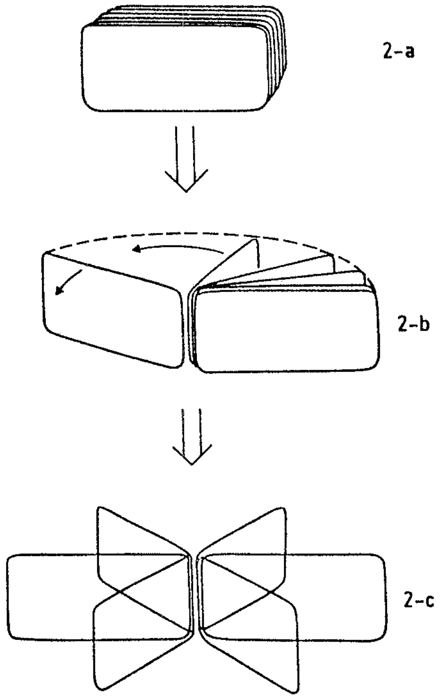

FIG.2 - Fan opening coils. (a) packed for the transportation system; (b) opening of the turns; (c) final configuration before current supply.

could transfer in the space the turns for a toroidal coil having a maximum radius of 8 m and 4 m height. The corresponding acceptance would be two orders of magnitude larger than the maximum available acceptance of any other possible configuration shipped in space as a unique block.

3. ACCEPTANCE AND BENDING POWER FOR DIFFERENT GEOMETRICAL PARAMETERS OF THE COIL

The main parameters of any toroidal coil are the total current, the number of turns in which this current is subdivided and the shape (essentially, height, inner and outer radii) of each turn. The total current is the critical parameter to determine the strength of the magnetic field and indeed of the total stored energy. In our evaluation we fixed the total current to 7.85 MA giving a total stored energy in the limit of 60 MJ. This current has been subdivided in 6 turns corrensponding to a minimization of the dead space for the incoming particles without loosing the 1/r field dependence of the toroidal structure. For different coils we have calculated the total acceptance, the acceptance for particles crossing the free space between two turns (sector), and the mean bending power for the total structure and for individual sectors. The input parameters of these calculations are the external radius of the turn, its height and its cross section. The height has been fixed at 4 m and the cross section equal to 20 x 40 cm^2. Therefore our results depend only on the outer radius. The shape of the turn has been approximated by a rectangle (see Fig. 3).

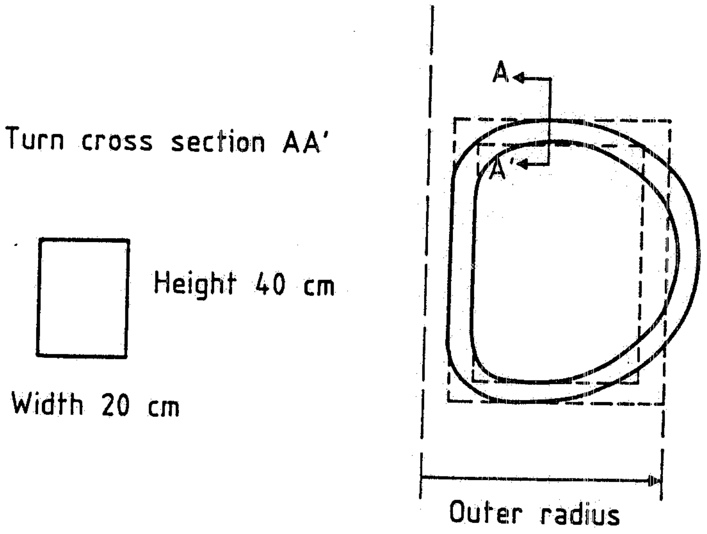

FIG.3 - Reduction of a D-shaped turn with a rectangular turn used in the calculations.

Particles are assumed not to be deflected by the magnetic field. They are generated isotropically in one emisphere and are considered lost, as shown in Fig. 4, either when hitting the coil or when crossing the lateral surface of the cylinder defining the coil volume.

