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Exploring the VHF Cavity Parameter Space (1990)

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AGS STUDIES REPORT

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Reported by: L. Ahrens

Subject: Exploring the VHF Cavity Parameter Space (1990)

Summary

This study had two aims, (1) to document and explore locally the parameter space where the Very High Frequency (VHF) cavity is presently working and (2) to move to some rather distant points where different behavior is predicted. No big surprises were uncovered in either the time dependence or the quality of the dilution for the various setups. Some variant of the normal setup gives the fastest and greatest dilution. A result which was a surprise was that the fraction of beam surviving transition passage was found to first increase but then to decrease as the setup was modified to give more dilution. Further, the highest efficiency fell short of 100%, by less than 0.5%, but clearly not 100%. These last observations resulted in a slight change in the setup for normal operations and have implications for the higher intensity future.

Introduction

The operation of the VHF cavity causes a controlled growth of longitudinal phase space leading to greatly reduced transition losses. The cavity is excited on a 3.5 GeV (kinetic) front porch for a period of 100 ms at a frequency which is phase locked to but 21-1/3 times the rf accelerating frequency. In fact, this is not quite true. In order to get dilution, the phase of the cavity is slowly modulated (usually sinusoidally) relative to the accelerating rf phase at a frequency of the order of two or three times the synchrotron frequency. A further step in the standard setup (suggested long ago by J. Kats, 1987 IEEE P.A.C. Pg. 1281) is to vary this phase modulating frequency (in a saw-tooth pattern).

Parameters and Experiment

The parameters explored include (1) ϵ, the voltage ratio of the VHF cavity to the accelerating cavities. The latter comprise 40 gaps so ϵ is small but the VHF cavity has a relatively high Q so ϵ is not too small, ϵ varies from 0.1 to 0.2; (2) γ, the frequency of phase modulation given normalized to the small amplitude synchrotron oscillation frequency; and (3) α, the amplitude of the phase modulation, a number of order π. In addition, whether the additional sawtooth frequency variation is invoked (and if so, its frequency swing and speed, although this gets to complicate the space too much) and indeed whether the basic phase modulation is sinusoidal or triangular (invoked unintentionally, but now the standard mode) are also explored.

The results of powering the cavity (dilution) is that the beam bunches get wider, and less high (lower instantaneous current) and the losses at transition usually go down. The effect of varying the parameters is quantified by measuring the bunch height ("peak detecting" the F-20 wall monitor signal; we thank E. Gill for arranging this) and individual bunch width (again, the wall monitor) as a function of time after the start of dilution. Also, the efficiency of accelerating across transition is measured from the L-20 current transformer. In each case, an attempt was made to optimize transition efficiency, but with the "knobs" restricted to the timing and magnitude of the rf phase jump. A "mneumonic" sketch of some parameters is given in Figure 1. The standard setup is sketched in Figure 2. The bunch height is measured at: (a) = just the start of dilution, (b) = 20 ms into dilution, and (c) = 100 ms, the end of dilution. This measure is easy, many cycles can be averaged over and the reproducibility of the result estimated. Further, the result is normalized to the height at (a) = the start. There is a small problem with this measure. The reference is ac ground rather than the base of the bunches. This (unnormalized) offset depends only on the beam intensity and so was constant throughout this study but was not measured. The offset translates into an "over estimation" of the relative height reduction which gets larger as the dilution increases. We estimate from a later measure under somewhat different conditions that:

(Actual relative bunch height [rbh]) =

5/6 (measured rbh) + 1/6

A measured rbh of 0.8 was really 0.83, a measured rbh of 0.5 was really 0.55. The measured values are reported below.

The bunch width is measured at 20 ms intervals during dilution. The result is messy in that the edge of the bunch is seldom sharp. Since we are interested in 1% losses at transition, the tails on these bunches are relevant.

