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Tune Measurements at Injection, and Comparison with Similar Measurements Made in July, 1986.

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Purpose

When the machine came up this month it was noticed by J.W. Glenn and others that the bare tunes of the machine - i.e. the tunes the machine would have with the tune-shifting nuquads turned off - were not the same as those measured in July, 1986.[1] (They are, in fact, rather different.) The purpose of this study was to measure the tunes at injection for several different settings of the nuquads to verify that the nuquads are working properly and that their calibrations have not changed.

Measurement Results and Conclusions

The tunes were measured at injection using the PIP (Pulsed Injection Parameter) device. The results are shown in Table I. These data were taken with the machine in sav-a-watt, DIFPK set at 2445, beta quads set at 2500, and the zero-theta skew quads set at 600 (coupling nulled). In Figures 1-4 the measured tunes have been plotted as functions of the nuquad settings and straight lines have been fit to the data. The slopes of the fitted lines are

$$\begin{aligned} \Delta\,(\text{HORZ TUNE})/\Delta\text{NUQH} &= -2.49(2) \times 10^{-4} \\ \Delta\,(\text{VERT TUNE})/\Delta\text{NUQH} &= +1.23(2) \times 10^{-4} \\ \Delta\,(\text{VERT TUNE})/\Delta\text{NUQV} &= +2.69(2) \times 10^{-4} \\ \Delta\,(\text{HORZ TUNE})/\Delta\text{NUQV} &= -1.10(2) \times 10^{-4} \end{aligned} \qquad (1)$$

which are the desired nuquad calibrations. In Table II we have listed these calibrations along with those measured in July, 1986[1] and along with those calculated by the BEAM code. The numbers are all in good agreement, so it appears that the nuquads are in good shape and that their calibrations have not changed.

The operating point of the machine on the day of this study was with NUQH = -98 and NUQV = 1040, and the tunes measured by the PIP device with these nuquads settings were

$$\begin{aligned} \nu_H &= 8.571(1) \\ \nu_V &= 8.898(1) \end{aligned} \qquad (2)$$

before going to sav-a-watt. Using the nuquad calibrations measured during this study we can calculate what the tunes would be with the nuquads off. We find

$$\begin{aligned} \nu_H(\text{nuquads off}) &= 8.661 \\ \nu_V(\text{nuquads off}) &= 8.630. \end{aligned} \qquad (3)$$

If the beta quads, which were set at 2500 during this study, are turned off the BEAM code predicts that the horizontal and vertical tunes will shift by -.012 and -.010, respectively. The tunes given in (3) then become

$$\begin{aligned} \nu_H(\text{bare}) &= 8.649 \\ \nu_V(\text{bare}) &= 8.620 \end{aligned} \quad (1/22/87) \qquad (4)$$

which we define to be the bare machine tunes. These are to be compared with the bare machine tunes measured in July, 1986 and reported in Ref. 1. The operating point of the machine on 7/9/86 was with the beta quads off and with NUQH = 0 and NUQV = 1050. The measured tunes under these conditions were

$$\begin{aligned} \nu_H &= 8.536(5) \\ \nu_V &= 8.961(5). \end{aligned} \qquad (5)$$

Using the nuquad calibrations given in (1) we then find the following bare machine tunes:

$$\begin{aligned} \nu_H(\text{bare}) &= 8.652 \\ \nu_V(\text{bare}) &= 8.679. \end{aligned} \quad (7/9/86) \qquad (6)$$

Comparing these with the bare tunes of 1/22/87 we see that the horizontal tunes are in good agreement but the vertical tunes differ by .06.

We can also compare the tune measurements given above with those made on 1/21/87:

$$\nu_H = 8.620(1)$$
$$\nu_V = 8.876(4). \qquad (7)$$

These tunes were obtained with NUQHB = -70, NUQVB = 1000, beta-quads set at 1800, and the zero-theta skew quads set at 600 (coupling nulled). Using the calibrations given in (1), and the respective shifts of -.010 and -.007 in ν_H and ν_V calculated by the BEAM code when the beta-quads go from a setting of 1800 to 0, the bare tunes for the 1/21/87 measurement are found to be

$$\nu_H(\text{bare}) = 8.703 \quad (1/21/87)$$
$$\nu_V(\text{bare}) = 8.609. \qquad (8)$$

Comparing these tunes with the bare tunes of 7/9/86 and 1/22/87 we again see differences of order .01 to .07. The three bare-tune measurements are summarized in Table III.

