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PROJECT STUDY AND TECHNICAL PROPOSAL

for the

EXTERNAL PROTON BEAM TRANSPORT CHANNEL FOR THE CERN - SERPUKHOV COLLABORATION

by

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1. INTRODUCTION

This report describes the external proton beam transport channel required for guiding the proton beam from the exit window in magnet unit 27 of the Serpukhov accelerator up to an external target station and for focusing the beam on the target for an RF separated beam.

The external proton beam channel comprises the complete system between the ejection window and the external target and incorporates as main equipment a system of magnetic lenses and deflectors, their power supplies, protection, measuring and control circuits and a vacuum and beam monitoring system.

Background

The present project study for the external proton beam transport channel has been based essentially on the beam layout and optical arrangement described by Myznikov and Tatarenko (Ref. 1).

Following the first preliminary note (Ref. 2) additional information has been obtained on the experimental requirements (Ref. 3,4,5,6,7), on the installation possibilities and on the initial parameters of the internal proton beam and its ejection from the accelerator (Ref. 3,7,8,9) which in the meantime has been operated up to the region of 10^{11} protons/pulse and 76 GeV.

Measured beam emittance data are not yet available. Further, the ejection trajectory and the beam emittance at the exit from the accelerator cannot be determined before the final type and parameters of the ejection system are known.

Our beam optics computations (Ref. 10) for determining the parameters of the beam transport elements have been based on a set of initial conditions for the ejected beam which was established by means of information obtained from the fast ejection group (Ref. 8), in consultation with J. Fronteau (Ref. 9).

It is hoped that these data are sufficiently close to the final values that any changes in beam emittance, ejection parameters and experimental requirements will not exceed the limits that can be accomodated.

The beam layout is shown in Fig. 1 (a) and 1(b) (drawing NPA 232-183-0 and 232-184-0).

2. SYSTEM REQUIREMENTS

The EPB transport system must match the beam as it is ejected from the accelerator to the condition required for the experimental application.

2.1 Accelerated beam conditions

A proton momentum of 85 GeV/c has been assumed as upper limit for the present proposal. The lower limit has been assumed to be 30 GeV/c since still lower momenta require an increased magnet aperture because of increased beam dimensions.

For accelerated momenta around the region of 70 GeV/c a repetition period of 7 - 8 s and a flat top duration of 0.8 s, that later will be increased to 1.5 s, have been indicated as typical values. The cycle shown in Fig. 2 (drawing NPA 232-180-4) has been assumed for this study.

The revolution period of the circulating beam is 4.5 μs and there are 30 bunches at 150 ns intervals.

2.2 Emittance and exit trajectory of ejected beam

The duration of a full single-turn ejected beam burst is 4.5 μs, given by the revolution period of the circulating beam. The fast ejection system (Ref. 11) has also been planned with multi-pulse facilities for partial extraction of the beam in several short bursts during the flat top of each acceleration cycle.

Only preliminary data have been available for the present study and the trajectory and emittance values shown in Fig. 3 a,b,c (drawings NPA 232-195-4, 232-196-4, 232-197-4) have been assumed for all beam optics computations for determining the optical parameters of the external channel.

2.3 Experimental requirements

The EPB channel is initially intended for an R.F. separated beam for the Mirabelle hydrogen bubble chamber. Some data on experimental requirements are collected in Table 2.2.

It has been stated that the experiments with the Mirabelle and CKAT bubble chambers may eventually require more than one beam burst for each PS cycle. The number of 2 or possibly 3 pulses at 0.5 s intervals during the flat top of each PS cycle seems a probable final requirement for Mirabelle. During the initial period a repetition rate restricted to one pulse per PS cycle has been planned.

