HIGH INTENSITY STOPPED K-MESON BEAM AT THE BEVATRON*

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Summary

A high intensity stopped K-meson beam with a design goal of 10^5 stopped K^+ per pulse is being constructed for the Bevatron. The facility is a large acceptance, 33-ft long beam line, which selects and transports 500 MeV/c K's to a stopper. The beam consists of a symmetrical arrangement of two large 90° bending magnets, three quadrupoles, and two electrostatic separators. Construction completion of this facility is scheduled for the Fall of 1973.

Design Goals

A new separated secondary beam line (Beam #34) is being constructed at the Bevatron to transport 500 MeV/c kaons, and it will provide substantially improved fluxes. This beam is particularly suited for use with "stopped kaon" experiments in which the kaon is stopped in a piece of material and its subsequent decay or interaction is studied.

The use of new, specially constructed magnets and separators rather than general purpose beam elements permits the incorporation of several unique features in this beam line. First of all, the problem of kaon decay in flight can be alleviated by constructing an unusually short beam line consisting of special short beam elements. Such a beam is practical at Bevatron energies because only a relatively small amount of shielding is needed to isolate the experimental area from the production target. Secondly, since the desired large acceptance causes severe design problems with both spherical and chromatic aberrations, the beam is designed to minimize or to correct the worst of these aberrations. Lastly, two stages of mass separation are incorporated, to ensure that this beam would be sufficiently pure so that a very intense proton flux can be used.

The following table gives the design parameters for this beam:

Table 1 - Beam Parameters

Solid angle	20 msr
Momentum bite	± 2%
Proton intensity	~ 3 x 10^{12}
K^+ accepted	3.2 x 10^6
Length	394 in.
Decay factor for 500 MeV/c K's	0.069
K^+ transmitted	2.2 x 10^5
K^+ stopped	0.74 x 10^5
π^+ transmitted (no separation)	2.1 x 10^8
Min. pion attenuation by separators	> 240 times
Max. π^+ transmitted (with separation)	< 8.6 x 10^5

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One can see from this table that this beam is designed to use the intense proton fluxes which will be available at the Bevatron when the 50 MeV injector becomes operational. Although the pion attenuation is difficult to calculate reliably, the use of two stages of mass separation is expected to attenuate sufficiently the pion background so that there will be fewer than 10^6 particles per pulse striking the kaon stopper when there are as many as 10^5 kaons stopping in that stopper. In comparison with the present Bevatron stopped kaon beam (Beam #28), which utilizes general purpose beam elements, the new beam is designed to provide two orders of magnitude improvement in beam flux. This improvement consists of a 4.5 times improvement in solid angle, a 2.4 times improvement due to fewer decays in flight, and a 6.6 times improvement in proton flux.

Beam Design

The design criterion of a ± 2% momentum bite requires that the beam be momentum dispersed (horizontally) at an intermediate focus and momentum recombined at a final focus. Also, two stages of mass separation requires two mass slits placed at two (vertical) foci. The beam therefore consists of two identical but reversed sections, symmetric about the intermediate focus, where the momentum slit and one mass slit are placed. At the final focus, the beam is momentum recombined and passes through a second mass slit. This symmetric arrangement cancels some aberrations, and the momentum recombination occurs naturally.

Each section of the beam then consists of a bending magnet, focusing elements, and an electrostatic separator. The horizontal acceptance is chosen to be large (± 210 mrad); but the vertical acceptance is kept fairly small (± 24 mrad), in order to achieve a clean mass separation.

Strong bending magnets are used to provide adequate momentum dispersion in spite of serious spherical aberrations. As it turns out, these 90° bends provide sufficient horizontal focusing so that only one quadrupole is needed in each half of the beam, to provide the necessary vertical focusing. Other focusing methods were considered, such as a bending magnet with a gradient or with rotated pole faces. However, these alternatives were found to be unattractive because they required larger magnets or beam apertures.

A very important benefit of using a bending magnet and one quadrupole to do the focusing is that this arrangement leads to substantially less chromatic aberration than is found in designs using the strong focusing of a quadrupole doublet.

