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Observation of Longitudinal and Transverse Instabilities in the PS Booster

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Introduction

The growth of both horizontal and vertical coherent oscillations have been observed in the PS Booster at intensities $\sim 3 \times 10^{12}$ particles per ring. A form of longitudinal instability has also been observed. Manifestation of the latter can be seen at intensities as low as 3×10^{11} per ring. The characteristics of these effects were discussed at a meeting on 22nd September 1972[1] and it is the purpose of this report to describe the results presented then as well as subsequent observations, made "parasitically" during normal operation.

Longitudinal Instability

This effect is characterized by the formation of numerous narrow (< 10 nanosec) spikes or depressions in the azimuthial beam density (Photo 1). These first occur some time after injection and the higher the intensity, the sooner they are formed. They were initially observed on 6th June 1972[2] when, with the normal magnet cycle, the beam was caused to bunch itself on the 5th harmonic by the voltage induced on the tuned, but not driven RF cavity. Subsequent observations on an injection flat top as well as the normal magnet cycle and with the cavities detuned, indicate the presence of the 5th harmonic was irrelevant to the appearance of these density variations.

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As time progresses the depth of the spikes increases and their number decreases. However, the width of the remaining depressions tends to become greater (Photo 2). These effects also depend upon intensity. When operating with an injection flat top quite regular density variations are formed though these do not necessarily remain stable throughout the entire $\approx$.6 sec. duration (Photos 3 - 6). The pattern of four gaps appears quite frequently and has been seen at 27 and 270 msec from injection. The spacing is not exactly at the 4th harmonic of the rotation period of 1.67 μsec. Preliminary measurements (at the time when Photo 2 was taken) indicate a small amount of voltage induced on the RF cavity at its zero current resonant frequency which is around 2.45 MHz for ring 4.

It can be seen from these photos that the edge of the depressions are very sharp. The depths of the gap in photo 5 is $\approx$ 17% and values as large as $\approx$ 25% have been seen. Some photos also show slight variations in the shape of the depression from one revolution to the next. Photo 7 was taken at $\approx 5 \times 10^{11}$ injected monoturn and shows how the spikes grow at low intensities, i.e. they appear symmetrically about the signal base line some time after the injected beam has debunched. At 3×10^{11} the formation is delayed until about 1 msec before the beam is lost on the vacuum chamber wall. This effect of symmetrical growth followed by a little additional increase in the gap depth has also been seen at high intensity ($\sim 3 \times 10^{12}$) though here is occurs immediately after the multiturn injection is completed.

The following lines of investigation have been proposed(1):

(a) Continuation of theoretical studies(3)

(b) Detailed study of the evolution of the wide depressions

(c) Relation, if any, of the size of the depressions to beam loss

(d) Relation of the formation of the wide gaps to the RF cavity resonant frequency (when it is not turned to a harmonic of f_o).

Transverse Instability

Coherent horizontal and vertical beam instabilities were first observed on 21st September 1972 with the magnet flat-topped at injection field and with multiturn intensities of from $2 - 4 \times 10^{12}$ particles in each ring. Early vertical blow-up was seen briefly in ring 3 at intensities $> 3 \times 10^{12}$. It occurred in the first 1.5 msec but disappeared before suitable photos could be taken. However, it was present on 30th September at intensities $> 4 \times 10^{12}$ and the normal magnet cycle and will be described later. On 21st September 1972 a fairly consistent horizontal blow-up was observed on ring 4 at intensities of $\simeq 2.4 \times 10^{12}$. Photo 8 shows the growth that started about 5 msec after injection. The e folding time here is $\simeq 7.2$ msec.*) If the intensity dropped to $\simeq 2 \times 10^{12}$ no early growth would appear. Observation of the beam current transformer indicated that loss occurred near the peak of the growth. Normalization of the difference signal for the total beam intensity would give only $\simeq 1.5$ cm peak amplitude for the oscillation. However, it is not necessary that the entire beam takes part in the oscillation.

As long as the intensity remained stable, the instability was quite reproducible and detailed measurements were possible. The initial growth was essentially a pure $n = 5$ mode. However, once the amplitude became large, growth of the $n = 6$ mode was also seen. Mixtures of both modes are then present with apparent beating back and forth between these two modes also taking place. The Q-value was almost exactly 4.67 at this time. It was raised slightly with the intensity dropping to $\simeq 2 \times 10^{12}$. At this level the growth did not occur very frequently, started later ($\simeq 70$ msec from injection), was not as large but was almost always in a pure $n = 6$ mode. At this point, the run was terminated. It should be noted that no growth was seen in ring 3 though it was essentially at the same intensity as ring 4 at this time.