Table 2.1 Some approximate internal beam and accelerator data

1.	Proton momentum range	30 - 85 GeV/c
2.	Beam intensity	10^{12} protons/pulse
3.	Flat top duration/repetition period at	30 GeV/c: 1.0 s/5.0 s
		70 GeV/c initially: 0.8 s/7.5 s
		later: 1.5 s/ ?
		85 GeV/c initially: ? s/? s
		later: ? s/? s
4.	No of bunches	30
5.	Bunch separation	150 ns
6.	Ejected beam burst duration for full single turn ejection	4.5 μs
7.	Multi-shot ejection :	to be determined
8.	Internal beam emittance at 30 GeV/c	horizontally 5.04 x 0.303 mm x mrad
		vertically 8.03 x 0.190 mm x mrad
	70 GeV/c	horizontally 4.08 x 0.245 mm x mrad
		vertically 6.50 x 0.154 mm x mrad
	85 GeV/c	horizontally 3.88 x 0.233 mm x mrad
		vertically 6.18 x 0.147 mm x mrad
9.	Average diameter containing 80 % of beam at	30 GeV/c : ? mm
		70 GeV/c : 10 mm
		85 GeV/c : ? mm
10.	Emittance increase due to ejection process, beam sharing etc.:	? %

Table 2.2 Experimental requirements

1. Proton momentum range required : 30 - 85 GeV/c or max. possible

2. Secondary beam momentum range : approx. 15 - 40 GeV/c (70 GeV/c for protons)

3. Target dimension :

	below 50 GeV/c	above 50 GeV/c
Horizontally	2.0 mm	2.0 mm
Vertically	3.0 mm	1.0 mm
Length	200.0 mm	200.0 mm

4. Focusing requirement at target : Beam size and divergence to be optimised for max. proton interaction with specified target. Approx. 2.10^{11} protons / pulse required on target. Secondaries are collected at zero angle.

5. Target position and orientation : X = 121.7521 m

   Y = 47.4182 m

   = 0.2356194 rad

3. TECHNICAL PROPOSAL

The beam layout is shown in Fig. 1 (a) and (b) (Drawings NPA 232-183-00 and 232-184-00), and some main beam optics parameters are collected in Table 3.1.

3.1 Beam Trajectory

The beam position and orientation at the exit window in M 27 depend on the ejection system parameters and for the present study we assumed the situation indicated in Fig. 4 (NPA 232-185-1) where the position and orientation of the E.P.B. with respect to the central orbit are 205 mm and 24.6 mr respectively at the end of M 27.

The horizontal deflector HD 1 is provided to correct for ejection errors up to $\pm$ 3.0 mr at 85 GeV/c or 4.0 mr at 70 GeV/c with a flux density of 2.0 T. In Fig. 1 a deflection of 2.1 m.r. is assumed. This is less than proposed in Ref. 1 due to space restriction since the first lens Q 1 had to be increased in strength and length.

The beam may if desired be shielded off from the stray field of M 28 by means of a steel pipe.

An additional horizontal deflector HD 2 with a maximum deflection of $\pm$ 3.0 mr (at 85 GeV/c) may be included close to M 29 if necessary to compensate for the reduction in bending power of HD 1. A vertical deflector VD 1 also located close to M 29 will provide a max. correction of $\pm$ 3.0 mr for vertical ejection errors. Finally two deflectors HD 3 and VD 2 located just after the last focusing stage will provide horizontal and vertical fine adjustment of the beam position at the target.

3.2 Beam optics

A typical 70 GeV/c beam profile is shown in Fig. 5 (NPA 232-179-1).

Table 3.1 External proton beam data and magnet requirements
(Conditions for variant 3, Ref. 10)

	M25	SS26	Q1	Q2	Q3	Q4	HD1	HD2	HD3	VD1	VD2	Beam (Target)
Beam and target:												
Distance from target approx. (m)		56.5	31.6	12.5	8.0	4.5	30.8	16.27	1.5	15.57	2.3	
Position coordinats X (m)												12175.21
" Y (m)												4741.82
Beam size, horizontal x vertical width at 30 Gev/c (mm^2)			12 x 14	17 x 30	20 x 43	23 x 15						1.50 x 2.20 (2.0 x 3.0)
" 70 "			10 x 12	25 x 28	42 x 17	15 x 23.5						1.70 x 0.68 (2.0 x 1.0)
" 85 "			9,5 x 11.5	24 x 26.5	40 x 16	14.5 x 22.5						1.62 x 0.65 (2.0 x 1.0)
Lenses:												
Lens strength $C_o = 0{,}3\ Gl/p$ at 30 Gev/c (m^{-1})			0.20	0.16	0.396	0.511						
" 70 "			0.25	0.14	0.405	0.453						
" 85 "			0.25	0.14	0.405	0.453						
Magnetic field gradient integral at 30 Gev/c (T)			20.0	16.1	39.6	51.2						
" 70 " "			58.5	32.6	94.5	106.0						
" 85 " "			71.0	39.6	115.0	128.5						
Magnetic equivalent length (m)			0.78	1.56	3.12	3.12						
Magnetic field gradient at 30 Gev/c (T/m)			25.7	10.3	12.7	16.4						
" 70 "			75.0	20.9	30.3	33.9						
" 85 "			91.0	25.4	36.8	41.2						
Deflectors:												
Deflection angle (m.r.)							3	3	3	3	3	
Magnetic field integral at 30 Gev/c (T/m)							0.284	0.284	0,284	0.284	0.284	
" 70 "							0.705	0.705	0.705	0.705	0.705	
" 85 "							0.85	0.85	0.85	0,85	0.85	
Magnetic équivalent length (m)							0.46	0,46	0.46	0.46	0.46	
Magnetic flux density at 30 Gev/c (T)							0.617	0.617	0.617	0.617	0.617	
" 70 "							1.53	1.53	1.53	1.53	1.53	
" 85 "							1.85	1.85	1.85	1.85	1.85	

