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A POSSIBILITY FOR INTERNAL BEAM DUMPING

IN THE CPS.

The Movable Dump Solution.

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1. Introduction

There are mainly three possibilities for internal dumping of a high energy, high intensity proton beam in the CPS :

a) dumping on a thick target while decreasing the machine acceptance with a downstream movable shower catcher,

b) dumping on a fixed absorber in an F section by means of a vertical fast kick (or a slow ejection),

c) dumping on a heavy mobile block, surrounded by a fixed absorber, by means of a vertical kick, also in an F section.

These different possibilities have been looked into for the CPS[1,2], as well as for the ISR[3] and the SPS[4]. Hence, we present only a preliminary study of the third solution.

The fast kicker system has been studied by D. Fiander and the mechanical installation by B. Szeless. Their descriptions are given in the Annexes.

As this is only a feasibility study, it is clear that many points require further and more thorough investigation.

2. <u>General Description of the System</u>

A fast kicker (FK1 on Fig. 1), located on s.s. 18,* deflects the beam vertically upwards in such a way that its centre passes at 24 mm above median plane at the beginning of straight section 21, where the dump is installed. The beam just grazes the vacuum chamber of the first half of the magnet unit MU 20 (see Fig. 1).

A second fast kicker (FK2), identical to the first one and located $n\frac{\lambda}{2}$ after s.s. 18, kicks back on the CPS equilibrium orbit the non dumped part of the beam, which is then dumped at its second passage in s.s. 21.

The dump itself consists of a fixed absorber 2 m long whose internal aperture (150 x 52 mm^2) is the minimum tolerable in s.s. 21 for a normal injection. Material such as Fe, Cu or Pb could be considered.

A movable copper block, one metre long, is introduced during the acceleration in such a way that it does not intercept the accelerated beam, while presenting a sufficiently large front face for absorbing the kicked beam. Materials other than Cu could be considered.

The figure 2 shows the beam enveloppe through MU 20 and the position of the movable block for dumping. We have taken as a criterion a margin of 2 mm between the edges of the beam and the internal face of the MU 20 vacuum chamber. Beam dimensions are always given for 95% of the accelerated particles.

It has been found more convenient to divide the absorber in two halves. The first part, containing the mobile block and its mechanism, is made of a rigid stainless absorber. The second part is only a passive load absorber

* The numbers of the straight sections indicated in this note are just an example. Their availability has not been studied in details.

on a girder. The Fig. 1 of Annexe 2 shows the overall dimensions of such a device.

3. The Deflection

Technical data of the two fast kickers are given in Annexe 1 by D. Fiander.

The lower part of Fig. 3 shows the kicker currents versus time for a rise time of 0,7μs to 90%. The current rises to 99,9% at 2μs. The two kickers FK1 and FK2 are identical and the delay between their firing is given by the proton time of flight from one to the other (0,3μs in this case).

Two factors influence the quality of dumping, the rise time and the pulse duration. The faster the beam is kicked up, the less it remains on the block edge and the higher is the efficiency but the hardware becomes more costly. On the other hand, if the pulse length is further stretched, the dumping of the small halo surrounding the beam becomes possible with further efficiency improvement.

In Fig. 3, one can see the case where the FK1 pulse duration corresponds to two PS turns (4,2μs), while the FK2 pulse lasts for one PS turn (2,1μs). In such a case, a good dumping of the halo can be expected. But we could also consider a more economic solution with the same rise time, but with a 3μs pulse for FK1 and 0,9μs for FK2. In this case, the small halo would be lost in the accelerator.

To understand the influence on cost of these technical requirements, we have drawn on Fig. 2 of Annexe 1 the cost of the kicker system versus rise time for a two turn pulse (curve A) and a one turn pulse (curve B). We can see that, starting from point M(0,7μs the rise time and 3μs pulse length), the economy is 65.000 SFrs for 1μs rise time, while the supplement is 120.000 SFrs. for a 4,2μs pulse length.

The upper part of Fig. 3 shows the dumped proton current for 0,7μs rise time in the case of a gaussian particle distribution and of a normal bunched beam. The hatched area shows the current lost in the dump. The fraction of the current in the remaining halo is difficult to estimate and we have taken 0,3% as a reasonable figure.

In each of the kickers, the deflection should be 1,66 mr up to 28 GeV/c, giving a beam displacement of 24 mm in straight section 21. The matrix elements between the middle of s.s. 18 and the front face of the dump are, for $Q_H = Q_V = 6{,}25$:

$$\begin{pmatrix} +\,0{,}316 & +\,14{,}42 \\ -\,0{,}0574 & +\,0{,}547 \end{pmatrix}$$

4. Main Parameters of the Dump

4.1 Emittances

The vertical PS emittance at high energy is expected to be around $1{,}5\pi \cdot 10^{-6}$ m.r for an intensity between 0,5 and $1{,}10^{13}$ p/p, with 95% of the beam[5,6]. The corresponding beam height in s.s. 21 is 8,5 mm for $\beta_V = 12$. The closed orbit deviation is already small and could be made even smaller in s.s. 21 (± 1 mm).

If we choose 14 mm as the final distance between the block edge and the PS axis, we have a large clearance of 8 mm between the accelerated beam and the block, which should be sufficient for avoiding any "scraping" effect during acceleration (see Fig. 2).

The largest vertical emittance which could be efficiently dumped by this system is $\varepsilon_V = 6{,}7\pi\ 10^{-6}$ m.r, which corresponds to a beam height of 18 mm and a block edge position of 10 mm from PS axis. The clearance is marginal in this case, but the particle density is small on the edges of such large emittances. Therefore, a factor 4 in emittance blow-up could be accepted.

The data which follow were obtained from MAGKA[7]. As this programme uses a cylindrical geometry, we have used the same approximation* as in (4) for rectangular holes.

4.2 The Length of the Movable Block

We consider that the minimum half vertical aperture is 25 mm in s.s. 21 and that a movable block of length L reduces this half aperture down to 14 mm. As we can see on Fig. 4, the dump has a half aperture of 14 mm along length L and 26 mm after, along a length 2 - L. We consider now that portion of the beam energy which is not absorbed in the enlarged part and we call it "losses due to the enlargement". We plot it versus L on Fig. 4 and see that a length L of 1 m is a reasonable choice leading to losses of 0,6%. The movable block dimensions will finally be 1000 x 150 x 70 mm^3.

4.3 Losses Through the Hole

From now on we shall call "loss" any fraction of beam energy which is not deposited into the dump.

Let us consider a rectangular hole with a half vertical aperture of 14 mm along 1 m and 25 mm along the following metre, whose horizontal width is 150 mm. Let us suppose a proton beam parallel to the axis and concentrated in a cylinder of 12 mm diameter with constant density. (This "safe" diameter comes from the vertical beam height plus a possible "jitter" in vertical position of $\pm$ 1,5 mm).

On Fig. 5 we can see the losses through the hole versus the distance between beam axis and PS axis, for the part of the beam hitting the

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* This approximation says that, through a rectangular hole whose axis ratio $\frac{a}{b}$ is $\frac{1}{4}$, the losses could be considered as given by $\frac{3}{4}$ from a round hole of diameter a and $\frac{1}{4}$ from a round hole of diameter b, when the beam is hitting the dump as it does in our case.

dump. We suppose that the non-dumped part is dumped at the second passage. This curve is mainly a quantitative figure because MAGKA does not allow a very precise approach in this particular case.

Now, if we look back to Fig. 3, and if we compute the losses for each bunch according to its vertical position, we find a total loss of 2,8% which could be divided into 2,2% for an instantaneous deflected beam plus 0,6% due to the non-zero rise time. If we call T_R, the rise time to 90% of the deflection, in μs, the loss through the hole, for small variations of T_R, is

$$2{,}2 + 0{,}9\ T_R$$

in % of the accelerated beam intensity. Due to the non-uniform density distribution, a small part of the beam forms a halo which could be dumped only if the pulse duration in the kickers is long enough, as we have seen above. Furthermore, a non negligible part of the beam will dump itself on the first half of the vacuum chamber in the unit 20 preceding the dump. This part was estimated to 0,5%.

To sum up, we could divide the loss as follows:

a) Loss through hole for an ideally deflected beam..........2,2%

b) " " " due to non zero rise time (= 0,9 T_R).. 0,6% (for T_R=0,7μs)

c) Loss in accelerator for a 4μs pulse in FK1 (non dumped particles)... 0,5%

d) Supplement to loss c) for a 3μs pulse in FK1............ 0,3%

Total loss in accelerator ≈ 3,6%

It is obvious that losses c) and d) are very difficult to estimate and should be considered only as a crude indication.

If the beam is blown up during operation, and if we consider the largest emittance which could be dumped ($6{,}7 \cdot \pi \cdot 10^{-6}$ m.r), we get a higher loss - 4,5% instead of 3,6%.

