BEAM DYNAMICS EXPERIMENTS IN SUPPORT OF RELATIVISTIC KLYSTRONS*

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Abstract

Experiments to study beam dynamics for Relativistic Klystrons (RK) are being performed with a 1-MeV, 600-A induction accelerator beam. The RK is a RF Power source based on induction accelerator technology and conventional resonant output structures. Capable of generating 100's of MW/m at frequencies up to K-band, the RK has been proposed as a driver for a future linear collider in one version of a Two-Beam Accelerator. A critical feasibility issue remaining to be demonstrated is suppression of the transverse instability of the drive beam. This kiloampere beam must transit about a hundred resonance output structures and many hundreds of induction accelerator cavities for the RK to achieve competitive efficiency and cost with respect to other proposed power sources. The RK's strong focusing used to contain the beam in the small aperture resonant structures, repetitive geometry, and reacceleration allow the resonant output structures to be spaced at a betatron phase advance of 360°. This phase advance (or any integral multiple of 180°) is beneficial in linear accelerators as the instability growth changes from exponential to linear. In our experiment the beam is contained in a solenoidal focusing channel, RF cavities are spaced every 60 cm, and growth in the transverse motion is measured as a function of phase advance. Details of the experiments and results are presented.

1 INTRODUCTION

Significant theoretical studies and experiments have been accomplished in support of the Relativistic Klystron Two-Beam Accelerator concept since it was described by Sessler and Yu in 1987 [1,2,3]. The Relativistic Klystron Two-Beam Accelerator (RTA) program was established at LBNL in 1996 to study engineering and physics issues related to the construction of RK's suitable as RF power sources for TBA applications. Initial efforts were directed towards constructing a 1-MV, 1-kA induction injector, ancillary systems, and experimental hall. During the past year, emphasis has moved from construction and testing of the injector to performance of beam dynamics experiments using the 1-MeV, 600-A beam produced by the injector. There are two physics issues for RK's that remain to be demonstrated: controlling the growth of the transverse instability and maintaining longitudinal bunching as the beam is transported through many RF extraction cavities. A scheme for reducing the transverse instability is the subject of present experiments and is described below. Longitudinal stability can be maintained using detuned cavities in a manner similar to the penultimate cavities in a standard klystron to rotate the bunches in phase space. Future experiments are planned that will combine detuned cavities with transverse instability suppression to demonstrate the beam dynamics of a RK.

2 BETATRON NODE SCHEME

The Betatron Node Scheme (BNS) is based on the plausible scenario that a transverse kicked given to a particle passing through a cavity will not result in a change in transverse offset at a cavity located an integer number of half betatron wavelengths later. Without an increase in offset, the mechanism for exponential growth of the transverse instability is avoided. This effect can be seen implicitly in the theoretical derivation of [4] and was stated explicitly in [5]. Linear accelerator designs at that time used cavity spacing much less than a betatron wavelength (λ_β) and the concept was not pursued.

The main power extraction section of a RK uses strong focusing to transport the beam through small aperture output RF output cavities and the beam energy is cyclic with respect to the cavities. The betatron phase advance is large and constant between cavities. The reduction in growth of the transverse instability was noted in simulations during a design study of an RK-TBA where the cavities were fortuitously spaced at $\lambda_\beta/2$. This led to further simulations to study the effects of cavity length, errors in phase advance, and beam energy or focusing variations [6].

3 RTA FACILITY AND EXPERIMENT

The experimental hall with the injector and beamline are shown in Figure 1. The pulsed power units and power supplies for the solenoids are housed in the racks to the right of the injector.

3.1 Injector

The injector has been described elsewhere [7]. It uses a diode arrangement with a 3.5" diameter, dispenser cathode and has a perveance of about 0.58 μperv. The 24 induction cells are divided evenly between the anode and cathode halves of the injector and provide about 42 kV per cell.

