/lmg

PS/AE/Note 76-11
20.5.1976.

INTERIM REPORT OF PS MULTIPULSING WORKING GROUP

D. Boussard, D. Fiander, B. Godenzi, R. Gouiran, H. Koziol, A. Krusche, D. Möhl, G. Nassibian, C. Steinbach.

This Working Group was set up in February by G. Plass to look into the possibilities of using the PS for multipulse filling of the SPS and to assess the implications in money and effort. This report gives a brief resumé of progress at mid-May.

1. GENERAL

The report deals with the following points:-

a) the possible transfer schemes

b) the reduction of the PSB-PS cycle time

c) associated matters such as radiation and reliability problems

d) costs

2. TRANSFER SCHEMES

The transfer schemes which have been considered are 1T Fast Extraction (FE), 2T mixed Continuous Transfer (CT) + FE, 2T, 3T and 5T CT. All are felt to be technically possible but reservations exist concerning certain schemes, either on account of induced radio-activity in the PS or because they are unlikely to meet the long term intensity requirements of the SPS. Table 1 summarises the estimates of intensities obtainable with the various transfer schemes.

All these transfer schemes were tried on the PS during an MD session on 13.5.1976, with a circulating beam intensity of the order of 8.5×10^{12} ppp and with one 1.2 s 'A' cycle per super cycle. Emittance of the extracted beam was measured with SEM grids (332, 333 and 334) in TT2, efficiency was measured with the equipment of the CT installation, and note was made of Fast Bumper (FB) or Full Aperture Kicker (FAK) settings for the different ejections. A brief summary of the results is given below (Table 2) and oscillograms of the ejected beam current in Fig. 1.

The following remarks apply to the results of Table 2.

a) General

The results were taken in a single MD session and therefore give a reasonable comparison of the different schemes. They were taken rapidly and there was insufficient time for optimisation. The emittance values are the average values for the ejected beam; measurements were not made of the emittance values of the separate turns. The values quoted are for operation with 4 Booster rings.

Table 1

SPS intensities obtainable with the various multipulse modes

number of batches (B)	1	2	3	5	10
number of turns, PS ejection	10 CT	5 CT	3 CT	2 mixed	1 FE
ejection efficiency (%)	93	94	95	95	98
SPS cycle time (sec), 200 GeV	3.6	4.2	4.8	6.0	9.0
400 GeV	6.0	6.6	7.2	8.4	11.4
SPS intensity:					
case 1: 10^{13} p/p	0.67	1.4	2.1	3.4	7.1
case 1: 10^{13} p/sec, 200 GeV	0.19	0.32	0.43	0.57	0.78
case 1: 10^{13} p/sec, 400 GeV	0.11	0.21	0.28	0.41	0.62
case 2: 10^{13} p/p	1.2	2.4	3.7	6.1	12.6
case 2: 10^{13} p/sec, 200 GeV	0.33	0.57	0.76	1.0	1.4
case 2: 10^{13} p/sec, 400 GeV	0.20	0.37	0.51	0.73	1.1

PS cycle time to 10 GeV : 0.6 sec
SPS " 200 GeV : 3.6 + (B−1) × 0.6 sec
SPS " 400 GeV : 6.0 + (B−1) × 0.6 sec

		case 1	case 2
p/p injected into PS at 800 MeV	:	1.0×10^{13}	1.5×10^{13}
efficiency of debunching + retrapping (either in PS at 1 GeV or in SPS at 10 GeV)	:	80%	90%
total other losses	:	10%	5%

TABLE 2

Mode of transfer	Efficiency %	Extracted beam (4 Booster Rings) ε_H (π mm. mrad)	ε_V (π mm. mrad)	Remarks
1. Fast Extraction	95	2,9	1.6	FAK 4 modules
2. 2T Mixed	89	3.0	1.8	FB 1st step + FAK
3. 2T CT	80	2.4	1.7	Inadequate FB 2nd step kick
4. 3T CT	94.5	2.1	1.9	
5. 5T CT	93	1.7	2.0	
6. 10T CT	90.5	1.6	1.7	

