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SIMULTANEOUS SLOW RESONANT EXTRACTIONS FROM THE SPS WITH HORIZONTAL TUNE-SPLIT

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Summary

With the upgrading of the West experimental area it became necessary to extract protons at 450 GeV/c simultaneously towards two experimental zones. However, the corresponding extraction systems are at locations which, when the normal periodicity is maintained, would not allow this procedure. During the time of extraction, the horizontal tune has therefore to be split unequally between two halves of the machine circumference such that the betatron phase difference between the electrostatic septa of the two extraction systems becomes a multiple of 2π. The separatrix then being the same at both septa entrances, the sharing ratio can easily be adjusted by changing the radial position of the circulating beam relative to the first septum with a compensated bump.

Introduction

In fixed target physics mode, the SPS can send slow ejected proton beams by third-integer resonant extraction towards two experimental areas: the West area (W) and the North area (N). Each area has its own independent extraction system consisting of an extraction channel, a horizontal and a vertical bumper system to control the closed orbit at this channel and a set of extraction multipoles which drive the resonance. These multipoles are distributed all around the machine whereas the two extraction channels with their corresponding bumper systems are located in the long straight sections (LSS) of sextant 6 (West extraction) and. sextant 2 (North extraction). Each extraction channel contains an electrostatic septum (ZS) followed by a thin (MST) and a thick (MSE) copper septum magnet which bend the extracted protons horizontally away from the machine into the corresponding beam transfer lines (TT60, TT20). These three elements, which are made up of several units each, are located at exactly the same relative positions within the corresponding sextant (superperiod) of the SPS. Both extraction systems are practically identical, except that they are two sextants (one third of the machine circumference) displaced from each other.

Before its upgrading, the West Hall which already existed when the SPS was built, could only accept beams up to 250 GeV/c whereas the North area was supplied with beams of 450 GeV/c. Consequently, the acceleration cycles had two flat-tops: an intermediate flat-top at around 250 GeV/c for slow extraction towards the West area and a final flat-top at 450 GeV/c for slow extraction towards the North area. Typical cycle lengths were in the order of 12 seconds and the duty cycle for a less than 2-sec. extraction to each of the zones was correspondingly poor.

In 1983 the West experimental area was upgraded for proton beam energies up to 450 GeV/c. In order to improve the duty cycle, it then became necessary to extract simultaneously towards both areas. However, unlike at Argonne where two beams were extracted simultaneously from the ZGS already in 1973,[1] the two extraction systems of the SPS are not located diametrically opposite each other. It was therefore necessary to adjust the phase between the two extraction channels by splitting the horizontal tune of the machine.

Description of the extraction process

Ordinary slow resonant extraction

Resonant extractions from the SPS have been described previously.[2,3] The mechanism of a slow third-integer resonant extraction towards only one of the experimental areas (W or N) can briefly be summarized as follows:

A set of 3 to 5 suitably located sextupoles are excited to create a stable area in the radial phase space which is somewhat larger than the one occupied by the beam. Subsequently the currents in the main machine quadrupoles (QF, QD) are changed such that the horizontal tune is gradually increased towards the resonance value $\nu_H = 26\ ^2/_3$. This causes the stable phase space area to shrink to zero. Protons with phase space coordinates outside the stable region move away from it along the outward going separatrices until they enter into the field of the electrostatic septum ZS which deflects them into the extraction channel. Since the septa are positioned outside the injection aperture, the horizontal closed orbit must be brought near to them such that its radial distance from the ZS corresponds to the desired horizontal size of the extracted beam, and assuring that the copper septa fit well into the gap between circulating and extracted beam. In order to avoid vertical beam losses at the septa, the vertical closed orbit at the extraction channel is centred during extraction. The spill-out is controlled by a servo-quadrupole acting on the ν-value of the beam in a way which is proportional to the error between a reference and the spill signal as measured by a secondary emission monitor.