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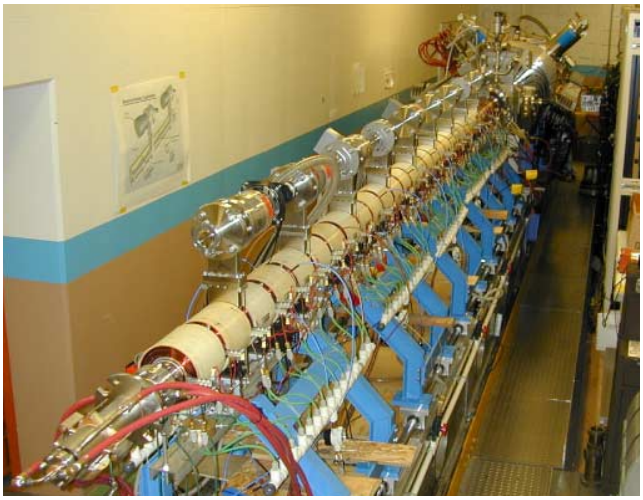

Figure 1. Photograph of the RTA experimental hall.

Beam energy was determined by summing the voltage at each cell. Capacitive probes were also used to measure the voltage and pulse shape for both cathode and anode stalks. Representative current pulses from the cathode and dump current monitors are shown in Figure 2. The transition section of the beamline prior to the BNS section acts as an energy selector, effectively scraping off the leading and trailing edges of the pulse. For the pulses shown, the beam energy was approximately 930 kV ± 1.4% for 130 ns.

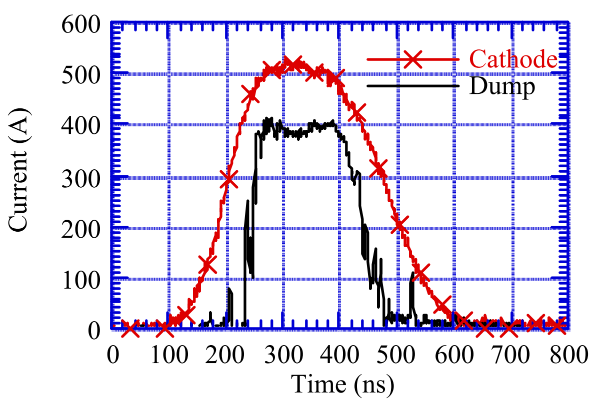

Figure 2. Typical Cathode and Dump current pulses.

3.2 BNS Section

The six meters of the beam line involved in the experiment consists of 10 identical sections of three solenoids each. A schematic of one section is shown in Figure 3. The RF cavities and BPM's are built into conflat flanges located between the solenoids [8]. The ~60 cm spacing is about a λ_β for a nominal 1-MeV beam and an average axial magnetic field of around 1 kG.

4 MEASUREMENTS

In addition to the primary effect of reducing the rate of growth of the transverse mode, we were interested in the growth along the beamline for different phase advances. For measurements shown below, the signal from a BPM was mixed with a local oscillator signal to reduce its

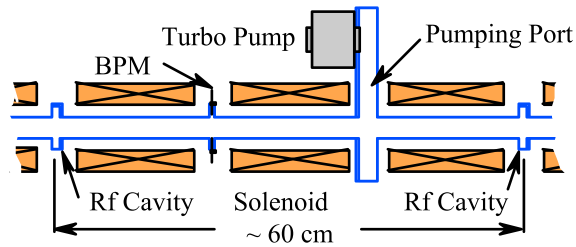

Figure 3. Repeating beamline section in BNS experiment.

frequency below 500 MHz for display on a digital scope. The digitized traces were then down loaded to a computer and Fourier transformed to yield the power spectrum. Figure 4 shows examples of the resulting power spectra. In the following figures, power refers to the peak spectral power associated with the 5.36 GHz transverse mode.

There was no externally driven cavity. The transverse instability was excited by noise and offseting the beam from the axis with dipole steerers. This resulted in the excitation of all modes associated with the cavities and beamline. However, the modes with the highest impedance dominated the spectum after a few sections of the beamline.

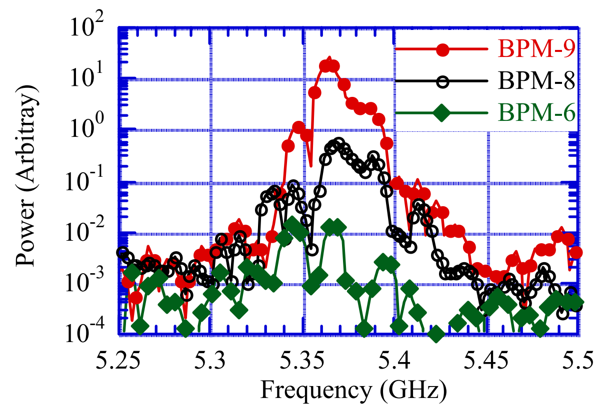

Figure 4. FFT Power Spectrum for 6th, 8th, and 9th BPM's.

