AUG 12 1986

SINGLE PASS COLLIDER MEMO

SLAC-CN--334

DE86 014118

AUTHOR: Heinz Schwarz and Jan Vancraeynest

DATE: June. 24, 1986

TITLE: MASTER OSCILLATOR STABILITY
REQUIREMENTS CONSIDERATIONS*

ABSTRACT

This note attempts to point out some ideas about the required stability of the 476 MHz master oscillator, assuming that the phase noise of the oscillator is the only source of noise in the accelerator system.

INTRODUCTION

In the past, there have been several mentions of some form of stability specifications, e.g. [1], [5]. None of these specs however consider the frequency of the phase jitter, which is an important parameter in specifying any real world oscillator in terms of phase noise.

To determine the phase noise specifications as a function of the offset frequency, we looked at the effects of oscillator phase noise on the beam (i.e. energy spread, stability,...) and at the effects of phase noise on the accuracy of the phase measurement by the phase and amplitude detectors (PADs). These considerations will impose short term stability requirements. For specifying the long term stability (or drift), the arguments of the Blue Book can be retained. A specific requirement for long term stability can be derived from the phase length measurement of the Main Drive Line. Here any frequency variation should not cause a phase change > 1 deg/day over the 2 mile length, which results in a long term stability requirement of $5E-7$ /day.

THE DIFFERENCE IN PROPAGATION VELOCITY OF THE BEAM AND THE WAVE ON THE MAIN DRIVE LINE (MDL)

* Work supported by the Department of Energy Contract #DE-AC03-76SF00515

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

The time delay between the arrival of the bunch and the wave at sector n, assuming that bunch and wave are in step at sector 1, is

$$\Delta t_n = L_n \left(\frac{1}{v_{MDL}} - \frac{1}{c} \right)$$

L_n is the distance between sector 1 and sector n, $\frac{1}{v_{MDL}} - \frac{1}{c}$ is given in [2] to be 8.612 ps/m.

This is a static delay the effects of which are corrected by a phase shifter in each sector. But phase jitter of the master oscillator within the timeframe Δt_n can affect the beam. Using the phase jitter tolerances specified in [1] (0.1 degree at S-band maximum for sector 2, 0.5 degree jitter max for sector 30) the following noise specifications can be derived :

max. noise sidebands in 1Hz
Bandwidth F_{jitter} removed
from carrier

Sector	$\Delta\phi$ @ S-band	F_{jitter} (freq. of phase jitter)	@2856 MHz	@476 MHz
2	0.1°	> 1.1 GHz	-157 dBc/Hz	-173 dBc/Hz
30	0.5°	> 38 MHz	-103 dBc/Hz	-119 dBc/Hz

This kind of phase noise will not be able to affect the beam since the klystron with its bandwidth of about 24 MHz will filter out noise sidebands 38 MHz and further away from the carrier.

THE FINITE FILLING TIME OF THE D(ISK) L(OADED)

W(AVE)G(UIDE)

During its passage through the DLWG, the beam sees the time history of the field in the DLWG, averaged over the filling time of the DLWG. The proper way to treat this effect is to fully take into account the finite passband character of the accelerating structure. Some numerical examples of this procedure are given in [3]. In order to obtain a simple analytical expression, we will treat this effect in the following intuitive way: the cavity is modeled as a transmission line

on which a phase disturbance in the field travels at the group velocity of the structure and the beam travels at the velocity of light. Our aim is to find an expression for the energy variation of the beam due to this propagating phase jitter.

$$\text{energy gain: } E = e \int_0^L \sin(\phi_N + \Delta\phi \sin \omega_m(t - \frac{z}{v_g})) dz$$

ϵ = amplitude of the longitudinal electric field

ϕ_N = nominal phase

$e = 1.60209 \times 10^{-19}$ Cb

L = length of the accelerator structure = 3.048 m

$\Delta\phi \sin \omega_m(t - \frac{z}{v_g})$ = sinusoidal phase modulation, propagating at v_g

$t = t_0 + z/c$, where t_0 = random time at which the wave enters the structure.

As far as jitter is concerned, we set $t_0 = 0$, i.e. upon entering the cavity, the beam sees the right phase.