With the final addition of a field lens at the intermediate focus, the beam design is shown in Fig. 1.

Optical Aberrations

The second-order aberrations were carefully considered during all stages of the beam design, since they were found to be dominating factors in controlling the spot sizes at the foci. In the final design, the chromatic aberrations and the horizontal spherical aberrations were found to be tolerable. However, it was found that curved pole tips on the bending magnets could correct the worst vertical spherical aberration and substantially improve the vertical spot sizes and mass separation.

The second-order calculations and the beam design were performed using the computer program TRANSPORT.[1] The final design was checked to all orders by using the ray-tracing program SOTRM.[2]

Bending Magnets

The parameters for the two large bending magnets are tabulated in Table 2.

Table 2 - Parameters of Bending Magnets

	Bending mag 1	Bending mag 2
Beam aperture (in.)	4 x 18	4 x 18
Magnetic field (kG)	19	19
Magnetic length (in.)	54.4	54.4
Mag bend radius (in.)	34.6	34.6
Bend angle (degrees)	90	90
Magnet gap (in.)	5.6	5.4
Magnet ampere turns	273,900	242,500
Magnet power (kW)	105	300
Magnet weight (lb)	400,000	110,000

Bending Magnet 1

This magnet is a Bevatron M-5 bending magnet with a modified core and pole. The large pole area is necessary since this magnet is the first element of two other secondary beams, which have higher momenta.

Massive field clamps, added to the entrance and exit of the magnet, minimize the fringe fields and allow quadrupole 1 to be placed very close to the bending magnet. The field clamps are attached to the core with a shimmable gap between the field clamp and the core. This gap can be adjusted to bring the field between the noses of the field clamp to zero.

A minimum lateral distance of 3.4 half gaps has been allowed from the edge of the beam aperture to the edge of the pole in order to ensure high field quality. If necessary, the field uniformity of the bending magnet will be improved by shimming the flat poles.

The effective length of the bending magnet can be adjusted by moving the noses of the field clamps. At the exit of bending magnet 1, a sextupole field is provided by curved pole tip edges. Further first- and second-order corrections, if required, can be made by modifying sections of the field clamp noses. Sextupole coils will be mounted on the exit end field clamps for beam trimming.

Bending Magnet 2

This magnet is basically a C magnet shaped in the form of a quarter circle. It is shown in cross section in Fig. 2. Tapered slits are used to achieve a very uniform field in the useful aperture, and the computer program MIRT[3] was used to optimize the design of these slits. This magnet design using slits does not require any additional iron than designs without slits, but it results in a much more uniform field. There is no need to machine field correction contours in the pole tips.

Field clamps are also needed in this magnet, and a sextupole field is provided at the entrance of bending magnet 2.

Quadrupoles

The beam channel will include 3 quadrupole magnets with parameters tabulated in Table 3. Quadrupoles 1 and 3 will run at nearly equal gradients and are physically identical. These will provide the necessary beam focusing and also some vertical deflection. Because the beam is 11 in. wide and only 4.6 in. high through the quadrupoles, the pole tips extend farther horizontally than vertically, saving space and power as shown in Fig. 3. Quadrupole 2 acts as a field lens. Its aperture is large enough to enclose an adjustable, high density, mass slit.

Quadrupoles 1 and 3 have severe restrictions on size in the vertical and longitudinal directions. Quadrupole 2 is restricted in length. These requirements underlie the somewhat unusual shapes of the cores: all these quadrupoles have pole tips longer than pole bases in order to minimize overall length. This design is permitted by the relatively low field gradients of about 1 kG/in. All quadrupoles have field clamps to limit the axial stray fields.