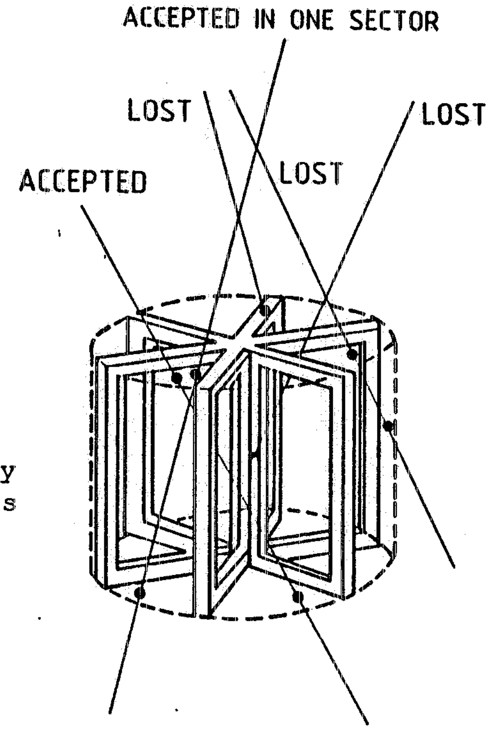

FIG.4 - Coil volume defined by the height and external radius of the turns.

Results are reported in Table II and in Fig. 5.

In Fig. 6 the acceptance versus different ranges of bending powers

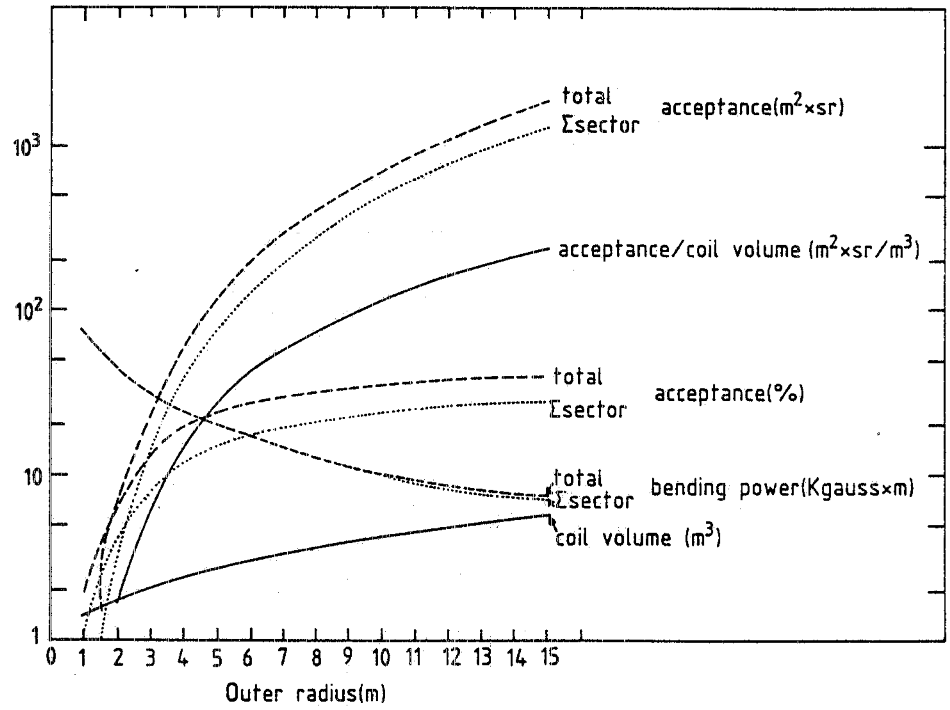

FIG.5 - Acceptances and average bending powers versus the external radii of the coil.