Photo 9 shows a ring 4 vertical difference signal at a higher sensitivity when the injected current was $< 2 \times 10^{12}$. The growth seen here was quite late in the cycle and is apparently non-linear. At times, a late horizontal growth was also observed with both being

*) Computed values (Reich & Schönauer) are $\tau = 5$ msec for $r_{R-CB} = \sqrt{31 \times 66} = 45$ mm and $\tau = 12$ msec for $r_{R-CB} = 66$ mm.

present on other occasions, i.e. one followed by the other. This effect did not last once the multiturn injection was increased to over 2 x 10^{12}. No detailed investigation was possible. The only additional remark that can be made is to note that the longitudinal effect mentioned above was quite marked here (upon the sum signal being lack of beam) early in the flat top and died out before growth appeared. Finally, one can see in Photo 8 that this effect was quite small and essentially symmetrical when consistent early horizontal growth was present.

Photo 10 shows the early vertical instability observed on 30th September 1972. The e folding time here is about .3 msec.*) Growth occurred only when the injected intensity was > 4 x 10^{12} and it was always accompanied by beam loss as can be seen on the current transformer signal on the lower trace. Somewhat larger and smaller growth rates were present on other pulses. The instability starts in the n = 5 mode(Photo 11) and at large amplitude, a longitudinal structure at the rotation frequency developes(Photo 12). After beam loss the n = 6 mode apparently is present along with the longitudinal modulation. The growth of the azimuthal density variations can of course be seen on the sum trace of Photo 11. These were also present when this instability was seen briefly on 21st September 1972, but their nature was not known at the time.

Further investigation will be devoted to the following topics :

(a) The presence of the horizontal growth since it had not yet been taken into consideration at the observed intensities.

(b) The nature of the late non-linear type growth occurring on flat top.

(c) The growth of the longitudinal density variations concurrently with the early vertical growth.

In conclusion it should be noted that at accelerated intensities of up to 1.3 x 10^{12} none of the above effects present any problem to the operation of the PSB.

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*) Computed value τ = 0.5 msec.

References

(1) Those present were : K. Schindl, I. Gumowski, H. Koziol, G. Gelato F. Sacherer, H. Schönauer, D. Zanaschi, K. Reich, E. Raka, G. Nassibian.

(2) I. Gumowski, K.H. Reich, Private Communication.

(3) I. Gumowski, K.H. Reich "Longitudinal Coasting Beam Instability in the PSB" - SI/BR Note/72-8.

Distribution (Restricted)

Participants of the meeting
C. Bovet
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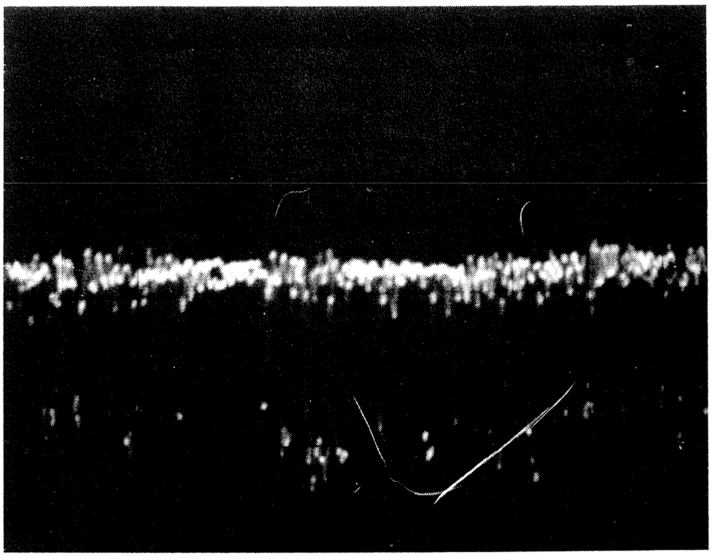

Photo 1 : Wideband PUE at 0.1 μs/cm, 0.1 V/cm, $\approx$ 2.5 msec after injection at $\approx 9 \times 10^{11}$.