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With the given initial condition of the beam at exit from the accelerator and the specified target dimensions ($2 \times 1 \times 200$ mm^3 at 70 GeV/c) the optics computations (ref. 10) have been aimed at an optical solution resulting in the most favourable parameters for the magnets. The requirements are most critical for the last two lenses Q 3 and Q 4 where the beam is 40 - 50 mm wide and lens strengths of 0.4 - 0.5 m^{-1} are needed for achieving a satisfactory waist size in the target.

As a reasonable compromise between lens strength and aperture requirements we propose magnets with a 60 mm aperture and with a useful field region extending over the central 70 percent of this aperture. The outer 10 - 15 percent of the magnet aperture is occupied by the wall of the vacuum pipe which leaves a free passage for the beam of 50 - 54 mm diameter everywhere except in the region of Q 1. The magnet aperture of Q 1 had to be reduced to 30 mm in order to achieve the required lens strength of 0.25 m^{-1} in the restricted space available in SS 28 and this is fortunately possible since the beam width at this point is only 15 mm max. at 30 GeV/c and 10 - 12 mm at 70 GeV/c.

More details of the beam optics are described in Ref. 10 and some main parameters are collected in Table 3.1.

3.3 Technical approach for equipment

A beam transport system that can handle short beam bursts ejected at repetition intervals of 0.5 s during the flat top of each accelerator cycle is proposed.

This will permit 4 bubble chamber expansions to take place at 500 ms intervals during the 1.5 s flat top planned for later extension, while for the initial period with 0.8 s flat top duration, 2 bubble chamber exposures can be taken every accelerator cycle.

In order to achieve a compact magnet coil construction with reduced power and cooling problems a pulsed type of excitation system working in synchronism with the short beam pulses of the ejected beam has been selected as the most obvious method.

A capacitor discharge type of pulse system is therefore proposed as the technically and economically most favourable solution for satisfying all specified operation requirements.

This solution also provides for some flexible extension possibilities. With operation at reduced precision and/or energy shorter pulse intervals than 0.5 s can be obtained by allowing less time for stabilisation of the capacitor voltage. Alternatively shorter pulse intervals can also be obtained by adding parallel discharge circuits when required at a later date.

Standardization of equipment

Most of the lenses and deflectors and associated circuits of the system have different strength, energy and current requirements but for practical manufacturing reasons and to facilitate exchanges and replacements the main equipment will be standardized as follows :

- All deflectors will be of the same type,
- All lenses will be composed of standard modular units of the same type except Q 1 which is mainly a scaled down version of the standard module as required by space restriction,
- All charging supplies will have the same rating of around 60 kVA average and 90 kVA peak d.c. output except the supplies for Q 3 and Q 4 which must have a d.c. output rating of 120 kVA average and 180 kVA peak.
- The storage capacitors will be composed of standard units of 1 - 2 kJ each and the number of units will be adjusted as required for each individual circuit.
- All switching circuits will be the same with the possible exception of the circuits for Q 3 and Q 4 which require more energy than the other circuits.

3.4 Magnets

The pulsed magnetic quadrupole lenses and deflectors have circuits of laminated magnetic steel and water cooled multi-turn excitation coils. The magnet parameters are listed in Table 3.2.