4.4 Loss Outside the Absorber

Inside the tunnel, the absorber has not to be as good as a beam stopper. Furthermore, the yoke of MU 21 could play an important role in the absorption.

Considering a lead absorber 2 m long, 0,6 m high and 0,7 m broad, the outside loss is 8,5%, including the gap above the movable block which is only partially filled.

Thus, the total losses will be 3,6% through hole, plus 8,5% ouside, leading to a total of about 12%. The total efficiency of the system will be around 88%.

For a 1μs rise time an extra loss of 0,3% should be added.

For a large emittance an extra loss of 0,9% should also be added.

5. The Mechanical Part

A description is given in Annexe 2 by B. Szeless.

5.1 Position and Angle

As the available space is small, the motion has to be very accurate. The standard position for dumping, from the low front corner of the movable block down to PS axis, will be 14 mm. This distance could become 10 mm for large emittance dumping.

The bottom face of the movalbe block will be inclined in order to avoid any grazing of the beam and to be sure that the particles always hit the front face first. Thus the irradiation of the following magnet unit is minimized. The inclination angle will be 1,6 mr $\pm$ 0,1, including the angle of the deflected orbit (0,9 mr) plus the half beam divergence (0,4 mr), plus the closed orbit angle (0,1 mr), plus a small margin for larger emittances.

5.2 Timing of Motion

The down motion should be such that the block never intercepts the accelerated beam and that it is in due position for dumping. Because of an uncertainty of $\pm$ 50 ms for the starting time and of $\pm$ 20 ms for the motion itself, we are lead to ask for a nominal fall time of 230 ms for a maximum stroke of 16 mm, if we want to be able to dump at 10 GeV/c. If we abandon this last idea, a fall time of 600 mr should be sufficient. We must take care of a possible, though small, vertical blow-up at transition.

5.3 Vacuum

Two ion pumps (400 l/s and 200 l/s at $5 \cdot 10^{-7}$ Torr) would provide the right vacuum. Also two ion pumps (400 l/s each) would be needed for each fast kicker vacuum tank.

5.4 Cooling

It is expected that 50% of the beam energy will be lost in the movable block, that is to say 5 kW for $5 \cdot 10^{12}$ p/p at high energy. In order to avoid temperatures above 1000^{o}C, a forced water cooling will be necessary and should even be able to evacuate 10 kW for higher intensities. It is very likely that this water could be taken from an existing cooling system. Special care should be taken to avoid water leaks and floods. No particular hazard coming from water radioactivity is expected. Though copper is presented here as a possible material for the movable block, deeper studies will be necessary for optimizing this choice. A compromise has to be found between high melting point, high thermal conductibility, low radiation danger parameter (for induced activity), small outgassing and technical possibilities.

Some data about these problems can be found in [8,9,10,11].

5.5 Radioactivity

Information from [7] and [12] allow us to make the following predictions concerning the radio activity of the movable dump block. These quotations are for the worse operating conditions in the "80s", according to some possible operations as described in [13]. These figures correspond to 5% of the total accelerated beam being dumped on the device, either at 10 GeV/c or at 28 GeV/c*.

Activity : in contact	at 40 cm
After 14 days cooling down: 3,5 rem/h	1 rem/h
After 6 months cooling down: 900 m rem/h	250 mrem/h

The outside face of the absorber could give around 30 mrem/h at 40 cm after a few days of cooling.

5.6 Mounting Structure

Special facilities will be provided for accurate alignment. Also special care will be taken in the design of quick and remote removal of the radioactive block.

5.7 Extra Shielding

An extra shielding, 25 cm thick, made of lead bricks, will be installed in front of the dump, between the absorber and the coil of

* We shall see in § 8 that these 5% could become 7% if we consider some other utilizations. The radioactivity will be increased in accordance.

MU 20, upstream. A compact lead shield could also be mounted downstream. This lead will provide a good extra protection of the magnet units on the one hand, and on the other hand it will provide a self shielding against the induced radioactivity.

6. Radiation Dose on the Following Magnet Unit (MU 21).

The weak point of such a dump is the irradiation of the low part of the first steel block and PFW on the magnet unit following the dump. Fortunately this is a very localized region which could be specially reinforced at this particular point.

A special experiment, done in December 1972, in collaboration with M. Höfert and Ch. Steinbach has shown that the most exposed part of this magnet unit will receive $2{,}5 \cdot 10^{-11}$ rad/int.p when the beam is well in its final position. However, during the rise time, the dump edge acts a pure target for a large fraction of the beam. Consequently we could expect to get a mean dose of $5 \cdot 10^{-11}$ rad/int. p for a 700 ns rise time. This figure would be $7 \cdot 10^{-11}$ rad/int. p for 1μs rise time.

These values have to be compared with the dose which would be created by a normal dump target, at the beginning of the same straight section, which is $2 \cdot 10^{10}$ rad/int. p [13]. Thus, at this particular spot, we gain only a factor 4 (and a factor 3 for 1μs rise time). However, we should keep in mind that this dose will mainly be distributed on the lower half of the magnet and that the upper half will remain well protected.

If we suppose that 5% of the accelerated beam is dumped there, we could get a maximum of $1{,}5 \cdot 10^{8}$ rad/year on the low PFW of unit 21. This is tolerable for a reinforced unit, able to withstand $5 \cdot 10^{9}$ rads.

7. Controls

The down position of the mobile block would be adjusted by a slowly varying device. The kicker voltage would be automatically adjusted to the beam top energy and to the block position. Only an "on-off" switch would be left at the disposal of the operating MCR crew, the other controls remaining fixed for a given period of time (voltage, timing, motion etc.)

It would be very interesting to keep a visual survey of the dumped beam position by means of a TV channel. As it is nearly impossible to use a classical screen, we should like to do further investigations on infra-red image transmission.

Some ionization chambers and temperature monitors would give the necessary information on the dump efficiency and on the irradiation of the magnet units on each side of the straight section.

8. Use of such a Dump

A survey of possible uses for a dump system can be found in[1]. For the time being, we do not see the necessity to consider its use for an emergency procedure, so it will only be adjusted on request at the top energy of the PS cycle.

Nevertheless, we have looked into the possibility to use it for emergency if it appears to be necessary.

The problem is to be sure that the deflection remains accurate at $\pm$ 1 mm, from 10 GeV/c up to 24 GeV/c as a first approximation.

According to D. Fiander, this could be achieved by dividing the resonant power supply capacitors into groups and firing the requisite groups to adjust the kick to energy. As a first approximation, 12 kick steps could do the job. For the type of resonant power supply foreseen, a delay of 5 ms would be necessary between the moment of the dump command and the time of dumping. This delay, which diminishes a little the interest of this possibility, is due to the charging time of the proposed pulsed power supply. Operation from a D.C. supply, which would not have this disadvantage, is not recommended on account of the increased risk of spontaneous break-down of the thyratrons. Such problems have already been observed at the ISR, where a possibility to suppress these spontaneous discharges is being looked into.

The main utility of the proposed device would appear to be during machine development and setting-up sessions. Due to the fact that a good efficiency could also be obtained even with a slightly blown-up beam, this dump could be used for fast and slow ejection, even when shared with an internal target, provided that only a few percent of the beam are given to the target. Such a dump cannot be used after a full target operation, nor for beam shaving.

Up to now, it was estimated that 10% of the accelerated beam is used during MD and SU sessions. It seems reasonable to think that, firstly, this intensity could be reduced down to 5% by stronger discipline, and secondly that a high fraction could properly be dumped on the proposed device.

During the CPS operation for physics, this dump could be used for absorbing some pulses refused by the ISR, and also for discharging the tail of the beam left by the slow extraction. This last part was estimated at 2 to 3% of the allocated protons.

These considerations show that, let us say, 7% of the accelerated beam could be absorbed by the proposed dump. Otherwise, if no other dump system is adopted, this fraction would be lost in the machine, creating strong irradiation and radioactivity.

As a comparison, for the period after 1978 where no internal targets are supposed to be in use any more, the percentage of losses described above could represent nearly 20% of the total PS irradiation, if not properly dumped.

9. Prices and Delays

We quote only the two main items : the kicker system, complete with power supply and auxiliary equipment and the dump itself with the mechanism and the controls.

For the kickers, the prices versus rise time and pulse duration are given in Fig. 2.

	Détails SF	Sub-Total MSF (1972)
- Fast kicker system for 1μs rise time at 90% and 3μs pulse length for FK 1	577.000	
- Dump itself (mechanical installation and various controls) with one spare unit	336.000*	
		0,913
- Supplement for 0,7μs rise time	65.000	
		0,978
- Supplement for 4μs pulse length	120.000	
		1,098
- Supplement for emergency dump (12 steps, 5 ms delay)	40.000	
		≈ 1,14

The time schedule could be of the order of 14 months, divided in 3 months for studies and specification, 9 months for manufacturing and 2 months for tests.