Table 3 - Parameters of Quadrupole Magnets

	Quadrupoles 1 and 3	Quadrupole 2
Beam aperture (in. x in.)	6.0 x 11.0	1.0 x 11
Nominal gradient (kG/in.)	0.828	1.031
Radius to pole tip vertex (in.)	5.00	3.90
Pole vertex field (kG)	4.14	4.02
Magnetic length (in.)	18	11
Pole tip length (in.)	16	9.2
Core length (in.)	13	8.0
Magnet ampere turns	21,600	16,350
Magnet power (kW)	31.1	15.2

Pole tip contours were optimized using the computer program MIRT. The program was applied after the preliminary quadrupole cross sections were conformally transformed to dipole sections. Two-dimensional optimization was pursued until the fields within the useful aperture were accurate to within 0.1%. Because the new electrostatic separators have no magnetic field, the kaons are deflected vertically. Quad 1 is adjustable ± 0.7 in. vertically to provide a vertical deflection to bring the beam back to the median plane at the first mass slit, and quad 3 is adjustable vertically ± 0.7 in. to restore the beam to horizontal direction. Positive and negative adjustment is required to handle kaons of either polarity.

Electrostatic Separators

The beam channel includes two electrostatic separators, each with electrodes 60 in. long. The flat width is 12 in. with 2-in. radius edges. The beam design requires the separators to operate at 750 kV when the variable gap is set at 4 in.

These units differ from our previous parallel plate velocity spectrometers in several important ways: there is no magnetic field to provide vertical deflection; the electrode positions and gaps are adjustable from outside the vacuum envelope instead of having fixed internal adjustments; high voltage is fed through the centers of the top and bottom of the envelope instead of horizontally at the ends of the older units; and there are no inclined added electrodes ("duck bills") at the ends to reduce the field concentration at the corners. The electrodes can be adjusted from a gap of 1 in. to 5 in., and each end is independently adjustable.

The separators will use the previously developed voltage-holding techniques of heated glass cathodes, ultra clean and smooth stainless steel surfaces, 2-in. radii on electrodes, uniform 4-in. separation from the ground plane, clean high vacuum technique, and a flow of argon at a pressure of about 1 μm Hg during operation. As before, there will be 2 power supplies feeding voltage above and below ground so that the peak voltage appears only between the two electrodes. The separator bodies are made of steel in order to intercept stray magnetic fields that may exist in the channel.

Each unit will have its own liquid nitrogen trapped diffusion pump system, which pumps directly on the volume between the electrodes and the ground plane.

Particle Mass Separation Slits

There will be mass slits at the two focal points of the beam. At the intermediate focus, where there is momentum dispersion, the focal plane is tilted because of chromatic aberration. The surface of this mass slit will be machined to correspond to the beam envelope. The gap in the slit will be adjustable so experimenters may optimize the pion separation versus beam intensity to suit a particular experiment. The slit will be made of tungsten alloy (or equivalent) and will fit within the aperture of quadrupole 2.

At the final focus the kaon beam passes through the second mass slit and an energy degrader, and comes to rest in a stopper.

Status

All the major components have been designed and are in fabrication with the exception of bending magnet 1 where detailed design is currently being completed. Installation of this system is now scheduled for Fall 1973.