The magnetic circuits are well dimensioned in order to achieve good magnetic field characteristics at high flux densities since the measured characteristics of our so-called "slim" magnets (figure-of-eight lenses, and C-shape deflectors) tended to give less than optimum results at high field levels due to dissymmetry and saturation effects in the narrow regions of the return circuits.

The coils are more bulky than desired because the number of turns had to be increased to reduce the current and losses in the cables since a location for the power supplies suitably close to the magnets could not be found.

The coil insulation must be radiation resistant and suitable for withstanding high voltage transients. This excludes most modern plastic insulating materials. The most probable choice to be made in consultation with the selected manufacturer will be a vacuum impregnated glass-reinforced mica insulation against the yoke with an inter-turn insulation of organic tape to simplify the fabrication process.

The main dimensions of the three different magnet types have been determined to satisfy the optical requirements, to fit with the space restrictions particularly in SS 28 and to permit the whole system to be composed of modular units of simple construction and reasonable size in order to avoid manufacturing difficulties.

On this basis all lenses except Q1 are composed of modular quadrupole units with a magnetic circuit of 60 mm aperture and 1.50 m length. The design of the 1.50 m modular quadrupole unit is shown in Fig. 6 (a) and (b) (drawings NPA 224-143-2 and 224-137-1). Q 3 and Q 4 are composed of 2 modular units each. For Q 2 one unit would be sufficient but 2 units are assumed for the time being since a symmetrical arrangement of the triplet may be preferred.

The first lens Q 1 has been designed especially to fit the restricted space in SS 28. It has a magnetic circuit of 30 mm aperture and 0.75 m length and the general design is shown in Fig. 7 (a) and (b) (drawings NPA 224-145-2 and 224-139-1).

TABLE 3.2 Magnet Data

Parameter	Deflecting magnet	Quadrupole lens 30 mm type	Quadrupole lens 60 mm type
Aperture (mm^2, mm diameter):	60 x 120	30	60
Good field region (mm^2, mm diameter):	50 x 75	20	40-50
Equivalent length of each unit (m):	0.46	0.78	1.56
External half-width of each unit (mm):	160 (inwards) 202 (outwards)	87.5	120.0
External height, approx. (mm):	560	455	537
External length, approx. (mm):	622	912	1662
Flux density, nominal max. (T):	2.2	1.5	1.5
Field integral, nominal max. (Tm):	1.06	---	---
Gradient, nominal max. (T/m):	---	100	50
Gradient, integral, nom. max. (T):	---	78	78
Current for 1.0 T for deflector (kA):	1.20	---	---
Current for 2.0 T for deflector (kA):	2.46	---	---
Current for 33.3 T/m for 60mm lens (kA)	---	---	2.0
Current for 66.6 T/m for 30mm lens (kA)	---	2.0	---
Current for 50 T/m for 60 mm lens (kA)	---	---	3.05
Current for 100 T/m for 30 mm lens (kA)	---	3.05	---
Number of turns (--)	2 x 20 = 40	4 x 3 = 12	4 x 6 = 24
Conductor outer dimension (mm):	5.0 dia	5 dia	5.0 dia
Conductor cooling channel (mm):	3.0 dia	3.0 dia	3.0 dia
Conductor cross-section (mm^2):	12.5	12.5	12.5
Inductance, (mH):	2.5	0.23	1.8
Resistance (mOhm):	71	38	153
Number of cooling circuits (--):	4	4	4
Cooling water pressure nominal (kg/cm^2):	25	25	25
Water flow at 25 kg/cm^2 (l/min):	9.0	6.5	6.5
Water inlet temperature (deg. C):	25 $\pm$ 20 %	25 $\pm$ 20 %	25 $\pm$ 20 %
Water outlet temperature, max. permissible (deg. C):	75	75	75
Applied voltage, max. pulsed (kV):	6.0	6.0	6.0
Insulation test :	12 kV peak 50 Hz for 60 seconds		
Magnetic steel lamination thickness (mm):	0.5	0.5	0.5
Weight (kg):	500	250	1000
C_o nom. max ($C_o = \frac{0.3\ LGo}{p}$ (m^{-1}):	-	0.26	0.26
Max. defl. angle at 85 GeV/c (mr):	$\pm$ 4.0	---	---

The deflectors are required only for small corrections in the horizontal and vertical plane. Only one type of modular unit is proposed. The design is shown in Fig. 8 (NPA 224-146-2). The aperture is 60 mm (gap-width) and the length of the magnetic circuit is 0.40 m which is determined by the maximum size that can be accomodated together with Q 1 in SS 28.