For small $\Delta\phi$, one obtains:

$$rms\left(\frac{\Delta E - \Delta E_{nom}}{\Delta E_{nom}}\right) = \Delta\phi \cot\phi_N \frac{\sin^2 \frac{\omega_m \Delta t}{2}}{\frac{\omega_m \Delta t}{2}} \quad (*)$$

$$\Delta t = L (1/v_g - 1/c)$$

In order for the total energy variation to be less than 0.1%, the right hand side of equation (*) should be < 0.001 since the bunch will see the same field in subsequent sections (neglecting the difference in propagation velocity between field on the MDL and beam in the accelerator and assuming no external noise contributions). With $\phi_N = 75$ deg, the limits for $\Delta\phi$ are obtained as :

f_m	$\Delta\phi <$	dBc@ S-band	dBc@ 476 MHz	dBc/Hz@ 476 MHz
10MHz	133 mrad	-23	-39	-100
1MHz	21 mrad	-40	-55	-116
100KHz	15 mrad	-42	-58	-119
10KHz	150 mrad	-23	-39	-100
1KHz	1.5 rad	-22	-33	-94

As the noise bandwidth we take the first zero of the $\sin x/x$, i.e. $1/\text{filling time} = 1.3 \text{ MHz}$, resulting in the required sideband levels in the table.

These considerations show that the most critical range of offset frequencies lies around $1/\text{filling time}$ of the DLWG (10 kHz to 1 MHz).

REQUIREMENTS OF THE PAD

Figures 1 and 2 show the measured spectrum and the phase jitter over Sub-booster Station 1 for the SLAC M.O. and for the HP M.O. based on the HP8640 signal generator.

SLAC M.O.: $\Delta\phi_{pp} = 0.6^\circ$

HP 8640 M.O.: $\Delta\phi_{pp} = 0.2^\circ$

Fig. 1

Fig. 2

Fig. 3 shows the frequency spectrum of the two respective oscillators after times 6 frequency multiplication. The PAD's together with the sub-boosters function essentially as a frequency discriminator, where the resonant nature of the sub-boosters klystron converts frequency noise into phase noise measurable by the phase detector part of the PAD. The amount of phase variation of the SLAC master oscillator can be estimated by integrating its noise spectrum

$$\phi^2 = 2 \int \left(\frac{\text{Noise power}}{\text{Carrier power}} \right)_{SSB} df$$

Fig. 3

This yields a $\Delta\phi_{pp} = 1.2$ degrees which is within the range of the measured $\Delta\phi_{pp} = 0.6$ degrees. The same phase jitter as for the SLAC M.O. was generated by frequency modulating the HP oscillator at 300 kHz with -50 dBc sidebands at S-band. In order to be able to display this $\Delta\phi$ on the PAD, a resonant circuit with a Q of around 2500 is needed. This resonant circuit is likely to be found in the sub-boosters klystron, although its Q seems to be lower in the order of 1000. The difference in pathlength between the two arms of the PAD also contributes to converting frequency noise to phase noise.

It is also interesting to note that the *6 frequency multiplier converts AM at 476 MHz to PM at 2.856 GHz.

From this section it seems that the accuracy requirement of the PAD (better than 0.1 degree) poses a more stringent limit on the phase noise than does the beam requirement of the previous section.

CONCLUSION

The phase noise requirements for the SLAC master oscillator as derived above are summarized below :

Long term stability : $< 5 \text{ E-7 / day}$ (MDL phase stability requirement)

Phase noise : -98 dBc/Hz at 10 kHz offset (beam requirement)

-138 dBc/Hz at 100 kHz offset (PAD requirement)

noise floor (offset $> 100 \text{ kHz}$) : -145 dBc/Hz (PAD requirement)

All specifications apply at 476 MHz.

In addition, the noise power at specific critical discrete frequencies should also be limited. For example, [4] gives as limit for noise power at 4.14 GHz 12 μW , which for 50 MW translates in a sideband level of -126 dBc.

The requirements at large offsets can be met by e.g. a cavity-stabilized oscillator (like the HP8640 the spectrum of which led to the specs at large offset frequencies). The close-in requirements can be met by phase locking this oscillator to a multiplied crystal oscillator like the SLAC M.O. The solution we adopted is to phaselock a S(urface) A(coustic) W(ave) R(esonator) O(scillator) to the SLAC M.O. This way the excellent phase noise performance of the SAWRO can be combined with the required long term stability and close-in phase noise of a crystal oscillator.

REFERENCES

- [1.] Stiening R., Collider Note 181
- [2.] Blue Book, p.286
- [3.] Blue Book, p.121
- [4.] Blue Book, pp. 231-233
- [5.] Higgins E., Collider Memo CN-207

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.