The indicated areas contain approximately 86% of the beam.

b) FE Mode

This required 4 FAK modules with kick enhancement. As there will be up to 12 available and each has a 5 shot capability, a total of 8 FAK modules would meet the needs of 10 x 1T FE. The only modifications necessary would be control/timing distribution changes.

c) 2T Mixed

This was only just possible with the hardware available, which for the FB excitation was the Reserve Staircase Generator. (RSG) (Had the Normal Staircase Generator (NSG) been serviceable there would have been more freedom to adjust the second turn because of the superior inverse hold-off of the thyratrons). The first turn, shaved by the electrostatic septum (ES), required an FB kick equivalent to 2.4 FAK modules (354 gauss m) and the second turn, directly ejected by FAK, required 3.2 modules. ε_H was minimised by adjusting the second turn FAK strength. There was no problem in time synchronising the second turn FAK kick with the first turn ES kick.

d) 2T CT

This was impossible with the hardware available because the strength of the second turn could not be raised sufficiently; 15% of the beam remained in the PS.

e) 3T CT

This was within the ability of the RSG and would be comfortably within the ability of the NSG.

f) 5T CT

This presented no hardware problems.

In conclusion it can be said that existing hardware could handle 1T FE, 3T and 5T CT, with in all cases some expenditure for timing and control circuitry and in the latter two cases some changes to the pulse generators to improve reliability and to permit repetitive operation in a super cycle. On the other hand 2T mixed transfer requires improved hardware for the fast bump; improvement is necessary in both kick strength and rise time. (The present FB kick rise time, 5 - 95%, is 650 nsecs, which can be improved to 520 nsecs by shunting the magnet with a capacitor; the FAK kick rise time is 70 ns). Improved hardware for a faster more powerful first turn bump could be based on FAK equipment but using series connected modules. Adequate kick strength, with rise time < 200 nsecs, would be given by 3 series connected modules and space exists for them in SS 21. The cancelling kick could be provided by a similar arrangement, but not in SS 9 if the present FB system is to be retained. There is a possibility that a scheme could be found whereby the cancelling kick could be provided by otherwise unused FAK modules in SS 71 or 79. 2T CT is considered to be much more difficult to achieve because of high strength needed in the FB system second step and because of the aperture requirement of the ES.

The problems of synchronisation and tolerances for multipulse injection into the SPS from the PS are under study on the assumption that 200 MHz acceleration will be used in the PS up to 10 GeV/c. A possible synchronisation technique is a controlled radial beam displacement in the PS while the RF is compared to the SPS which in turn is stabilised from an external generator. Alternatively a more complex "homing" system which anticipates the evolution of the revolution frequency could be used and which has the advantage of saving about 25 ms in cycle time which would otherwise be needed to steer the kicker rise gap around the PS. It seems that in both schemes the required B field precision at transfer is $\pm 10^{-4}$ in the PS and $\pm 10^{-3}$ in the SPS. Work continues on the study of alternative schemes.

3. REDUCTION OF PSB - PS CYCLE TIME

This has been investigated with a view to shortening the present 'A' cycle time of 1.2 s to about 0.6 s. It was assumed that this shortened cycle would not be introduced before the new Linac (minimum cycle time 0.5 s) becomes operational. Further it was assumed that the shorter 'A' cycle time would be required only for 800 MeV PS injection energy. The major changes which are required are outlined below.

3.1. PS Main Magnet Supply

Two possibilities have been studied

a) with 9.5 MHz acceleration and

b) with 200 MHz acceleration from 1 GeV.

The magnet supply cycle for 9.5 MHz acceleration would start with a waiting field of about B_o = 500 gauss of duration determined by the cycle programme but in the case of repetitive 'A' cycles this would be short. From the waiting field B_o the field would rise with a $\dot{B}$ higher than used for 50 MeV injection and a "peaking strip" would give the start pulse for the cycle corresponding to a defined B. There would then be a front porch before initiating the 800 MeV injection period with the C100 pulse. Acceleration to 10 GeV would be followed by a flat top composed of two parts; the first is a stabilisation period of minimum duration 30 ms and the second a flat top of length determined by the transfer mode.

