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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 intensity-dependant effects are observed in the CERN Proton 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.

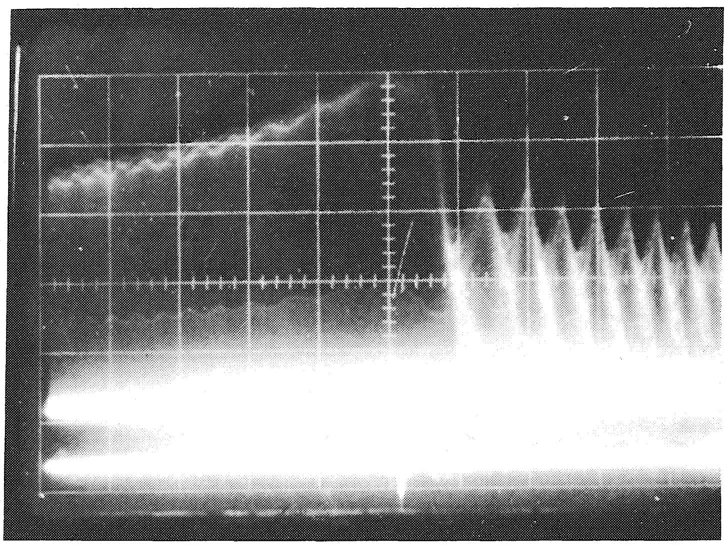

Fig. 1

Envelope of pick-up signal (≈ inverse of bunch length)
The dash on the bottom line marks the RF switching point
Intensity : 1.45×10^{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

The bunch length oscillations are caused by the linear part of the longitudinal space-charge forces and are apparently well understood theoretically. The increase in average bunch length is less well understood, but two mechanisms have been proposed : non-linear longitudinal space-charge forces, and a spread in Q_H or γ_{tr} by transverse space-charge forces. Q_H and thereby γ_{tr} will be smaller for a particle in the middle of the bunch than for a particle at one of the ends of the bunch. Therefore, different particles will cross transition at different times [4]. These mechanisms may both play a rôle.

The Cure

If we pass faster through the transition region, all these mechanisms will be less pronounced. Now, it is not so easy to accelerate faster than we already do. Therefore, we do something which is equivalent, but easier to achieve : By means of a set of quadrupoles we rapidly reduce the horizontal focusing - and thereby γ_{tr} - just as the beam is passing the transition energy.

Other cures [1] for space-charge effects at transition have been discussed, but the Q-jump method is the only one known by us which 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.