These differences in the bare tunes of the machine are presently not understood, but some speculative remarks can be made. Before the January, 1987 measurements were made, eight of the horizontal high-field quadrupoles, which normally operate with currents of no more than 100 Amps, were excited with currents of up to 500 Amps during γ-transition studies. (The current in one of the quads may have gone as high as 800 Amps during preliminary tests before the γ-transition studies.) Perhaps the resulting changes in the remanent fields of these quads could account for the differences in the bare tune measurements.

It should also be noted that the field at which we inject varies from day to day depending on how the machine has been tuned. The effect of these differences in field on the tunes is easy to estimate:

$$\frac{\Delta\nu_H}{\nu_H} = -\xi_H \frac{\Delta B}{B} \; ; \quad \frac{\Delta\nu_V}{\nu_V} = -\xi_V \frac{\Delta B}{B} \qquad (9)$$

where ξ_H and ξ_V are the horizontal and vertical chromaticities, and ΔB is the change in the B-field. The change in radius, R, due to the change in B-field is given by

$$\frac{\Delta R}{R} \simeq \frac{-1}{\nu_H^2} \frac{\Delta B}{B} \qquad (10)$$

which can be used in (9) to obtain the tune shifts in terms of the radius shift:

$$\Delta\nu_H = \nu_H^3 \, \xi_H \frac{\Delta R}{R}; \quad \Delta\nu_V = \nu_V \, \nu_H^2 \, \xi_V \frac{\Delta R}{R} . \tag{11}$$

Using $\xi_H = -1.3$, $\xi_V = -0.7$, $\nu_H = 8.7$, $\nu_V = 8.7$, and $R = 12845$ cm in (11) we find

$$\Delta\nu_H = -.067 \, \Delta R; \quad \Delta\nu_V = -.036 \, \Delta R. \tag{12}$$

Thus, if the radius changes by 1 cm, which is a large but not unreasonable shift, then we get tune shifts of the same order as the differences observed in the bare tunes. A careful study of the dependence of the bare tunes at injection on the field at which we inject should be carried out.

References

1. AGS Studies Report, No. 213.

NUQH	NUQV	ν_H	ν_V	ξ_H	ξ_V
-1098	1040	8.795(1)	8.755(4)	-1.4(1)	-1.4(3)
- 898	1040	8.748(1)	8.788(2)	-1.3(1)	-0.7(2)
- 698	1040	8.693(2)	8.813(2)	-1.1(1)	-0.8(1)
- 98	1040	8.547(2)	8.885(1)	-1.1(1)	-0.6(1)
- 898	140	8.847(1)	8.549(1)	-1.2(1)	-1.1(1)
- 898	540	8.803(1)	8.661(1)	-1.3(1)	-0.7(1)
- 898	1040	8.748(1)	8.788(2)	-1.3(1)	-0.7(2)

TABLE I

CALIBRATION FACTOR	MEASURED		CALCULATED BY BEAM CODE
	7/9/86	1/22/87	
$\Delta\nu_H/\ \Delta$NUQH	$-2.22(8) \times 10^{-4}$	$-2.49(2) \times 10^{-4}$	-2.44×10^{-4}
$\Delta\nu_V/\ \Delta$NUQH	-	$1.23(2) \times 10^{-4}$	1.09×10^{-4}
$\Delta\nu_V/\ \Delta$NUQV	$2.38(4) \times 10^{-4}$	$2.69(2) \times 10^{-4}$	2.37×10^{-4}
$\Delta\nu_H/\ \Delta$NUQV	-	$-1.10(2) \times 10^{-4}$	-1.14×10^{-4}

TABLE II

DATE	ν_H(bare)	ν_V(bare)
July 9, 1986	8.652	8.679
January 21, 1987	8.703	8.609
January 22, 1987	8.649	8.620