* In this price the 80.000 SF estimated for "tests" in Annexe 2 have not been counted. But a spare unit (71.000 SF) has been included.

Acknowledgements

The authors should like to thank G. Plass and Ch. Steinbach for their comments and support.

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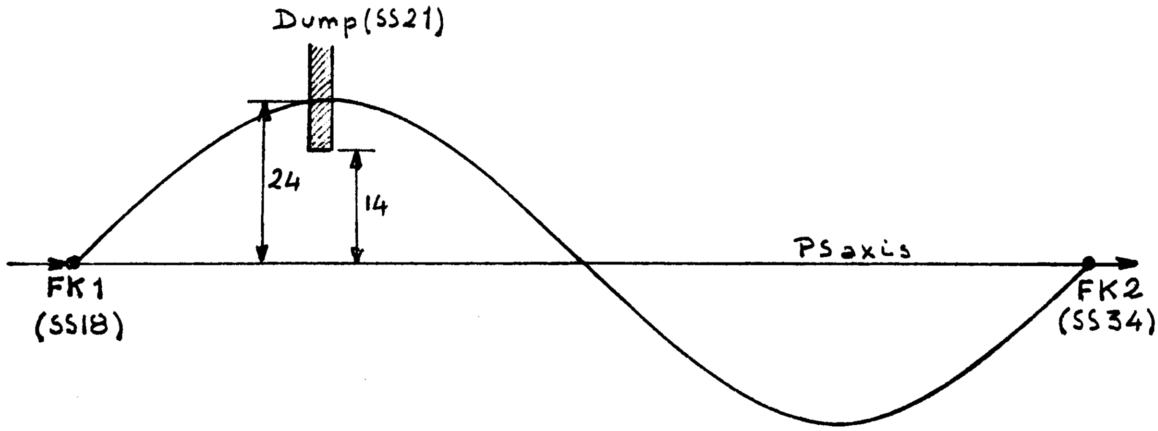

Fig 1. Orbit deformation

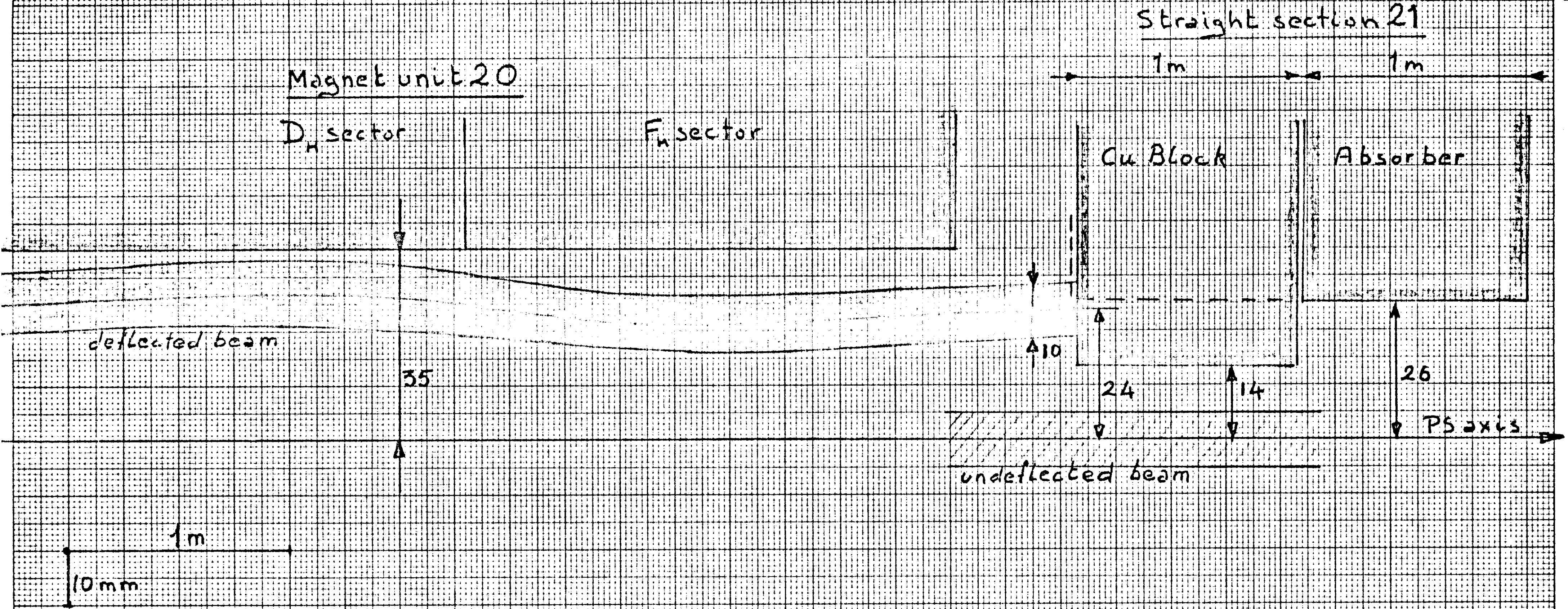

Fig. 2. Vertical beam envelope, with dump down ($\mathcal{E}_v = 2\pi\, 10^{-6}$ m.r).

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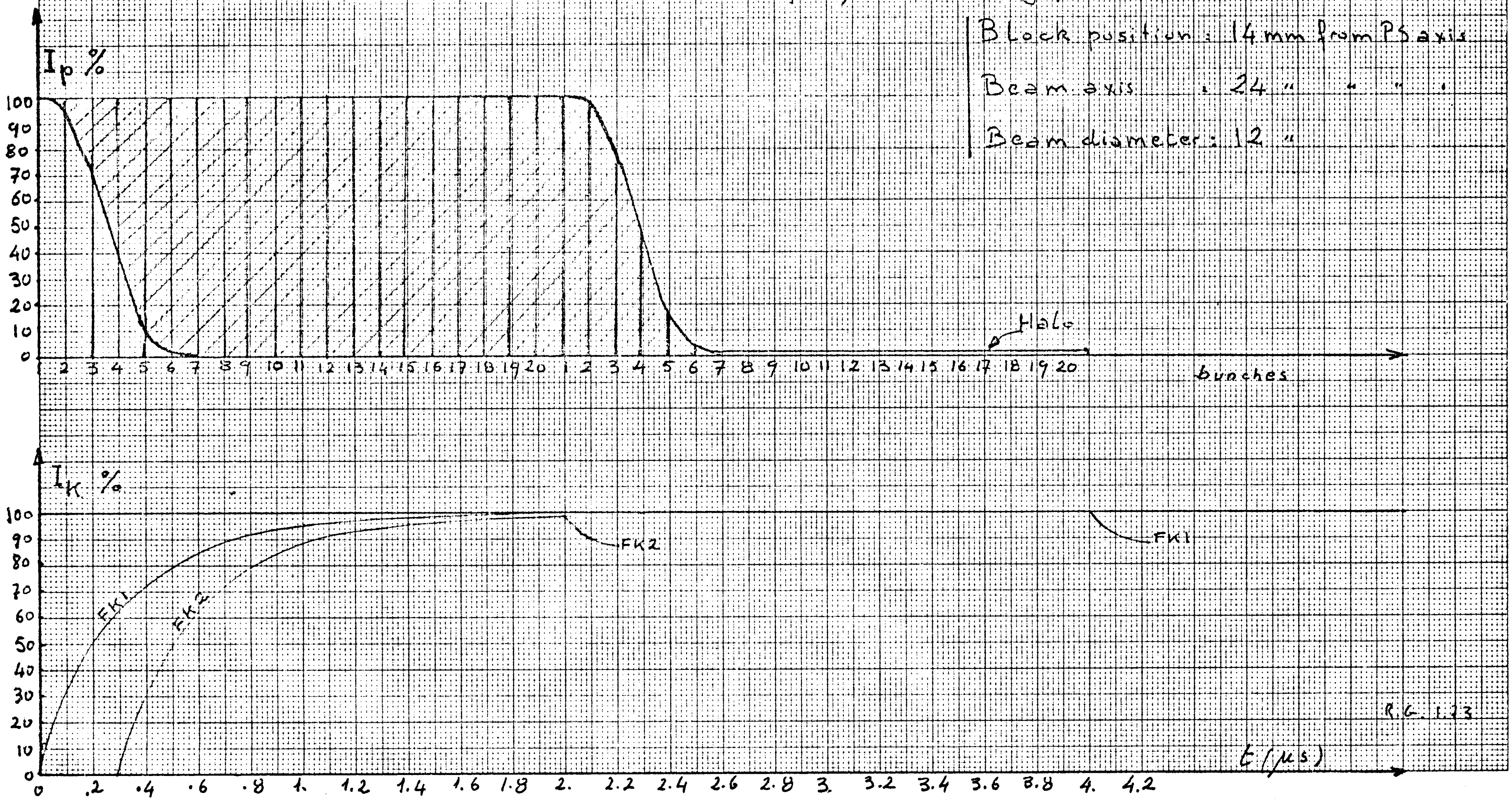
Fig 3. Kicker currents I_K and proton current I_p versus time. (One PS turn is represented here by 2 μs instead of 2.1 μs, for clarity.)