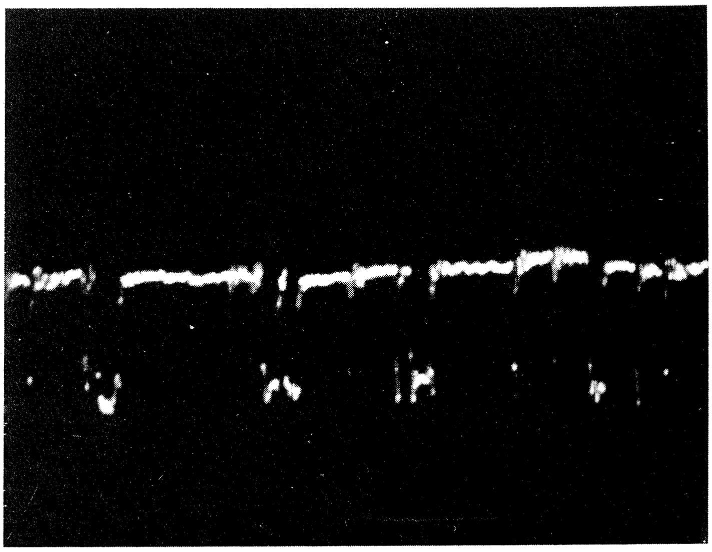

Photo 2 : Wideband PUE 0.2 μs/cm, 0.1 V/cm, $\approx$ 5 msec after injection at $\approx 9 \times 10^{11}$.

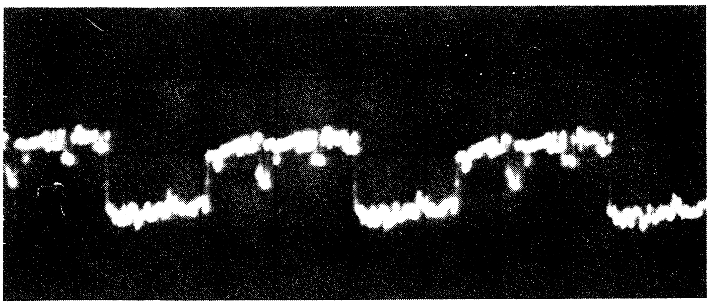

Photo 3 : Wideband PUE at 0.2 V/cm, 0.5 µs/cm $\approx$ 27 msec after injection on flat top; intensity $\approx 3 \times 10^{12}$.

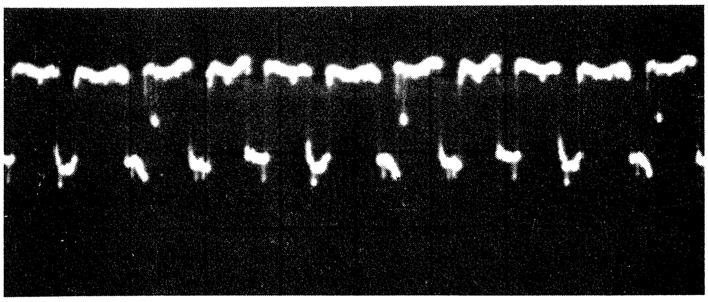

Photo 4 : Wideband PUE at 0.2 V/cm, 0.5 s/cm $\approx$ 27 msec after injection on flat top; intensity $\approx 3 \times 10^{12}$.

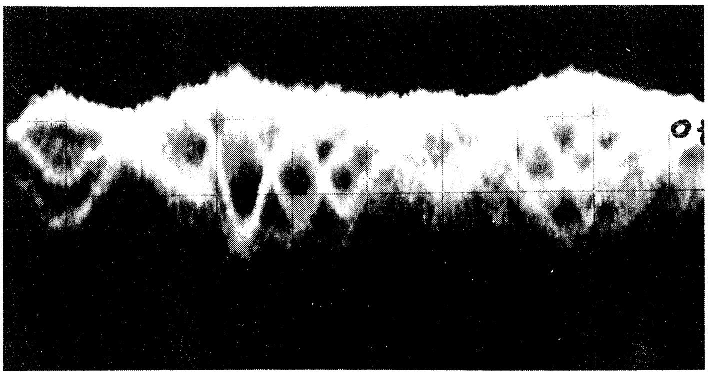

Photo 5 : Wideband PUE at 0.1 V/cm, 50 msec/cm on flat top. Intensity $\approx 3 \times 10^{12}$.

