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EXPERIMENTAL VERIFICATION OF THE Q-JUMP METHOD FOR PASSING TRANSITION WITH DENSE BEAMS

by

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The Disease

The following effects are observed in the CERN Protron Synchrotron when crossing transition [1] :

1. Bunch length oscillations are excited.
2. The average (or equilibrium) bunch length is increased.

Both phenomena disappear when the intensity is reduced.

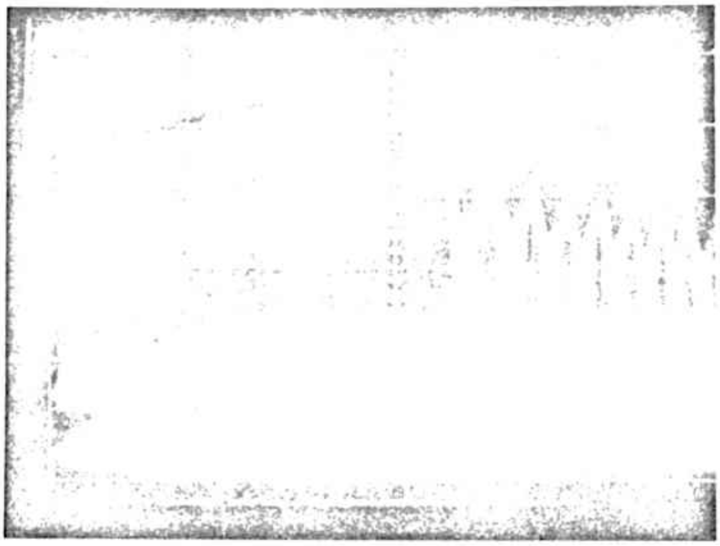

Fig. 1

Envelope of pick-up signal (≈ inverse of bunch length)
The dash on the bottom line marks the RF switching point
Intensity : 1.45 x 10^{12} p/p
RF phase switch : transition + 1 ms
5 ms/cm →
No Q-jump

These effects will be very harmful for the Intersecting Storage Rings under construction, as the interaction rate will be proportional to the square of the phase-space density, that is, to the fourth power of the bunch length.

As CERN is building a Booster for the Proton Synchrotron to increase the intensity by a factor 10, we expect these effects to be more pronounced in the future; perhaps the blow-up will be so large that particles are lost out of the RF bucket.

Similar effects will also be troublesome in the European 300 GeV machine, in the booster as well as in the main ring [2] . The same is true for the NAL machine [3] .

The Diagnosis

One expects bunch length oscillations even in a model in which longitudinal space-charge forces are assumed to be linear since a mismatch is unavoidable when the non-adiabatic region around transition is crossed.

In reality space-charge forces are non-linear and transition is not crossed simultaneously by all particles since there is a Q spread in the bunch due to the influence of transverse space charge forces. The increase in average bunch length is thought to be caused by both these mechanisms.

The Cure

As the energy of the beam approaches transition the horizontal Q, and hence γ_{tr}, is rapidly reduced by means of a set of quadrupoles. This is equivalent to passing transition more rapidly so that space charge effects are alleviated.

Other cures [1] for space-charge effects at transition have been discussed, but the Q-jump method is the only one known to us with cures the bunch distortion due to a γ_{tr} -spread as well as longitudinal space-charge effects [2] .

The Q-jump Pulser

The circuit consists essentially of two capacitors between which the inductive load (quadrupoles) is switched [2], [5] . Fig. 2 illustrates its working principle and the idealized current waveform.