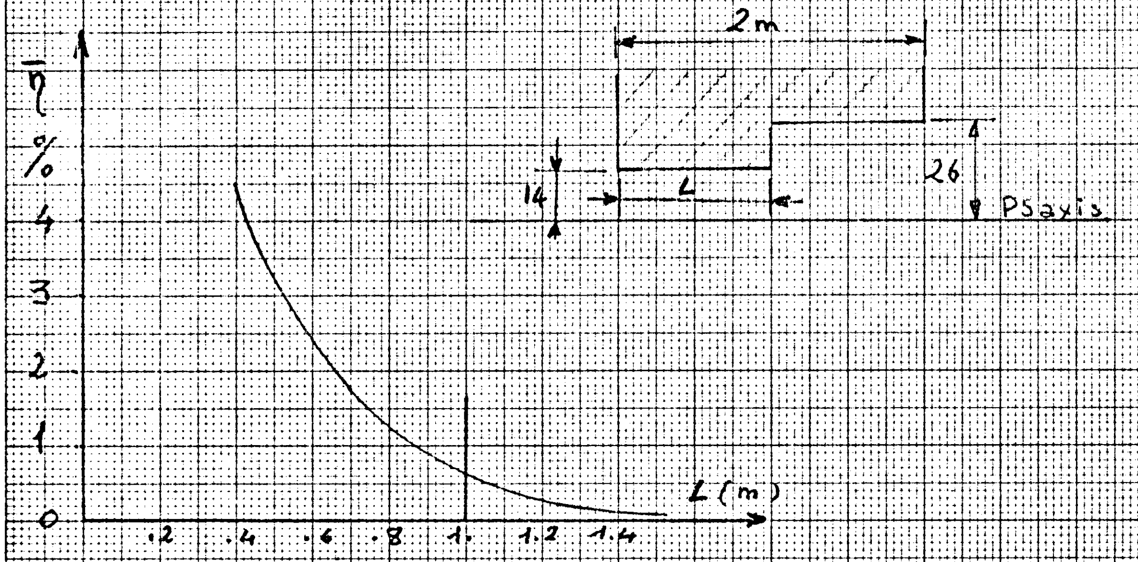


Fig 4. Loss due to the enlargement to r = 26 mm, after a length L at r = 14 mm

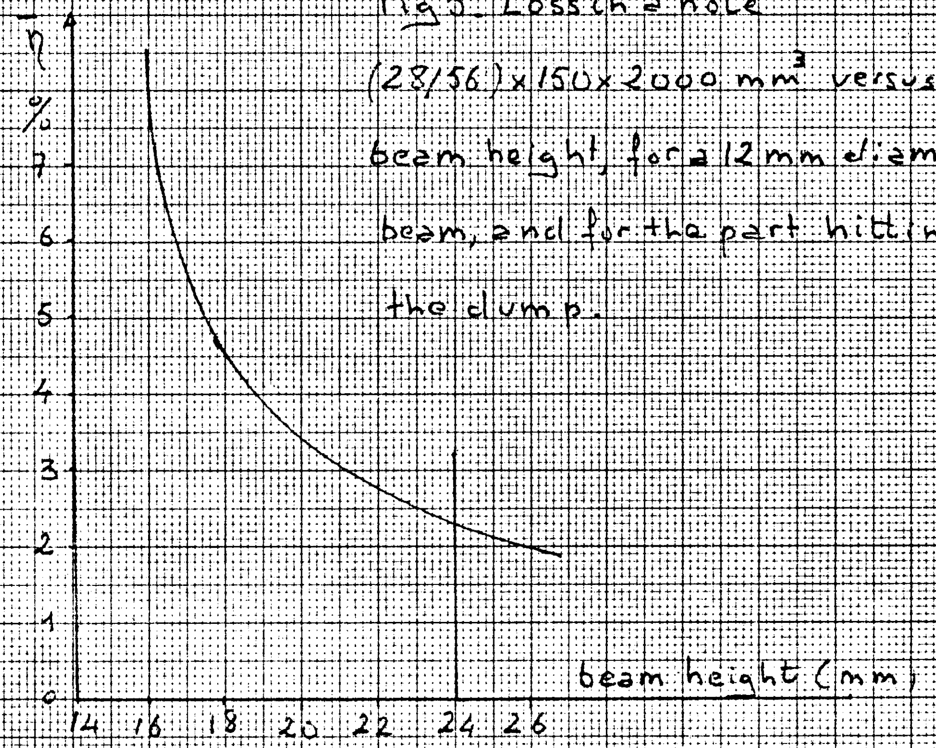


Fig 5. Loss in a hole (28/56) x 150 x 2000 mm³ versus beam height, for a 12 mm diameter beam, and for the part hitting the dump.

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ANNEX 1

KICKER MAGNETS FOR THE PS BEAM DUMP

D. Fiander

1. General

The PS beam is deflected vertically into the dump by a full aperture kicker located 3 magnet units upstream. The cost of this magnet and its pulse generator is greatly influenced by the kick rise time which is specified. Alternatives to the single magnet, fast rise time principle usually applied to fast extraction have been studied in order to produce a high efficiency dumping system at lower cost and of greater reliability. The solution which is proposed is that of a two magnet system of relatively slow rise time (0 - 90% kick in 1 μsecs). The first magnet is located 3 magnet units upstream of the dump and the second any multiple of 8 magnet units downstream of the first. In simplified terms the two equal strength kickers produce a bump during the slow rise time, permitting that part of the beam which has not been dumped during the first turn to be dumped during the second. The upstream magnet has to be excited for a time equal to its rise time plus a PS rotation and the downstream magnet for its rise time. A further variant has also been studied in which both magnets are excited for longer durations in order to dump the protons of the beam "halo".

This annexe gives provisional specifications for the kicker magnets and pulse generators. Curves of cost as a function of kick rise time are included, both for the normal pulse length and the extended pulse length for dumping the halo. A price breakdown is given for the design most favoured from the technical viewpoint.

2. Magnets

The specified kick strength of 1,66 mrad at 28 GeV/c requires an excitation of approximately 1700 ampère turns for a magnet having the full PS aperture and able to fit into a short straight section. From a rise time standpoint the optimum performance is obtained from a single turn design; such a design, however, presents two serious technical problems. Firstly the requirement to switch 17,000 ampères and secondly the imposition of a low characteristic impedance for the pulse generator and associated transmission to the ring located magnets.

The proposed two magnet system of slower rise time permits the use of multiturn magnets. If thyratron switching is to be adopted, the current should be restricted to about 6000 ampères, which limits the choice of N (magnet turns) to 3 or 4. Further consideration of the rise time specification, namely 90% kick in < 1 μsecs, eliminates both of these choices if the magnet is constructed as a single full length module, assuming that a reasonable upper limit of 80 kV be taken for the pulse generator charging voltage. Two alternatives remain to overcome this difficulty. Firstly, the magnet may be divided into two identical 3 or 4 turn modules. This is the classical solution as used in FAK - however, in the case of multiturn modules it loses much of its interest because of the very great loss of useful axial length to accomodate the turn crossovers. Secondly, the magnet may be excited by two independently excited two turn full length windings - this effectively halves the pulse generator voltage compared to that which would be necessary for a 4 turn design. Further there is no loss of useful axial length as in the separate module concept. It is therefore this second solution which has been retained for this design proposal. However, for its satisfactory application it is essential that the pulse generator performance be extremely reliable. Failure to simultaneously excite the two independent windings converts the magnet into a pulse transformer, produces reverse voltage conditions in part of the transmission system and overvolts the switchgear of one of the pulse generators. Operating

TABLE 1

MAGNET DESIGN AND PERFORMANCE

Number of magnets	2
Location	SS18 and SS18 + n. 8
Type	Lumped inductance window frame
Kick sense	vertical
Kick strength at 28 GeV/c	1,66 mrad
Displacement at dump SS 21	24 mm
Aperture for beam	70 mm vertical 110 mm horizontal
Ferrite aperture	120 mm vertical 110 mm horizontal
External window frame dimensions	220 mm vertical 210 mm horizontal
Ferrite weight / magnet	139 kg
Air gap flux density	1940 gauss
Mean ferrite flux density	1360 gauss
Estimated remanent kick per magnet	< 0,5 gauss m.
Magnet length (effective)	0,8 m
Excitation system	2 x 2 T coils
Inductance per coil	5,6 μH
Magnet terminating resistor per coil	5,2 ohms
Shunt capacitor per resistor	36 nF
Excitation current for specified kick strength	4250 amps.
Kick strength at 1 μsecs	0,90 p.u.
Kick strength at 2 μsecs	0,99 p.u.

experience to date with similar equipment (FAK, 300 GeV multi-turn extraction) has shown that the requisite reliability can be obtained.