The total cycle can be subdivided into the following phases if 9.5 MHz acceleration is used.

	800 MeV injection period	60 ms	
	Acceleration	191 ms	
10 GeV	Stabilisation period	30 ms	
10 GeV	Flat top	65 ms	($\dot{B}$ = 0 for 50 ms)
	De-excitation	194 ms	
	Preparation time (minimum)	110 ms	
	Total	650 ms	

There is the further hope that this cycle may be reduced to 610 ms by reducing the time allowed for the 800 MeV injection period to 40 ms and shortening the 10 GeV flat top to 45 ms, with $\dot{B} = 0$ during 30 ms.

If 200 MHz is used an additional period with $\dot{B} = 0$ must be created near 1 GeV for the frequency conversion to 200 MHz but the 10 GeV flat top can be shortened. The subdivision of the cycle becomes

	800 MeV injection period	60 ms	
	1 GeV $\dot{B} = 0$ (minimum)	20 ms	($\dot{B} = 0$ for 5 ms).
	Acceleration	191 ms	
10 GeV	Stabilisation period	30 ms	
10 GeV	Flat top	20 ms	($\dot{B} = 0$ for 5 ms).
	De-excitation	194 ms	
	Preparation time (minimum)	110 ms	
	Total	625 ms	

If the 800 MeV injection period can be reduced to 40 ms then the cycle time becomes 605 ms.

The minimum cycle time of 610 ms for 9,5 MHz acceleration is conditional upon satisfactory results from tests which it is intended to perform before the end 1976.

Proposed field and timing diagrams for the PS main magnet supply are given in Figs. 2 and 3.

3.2. Other PS Equipment

The following equipment must be modified, mainly for thermal reasons, to make it suitable for a cycle time of 0,6 s.

i) septum 16 pulse generator
ii) "peaking" strip 101st magnet unit
iii) PFW correction resistor network
iv) γ-transition jump power supplies

v) bump 16 power supply

vi) γ-transition jump fast quadrupoles

vii) injection air quadrupoles

viii) transfer injection kicker TIK 45

ix) timing, programme line sequencer, general controls.

This list excludes modifications to the Fast Bumper of the Continuous transfer as these depend upon the transfer scheme(s) chosen.

3.3. PS Booster

The Booster cycle time can be reduced to a figure which will be equal to or better than that given for the PS main magnet supply in (3.1). To bring this about the Booster main power supply must be modified by putting one more rectifier/inverter group in series and installing a new compensation system for reactive power. Further, agreement has to be obtained from the Services Industriels de Genève (SIG) to pulse at the higher repetition rate which multipulsing implies. To this end joint CERN/SIG tests are to be held in June. Ultimate agreement with the SIG might well evolve around the guarantees which CERN is prepared to offer against the long term deterioration of SIG equipment under the faster pulsed loading conditions.

In addition other power supplies and equipment must be modified, mainly to cope with the thermal effects.

There is also the possibility that certain other changes may be needed, depending on further study and experience. These are an active filter for the main power supply and changes to the RF system to cope with higher average power. Finally there is the question of whether a second RF cavity is required; at present there are strong indications that this will not be necessary but a definite conclusion cannot yet be drawn.

4. RADIATION AND RELIABILITY PROBLEMS

4.1. Radiation

At present the PS accelerates about 2.5×10^{19} p/year. On the assumption of 5×10^{13} p/SPS pulse, this would rise to about 2×10^{20} p/year of which 10% would be used for 25 GeV physics. It is felt that this represents the limit which the PS can reasonably take if it is to continue to operate reliably for a further substantial time. The long term repetitive transfer of 10^{14} p/SPS pulse would raise problems which could render operation and maintenance of the PS difficult and endanger its equipment. It is therefore not included in the present costing.