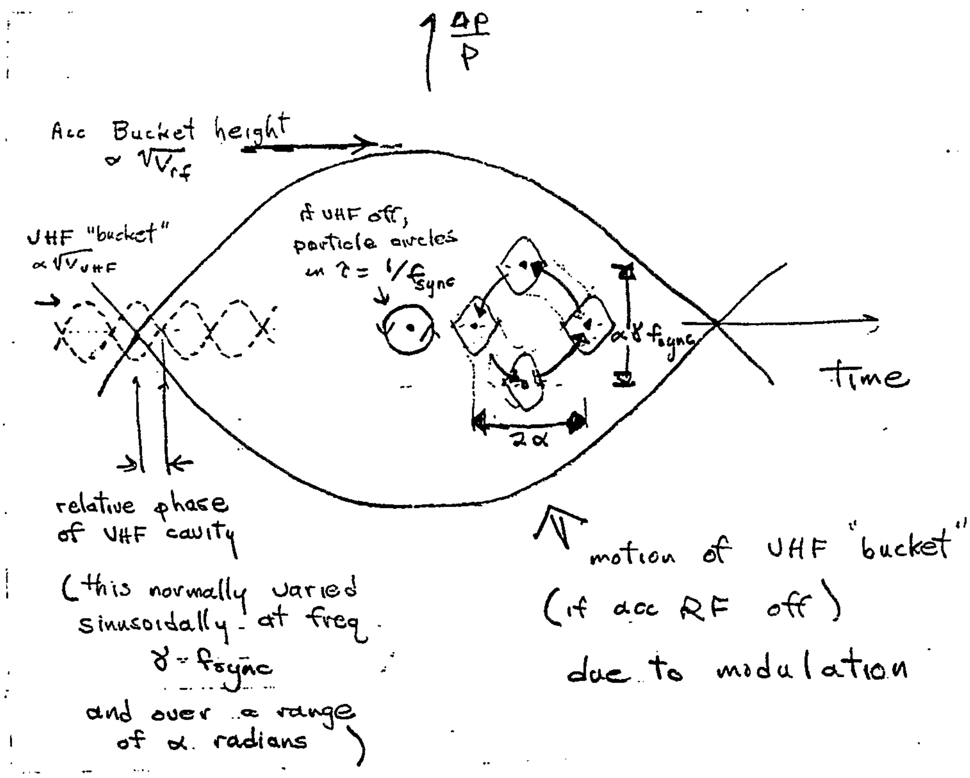

Figure 1. A sketch of the parameter space.