The magnets would be of the classical lumped inductance window frame design. The return magnet circuit would be of low remanence ferrite blocks. The magnets would operate in the PS vacuum. External to the vacuum would be the terminating resistor and shunt capacitor, the latter for improving the rise time, but of such a value as to produce no significant overshoot. A provisional specification for the magnet design and performance is given in Table 1.

3. Pulse Generators

The proposed scheme for the excitation of the 2 x 2 turn magnets is shown in Fig. 1. The two coils of a magnet are excited from two identical pulse generators which share a common recharging power supply. This solution reduces considerably the risk of exciting one coil without the other. The pulses are derived from lumped element pulse forming networks (PFN's) of conventional design. No special first mesh is required because of the slow rate of rise of current in the magnet. The PFN's for the excitation of SS 18 provide a pulse of 3 μsecs duration. For the purposes of costing the project a further variant has been studied in which the PFN's for SS 18 provide a 4,2 μsecs pulse and those for the downstream magnet 2,1 μsecs - this would be the solution for the dumping of the so-called "halo".

The proposed pulse switching is by English Electric Valve Co. ceramic thyratron CX 1194. This is a 50 kV, 6000 ampère tube of single stage construction which simplifies its installation and increases reliability due to the elimination stage voltage dividers. It should be able to handle comfortably the design operating conditions, namely PFN voltage 46 kV and pulse current 4250 ampères. For the purposes of the proposal it has been assumed that the CX 1194 cannot switch the current of two magnet coils in parallel i.e. 8500 ampères. However, such a possibility is not excluded, particularly in view of the low $\frac{dI}{dt}$; it is recommended that tests to prove this point should be made prior to the execution of the project. Should this solution be possible, there would be a worthwhile saving in running costs and also the risks of exciting one magnet coil without the other would be eliminated.

Pulsed resonant power supplies similar to those used in other kicker magnet projects have been chosen for recharging the PFN's. They consist of three winding step-up transformers with D.C. bias, primary capacitor bank with thyristor switching and high voltage diode between transformer output and load. No difficulties are foreseen in the execution of these supplies, although the load to be charged (640 nF to 46 kV) is greater than in previous MPS projects (but less then in an ISR project). Shot to shot voltage stability of better than 0,2 % can be expected.

For estimating purposes the pulse generators are assumed to be located in an existing building (typically the Centre Building Hall 359) and the pulses are transmitted over a coaxial cable transmission system of Z_o = 5,2 ohms (per magnet coil).

The essentials of pulse generator design and estimated performance are given in Table 2.

TABLE 2

PULSE GENERATOR - DESIGN AND PERFORMANCE

Number of PFN's per magnet	2
Characteristic impedance Z_o	5,2 ohms
Charging voltage	46 kV
Rise time 0,1 - 0,9 pu into matched load	< 150 nsecs.
Pulse length, upstream magnet	3 μsecs.
Pulse length, downstream magnet	0,9 μsecs.
Flat top ripple	< 3 %
Switching tube	CX 1194
Pulse current per tube	4250 amps.
Pulse transmission per tube	6x31Ω cables in parallel
Upstream resonant power supply - load	640 nF
- primary capacitor	50 mF
- transformer rating	30 kVA
- transformer turns ratio	175/1
- primary voltage	221 volts
- shot/shot stability	better than 0,2 %
Downstream resonant power supply - load	200 nF
- primary capacitor	18 mF
- transformer rating	10 kVA
- transformer turns ratio	175/1
- primary voltage	221 volts
- shot/shot stability	better than 0,2 %
Maximum repetition rate	1 pulse per second
PFN recharging time	3 msecs. (approx.)

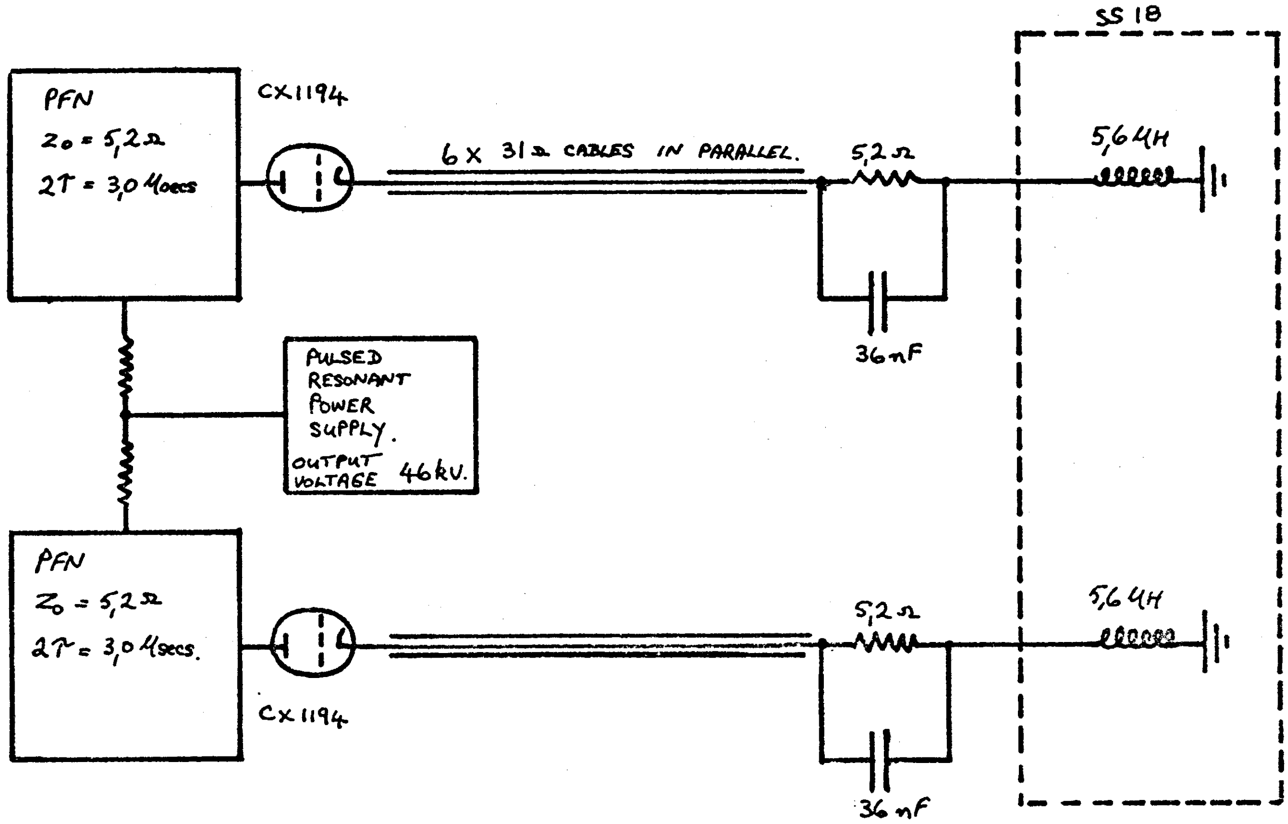
4. Costing

The influence of permissible kick rise time on cost has been studied for the two cases of short and long magnet excitation i.e. normal dumping or "halo" dumping. These results are shown in Fig. 2. From a technical standpoint the solutions which permit a slower rise of kick are to be preferred not only on account of cost, but also on account of the lower operating voltage, and hence improved reliability, e.g. the PFN voltage for a kick rise time (0,9 pu) of 600 nsecs. is 75 kV, that for 1000 nsecs. 46 kV.

A price breakdown is given in Table 3 for the cheapest solution, namely 0,9 pu kick at 1000 nsecs., "short" pulse excitation.

