OBSERVATION OF A LONGITUDINAL COUPLED BUNCH INSTABILITY WITH TRAINS OF BUNCHES IN CESR

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Abstract

A longitudinal coupled bunch instability has been observed in the operation of CESR with multiple trains of bunches. The instability threshold is dependent on the number of bunches per train and the spacing between those bunches. The threshold is also sensitive to parameters in the RF system leading to the conclusion that the RF cavities play a significant role in the dynamics. A summary of these observations is presented along with the design and status of a feedback system to stabilize the beams.

1 OBSERVATIONS

CESR has been operating as an electron-positron high energy physics collider using trains of bunches since February of 1995 [1]. Operating with nine trains of two bunches as the beam currents increased to above 230 to 250 mA in both beams, a reduction of the filling rate of the counter-rotating electron beam was first noticed as was an associated reduction of the vertical beam-beam tune shift parameter during collisions. These effects were traced to the growth of a self-limiting longitudinal coupled bunch dipole oscillation which increased the horizontal aperture required by the injected electrons and which caused the collision point of the bunches to oscillate about the minimum vertical beta point. The colliding beam vertical tune shift parameter continued to decline above 280 mA total current in both beams and the oscillation amplitude grew to be approximately a one sigma energy oscillation at 300 mA total current in both beams. This instability was also observed with either positron or electron beams separately; the following observations reported in this paper have been made with nine trains of equally populated bunches.

Above the instability threshold, observations of the frequency spectrum of a beam position monitor (BPM) showed the rapid growth of synchrotron sidebands of the rotation harmonics. Since the spacing between trains of bunches in CESR in nine train patterns is not uniform but has a three-fold symmetry, the amplitude of synchrotron lines above threshold tends to exhibit a three-fold periodicity at low frequencies and also at frequencies near one divided by twice the bunch-to-bunch time spacing within the train. The specific spectral lines which have amplitudes that grow most rapidly above the instability threshold depend on the number of bunches per train and the spacing of the bunches within the train. For a few bunch train patterns with positrons alone investigations were made using a BPM signal gated for individual bunches and comparing the relative phases of each of the bunches. As an example in the case of 9 trains of 2 bunches having a 28 ns spacing the bunches within a train have been observed to oscillate nearly 180 degrees out of phase with respect to each other, while in the case of a 42 ns spacing between bunches the phase difference between the bunches in the same train is nearer to 45 degrees. The rapid variation of the phase of the longitudinal oscillation between bunches in the same train is indicative of a high frequency mode or modes in one or more structures within the storage ring as being responsible.

The threshold current for the onset of the instability is a function of the number of bunches within a train and the spacing between the bunches within the train. In CESR the standard filling patterns allow the bunches within each train to be spaced in increments of 14 ns with up to 5 bunches permitted per train. Figures 1 through 3, respectively, show the instability threshold for the total stored current vs. bunch spacing for 9 trains of 2, 3 and 4 bunches per train for beams of positrons alone and for beams of both positrons and electrons in the standard horizontal electrostatically separated closed orbits (Pretzels) with a 2.4 mr half crossing angle at the interaction region. (N.B.. measurements with two beams and four bunches per train have not yet been made and in addition the configuration of 9 trains of 1 bunch is not longitudinally unstable.) The threshold current plotted in Figures 1 through 3 is the highest threshold current that has been measured for each set of bunch spacings; over long periods of time it has been observed that this threshold can vary downward by as much as 10-15%. From Figures 1 through 3 we see that there is more than a factor of two variation in the measured threshold currents for all the different bunch spacings within the nine trains and in some cases the threshold current more than doubles when the electron beam is stored indicating some cancellation of the RF fields with counter-rotating beams.

In addition to the instability current threshold depending on the number and spacing of bunches, it has been observed that there is a slight dependence on the amplitude of the Pretzel which extends around the entire circumference of CESR. After further investigation using horizontal bumps in CESR it has been observed that those bumps which displace the beam within the 500 MHz RF cavities are the major contributors to instability's dependence on Pretzel amplitude. For some bunch train patterns it was observed that changing the RF cavity temperatures by a few degrees C or changing the RF tuning angles on the order of 20 to 40 degrees can make very slight differences in the current threshold. Observations of beam induced RF signals on field probes in 16 of the 20 cells show the presence of a few modes in each cell in the frequency range of 1.8 to 3 GHz which have Q's in excess of 10,000. Modes with these high Q's have damping times for the RF fields which are 3 to 6