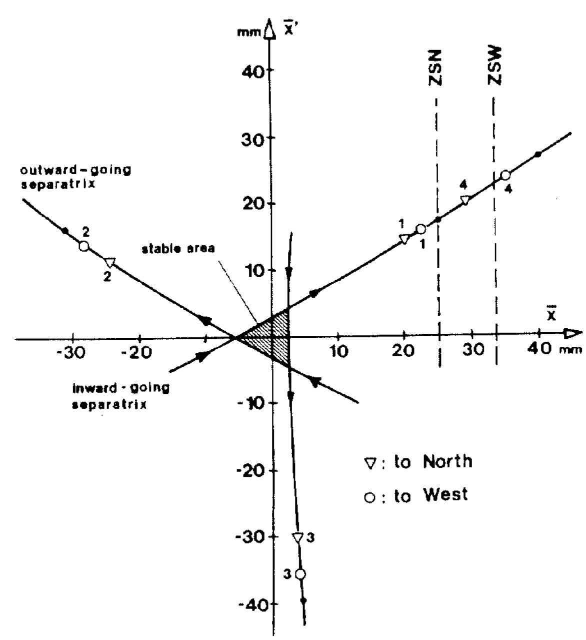

Fig. 1 - Normalized phase space locations of particles at the entrances of the ZS's during the last 3 turns before extraction.

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Simultaneous slow resonant extraction

When maintaining the normal periodicity in the SPS, the separatrix at the ZSN would be rotated counter-clockwise by about 40° with respect to the separatrix at the ZSW and would therefore be unsuitable for simultaneous extraction. Consequently the horizontal tune must be split such that the phase difference between ZSW and ZSN becomes an integer multiple of 2π, thus assuring the same phase space orientation of the separatrix at the entrances of both septa (Fig. 1). In the SPS this is achieved by dividing the set of F-quadrupoles into 2 halves (QF1, QF2) and supplying them with slightly different currents (Fig. 2). This permits the adjustment of the horizontal phase advance in the half containing the two extraction channels to 13.5 betatron wavelengths while keeping the global tunes ν_H and ν_V unchanged. In this way the condition for a phase difference of 9 wavelengths between ZSW and ZSN is satisfied. In addition, to keep the machine linear between the two septa, no sextupoles for driving the resonance are used in this part of the machine.

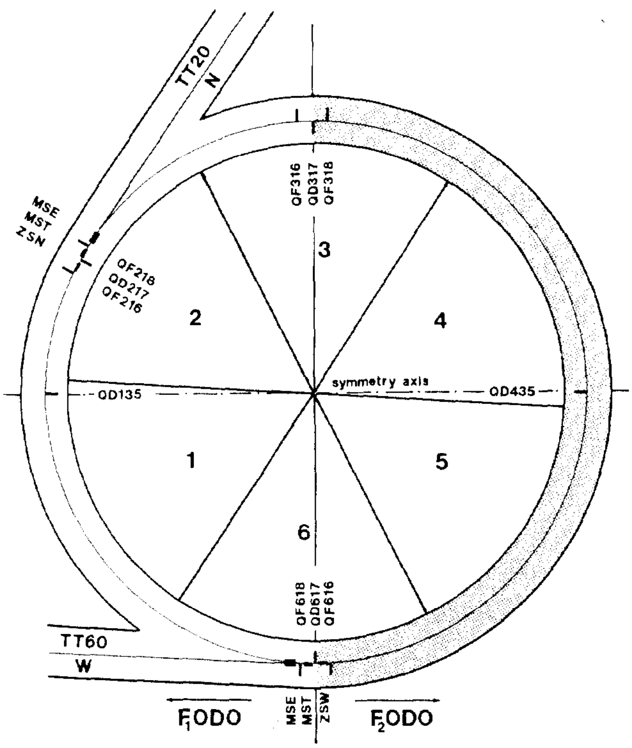

Fig. 2 - Layout of SPS with split horizontal tune

The relative amount of beam being extracted into the two zones (sharing ratio) is determined by the positions of the septa with respect to the centre of the circulating beam, the trajectory of which can be adjusted independently in each channel with the corresponding bumper system. Fig. 1 shows the phase space locations at both ZS's of two particles during their last three revolutions before being extracted towards either the West or the North area. The radial beam position at the ZSN, which defines the maximum horizontal size of the extracted beams, is usually fixed, whereas the position at the ZSW is varied according to the desired sharing ratio.