4.1 Growth as Function of Focusing

Figure 5 shows the growth in the power of the transverse mode from BPM-7 to BPM-9 as a function of betatron phase advance between RF cavities. Note that a 6° change in phase is equivalently to about a 1.5% change in magnetic field or beam energy. The total growth from the initial cavity to the eighth cavity (prior to BPM-9), would require raising the power shown in Figure 5 to the fourth power. At the exteme limits of the scan this would equate to a power growth of almost 12 orders of magnitude greater than for the minimum, or 13 e-foldings of the transverse beam motion.

For this data the beam energy was held constant and the solenoid current varied. The asymmetric growth of power about 360° phase advance is a characteristic feature of the Betatron Node scheme observed in simulations for several different configurations [3].

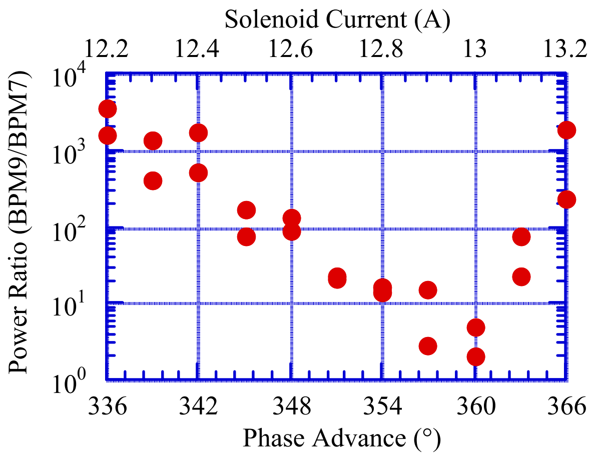

Figure 5. Spectral peak power as function of phase advance.

4.2 Growth along the Beamline

Figure 6 shows the increase in growth as the signal is measured along the beamline for an under-focused condition and a nominally on focus condition. Only the last four periods are shown with BPM-5 used as a normalizing value. For earlier periods the relative low signal strength and number of modes with comparable power levels makes consistent measurements problematic. An under-focused deviation of 18° from the desired 360° of betatron phase advance between cavities clearly shows the expected exponential growth. Within experimental uncertainty, the theoretical linear growth is realized as the phase advance approaches 360°.

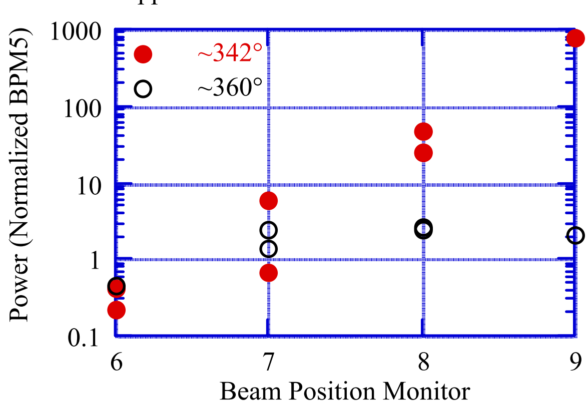

Figure 6. Spectral peak power as function of BPM for two different betatron phase advances.

5 CONCLUSIONS

An argument often made against the BNS scheme is that it may work under the ideal conditions assumed in theoretical derivations, but for practical systems the inherent energy variations and system tolerances will hide the effect. Simulations have tried to model practical situations, but normally with some assumptions required. However, it has now been shown under very average conditions that the BNS effect is real. For the data shown, there was a 50-ns rise time to the current pulse, the beam energy varied ±1.4% over the "flattop" portion of the pulse, and no special alignment or machining tolerances were used in the fabrication and assembly of the experiment. Also, only standard diagnostics are required to determine the optimum focusing field. It will be interesting to see if future accelerators or klystrons will incorporate this scheme.

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