3.5 Pulsed power supplies and control electronics

Basic circuit

The magnet power supplies are of the high voltage capacitor discharge type. An appreciable energy recuperation of the order of 50 percent is obtained by means of a recuperation circuit with a low-loss reactor in series with a diode connected across the storage capacitor, as shown in Fig. 9 (drawing NPA 224-149-4). The main circuit parameters and component ratings are listed in Table 3.3.

Energy storage capacitor

The energy storage capacitor will be made for a mean life of at least 10 million pulses, for a capacitor voltage reversal limited to 50 percent. The maximum capacitor voltage will be at least 4 kV in order to obtain an economical solution for the energy storage capacitors but will not exceed 6 kV in order to reduce the problems of magnet insulation and energy switching.

Discharge switches

The main discharge switches will be of either the thyristor or the ignitron type depending comparative cost and performance possibilities now being reconsidered since both characteristics and prices of commercially available high voltage solid state devices have recently become more attractive and competitive. The diodes of the recuperation circuits will in any case be of the solid state type.

D. C. charging supplies

The charging supplies will have independent control facilities for the capacitor charging voltage and the charging current by means of a thyristor controller on the primary side of the high tension transformer. For operation with an 0.5 s repetition period (for obtaining 4 pulses during a 1.5 s flat top duration) the capacitor will be charged at roughly constant current to within a few percent of the required voltage during the first half of the pulse interval. During the second half of the interval the current diminishes gradually as the exact voltage is approached.

Extension to shorter repetition intervals

Extension to shorter repetition intervals have been considered since this may possibly be required for later developments. If a much shorter repetition interval than 0.5 s (corresponding to 4 pulses equally spaced during a 1.5 s flat top duration) should be required this can be achieved in the two following ways :

a) Booster storage capacitor sections which are charged in parallel with the main storage section during the approx. 5 s space between flat tops may be added. Just after each discharge a part of the energy in the booster storage is transferred to the main storage by a thyristor switched LC transfer circuit. Only a small fraction of the total charge has then to be supplied by the charging supply in the short intervals during the flat top duration.

b) By adding one or more equal extra storage and switching sections which are charged in parallel with the original section during the long intervals and then discharged one after the other as required during the flat top. As an example by 3 additional sections 7 pulses at 0.25 s intervals during the 1.5 s flat top of each PS cycle can be obtained.

Low inductance high tension pulse cables

The resistive and inductive losses in the pulse cable should preferably be negligibly small compared to the energy transmitted to the magnet. Since no suitable low-inductance coaxial cable exists as a standard commercial product a symmetrical 4-conductor cable is proposed as the best substitute. With diametrically opposite conductors connected in parallel an inductance of 200 - 250 nH/m is obtained or 60 - 75 μH total for 300 m as compared to the 1 - 5 mH inductance of the various magnets. The magnet resistance is in the range 40 - 300 mOhm and 300 m of 4 x 50 mm^2 copper conductor has a loop resistance of 100 mOhm. This is an acceptable value giving a reasonable energy recuperation efficiency.

The cable insulation must withstand at least the same high voltage test (12 kV) as specified for the magnet coils and it must also be reasonably resistant to nuclear radiation. An improved execution based on a commercial standard power cable will be satisfactory.

Table 3.3 Power supply data

Type of circuit	: Capacitor discharge circuit with separate energy recuperation circuit
Current pulse form	: Sinusoidal pulse
Pulse length	: In range 1 ms (for Q1) - 10 ms (for Q 4)
Current reproducibility	: $\pm$ 0.1 % of max. current

Storage capacitors

Charging voltage :	5 kV
Voltage reversal :	50 percent
Energy per container :	approx. 2 kJ
Self-resonance frequency :	approx. 50 kHz
Life expectance, 10 % failure limit :	5 million pulses
Pulse repetition frequency, permissible average :	1 pulse / s
Stored energy per circuit:	5 - 20 kJ as required for individual circuits