This means that the particle density at the ZSN, and therefore the extraction losses, are proportional to the sum of the extracted beam intensities towards both zones and independent of the sharing ratio. The proton density varies little over most of the range of possible positions of the ZSW, so that the beam losses at this septum are comparable to those at the ZSN, unless the fraction of beam extracted towards the West area is very small. As a consequence, the total beam losses in both extraction channels are almost double the losses resulting from two subsequent extractions of the same intensities.

Modification of the QF-power supply

The power supply for the focussing quadrupoles (SQF) is located in the auxiliary building BA3 and was originally built with two 12-phase transformer and thyristor sets connected in series, and one ripple filter (Fig. 3a). The simplest solution for the tune splitting was to divide the existing power part into two separate systems, using the existing ripple filter for one and supplying a new filter for the other (Fig. 3b). A small cable (200 A peak) for carrying the current difference between the two halves of the SPS had to be installed between LSS3 and LSS6.

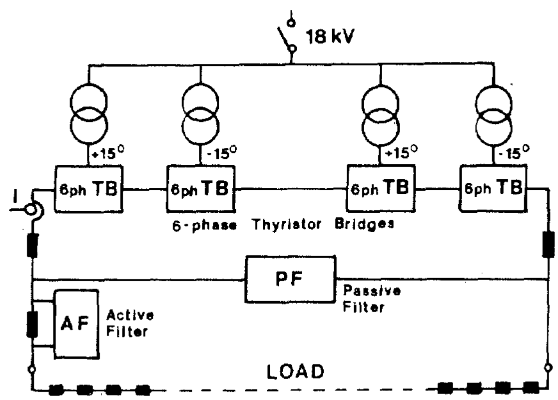

Fig. 3a - Original SQF Power Supply

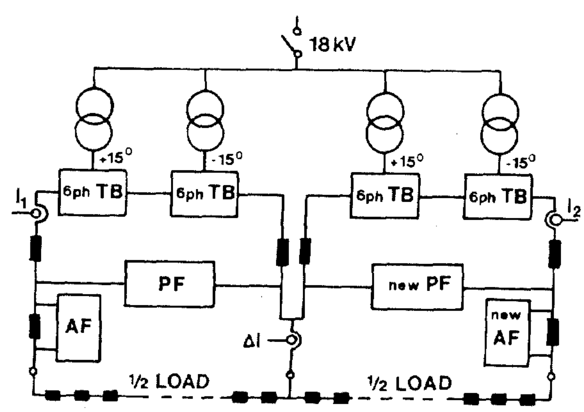

Fig. 3b - Modified SQF Power Supply

Fig. 4 shows the block diagram of the regulation system. Each 12-phase set is controlled by its own current regulator. The basic reference is generated every 30 ms by the power-supply computer and drives each current at the same level (~ 2150 A at 450 GeV/c). The magnetic characteristics (hysteresis, saturation, etc) of the quadrupoles are taken into account. When needed, an auxiliary reference is generated and added to the basic reference of one system while it is subtracted from the other. This solution requires precise and stable devices for the current

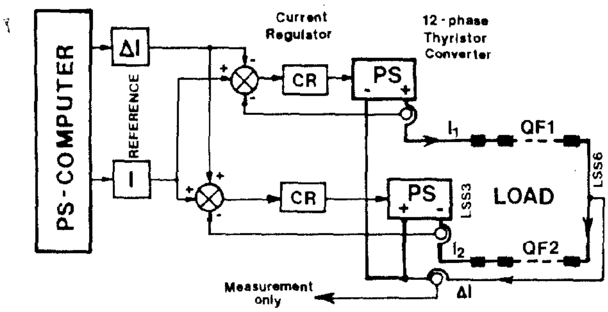

Fig. 4 - Current Regulation for Tune-Split

measurement and comparison resistors which drift less than 10 ppm per day. The current lag is precalculated and corrected for on the reference. The dynamic behaviour must be controlled very carefully: When a new cycle is started, the dynamic errors are measured and the current tables are corrected by a digital loop, thus eliminating all errors other than measurement errors. The settling time for ΔI (~ 65 A at 450 GeV/c) is in the order of 240 ms.

