MEASUREMENTS OF FAST TRANSITION INSTABILITY IN RHIC*

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Abstract

A fast transition instability presents a limiting factor for ion beam intensity in RHIC. Several pieces of evidence show that electron clouds play an important role in establishing the threshold of this instability. In RHIC Runs8 the measurements of the instability, using a button BPM, were done in order to observe details of the instability development on the scale over hundreds and thousands turns. The paper presents and discusses the results of those measurements in time and frequency domains.

INTRODUCTION

During the acceleration the beams of all species used in RHIC, except protons, have to pass the transition energy. Beam conditions near the transition energy, such as shortened bunch length and small synchrotron frequency, are favourable for developing both transverse and longitudinal instabilities. Also, in a beam consisting of many, closely spaced, bunches, the short bunch length leads to the enhancement of the production and accumulation of electron clouds, which in turn may start to affect the beam dynamics.

A so-called gamma-T jump [1] is applied in RHIC to effectively speed up the transition crossing and prevent longitudinal microwave instability and associated longitudinal emittance blow-up.

A single bunch transverse instability was observed and studied in early RHIC runs [2,3]. The instability happened at the level of about $0.5\text{x}10^9$ gold ions per bunch and was stabilized by powering octupole magnets. With a small number of bunches the application of the octupoles allows to increase the single bunch intensity, with no transverse instability seen, at least up to $1.4\text{x}10^9$ ions per bunch.

In the following RHIC runs the number of bunches, circulating in RHIC rings, was increased to 111 bunches in total. In this bunch pattern, the individual bunches are separated by 106 ns distance. The bunch train is ended with a 1 μs abort gap. With a large number of bunches (more than 90) the transverse instability was noted again, even with strong octupole magnets turned on, at the intensity level of $1.1\text{x}10^9$ gold ions per bunch. An enhanced effect of the instability on later bunches in the bunch train was also seen following emittance and intensity measurements for different bunches [4].

Presently the leading explanation for the observed appearance of the transverse instability with a large number of bunches involves the electron cloud, which lowers the instability threshold. Since the electron cloud density grows along the bunch train, the stronger effect of the instability on later bunches the electron cloud can be naturally expected. Enhanced accumulation of the electron cloud near the transition energy followed from several direct and indirect observations [5]. In order to increase the bunch length and reduce the density of the electron cloud, the RF voltage is lowered when accelerating through transition. This helps to increase the instability threshold.

MEASUREMENT OF INSTABILITY CHARACTERISTICS

During RHIC Run-8 dedicated measurements were done to get a better understanding of the instability development in the time and frequency domains, and its dependence on a bunch position in the bunch train. A button BPM was used as the main instrumentation tool to collect data on details of the instability. The button BPM signal was recorded with 0.1 ns resolution. An individual data snapshot included all bunches on one turn. The snapshots were logged, typically, with 50 turns spacing.

The measurements presented in this paper, were done with a gold ion beam having a specific 103 bunch pattern, which contained two small gaps in the bunch train. Thus, the beam effectively consisted of three mini-trains of bunches. Figure 1 demonstrates a one turn snapshot of the button BPM difference signal at the time when the instability happens. It is seen that the instability affects the last parts of the second and third mini-train and is strongest in the last train. A major observed feature is the dependence of the strength of the instability on the bunch position in the train. As result of the instability, the bunch intensity losses escalate towards the tails of the mini-trains Figure 2 shows the ratio of bunch intensities, measured after and before the transition by a Wall Current Monitor.

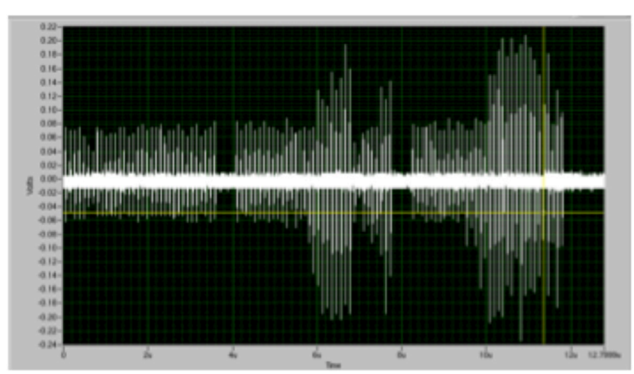

Figure 1: A one turn snapshot of the button BPM difference signal shows the transverse instability affecting bunches at the end of mini-trains.