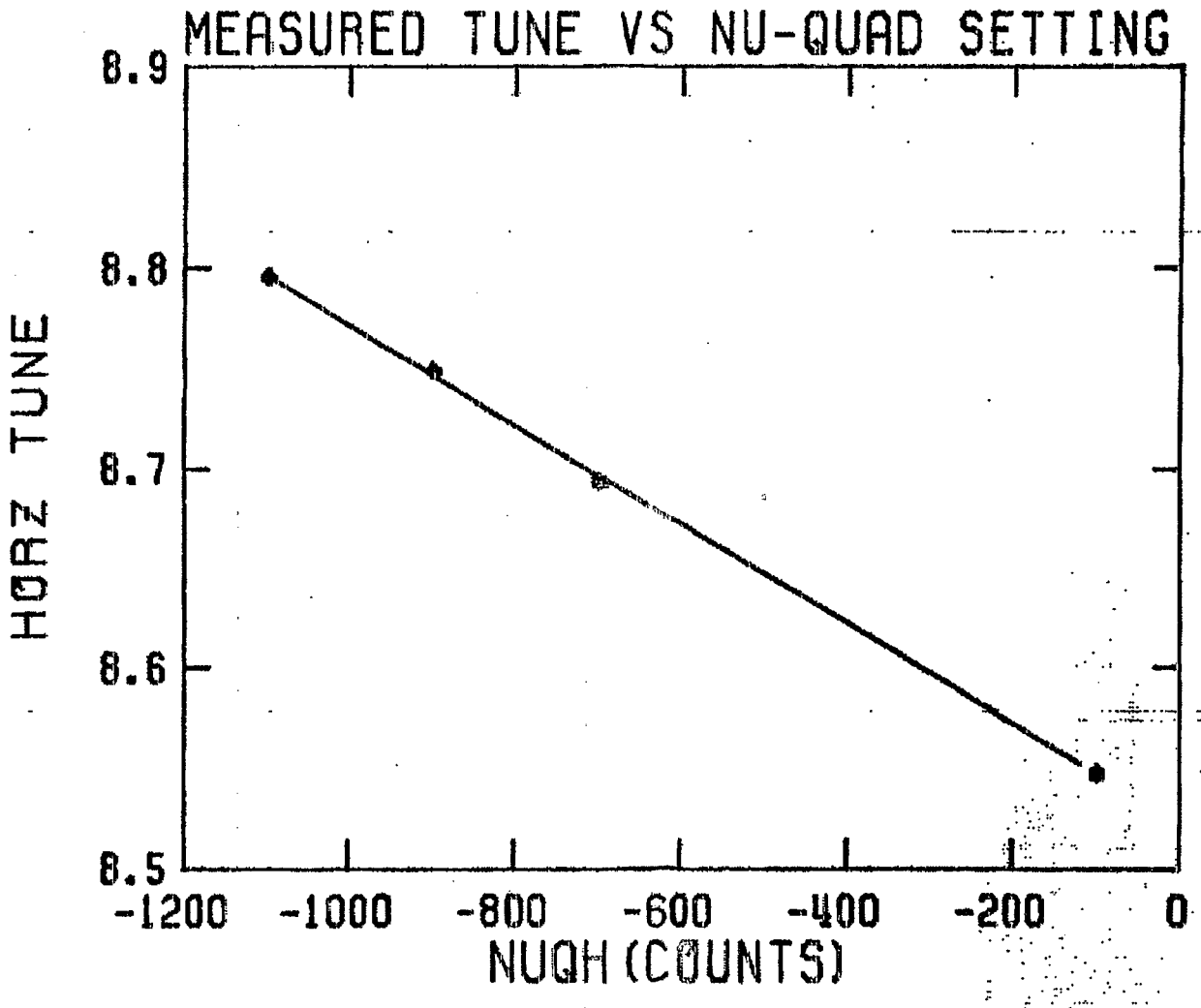
TABLE III

22-J[illegible]-87 NUQUAD CALIBRATION DATA

SLOPE= -0.000249 +/- 0.000002

INTERCEPT= 8.522708 +/- 0.002022

Figure 1