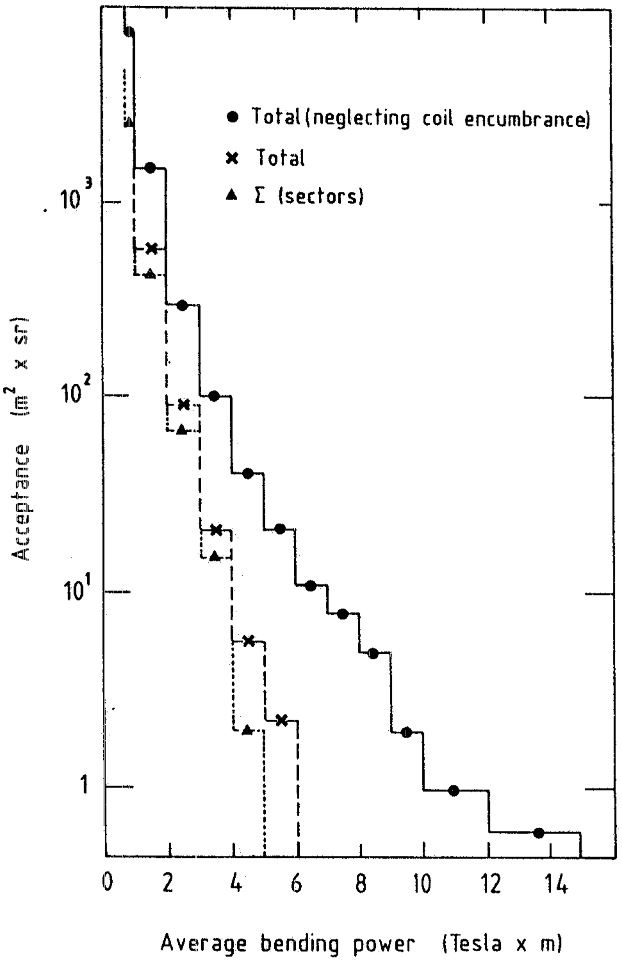

FIG.6 - Acceptance of the coil versus the bending power.

TABLE II

Outer Radius R* m	Coil Volume m^3	B(R*) tesla	< B > tesla	Acceptance				Bending Power $<\int Bdz>$	
				Total		ΣSector		Total tesla	ΣSector tesla
				%	m^2xsr	%	m^2xsr		
1.	1.408	1.40	2.33	2.0	.4	1.0	.2	7.66	7.60
1.5	1.632	.93	1.65	3.9	1.8	2.4	1.0	5.42	5.38
2.	1.792	.70	1.27	6.9	5.4	4.3	3.4	4.34	4.28
3.	2.112	.466	.885	13.4	23.8	8.45	15.0	3.16	3.09
4.	2.432	.35	.668	19.5	61.6	12.4	39.2	2.50	2.43
5.	2.752	.28	.539	24.2	119.4	15.7	77.4	2.05	1.99
6.	3.072	.233	.452	27.8	197.4	18.45	131.0	1.73	1.68
8.	3.712	.175	.342	32.6	411.8	22.5	284.2	1.32	1.26
10.	4.352	.140	.274	35.0	691.0	25.0	494.0	1.07	1.01
15.	5.932	.093	.184	41.0	1820.0	30.0	1332.0	.73	.67

is given in the following cases: (a) neglecting the coil encumbrance; (b) accepting all the particles crossing the coil volume; (c) accepting only particles crossing one sector and adding up all the 6 sectors.

In conclusion we stress that for the toroidal configuration, the ratio between the acceptance and the weight of the coil is rapidly increasing with the outer radius without major losses in bending power so that, as the outer radius of the coil increases, larger acceptances are easier achieved. The toroidal magnet is in fact the best compromise between large acceptance and strong bending power and it represents an excellent solution for experiments in which the counting rate is the main limitation.

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1) "The particle Astrophysics Program for 1985-1995". Report of the NASA Cosmic Ray Program Working Group (Sept. 1985).

2) V.M. Chechetkin, M.YU. Khlopov and M.G. Sapozhnikov, Riv. Nuovo Cimento 5 (1982).