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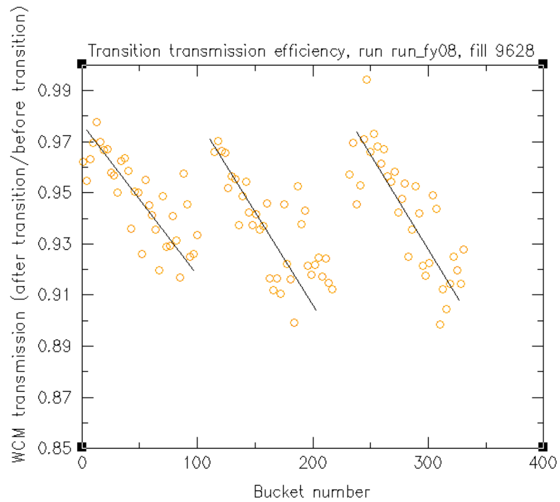

Figure 2: Bunch intensity transmission through the transition in dependence on bunch position in the train.

By disentangling the information present in the difference and sum signals of the button BPM we obtained details of the instability evolution for an individual bunch. Figure 3 shows space pattern of the instability development in time. Each trace presents the mean vertical position measured along the bunch. The time interval between the traces is 4ms. The head of the bunch is on the left side of the plot. Initially the instability develops as the oscillations of the tail of the bunch. But at later times more complicated oscillation patterns develope, with the oscillations propagated to the bunch head. The instability rises up and goes through its evolution on the time scale of few tens of ms. It is faster than the synchrotron period , which becomes as long as 130 ms right before the activation of gamma-T jump. The dynamics of the fast instability, at least at its initial stage, should be similar to the beam break up observed in linear accelerators.

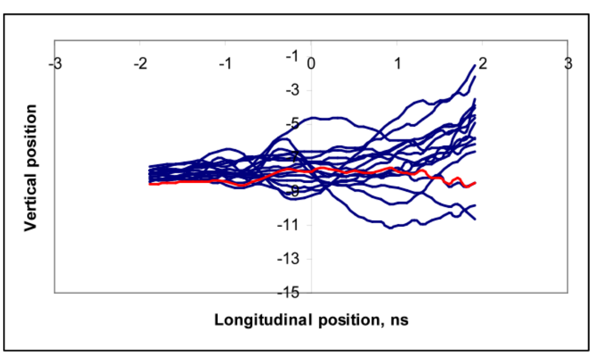

Figure 3: The space pattern of the vertical instability development with time. The vertical axis shows the mean vertical position in arbitrary units.

The evolution of the transverse instability spectrum with time is shown in Figure 4. The case shown in the bottom plot corresponds to the instability measured with 103 bunches, thus in the presence of the electron cloud. As seen from the bottom plot, the instability spectrum makes the evolution from low to high frequency oscillation pattern. The instability growth happens at a frequency of about 300 MHz, but at later stages the spectrum peak gradually shifts to higher and higher frequencies. For the sake of comparisons, we also did a measurement of the instability just with few bunches, circulating in RHIC, so that the electron cloud could not be a factor. The octupoles had to be turned off in order to observe the instability. The top plot in the Figure 4 demonstrates the spectrum of the oscillations measured in this case. The pattern of the oscillation spectrum remains the same during whole time of the instability development, which is quite different from the multi-bunch case shown in the bottom plot.