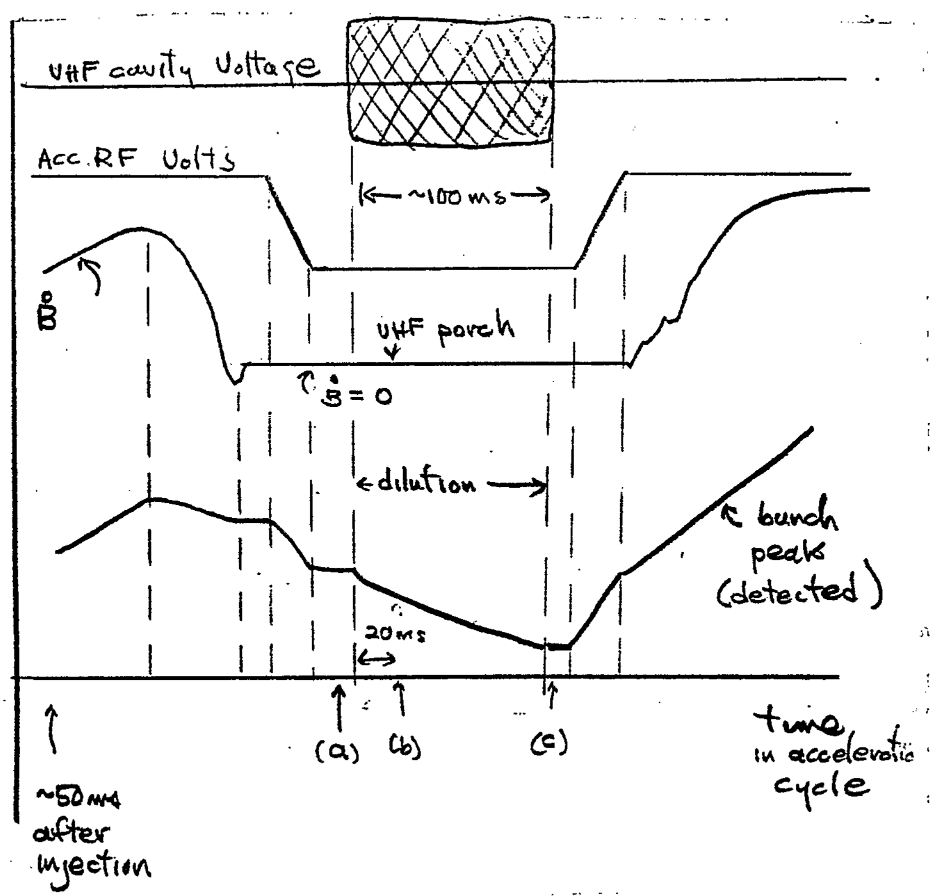

Figure 2. Time dependencies, normal cycle dilution.

Results & Observations

Table I gives results for the exploration near normal running parameters. In fact, Case 1 of that Table was the running situation prior to the study. All four cases have a slow sawtooth (ramp up, step down) variation of the modulation frequency. The use of a triangular rather than sinusoidal frequency modulation apparently happened accidentally some time back. Some apparent patterns from Table I: (a) a larger relative VHF cavity voltage (actually V_{rf} was decreased) gives more rapid dilution; (b) the triangular waveform gives a bit faster dilution initially, but less dilution on the larger time scale; and (c) perhaps most importantly, beyond some point more dilution actually resulted in lower transition efficiency. This suggested that a shorter dilution with the parameters of 3 or 4 might yield the same transition efficiency as a long dilution at (1) -- a possibility which was investigated and found to be true. Table II gives transition efficiency for three different dilution intervals with the parameters of (3). Figure 3 gives transition efficiency vs. peak reduction for all setups with reduced accelerating gap volts. It is speculated that a little dilution is a good thing since it reduces the longitudinal mismatch at transition while a lot of dilution increases the momentum spread so much that some beam is lost from the bucket just because it arrives at transition too early or too late relative to when the phase is jumped. This matter deserves further work.

The other objective of the study was to observe dilution behavior at a few other "special" places in the parameter space. In particular, the sawtooth slow frequency variation program was replaced by a fixed frequency. This frequency and the phase amplitude were varied. Table III gives these points. The column labeled width (80 ms)/width (0) uses in each case two width measurements taken on a particular cycle. The width (0) is taken just before dilution starts and so should not depend on the setup. Nevertheless, this width varies by 10% over the data. This may point up the difficulty of the width measure, may reflect a real problem with the first trigger, or may be a real shot-to-shot variation. This column should be regarded with skepticism. Some apparent patterns from Table III: (a) none of these points come close to matching the sawtooth for speed of dilution; (b) qualitatively the shape or aspect ratio of the bunches changed such that the product (peak x width) is not varying drastically. This conclusion is rather subjective given the uncertainty in bunch width measurement mentioned above; (c) the relation between dilution and transition efficiency is consistent with the sawtooth results. These points are included in Figure 3. J. Kats has simulated some of these conditions and will give a better analysis than the above.