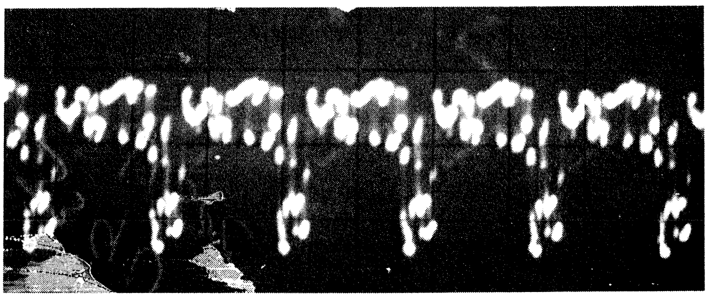

Photo 6 : Wideband PUE at 0.1 V/cm; 1 µs/cm at 270 msec from injection on flat top. Intensity $\approx 3 \times 10^{12}$.

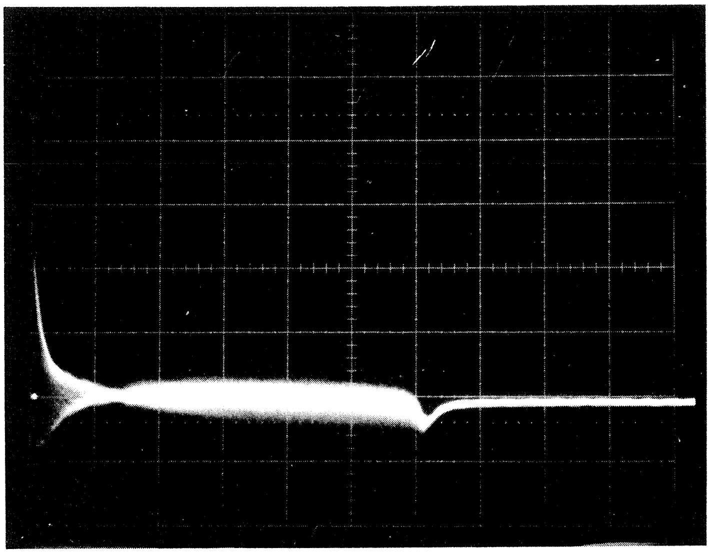

Photo 7 : Fast XFMR at 50 mV/cm, 1 ms/cm $\approx$ 5 x 10^{11} injected in 3/4 of a revolution.

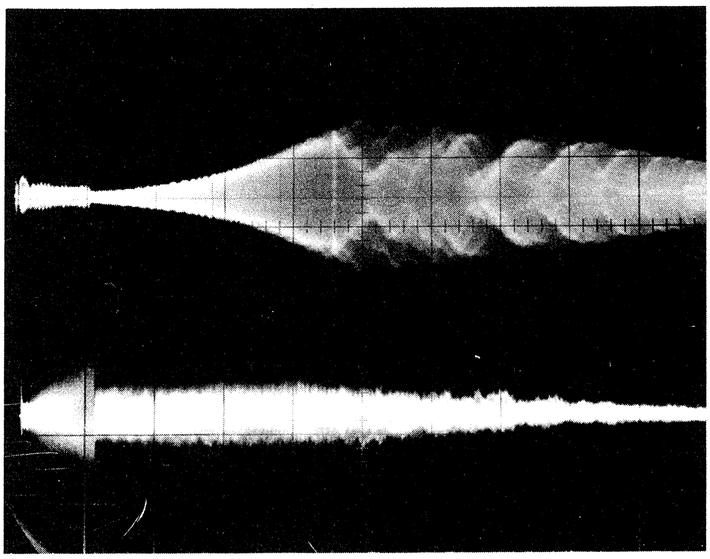

Photo 8 : Horizontal difference and sum at 0.2 V/cm, 5 msec/cm. Intensity $\approx$ 2.4 x 10^{12} on flat top.

Photo 9 : Vertical difference at 0.05 V/cm, sum at 0.2 V/cm, 50 msec/cm. Intensity $\approx 2 \times 10^{12}$ on flat top.