In the original forecast of induced radiation for PS high intensity running (MPS/SR/Note 73-43) the Total Irradiation of Ring (TIR) was predicted for end 1983 as 6.4×10^{10} rad. With the acceleration of 2×10^{20} p/year this estimate for TIR has to be increased to 8×10^{10} rad, which implies that two magnet repairs will be necessary by 1982 (assuming multipulsing starts in 1978). An annual repair rate of 1 - 2 magnets must be expected after 1982; about 9 - 10 magnet units will be exposed dangerously to radiation. These assumptions are based on the hypothesis that the whole PS magnet will have been reinforced, as foreseen, by 1979 (binding of all magnet end blocks, installation of new poleface windings).

The Total Activity in Ring (TAR) is at present 7 rem/hr. The forecast of TAR for end 1983 was 16 rem/hr. but with the acceleration of 2×10^{20} p/year this must be revised upwards to 20 rem/hr.

The radiation problem will be further aggravated with the frequency conversion from 9.5 MHz to 200 MHz at 1 GeV. If a 10% loss is assumed then the TAR is likely to rise by about 6 rem/hr. to a total of 26 rem/hr. In order that the apparent TAR should not exceed say 12 rem/hr. to a person walking in the ring tunnel it is proposed to concentrate the 9.5 - 200 MHz conversion losses on at least 2 fixed dump scrapers, which should be shielded, and to add suitable shielding in other high loss regions

---

TIR = Σ 100 doses measured at the entrance to the PS main magnet 5 cm below beam axis.

TAR = Σ 100 dose rates at 40 cms from SS chamber after 2 days cooling.

(typically SS 16, 31, 37, 42).

4.2. Reliability

The number of PS pulses/year can be expected to increase by a factor of 2 or 3 with multipulsing. This will present a reliability problem for certain elements, which in some cases will be further aggravated by the higher radiation. The following are considered to be elements which must be rebuilt or have additional spares in order to maintain reasonable PS reliability.

a) Septum 16 - the present 6 x 10^6 pulses per annum could more than double with multipulsing. In view of the greatly increased radiation and higher pulse count additional spares must be provided both for magnets and ring installed transformers.

b) Some additional spares must be provided for important auxiliairy power supplies.

c) The transfer injection kicker TIK should be either seriously modified or replaced. This is one of the least reliable elements of the PSB - PS complex which is being pushed to the limit to obtain adequate kick strength. Further it has no built-in redundancy. A design proposal has been completed for a new modular TIK, based on FAK equipment, which would have improved kick strength and better reliability through built-in redundancy. It would also have equal rise and fall performance and would permit multipulse filling of the PS from the PSB (this feature may be of no interest for multipulse filling of the SPS but could be of use for other PS projects).

5. COSTS

Approximate costs are given for the various changes or improvements necessary to bring about multipulsing. Table 3 gives a breakdown of costs for a reduction in cycle time, Table 4 gives the costs for the changes to the extraction equipment for the different modes of transfer and Table 5, gives the costs which should be included to meet the radiation and reliability problems. No costs have been included for 200 MHz acceleration other than for the dump scrapers to localise the radiation losses at frequency conversion.

Summarising, the minimum total cost would be about 7.9 MFr. and would apply to 3 of the possible transfer schemes (10 x 1T FE, 2 x 5T CT and 3 x 3T CT). The maximum total cost, taking the most expensive transfer scheme (2T Mixed) and assuming maximum expenditure on the PSB, would be 12.5 MFr. In both the totals it is assumed that the estimate of ≃ 2.6 MFr. for radiation and reliability problems is fully accepted.

It must be added that these costs are given conditionally upon the satisfactory outcome of further tests and MD sessions planned up to the end 1976. They are further conditional upon the acceptance of pulsed PSB operation at the higher repetition rate by the SIG without major changes to the CERN or SIG supply networks.

No estimate has been made of the internal PS effort required to achieve multipulsing. Multipulse transfer using 3T or 5T CT and with the present 'A' cycle duration could be possible rapidly (say 3 - 6 months). Progression to the final goal could be gradual but it is thought unrealistic to expect completion in less than 2 years from the project authorisation, due mainly to delivery schedules for heavy electrical equipment from outside suppliers.