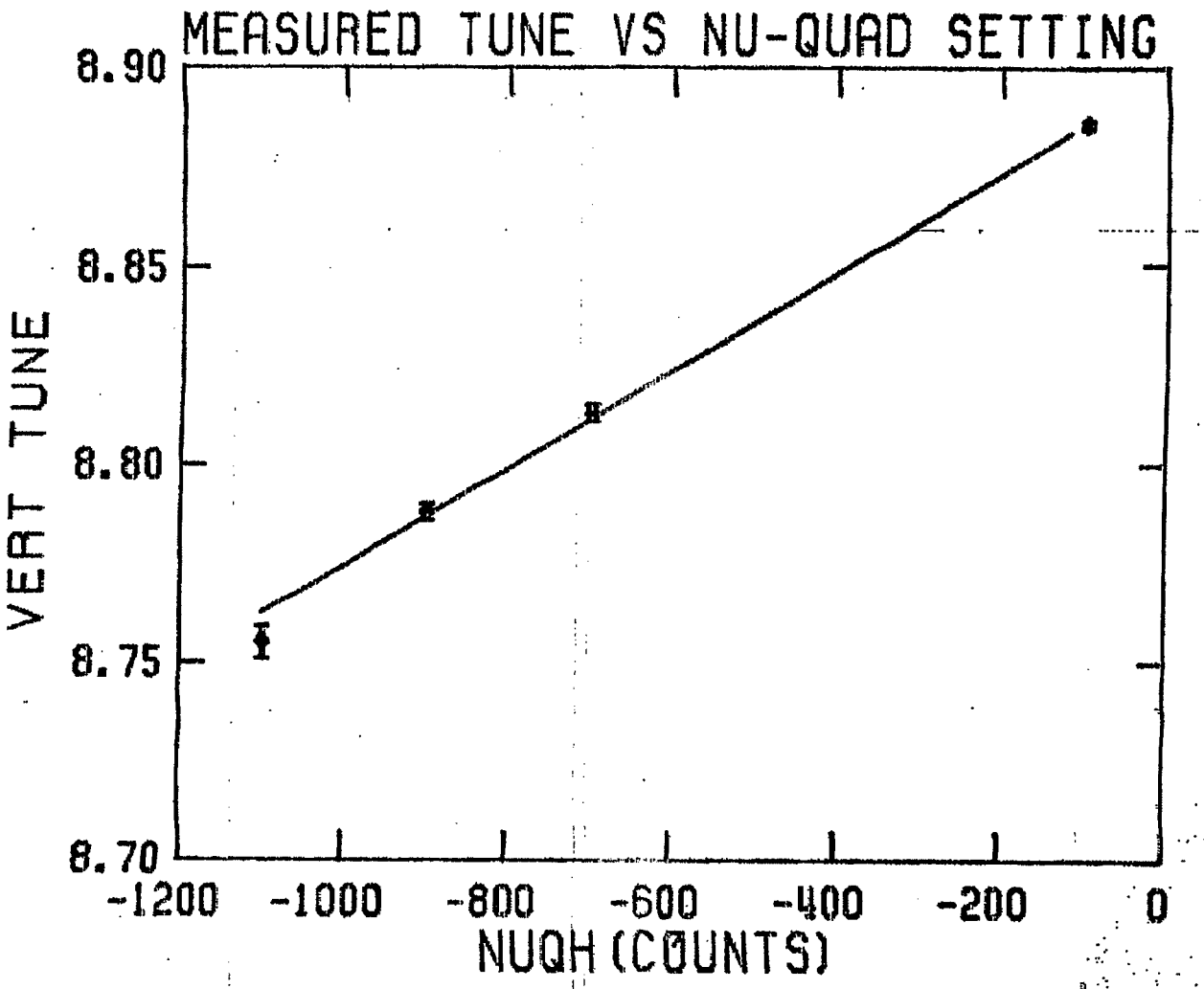


23-JAN-87 NUQUAD CALIBRATION

SLOPE= 0.000123 +/- 0.000002

INTERCEPT= 8.897256 +/- 0.001133

Figure 2

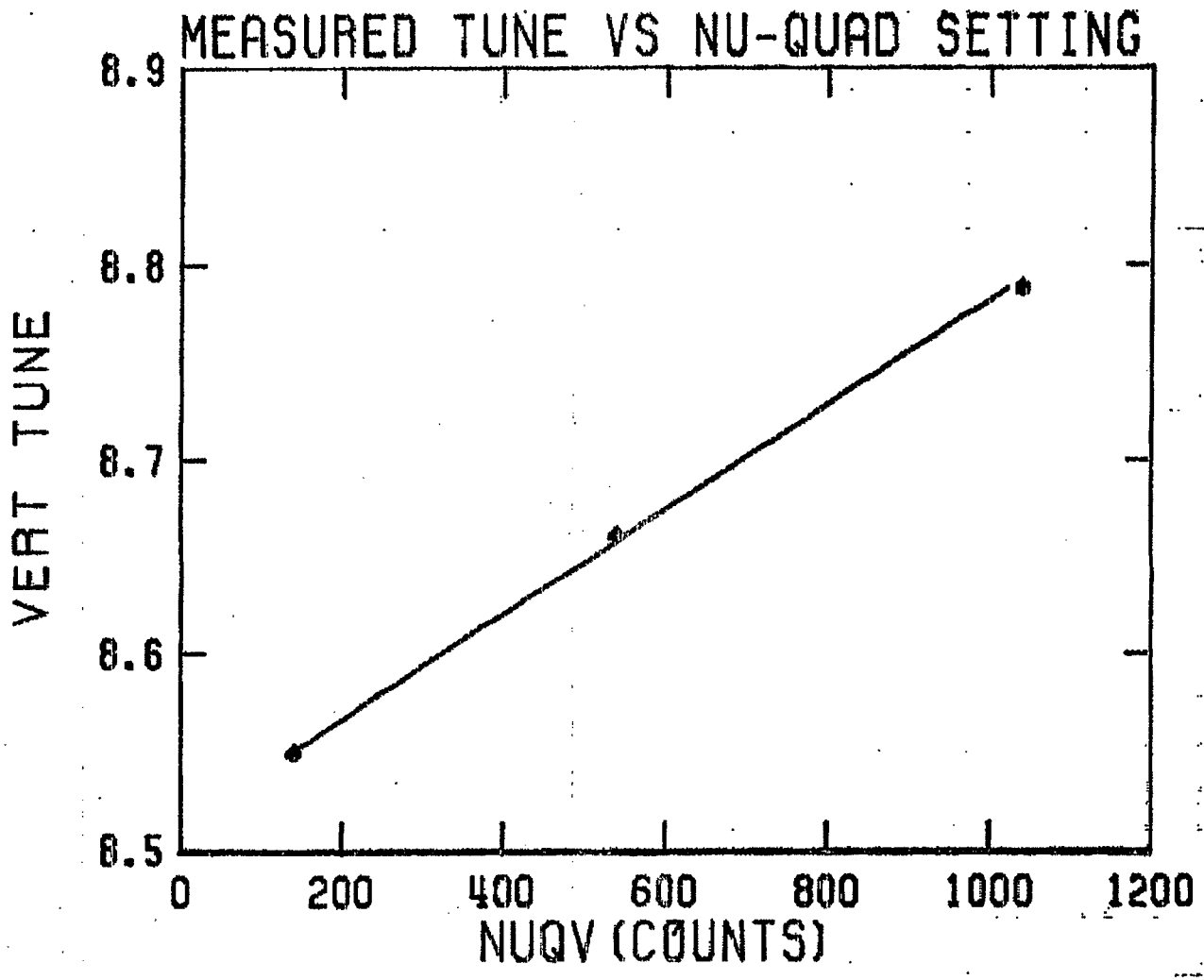


22-JAN-87 NUQUAD CALIBRATION

SLOPE= 0.000269 +/- 0.000002

INTERCEPT= 8.512828 +/- 0.001170

Figure 3



22-JAN-87 NUQUAD CALIBRATION

SLOPE= -0.000110 +/- 0.000002

INTERCEPT= 8.862400 +/- 0.001068

Figure 4