Operational Aspects

Since the magnetic properties of the main machine quadrupoles are well known, it is possible to set up the acceleration cycle in a way which guarantees an almost perfect ν_H-split during the flat-top. The extractions are then set up such as to extract the whole beam first towards one and then towards the other zone. This is done by precise adjustment of the position of the beam with respect to the corresponding ZS using the horizontal bumper system. If the phase difference between ZSW and ZSN is correct (= 9 betatron wavelengths), identical beam profiles will be measured in both extraction channels. If this condition is not reached, the quadrupole currents are slightly trimmed until it is satisfied, which is in general achieved after one or two iterations.

Once the tune is accurately split, any desired sharing ratio between the two zones can easily be obtained by appropriate adjustment of the beam positions at the ZS's. The associated bumper and septa currents are linearly interpolated from those which correspond to 100% resp. 0% extraction towards the respective zone. However, since the particle density distribution along the separatrix is not constant, two or three iterations may be necessary to adjust the sharing ratio precisely.

The servo quadrupole which controls the spill-out can receive its feedback signal from either the North or the West spill. Usually one selects the secondary emission monitor in the beam line with the higher extracted intensity in order to obtain a better signal to noise ratio.

All these adjustments (tune splitting, sharing ratio, etc) should be very simple operational procedures. In addition the simultaneous slow extraction has often to be compatible with other types of extractions through the same physical channel (e.g. fast or fast resonant extraction towards the neutrino experiments). This required new, flexible software to be developped. The reference waveforms for the currents of the extraction elements are generated automatically from a database which contains all characteristics of the acceleration cycle (chronology and energies of extractions, timings, etc), from precalculated bumper and multipole strengths corresponding to optimum beam trajectories and from measured closed orbit errors at the extraction channels. All these data are handled separately by appropriate file systems such that the current waveforms can easily be readapted to any given new situation.

Further observations and conclusions

Splitting of the horizontal tune destroyes the 108-fold periodicity of the beam envelope function β which is imposed by the SPS-lattice. However, since the currents in the two sets of F-quadrupoles are only slightly different from each other, the resulting perturbation of the original β-function is very small and has almost no effect on the phases at the locations of the sextupoles used for chromaticity correction. Since the fundamental of β_V is much weaker than its 108th harmonic, it contributes only to a slight beating of about ±2% with respect to the original β_V. Because of the special value (multiple of π) of the horizontal phase shift in one half of the machine, the β_H is fully periodic between QD317 and QD617 (54 periods) whereas the half including the two extraction channels has 27 periods, each extending over 2 original periods.

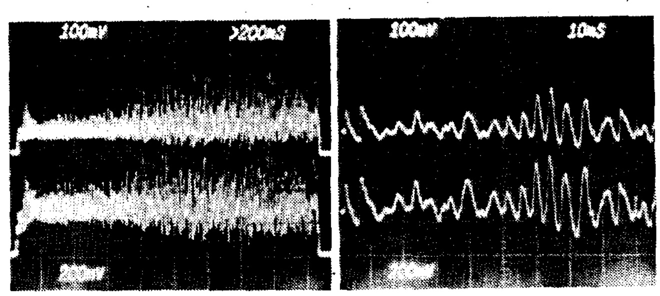

Fig. 5 - Spills of simultaneous slow resonant extractions towards two areas.
Upper trace: Spill to West area (35%)
Lower trace: Spill to North area (65%)

Simultaneous slow resonant extraction towards two experimental areas has been working very successfully for almost 2 years. The maximum total intensities extracted to both zones during about 2.5 sec. were in the order of $2 \cdot 10^{13}$ ppp. The spills in both zones have exactly the same structure regardless of the sharing ratio (Fig. 5). Any desired sharing ratio can easily be adjusted and stable extractions achieved over practically the full range from 0% to 100%.

References

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