D.C. charging supply	Small type	Big type
D.C. voltage range :	0.5 - 5 kV	0.5 - 5 kV
D.C. current range :	1.8 - 18 A	3.6 - 36 A
D.C. current continuous average :	12 A	24 A
D.C. output for 100 % duty ratio:	5 kVx12A = 60kVA	5 kVx24A =120 kVA
D.C. output for 50 % duty ratio and 1.0 s averaging period :	5 kVx18A = 90 kVA	5 kVx36A =180 kVA
Capacitor voltage reproducibility for charging with 0.5 s repetition period :	$\pm$ 0.1% for 10 kJ	$\pm$ 0.1% for 20 kJ

Primary supply : 380 V 50 Hz 3 - phase + neutral + earth

Low inductance H.T. pulse cables :

Conductor	: 4 x 50 mm^2 symmetrically arranged
Inductance	: 200 - 250 nH/m, max. 75 μH for 300 m
Insulation test:	12 kV peak, 50 Hz for 60 seconds
D.C. Resistance	350 $\mu\Omega$/m, max. 105 mΩ for 300 m

Control electronics

The remote location of the beam control station of the order of 0.5 km requires all accurate and sensitive signals to be transmitted in digital form (Ref. 12).

The system of timing pulses available as a fixed laboratory facility is for the time being understood to be sufficiently extensive for providing all necessary timing signals without requiring intermediate delay units to be included as part of the E.P.B. equipment. For each magnet 4 timing signals are required for each beam pulse (stop pulse, firing pulse, measuring pulse, interlock pulse).

The magnet currents are measured by means of shunts and an analogue-to-digital converter located close to the supplies from which the digital signals are transmitted to the beam control station. Analogue signals from current transformers with integrators will permit oscilloscope display observation of the time structure of the various currents.

An alarm, protection and interlock system will short-circuit the storage capacitor by means of an auxiliary discharge circuit with a mechanical switch and block the thyristors of the charging supply whenever the fault detection circuits signal a danger status for equipment or personnel such as magnet cooling failure, over-heating, H.T. safety interlocks etc. The detection of less serious malfunctioning will only be indicated optically on an interlock status panel and by acoustic alarm.

3.6 Beam Observation and Monitoring

Requirements

The beam observation and monitoring system is required for the following main purposes :

a) For normal beam control the beam operators need information about the beam parameters (position, direction, shape and size, divergence and intensity) at selected points at any desired time in order to determine the adjustments required for achieving and maintaining good beam quality and operation efficiency.

For automatic beam control the same is true but the means for providing the information in the form required for the computer or servosystem are more restricted.

b) For certain experiments a record of the beam condition during the experiment may be useful or essential as a part of the experimental data for evaluation of the final results.

For continuous monitoring of the external beam the probes cannot be allowed to intercept the good region of the beam profile except in certain cases immediately close to the target since even very small amounts of material in the beam path tend to increase the beam emittance quite considerably.

For occasional checks and measurements and for detecting errors exceeding predetermined limits in position or size, methods based on interaction with the beam are normally permissible.

Relative measurements from point to point are necessary and often sufficient for adjusting the beam to optimum condition but absolute measurements will be desirable and in some cases essential.

Technical solution

The following beam observation and monitoring facilities are required for the initial operation period and the system may then subsequently be extended as required according to local experience.

a) Scintillating screens viewed by television at 5 selected observation points along the beam line (TV1 - 5).

Each screen can be moved into two alternative positions by remote control. Position 1 is intended mainly for setting-up and occasional checks and the central region of the screen is cut away such that only a small outer region of the beam is intercepted when the beam is properly aligned. Position 2 is intended for normal operation condition and for this case a larger central region of each screen is cut away such that beam interception is negligible and no light is observed except in case of serious mal-functioning.

3 display units (receivers) are required, two are permanently connected to TV1 and TV5 and the third unit can be switched to any of the intermediate positions TV2-3-4 as required.

b) Beam position monitors at 3 positions along the beam line (BPD 1-3).

These should be differential electrostatic pick-up detectors with digital display and recording facilities.

c) Beam intensity monitors at 3 positions along the beam line (BCT 1-3).

These are current transformers with toroidal secondary windings on high permeability cores and with digital display and recording facilities.

The various detectors in the positions shown on Fig. 1a and b (NPA 232-183-00 and 232-184-00) cover the following main requirements :

TV1 observes the position and cross-sectional size and shape of the beam as it enters the external channel.