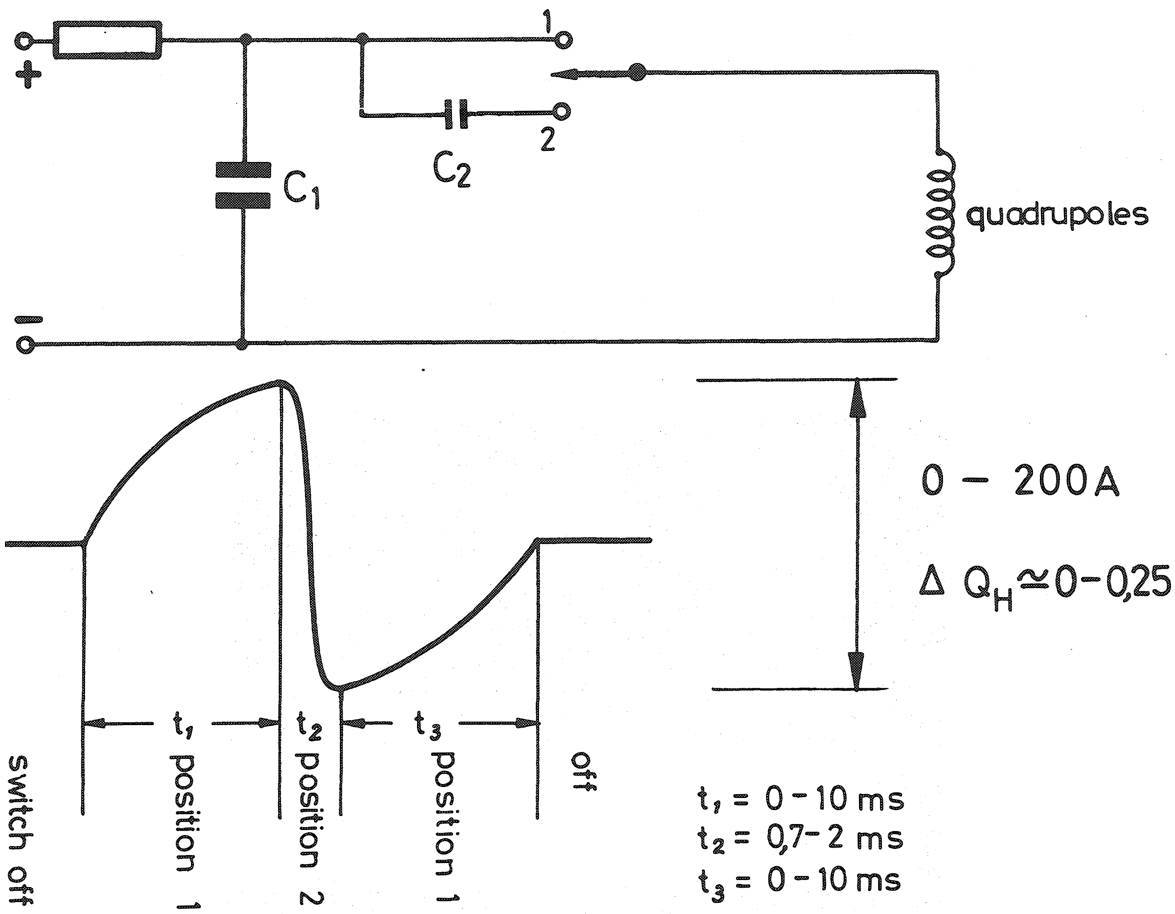

Fig. 2

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.

The Experiment

With a Q-decrease $\Delta Q_H \gtrsim 0.2$ in a time $t \lesssim 1$ msec, both the oscillations and the increase in average bunch length disappeared almost completely.

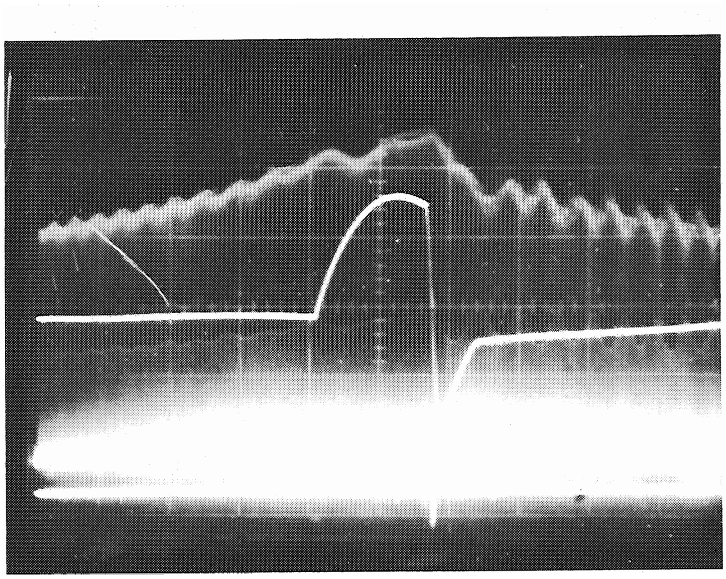

Fig. 3

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 : transtion + 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

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.

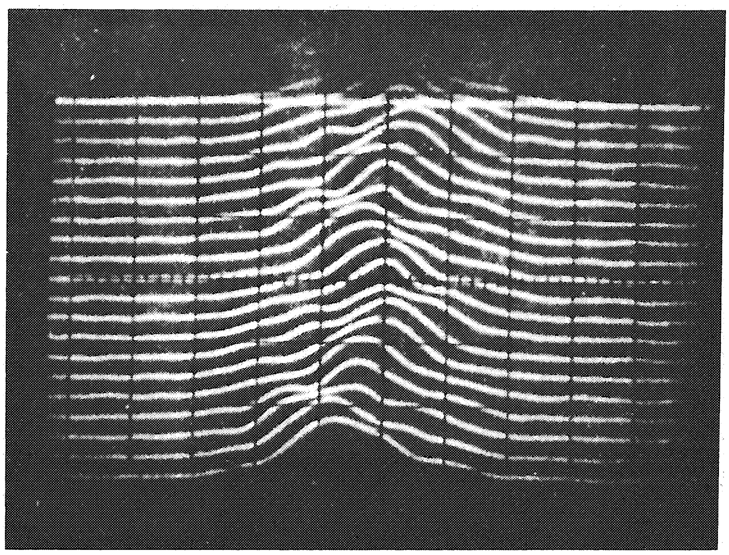

Fig. 4

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 a future report.

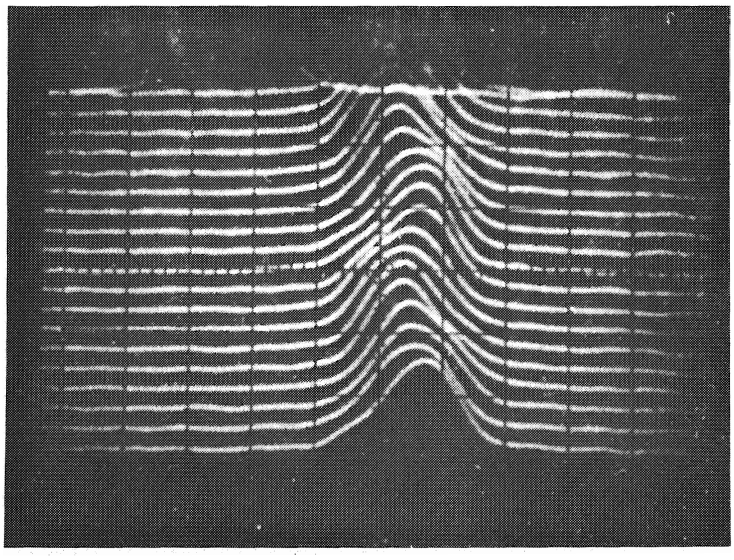

Fig. 5

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

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