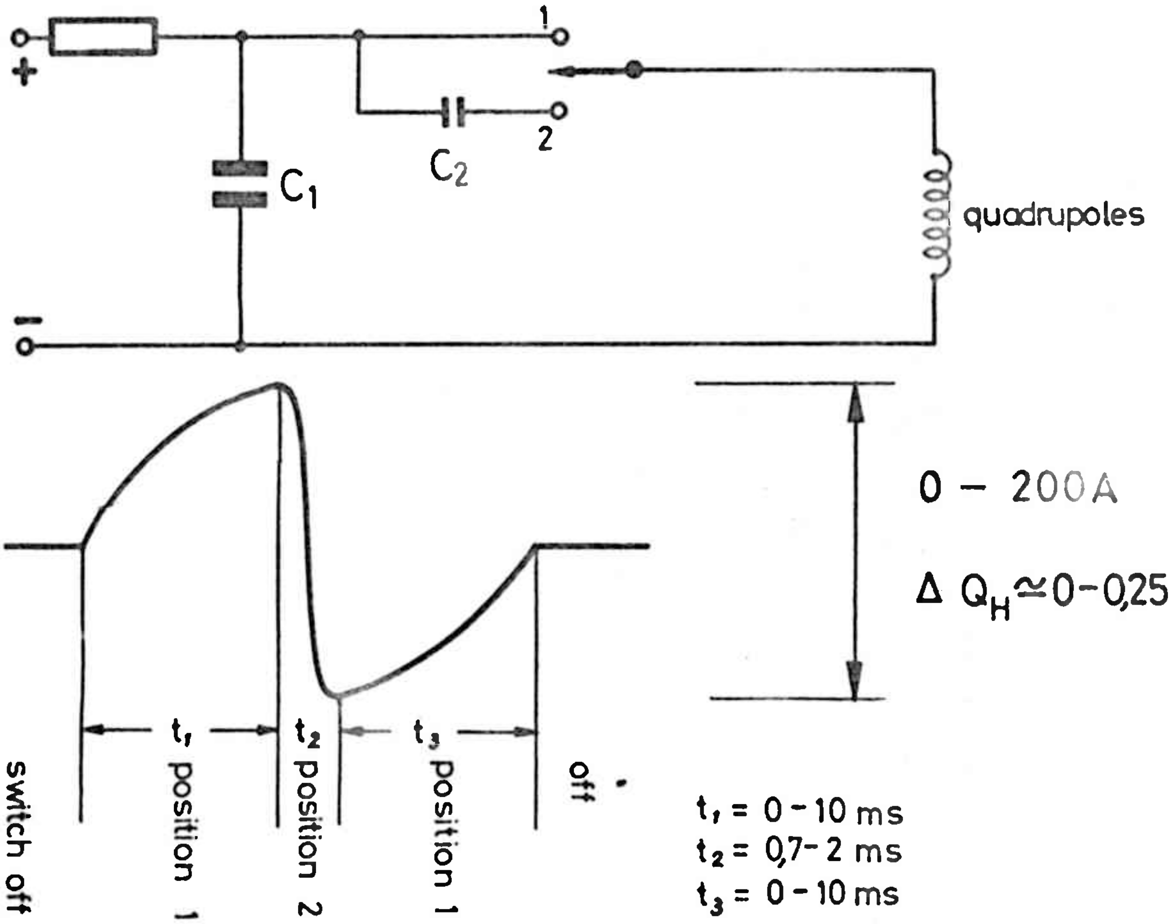

Fig. 2

Circuit to generate the Q-jump current waveform. At the beginning the switch is put in position 1 and C_1 discharges sinusoidally through the quadrupoles. When the current reaches its maximum the switch goes to position 2 and the current is rapidly inverted, C_2 being much smaller than C_1 ($C_2 \approx \frac{1}{100} C_1$). Then the switch returns to 1 and the current goes slowly to zero.

The switching is done with two diodes and two thyristors.

The Q-jump pulser occupies a volume of approximately 40 litres and weighs less than 10 kilograms.

Experimental Results at the CPS

With a Q-decrease $\Delta Q_H \gtrsim 0.2$ in a time $t \lesssim 1$ msec transition is crossed about 8 times faster than without Q-jump. Both the oscillations and the increase in average bunch length disappeared almost completely.

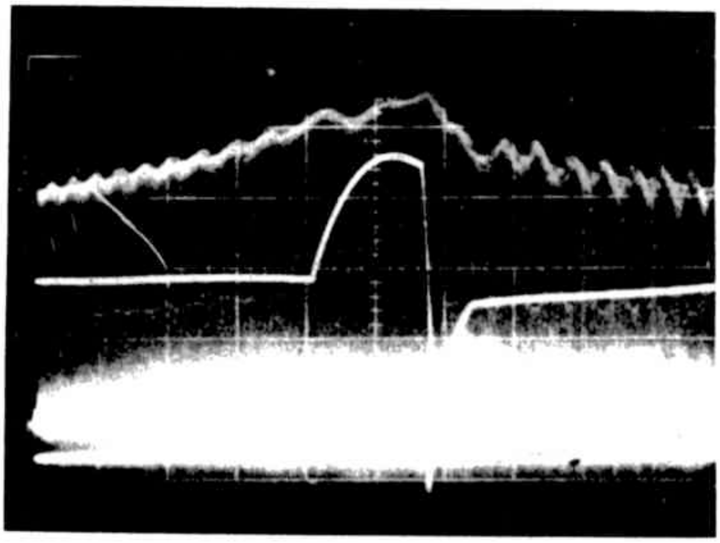

Fig. 3

Envelope of pick-up signal (≈ inverse of bunch length)
The dash on the bottom line marks the switching point
The current waveform is superimposed
5 ms/cm →
Intensity : 1.45×10^{12} p/p
RF phase switch : transition * + 4 ms
Q-jump : 150 A peak-to-peak, corresponding to $\Delta Q = 0.19$
Start of the fast descending branch : transition * + 3.5 ms

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[*] Transition point without Q-jump. With Q-jump transition is crossed 3.7 ms later.