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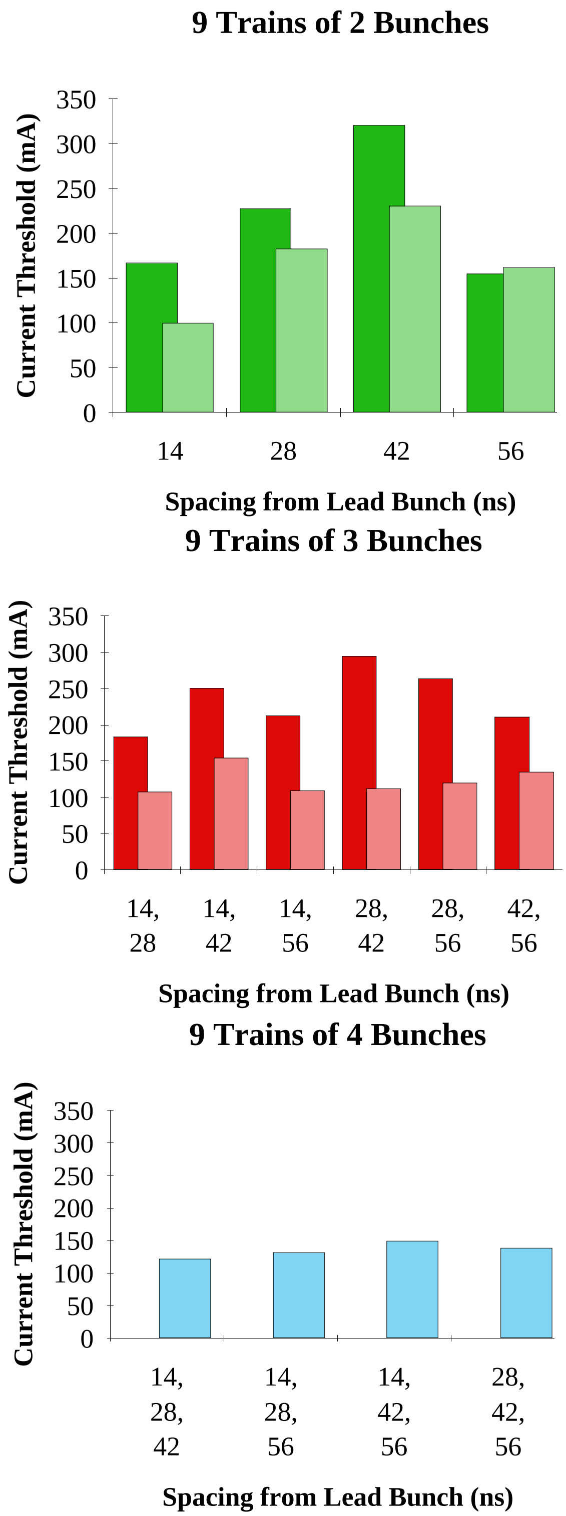
times the spacing between trains, easily permitting the wakefields to couple the motion of one train to the next. So the RF cavities must be considered to have at least a partial role in the dynamics which causes



Figures: 1, 2 and 3. Current Threshold vs. Bunch Spacing for Various Numbers of Bunches per Train. Lighter bars are for single positron beam currents only and darker bars are for total current for both positron and electron beams.

the present longitudinal dipole coupled bunch instability. Additional measurements indicate that the current threshold seems to be generally unaffected by changes in the synchrotron oscillation frequency or bunch length which is consistant with modes having frequencies less than 3 GHz.

Damping measurements for different coherent oscillation patterns of the trains of bunches have been made by exciting different synchrotron sidebands separately, modulating either the phase of an RF cavity or voltage on a stripline kicker and then allowing the motion to decay.[2] The signal from a beam position monitor (BPM) at a location of non-zero dispersion is viewed on a spectrum analyzer tuned to the coherent mode frequency in general yielding a decay which is not purely exponential. Although the decay of the BPM signal is not exponential, the decay envelope can be bounded above by an exponential curve; this curve is then used to give the characteristic damping rate for this synchrotron sideband. Measurements of several different synchrotron sidebands of single positron beams having different numbers of bunches and different spacings indicate that the natural damping rate at zero current is in the range of 200 to 900 sec^{-1} and the growth rate of the instability is between 1 and 9 sec^{-1} mA^{-1} depending on bunch pattern.