TABLE 3

Item	per unit cost KFS	Total cost KFS
Vacuum tank and pumps	75	150
Magnet	35	70
Pulsed resonant power supplies - upstream magnet	34	34
- downstream magnet	23	23
Pulse forming networks - upstream magnet	37	74
- downstream magnet	11	22
Terminating resistors + shunt capacitors	7	28
Thyratron switches	17	68
Cable transmission system, including plugs and sockets	87	87
Oil cooling (terminators, thyratrons)	10	10
Installation	6	6
MCR controls (manual control only)	5	5
All 1972 prices		577



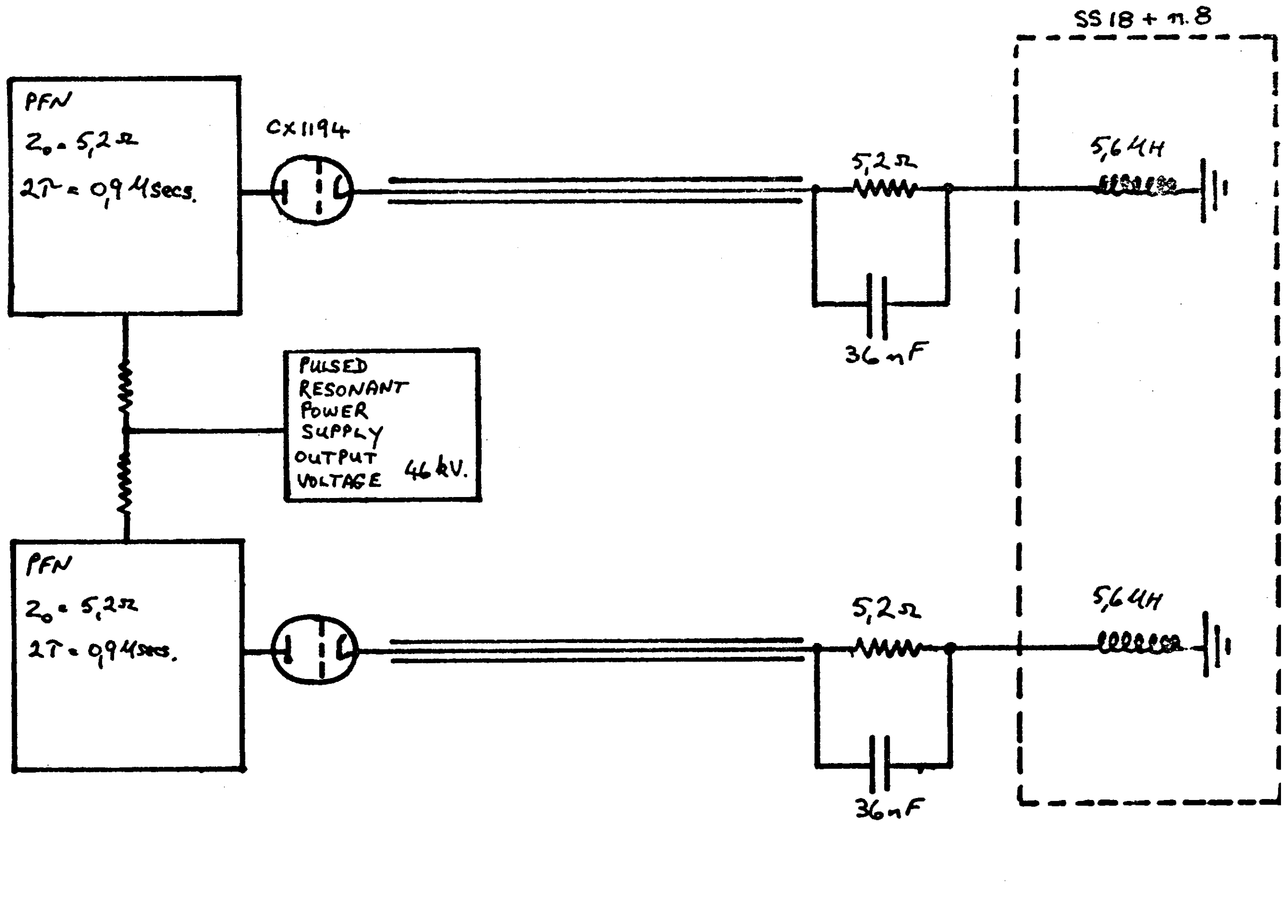
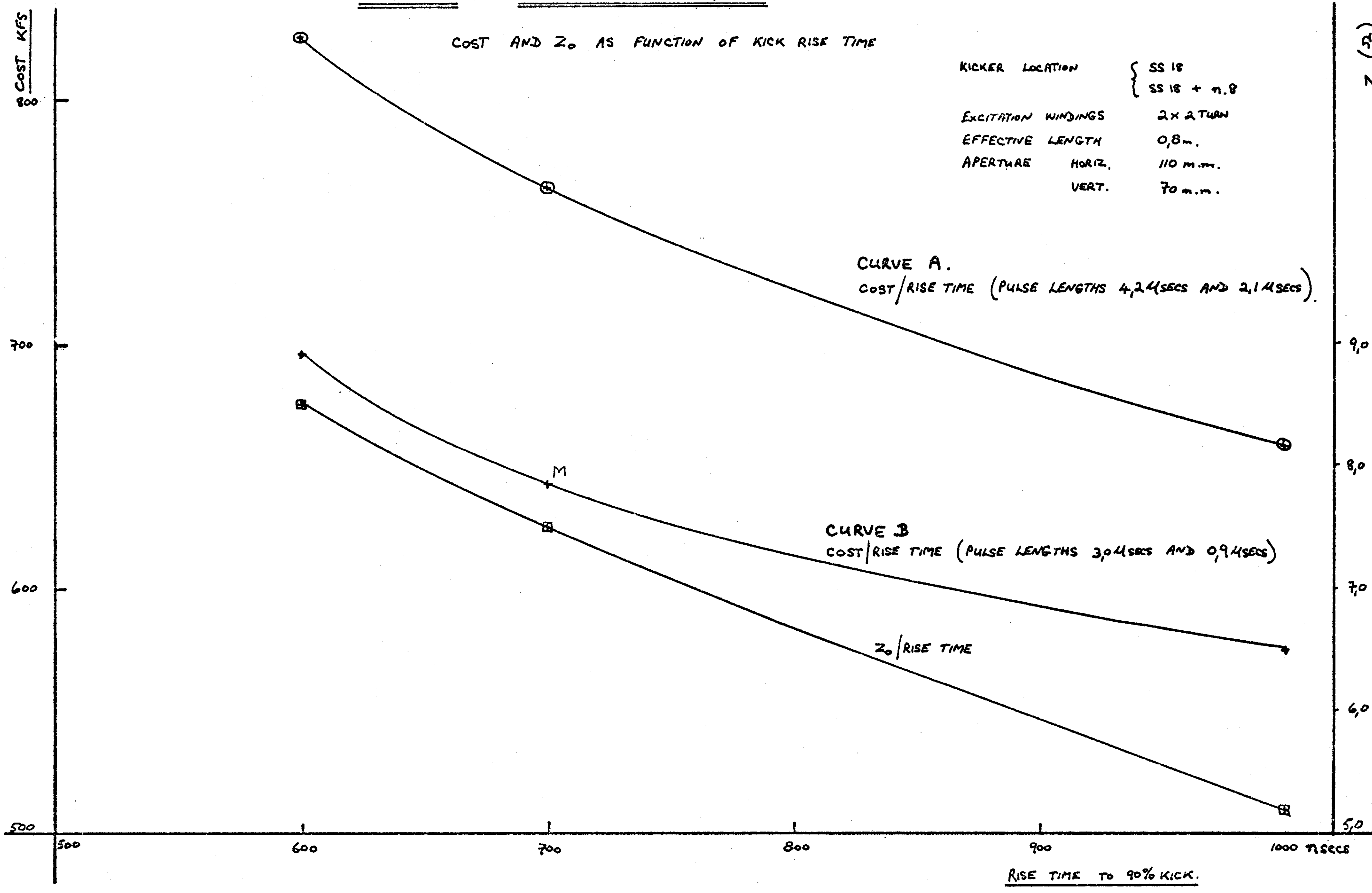


FIG 1. PROPOSED CIRCUIT FOR P.S. BEAM DUMP KICKERS.

FIG 2. P.S. BEAM DUMP SYSTEM



ANNEXE 2

DESIGN STUDY FOR A BEAM INTERCEPTOR IN S.S. 21

The purpose of this study is to get an idea of the feasibility and safety of the construction on one hand, and of the costs on the other hand. In other words, the study is of a general nature, the details have been studied thoroughly only where they were influencing the feasibility or the price.

The beam interceptor, located in s.s. 21, shall allow, in co-operation with a fast kicker in s.s. 18, to dump the proton beam at any energy between 10 GeV/c and 28 GeV/c.

A. SPECIFICATION

The specification is based on Memo MPS/SR/72-104 (Prel. spec. for beam dumping device) from 5.12.1972 and on discussions with Messrs G. Plass, R. Gouiran and Ch. Steinbach.

1. Absorber block

1.1 Copper block 150* 70* 1000, water-cooled (10 kW max.)

1.2 Vertical movement :

a) Stroke

zero position : 26 mm above orbit

dumping position : anything between 16 and 8 mm above orbit.

The stroke is remote controlled.

b) Timing

start of movement : within ± 0,05 sec

stroke "in" : 0,250 sec

time "in" position : anything between 0 and 0,6 sec

stroke "out" : ∿ 0,3 sec

repetition rate : anything between 0,72 and 2 sec

c) Life-time : several years. About $3 \cdot 10^6$ cycles/year.

d) Accuracy of positioning :

longitudinal angle : ± 0,1 mrad

vertical position : ± 0,5 mm

from pulse to pulse : ± 0,3 mm.

2. Shielding and supports

The reciprocating absorber block and its tank are surrounded by a stainless steel or/and lead shielding (600 x 700 x 2000).