TABLE 3

COSTS FOR REDUCTION OF CYCLE TIME TO ≈ 0.6 SECS.

Machine	Equipment	Definitely necessary MFr.	As yet uncertain MFr.
Booster	Main power supply	1.9	
↓	Other supplies	0.9	
	Cooling	0.25	
	Timing, sequencing, data acquisition	0.25	
	Active filter for main supply		0.4
	RF equipment modification		0.1
	Second RF cavity/ring		3.0
PS	Main power supply	0.03	
↓	Auxiliairy supplies	0.09	
	Auxiliary magnets	0.8	
	Peaking strip	0.03	
	PFW resistors	0.01	
	RF system mods	0.01	
	Septum 16 mods	0.34	
	Controls	0.20	
PSB + PS	Contingency	0.30	
		5.11	3.5

TABLE 4

EXTRACTION EQUIPMENT COSTS FOR DIFFERENT TRANSFER MODES

Transfer Mode	Equipment				Total
	FAK (MFr.)	FB (MFr.)	ES (MFr.)	Synchronisation (MFr.)	
2 x 5T CT	-	0.05	0.10	0.05	0.20
3 x 3T CT	-	0.05	0.10	0.05	0.20
5 x 2T Mixed using FAK 71 (79) to cancel first turn kick	0.01	0.73	0.10	0.05	0.89
5 x 2T Mixed	-	1.19	0.10	0.05	1.34
10 x 1T FE	0.02	-	0.10	0.05	0.17

Notes:

1. It is assumed for all above transfer modes that the possibility to make 10T CT would remain,but that the conversion from 3T or 5T CT to 10T CT would be manual and would involve a shutdown of all equipment for up to 1 hour.

2. The 5 x 2T Mixed mode is based on the use of 3 series connected FAK modules in each of the dipoles forming the first turn bump. An alternative and cheaper solution might be possible using predistorted pulses to improve the rise time of a simpler lumped inductance dipole but the problems of reflections and their effect on the thyratron switches would need detail study.

3. The costs for 2 x 5T CT and 3 x 3T CT are based on the assumption that only the NSG is converted. The RSG would be suitable only for 10T CT (and under manual as opposed to computer control).

TABLE 5

COSTS FOR RADIATION AND RELIABILITY PROBLEMS

Equipment	Reason	Cost MFr.
TIK 45	Reliability (and performance)	1.55
Main PS Magnet coil spares	Radiation	0.2
Septum 16 spares	Radiation + reliability	0.2
Auxiliary power supply spares	Reliability	0.06
Additional moveable shielding PS ring	Radiation	0.15
Dump scrapers for localising 9,5/200 MHz trapping losses	Radiation	0.4
		2.56

Note: If TIK 45 is excluded on the grounds that its present reliability is satisfactory then approximately 0,2 MFr. must be added to Table 3 to make the present TIK 45 suitable for multipulsing (but without changing its present reliability).

Distribution:

O. Barbalat
D. Bloess
M. Bouthéon
D. Dekkers
J. Gareyte
M. Georgijevic
C. Germain
P. Germain
W. Hardt

L. Hoffmann
J. Jamsek
I. Kamber
B. Kuiper
P. Lefèvre
C. Mazeline
R. Mosig
G.L. Munday
G. Plass

F. Rohner
C. Rufer
R. Tinguely
F. Völker

F. Bonaudi, DI

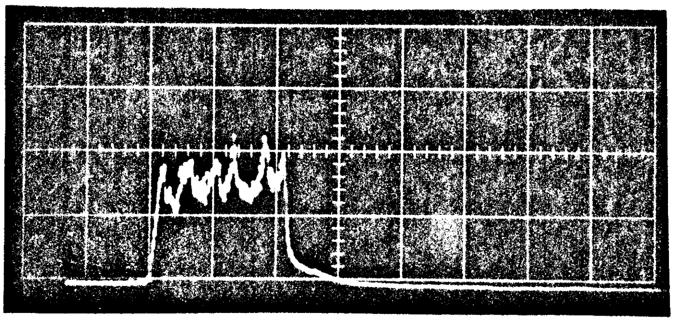
Y. Bacconnier } SPS
M. Cornacchia } SPS

M. Crowley-Milling
B. de Raad
P. Faugeras
W. Middelkoop
G. Shroeder
E. Wilson
C. Zettler
} SPS

MD 13/5/76 Multipulsing Tests

Circulating beam intensity $\simeq$ $8{,}5 \cdot 10^{12}$

Ejection 10 GeV/c

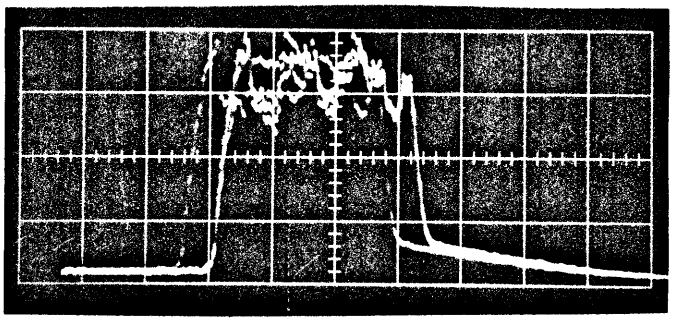


5T Continuous Transfer

5 μs/div.

Ejected beam $7{,}5 \cdot 10^{12}$

Efficiency 93%

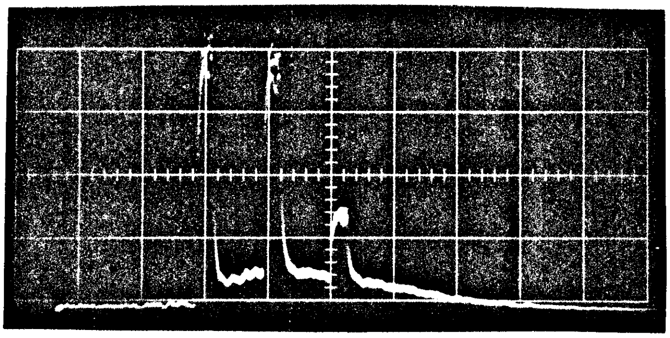


3T Continuous Transfer

2 μs/div

Ejected beam $8{,}4 \cdot 10^{12}$

Efficiency 94%.

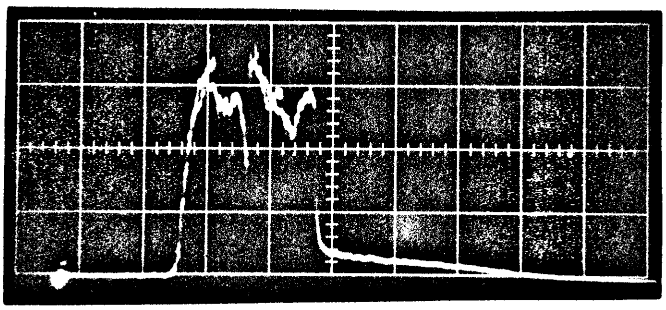


2T Continuous Transfer

2 μs/div

1 Booster Ring only.

Efficiency (beam ejected on first two turns only) 80%



2T Mixed Transfer

2 μs/div

Ejected beam $8{,}0 \cdot 10^{12}$

Efficiency 89%

FIG. 1.