The optimum timing of the phase switch and of the Q-jump was found to be in good agreement with calculations. The necessary speed of the Q-jump itself (i.e. of the fast descending branch of the waveform) also agreed with calculations.

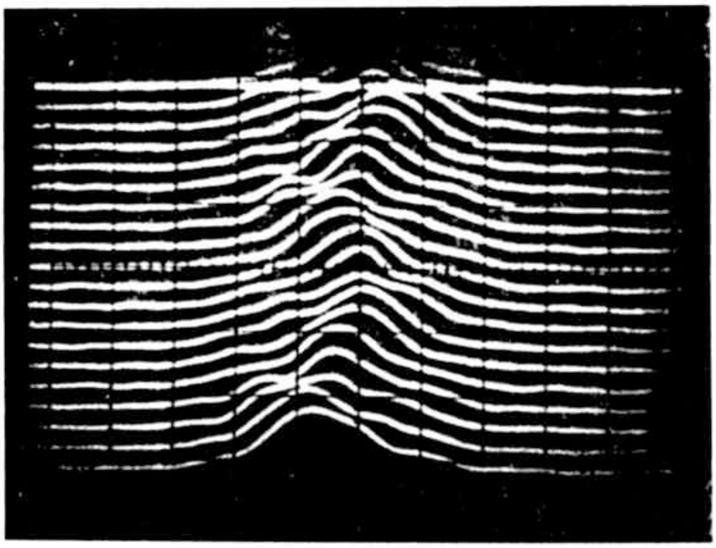

Fig. 4

Mountain-range display of the pick-up signal at 18 GeV/c
5 ns/cm → , 1 ms/cm ↑
The same bunch is shown once in 150 revolutions
Intensity : 1.29×10^{12} p/p
No Q-jump
Bunch length roughly 20 ns

The improvement in bunch length just after transition was retained at top energy, but not fully. The very short bunches were more liable to instabilities later in the cycle than the normal longer bunches.

A description of the computations, and more details of the experiment, will appear in future reports.

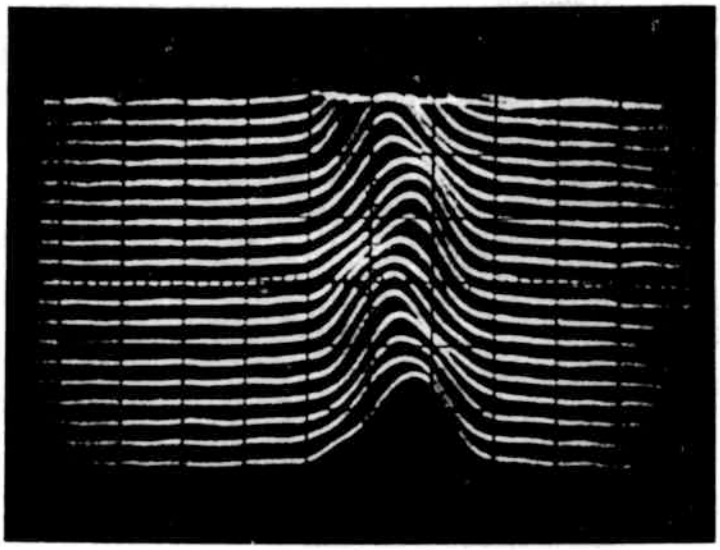

Fig. 5

Mountain-range display of the pick-up signal at 18 GeV/c
5 ns/cm →, 1 ms/cm ↑
The same bunch is shown once in 150 revolutions
Intensity : 1.46×10^{12} p/p
Optimized Q-jump
Bunch length roughly 13 ns

Acknowledgement

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References

[1] A. Sørenssen : Longitudinal Space-Charge Forces at Transition. Proc. of the 6th Int. Conf. on High Energy Accelerators, p. 474.

[2] W. Hardt and D. Möhl : 300 GeV Booster Design Note No.5 : Q-Jump at Transition. ISR-300/GS/69-16.

[3] E. D. Courant : Longitudinal Space-Charge Effects at Transition in NAL Booster and Main Ring. FN-187/0300.

[4] H. H. Umstätter : Private Communication.

[5] L. Thorndahl : Q-jump Pulser for Transition Experiments. ISR-300/LIN/69-38.