The support structure must allow an accurate alignment and stability of the mechanism within ± 0,1 mm.

B. PROPOSED SOLUTION

A commercial hydraulic linear actuator (1.1, see Fig. 1) working in phase with the PS, is connected to the reciprocating, water-cooled copper block (1.2) with its arm and guiding system (1.3). The actuator with its support is quickly dismountable, as its height interfers with the PS magnet surveyor sighting lines.

The mobile mass, tank (3.2) and part of the shielding (3.1) form a unit (Fig. 3) and can be taken out of the ring with a minimum of radiation danger. It is replaceable by an identical spare unit.

This unit is supported as a whole on concrete blocks (1.4). An adjustment allows to position the unit, which is itself already aligned (lab.).

Two stainless steel side-plates (2.1, see Fig. 2) and two lead blocks (2.2) hanging on the main shielding block (3.1) complete the shielding of the exchange unit.

The down-stream hippodrome shaped (52 mm high, 146 mm wide, 4 mm thick) chamber (1.5) with a 400 l/sec ionic pump (1.6) is supported and adjusted on the lower shielding structure (2.3), which itself is resting on the concrete support. The chamber is covered with the upper shielding structure (2.4). The shieldings consist of rigid frames filled with lead bricks.

The up-stream chamber (1.7), provided with an elbow and an oberservation window, has its own support and shielding (2.5) resting on the concrete blocks.

The tank has two SI-type connections (1.8), each one having its U-shaped shielding block (1.9).

A 200 l/sec ionic pump mounted on the manifold MU 20 and a 400 l/sec ionic pump (1.6) connected to the down-stream chamber will take care of the increased degassing rate of the bombarded absorber.

The hydraulic and electronic equipment for the actuator (both in the PS ring and the MCR) will be very similar to that of the fast kickers in s.s. 13 and s.s. 97.

A TV-camera with its monitoring system is placed up-stream in front of the elbow-chamber (1.7).

C. CONCLUSIONS

The general philosophy about beam-dumps in accelerators - whether to keep the dumps out of the ring or to accept them in the ring - shall not be discussed here. Even a carefully designed beam interceptor will always present a certain risk for the PS machine.

1. Feasibility of the system

1.1 The requirements on the movement have very heavy implications on the actuator, which shall work in phase with the PS.

A pneumatic drive was eliminated because of life-time and timing-precision problems (compressibility of air). Ordinary electromotors cannot be used because of the flexibility of timing demanded. The commercial stepping motors are not powerful enough to satisfy the requirements. A three-stage commercial hydraulic linear actuator, similar in service and feasibility to the one in s.s. 13, will be flexible and precise enough.

For the oil supply, either the prolongation of the existing fast kicker line, or an independent small commercial pumping unit (2 l/min) placed close to s.s. 21, can be envisaged, depending on the future of the kicker lines.

1.2 The positional stability requirements need a very careful study :

a) the copper absorber block will be cooled by two parallel water circuits, the majority of the temperature gradients being more or less in the horizontal plane to avoid a deformation. Nevertheless, due to the dynamic forces and the heating up of the block, its deformation will be close to 0,1 mm;

b) the guiding of the mechanism requires necessarily some play. This play transmitted to the absorber block will give some 0,2 mrad angular movement;

c) to keep the long-term stability in the horizontal plane of the support structure within ± 0,1 mm requires a very heavy and elaborate construction (concrete block with embedded steel plates for the base).

As the stainless steel shielding of the mechanism represents a very big and compact structure, it is used as upper supporting element of the mechanism and the tank.

The same reasoning can be used for the down-stream vacuum-chamber: the proposed structures (upper and lower), filled with lead bricks, could be replaced by solid stainless steel blocks (for a somewhat higher price).

1.3 Handling, radiation

The actuator and its mounting form a constructional unit which can be easily separated from the mechanism without effecting the alignment. This is necessary for inspection and repair of the actuator on one hand and the deblocking of the surveyor sighting lines on the other hand.

If any faults appear during operation of the beam interceptor (water-leak, damage to the guiding, vacuum-leak on bellows or tank, broken screen in front of block etc.), the whole unit (Fig. 3), consisting of mechanism, tank and part of the shielding, is replaced by an identical spare unit, already aligned and tested. The philosophy applied here is to have a minimum of intervention time under maximum protection against radiation.

1.4 Further points

In this study the problem of life-time tests, which will be necessary before installation, have been treated very briefly. It should be stressed that this part of the development is rather time and money consuming, based on past experience with the fast kickers.

The height of the vacuum-chamber in MU 20 cannot be enlarged (70 mm) as required, unless one would consider specially constructed flat pole-face windings.

2. Prices

2.1	Mechanism, block, guiding, tank, membrane, support	Frs.	50.000.-
2.2	Actuator with support	"	21.000.-
2.3	Vacuum-chambers, ionic pump	"	26.000.-
2.4	Hydraulic and electric installations and instrumentation on the ring and the MCR	"	90.000.-
2.5	Shieldings and supports	"	66.000.-
2.6	Spare unit and spare actuator (pos. 2.1 and 2.2)	"	71.000.-
2.7	Assembly work	"	12.000.-
	Total	Frs.	336.000.-
2.8	Tests (approximation)	Frs.	80.000.-

3. Assembly times in the PS

First assembly in the s.s. with alignment and tests	4 days (12 man days)
Replacement of eventually damaged interceptor for spare unit	4 hours (10 man hours)
Replacement of the faulty actuator by a spare one	1 hour (2 man hours)

The design effort will be around 40 man weeks. The production time will take about 6 months.