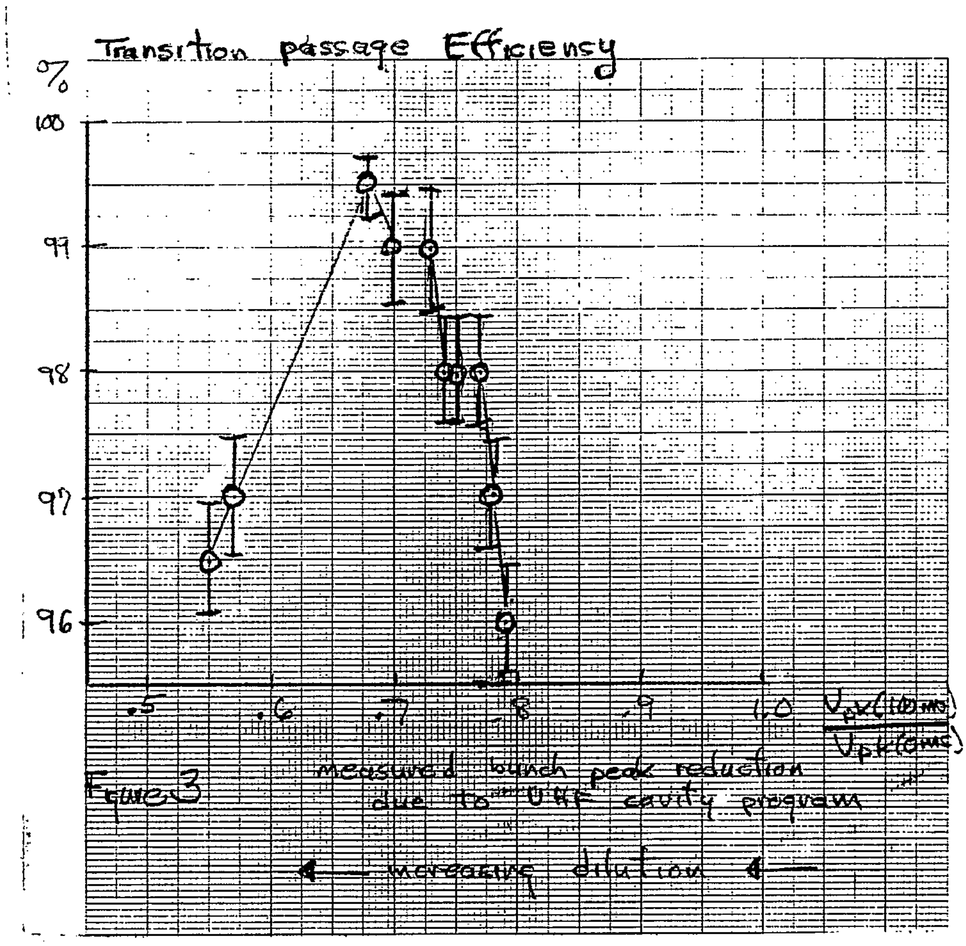

Figure 3. Transition efficiency vs. dilution.

TABLE I

Sawtooth Dilutions

Modulation	$\epsilon = \frac{V_{VHF}}{V_{rf}}$	Bunch Height Rel. to t=0 ms		Width (ns)		Trans. Eff.
		20 ms	100 ms	0 ms	80 ms	
1 Triangle	0.11	0.85	0.65	60	80	99.0
2 Sine	0.11	0.89	0.64	65	95	98.0
3 Triangle	0.16	0.86	0.57	75	110	97.0
4 Sine	0.16	0.88	0.55	68	115	97.5

TABLE II

High "ϵ" Sawtooth (Case 3 above)

Trans. Efficiency vs. Dilution Time

20 ms	97%
40 ms	99%
100 ms	97%

TABLE III

Fixed Phase Modulation Frequency Dilution

γ (f_{mod}/f_{sync})	α radians (phase shift)	$\alpha\gamma$	pk/pk(0) 20 ms	pk/pk(0) 100 ms	Trans. Eff.	Width (80 ms) / Width (0)
1.5	4	6.0	0.90	0.79	96	
1.7	4	6.8	0.88	0.74	98	1.24
2.4	3.5	8.4	0.88	0.68	>99	1.36
2.8	3	8.4	0.89	0.73	99	1.50
3	3	9.0	0.89	0.75	98	1.35
3	π	9.43	0.91	0.77	98	1.31
3	4	12.0	0.94	0.75	98	1.42