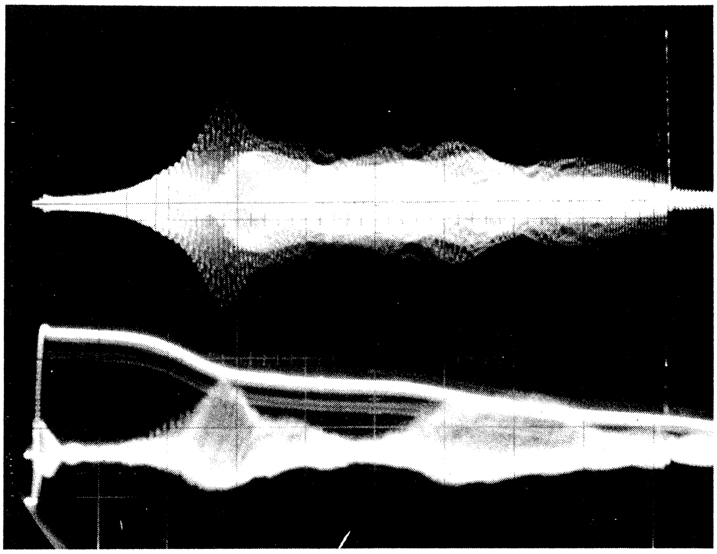

Photo 10 : Vertical difference at 1 V/cm sum at 0.5 V/cm, 0.5 msec/cm. Intensity at $\approx 4.5 \times 10^{12}$.

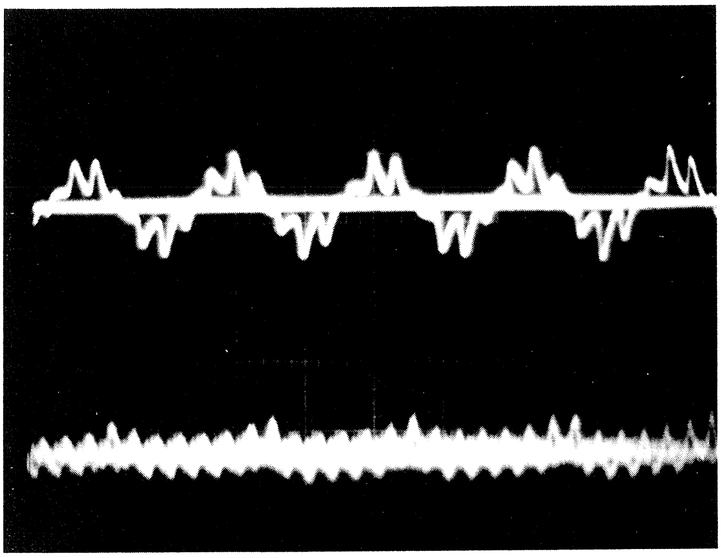

Photo 11 : Vertical difference at 1 V/cm sum at 0.5 V/cm, 5 μs/cm at 1.25 ms from injection. Intensity ∿ 4.3 x 10^{12}.

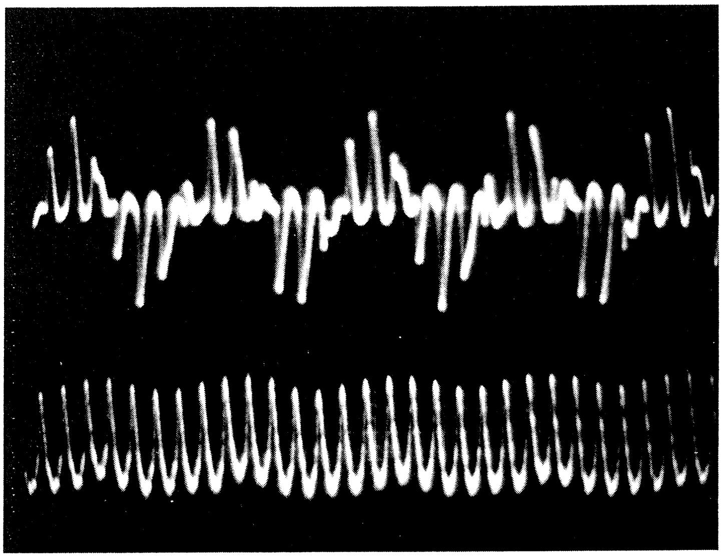

Photo 12 : Vertical difference at 1 V/cm sum at 0.5 V/cm, 5 μs/cm at 1.25 ms from injection. Intensity ∿ 4.3 x 10^{12}.