Fermilab

12 BATCH COALESCING STUDIES

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Purpose:

The purpose of the study was to identify and correct the problems in the 12 batch coalescing. The final goal is to be able to coalesce 12 booster batches of 11 bunches each into 12 bunches spaced at 21 buckets apart with an average intensity of 200 E9 ppb.

Beam loading:

The main problem encountered during the multibatch coalescing tests was beam loading. During snap coalescing the rf voltage is snapped down from about 500 kV to about 50 kV in about 1 msec, and the bunch is allowed to rotate for a quarter of a period in order to achieve a small $\Delta p/p$. This rotation is relatively fast , requiring only about 16 msec, and has the advantage of preventing instabilities by requiring a very fast growth rate. On the other hand it has the disadvantage that the rf cavity mechanical short rods are not fast enough to be inserted during the 16 msec rotation time. At high beam intensities and a large number of bunches this leaves a large beam induced voltage in the rf cavities that can destroy the controlled $\Delta p/p$. reduction.

The beam loading voltage Δv , generated by a single narrow proton bunch passing through a MR cavity is given by:

$$\Delta v = \omega \frac{R}{Q} \Delta q$$

where $\omega = 2\pi \times f_{rf}$, R is the cavity shunt impedance, Q the unloaded rf cavity Q (R/Q=100 for the MR cavities), and Δq is the charge of the bunch. During the current collider run we have accelerated in MR bunches with $\Delta q = 3.5 \times 10^{10}$ppb. In this case the above equation gives $\Delta v = 187$ volts/cavity-bunch. For a train of 132 proton bunches (12 times 11 bunches with 21 bucket separation) the incremental voltages, Δv, from each bunch must be summed over all bunches to obtain the final beam loading voltage V in each cavity. Since the Q of the cavities at 150 GeV is very large (4500-5000), the cavity voltage does not decay appreciably during a single passage of the 12 batches so that we can assume that:

$$V = \sum_{i} \Delta v_i$$

With the further assumption that all the bunches have the same charge the last bunch going through the cavity will see a beam loading voltage 132 times the voltage of the first bunch i.e. 24.7 KV. Since there are a total of 18 cavities the total voltage difference seen by the first and the last bunches is 18x24.7 kV =445 kV.

Beam loading compensation:

Most of the time of our study was spend applying and understanding the beam loading compensation during coalescing. To compensate for beam loading in the RF cavities during snap coalescing we had to modify the existing coalescing procedure. Instead of shutting off the 16 RF cavities during the first rotation, we left them on and paraphrased two sets of cavities (1-9, and 10-18) to about 86 degrees difference so that the vector sum is equal to the 50-60 kV required for the rotation. We then added another component proportional to the 53 MHz component of the beam current and opposite in phase to the beam induced voltage to the rf drive signal to the 16 paraphrased cavities (2-9, 10, 12-18). That signal was timed in so that it was only applied during the time the beam was traversing the cavities, i.e. for 4.6 μsec in the case of 12 batches.

It was clear from the early part of our studies that even when we compensated the first rotation beam loading was still a problem. We found out that even when we tried to coalesce 6 batches with medium intensity the last two batches were coalesced in the wrong bucket (a bucket earlier). This was due to the beam loading voltage in the cavities after we turned the 53 MHz rf off at the beginning of the 2.5 MHz rotation. The beam loading voltage was rebunching and decelerating the bunches in the end batches resulting in a less efficient 2.5 MHz rotation, and coalescing in an earlier bucket. This problem was solved by keeping the 53 MHz rf voltage and the beam loading compensation on for the first 20 msec of the 2.5 MHz rotation. Instead of turning the stations off at the end of the first rotation, we paraphrased further to 90 degrees for a total voltage of 2-3 KV, kept them on for 20 msec, and then turned them off. With this correction we were able to coalesce 12 batches with 1×10^{12}

particles with a coalescing efficiency of 65% and an average coalesced intensity of 55×10^9 ppb.

Another problem that showed up at higher beam intensities and higher compensation levels , especially with the compensation staying on for longer times, was that the average value of the rf sum was getting higher (almost a factor of two) and was fluctuating both during the first rotation and during the 2.5 MHz rotation when the 53 MHz rf was on. This problem was preventing us from reducing the $\Delta p/p$ during the first rotation resulting in low coalescing efficiency. With an intensity of 2×10^{12}p we achieved an average coalesced intensity of 90×10^9 ppb corresponding to an average coalescing efficiency of 56%.

At the end of our studies we found that the rf sum problem was caused by the cavity loops trying to tune the cavities in such way that the gap voltage be in phase with the rf generator current. To prevent the cavities from tuning while the compensation is on, we must hold the stations errors just before the paraphrasing starts and track the errors again when we turn the stations on for recapture.

Conclusions:

A method of beam loading compensation was successfully implemented during snap coalescing in order to be able to coalesce 12 batches of 11 bunches at the same time. Most of the problems are understood and solved and more tuning is needed with higher intensities, since so far we managed to achieve only about 65% of the required beam intensity at 150 Gev before coalescing.