BPD 1 gives the entrance position of the beam in a more precise and recordable form.

TV 2 and BPD 2 give the information required for adjusting HD 1 and Q 1 to obtain the correct position, shape and size of the beam at the entrance to the first lens Q 2 of the last focusing stage.

TV 3 and TV 4 give the best information easily obtainable on the beam condition in Q 3 and Q 4. A better information would be obtained by placing the screens between the two magnet units of which each lens is composed and this solution is to be considered as a second alternative.

TV 5 gives the position, size and shape of the beam just at the front face of the target. The beam divergence at the target can be estimated by combining the information from TV 4 and TV 5.

BPD 3 gives additional precision on the beam position at the target. Beam instabilities caused by the external transport system can be distinguished from those already present at the exit from the accelerator by comparing the information from BPD 1 and BPD 3.

BCT 1 and BCT 3 measure the intensities at the entrance and the exit of the external channel in order to detect possible beam losses between the two points. The measuring error due to scattered protons and secondary particles produced by beam interception with the septum of the ejection magnet may hopefully partly be detected as a difference between BCT 1 and BCT 2 although the condition for directional and momentum separation is very poor in this case.

The additional and special measuring for determining beam density distributions, for monitoring the number of protons interacting with the target and similar requirements are not considered in the present note since such problems can be solved most adequately in connection with individual experiments.

3.7 Vacuum system

To reduce scattering to a negligible amount a vacuum channel is required all along the beam line. For safety reasons the external vacuum channel must be independent from the accelerator vacuum system although this requires at least one additional window at the entrance to the external channel.

A system pumped down to a pressure of the order of 1.0 mm Hg by an ordinary rotary pump will be satisfactory.

For practical reasons the vacuum and beam observation systems must be designed together since the main parts of the beam observation equipment is mounted inside or together with the vacuum channel in such a way that interruption and dismantling of the vacuum is necessary for most replacements, adjustments and other manipulations of the primary beam detecting parts.

Inside the pulsed magnetic field regions the vacuum pipe must be made of non-conducting material to avoid eddy-currents and a glass pipe with 58 mm outer and 52 mm inner diameter is proposed while an aluminium alloy pipe is more suitable in the field-free regions. The channel is closed at each end by a 0,1 mm thick aluminium window for beam entrance and exit.

Radiation damage due to beam losses under unstable condition may necessitate replacements of the vacuum joints a few times every million pulses.

4. CONCLUDING REMARKS

A typical set of operation parameters for the proposed system is collected in Table 4.1.

For most of the equipment the operation parameters are within conservative limits even at 85 GeV/c. The most critical exceptions are the first lens Q 1 which is operating close to saturation at a gradient of 90-100 T/m, the switching circuits for Q 3 and Q 4 which can handle 20 kJ each and the accuracy in current reproducibility for Q 3 and Q 4 since with 0,5 s pulse intervals the precision decreases when the required energy exceeds 20 kJ unless also the charging supply rating is increased. The magnet aperture of the proposed design can comfortably accomodate the beam computed with the given input condition but without much reserve margin. The consequences of increasing the aperture are considerable and it is therefore of supreme importance that the most realistic and experimentally established values for the emittance of the beam at ejection as well as for the exit trajectory, be confirmed at the earliest possible stage of the project.

Table 4.1 External proton beam operation parameters at 85GeV/c

Operating Conditions for Variant 3 (FDFD)

	LENSES				DEFLECTORS
	Q1	Q2	Q3	Q4	
LENSES					
Lens strength, C_o (m^{-1})	0.250	0.140	0.405	0.453	
Gradient integral, $G\ell$ (T)	71.0	39.6	111.6	128.5	
Equivalent length, ℓ (m)	0.78	1.56	3.12	3.12	
Field gradient, G (T/m)	91.0	25.4	36.8	41.2	
Aperture radius, R_o (mm)	15	30	30	30	
Flux density on pole face, $B_o = G_o R_o$ (T)	1.37	0.76	1.10	1.24	
DEFLECTORS					
Deflection angle (mr)					3.0
Field integral, $B\ell$ (Tm)					0.85
Equivalent length, ℓ (m)					0.46
Pole gap, g (mm)					60
Flux density, B (T)					1.85

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