Fig. 2

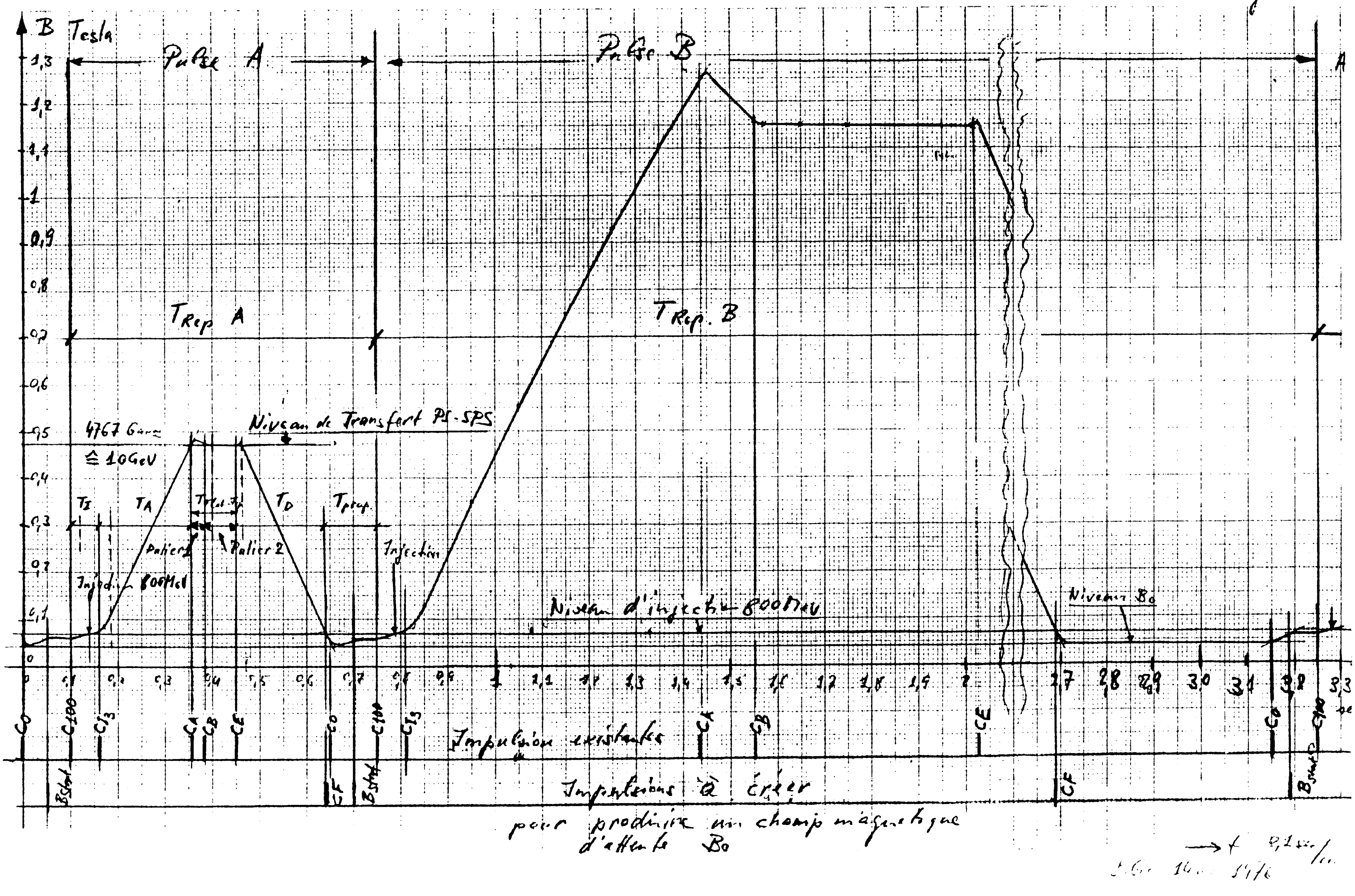
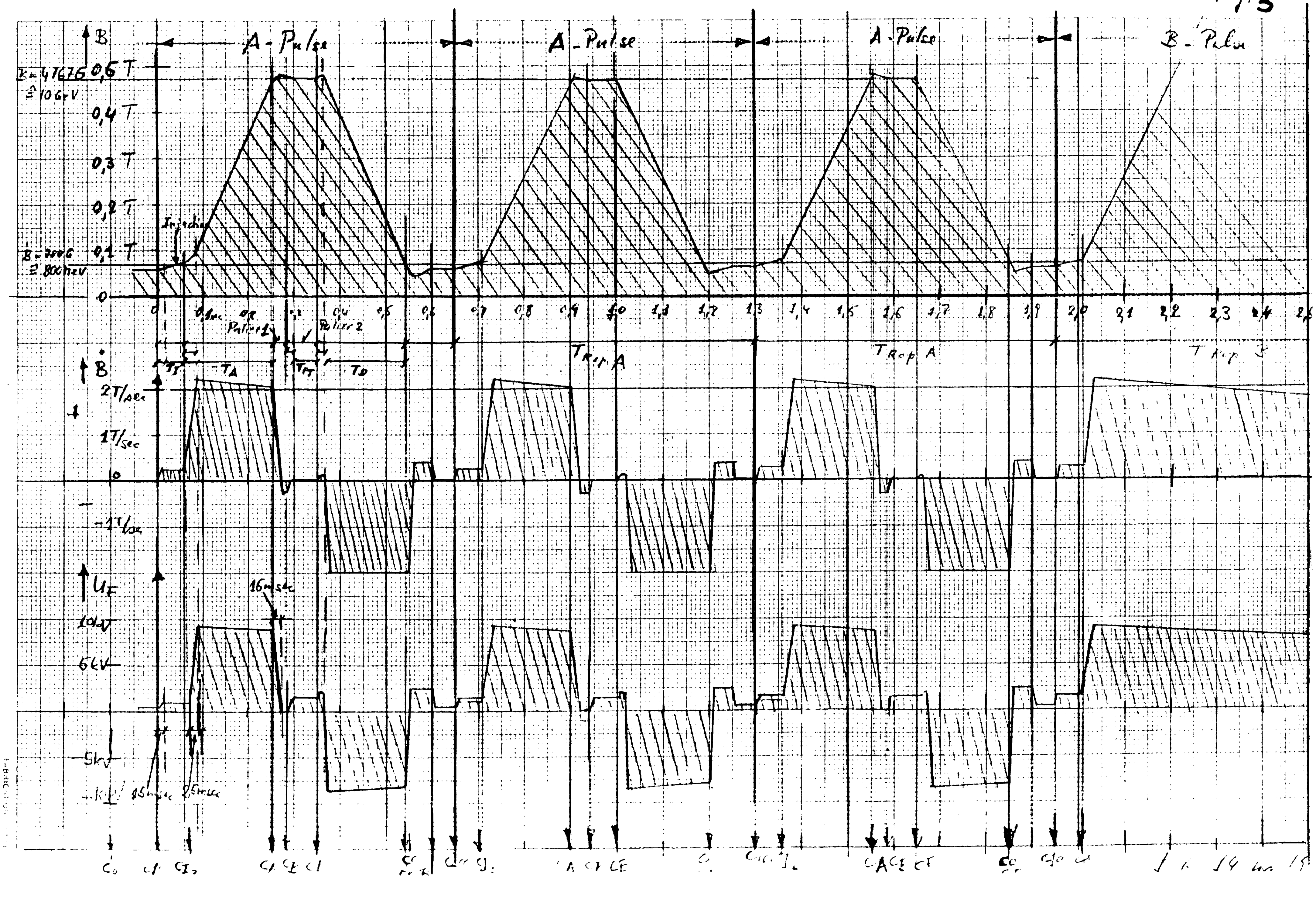

B Tesla
Pulse A
Pulse B
T Rep A
T Rep. B
4767 Gauss
≙ 10 GeV
Niveau de Transfert PS-SPS
Niveau d'injection 800 MeV
Niveau B0
Injection
Palier 1
Palier 2
Impulsions existantes
Impulsions à créer
pour produire un champ magnétique d'attente B0

Fig. 3


A - Pulse
A - Pulse
A - Pulse
B - Pulse
B
0,5 T
0,4 T
0,3 T
0,2 T
0,1 T
0
Injection
T Rep A
T Rep A
2T/sec
1T/sec
-1T/sec
16 msec
10 kV
5 kV
-5 kV
CA CE CI
CA CE CE
CA CE CT