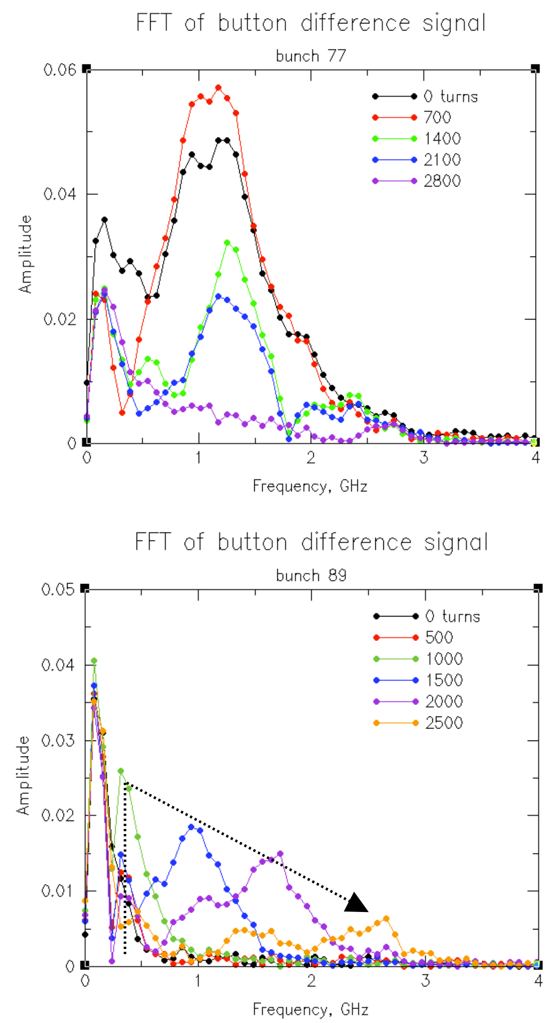

Figure 4: FFT spectrum of button BPM difference signal. Bottom plot: many bunches in the beam, present electron cloud and powered octupole magnets. Top plot: only few bunches in the beam, no electron cloud, octupoles are off.

Having the button BPM data collected for all bunches in the beam we were able to compare the instability development for different bunches. Following results shown in Figure 4, a peak frequency of the button BPM difference signal may be considered as a parameter characterizing the instability development with the time. The peak frequency should be taken at the frequency range above 250 MHz, in order to exclude the part of the signal originating from normal longitudinal profile of the bunch. The Figure 5 presents the development of the instability for several selected bunches in terms of the dependence of the peak frequency on the time. Again, the train of 103 bunches with small gaps was used. In each of three bunch mini-trains we selected 4 bunches, distributed equally along a given mini-train. Zero time on the plots corresponds to the transition crossing. As seen in the Figure 5 later bunches in mini-trains starts to experience the instability at earlier times. Among the bunches located at similar position in mini-trains the instability develops at earlier time in later mini-trains.

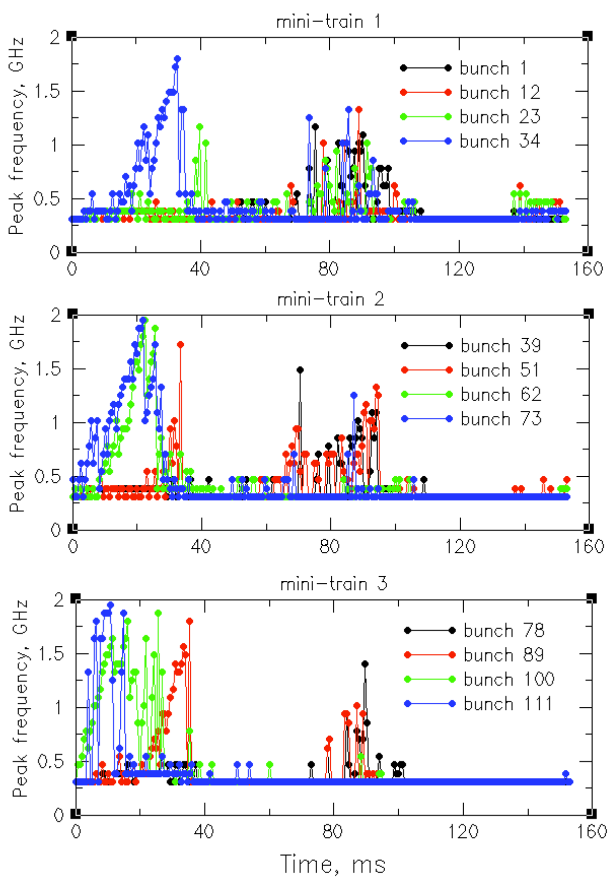

Figure 5: Dependence of the peak frequency of the button BPM difference signal on the time for selected bunches in three mini-trains.

It is interesting to note the re-appearance of the instability in some form at later times. It happens with the time interval (~60ms) consistent with doubled value of the synchrotron frequency. The quadrupole oscillations of longitudinal bunch distribution are excited at the transition crossing. These oscillations lead to larger peak currents which can enhance electron clouds. Later in the Run-8 a feedback against the longitudinal quadrupole oscillations was successfully tested [6].

SUMMARY

The transverse instability at the transition region presents one of the limiting factors for achievable ion beam intensities in RHIC. The measurements of the details of the instability development were done using the button BPM. The instability initially develops as the oscillations of the tail of the bunch. But at later times the longitudinal pattern on the oscillations is shifted to higher frequencies. The instability starts earlier and develops stronger for later bunches in the bunch train.

As the electron cloud is suspected to decrease the instability threshold the remedies against the e-cloud accumulation should also help against the instability. In Run-10, higher ion beam intensities were achieved, as believed in a part due to a beam scrubbing done in previous proton run.

A high-bandwidth feedback system to damp the instability is also under consideration.

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