B. Szeless

Enclosures : 3 sketches

Distribution

R. Gouiran
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C. Rufer
Ch. Steinbach

BS/bb

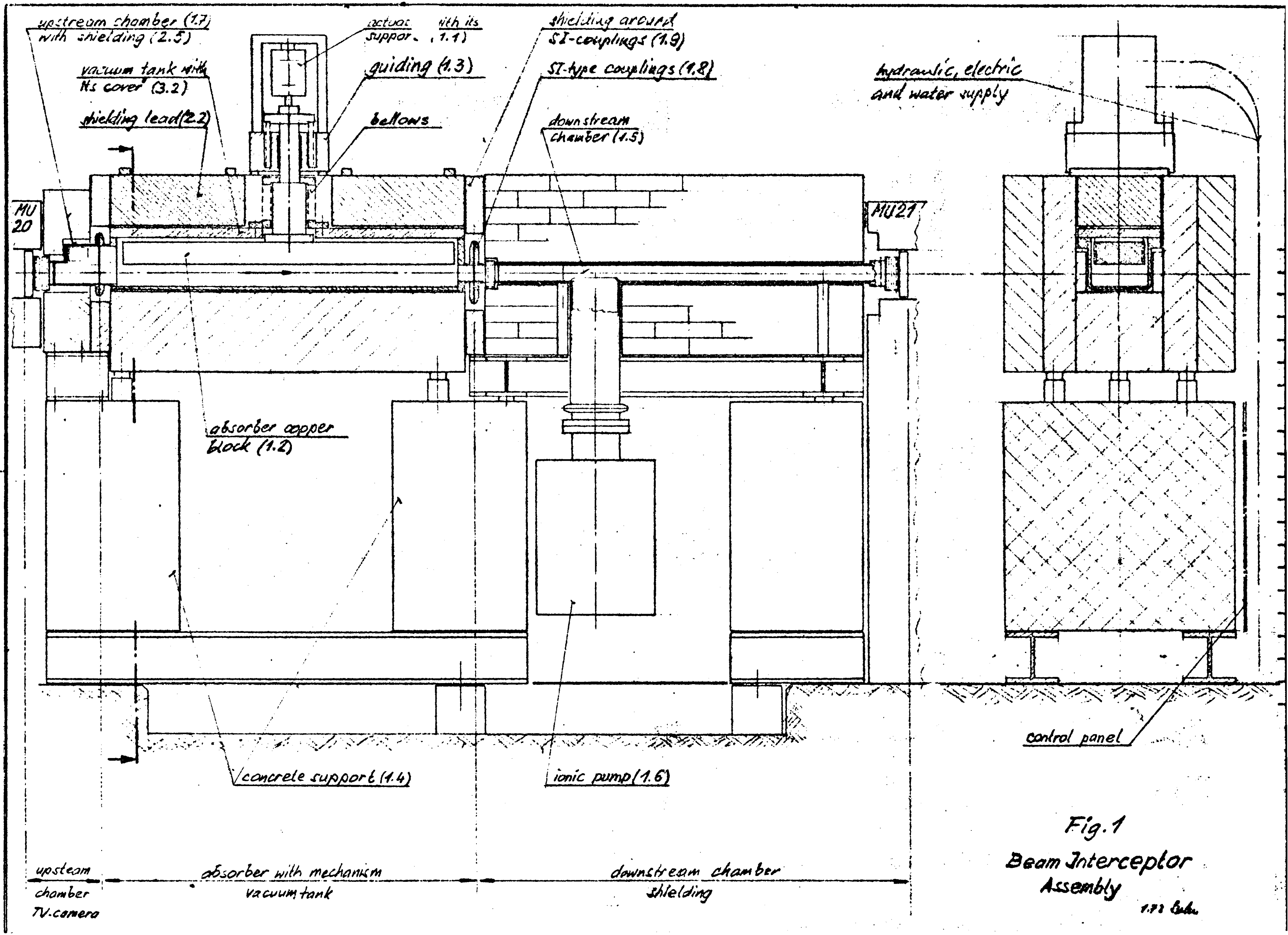
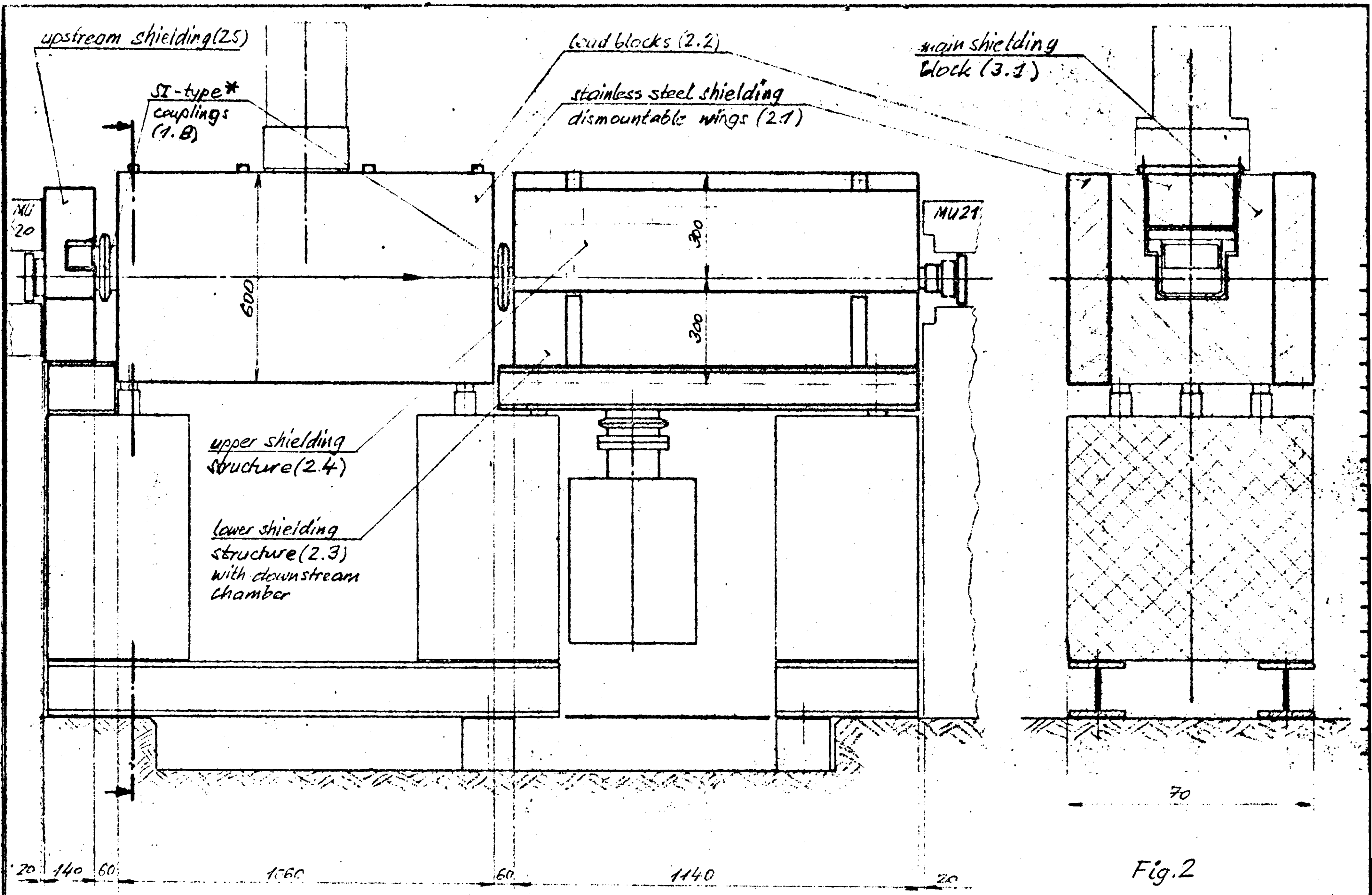


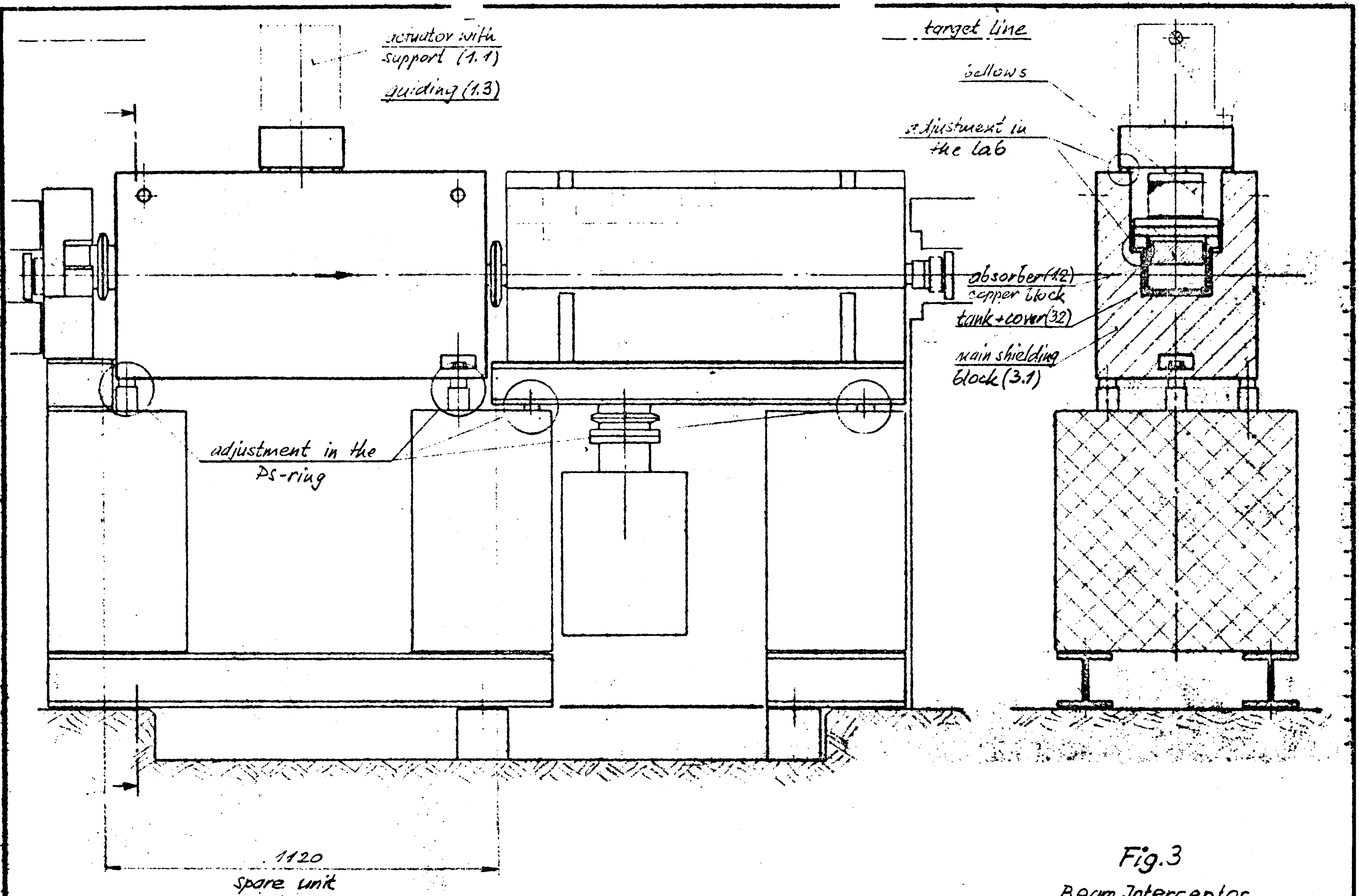
Fig. 1
Beam Interceptor Assembly

1.72



*Shielding (1.9) around SI-type couplings (1.8) not shown here.

Fig.2
Beam Interceptor
Shielding Units



Shielding (1.9) around SI-type couplings, lead blocks (2.2) and shielding wings (2.1), all to be mounted on the unit, are not shown.

Fig.3
Beam Interceptor
Spare Unit