Acknowledgments

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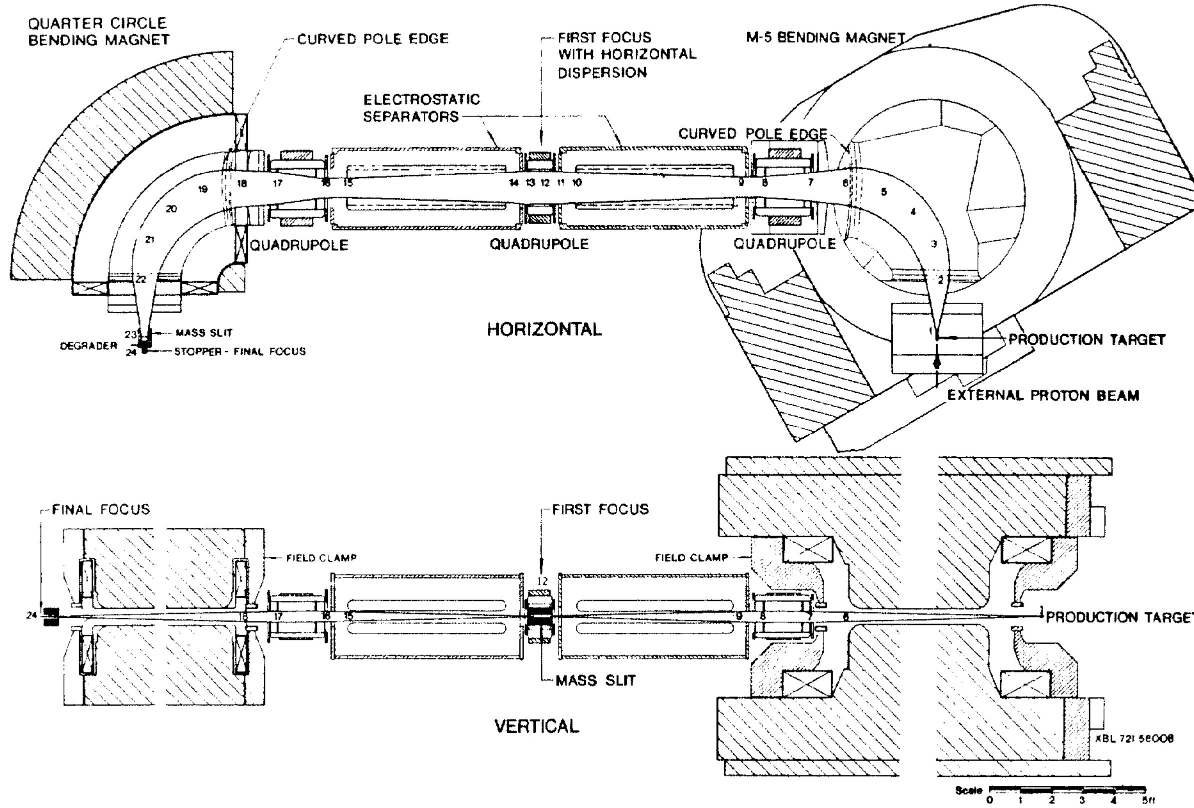

Fig. 1. High Intensity Stopped Kaon Beam

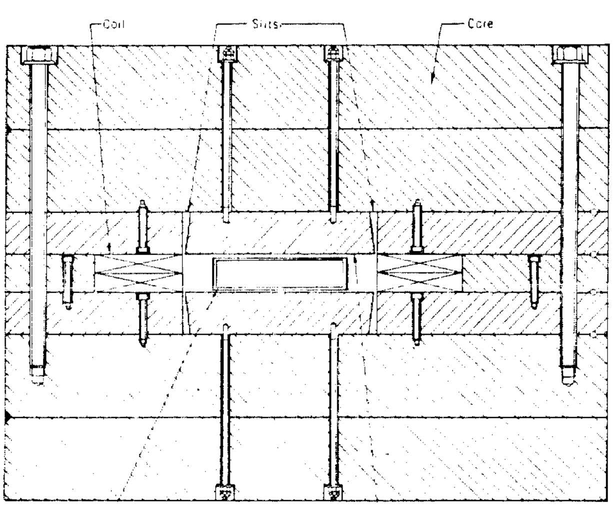

Fig. 2. Cross-Section View of the Quarter-Circle Bending Magnet showing Slits at the Pole Edges.

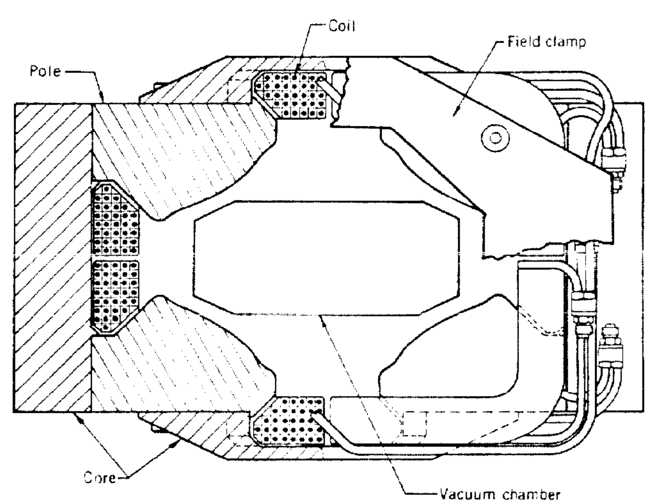

Fig. 3. Quadrupoles 1 and 3.