2 CURES

When this longitudinal coupled bunch instability was first encountered, CESR was operating with nine trains of two bunches having a 28 ns spacing. After learning that two bunches per train with a 42 ns spacing had a higher current threshold, the routine operation of CESR was changed to this bunch spacing. Since CESR has no longitudinal feedback cavities, the use of a transverse deflection from the horizontal stripline kicker (in routine use for horizontal feedback) which is located at a point with non-zero dispersion was determined to be a means of generating a path length change. This kicker is capable of independently deflecting bunches with as little as a 14 ns spacing allowing the creation of a bunch-by-bunch feedback system. A low noise phase sensitive detector has been developed to detect the energy-phase oscillation of each bunch. A prototype longitudinal feedback system has been assembled using this phase sensitive detector, the horizontal stripline kicker plus 150 MHz bandwidth RF amplifiers and digital processing electronics of the same type as is used with the transverse bunch-by-bunch feedback systems.[3] This feedback system was put into operation in February 1997 and it produces a damping rate of approximately 1.5 sec^{-1} mA^{-1} with the present feedback loop gain limited by noise and interference in the phase detection circuit. Although improvements of this phase detection circuit are underway to allow higher gain and damping rates, this prototype bunch-by-bunch longitudinal system has already permitted colliding beam operation with total two beam currents above 325 mA.

A final version of the longitudinal bunch-by-bunch feedback system is planned for operation beginning in the summer of 1997. In this design the linear RF amplifiers will be replaced by two FET pulsers each followed by a transmission line impedance transformer; the combination of these is capable of delivering 14 ns long pulses of 1.5 KV into the 50 Ω stripline kicker. This more than ten times the peak voltage capability of the present RF amplifiers. To limit the power dissipation in the pulsers, the pulsers will operate at full amplitude and be modulated with a duty cycle proportional to a phase error signal when it exceeds a threshold level. Simulations of this feedback pulser configuration indicates this should function quite successfully and produce a linear damping of large amplitude oscillations (as compared to exponential damping for conventional proportional feedback systems.) A prototype pulser has been tested and the final design is in production. The digital processing electronics will also be replaced with a new design that incorporates such features as an internal steady state, bunch-by-bunch phase offset correction circuit to compensate for the bunches in the trains operating at slightly different phases due to beam loading of the RF system and a more sophisticated bunch-by-bunch digital filtering section to improve the signal to noise ratio. This feedback system should increase the damping rate by at least a factor of ten and should be capable of stabilizing total two beam currents in excess of the 600 mA CESR+ phase 2 and 1 A CESR+ phase 3 design levels.[1]

Plans are also underway to procure a low Q 1.1 GHz accelerating cavity as a longitudinal bunch-by-bunch feedback kicker. The cavity and RF amplifier is based on the design for a longitudinal feedback system for DAΦNE.[4] This configuration for CESR would simplify the horizontal and longitudinal feedback loops which presently share the same feedback kicker. This cavity is expected to be installed in CESR in the fall of 1997.

One other change to CESR which is likely to improve the longitudinal dipole coupled bunch instability threshold will be the installation of four single superconducting RF (SRF) cells over the next two years to replace the 20 normal conducting RF cells in the present RF system.[5] The loaded Q's of these cells are below 100 for all higher order modes. Since the present RF system contributes significantly to the total impedance of CESR and since it also is known to be an important source of the impedance which drives this instability, installing the entire SRF system will decrease the overall impedance of CESR and should likely increase the threshold current for this instability.

3 CONCLUSIONS

The longitudinal coupled bunch dipole instability that has been observed in the operation of CESR with multiple trains of bunches has limited the total colliding beam currents. With the installation of a prototype longitudinal bunch-by-bunch feedback system the instability threshold has been raised. An improved version of this feedback system should be capable stabilizing the total current in the two beams in excess of 1 A for CESR.

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REFERENCES

[1] D. Rubin, "CESR Status", this conference.
[2] M. Billing, "Introduction to Beam Diagnostics", Fourth Annual Accelerator Instrumentation Workshop, Berkeley, CA, AIP Conf. Proc. No. 281, 72-3.
[3] J. T. Rogers et al, "Operation of a Fast Digital Transverse Feedback System in CESR", Proc of 1995 Part Acc Conf, (RAE14), 2426.
[4] R. Boni, "Experimental Tests of the DAFNE RF Feedback System", Proc of 1996 European Part Acc Conference.
[5] S. Belomestnykh, "Development of Supercon-ducting RF for CESR", this conference.