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Linear Collider Collaboration Tech Notes

NLC Crab Cavity Phase Stability

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Abstract: The NLC design includes a pair of "Crab Cavities" to rotate the bunches at the IP and allow a larger crossing angle. These cavities must be phased relative to each other with very high stability. Slow drifts can be measured with the electron beam, and corrected with feedback. Pulse to pulse jitter in measurement and in the cavity drive is a potential problem. We try to estimate the size of these effects.

Crab Cavity Phase Noise Calculations

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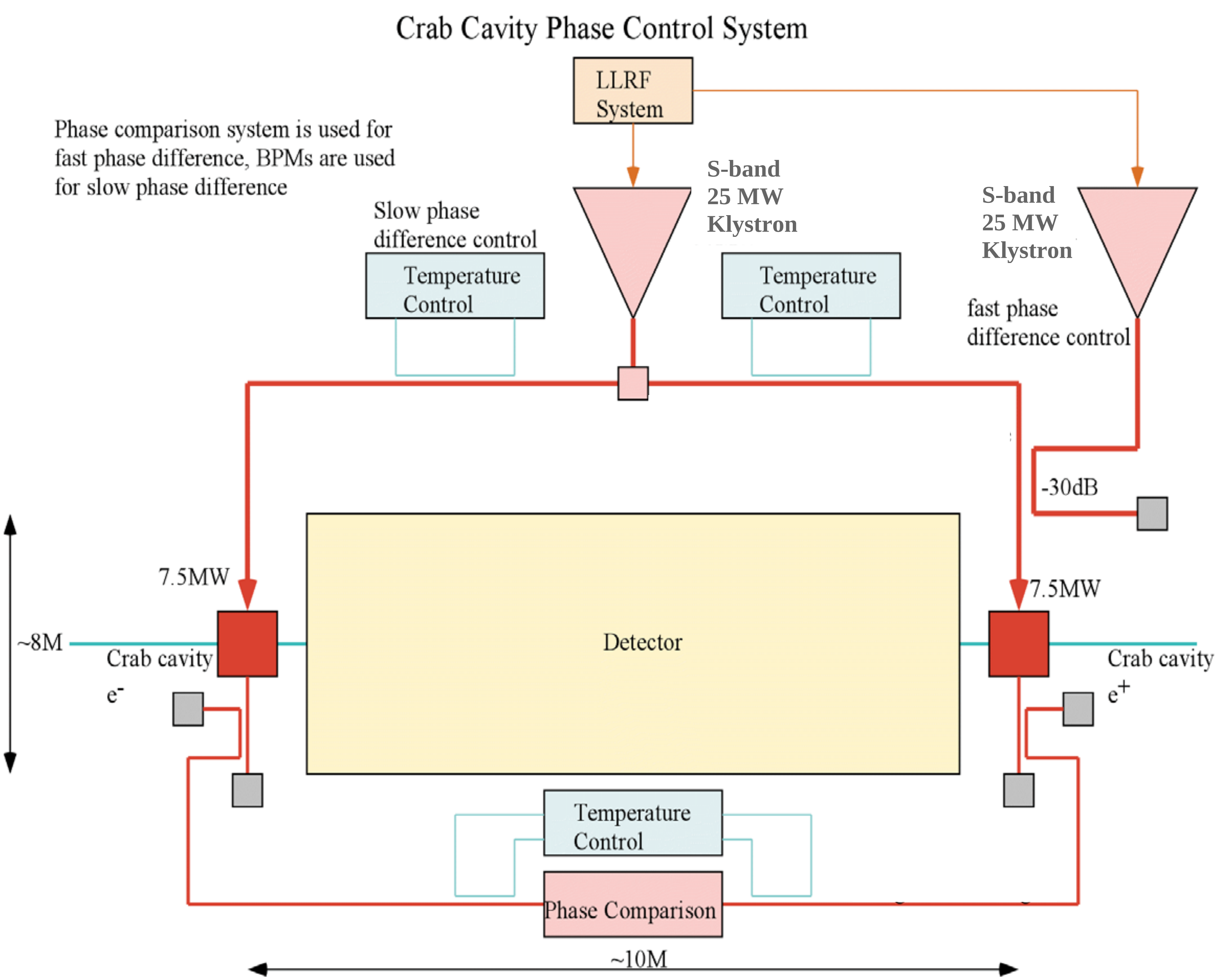
In the ZDR, both S-band and X-band were considered for the crab cavities. S-band was preferred because the larger iris would reduce problems caused by wakefields, but an S-band system has tighter phase tolerances than X-band. Preliminary design studies indicated that even an S-band system was feasible, and S-band crab cavities were adopted as the baseline design.

System Requirements: At 250 GeV beam energy, the RF voltage required is about 4.5 MV. This implies 7.5 MW of klystron power to feed each 1 meter S-band structure, 20 MW in total. The cavity voltage stability requirement is relatively loose, about 6%, and



should be easy to obtain. The common mode phase jitter tolerance is 0.5 degree. The differential mode phase tolerance is the most difficult specification at 0.05 degrees S-band. Beam-based feedback can be used to match the phases at timescales longer than about 0.2 seconds. The challenge is differential phase jitter.

Drive System: To provide the required stability, the planned system uses a single klystron to drive both cavities. The power is split and transported using temperature-controlled waveguide. Relative phase adjustments between the cavities are made with a second RF source, (probably also a klystron) a small fraction of whose power is sent to one of the cavities. This power is used to make small changes to the relative phases and amplitudes. A block diagram of the proposed system is shown if Figure 1.

Drive Jitter: In the absence of a breakdown, with the two cavities driven by the same klystron, any phase jitter is presumed to be due to path length changes in the drive waveguide. 0.05 degrees S-band corresponds to a waveguide length change of about 15 microns. To set the scale, the stability tolerance for the final quadrupole magnets is much tighter than this. Changes in the shape of the S-band waveguide can affect the propagation velocity, and therefore the output phase. The length of waveguide from the klystron to each crab cavity is estimated to be about 40 meters. This means that the allowable phase shift corresponds to a change in propagation speed in the waveguide of 3×10^{-7}. This is roughly equivalent to a change in the dimension of the waveguide of 30 nanometers.

Measurements on standard SLAC waveguide (performed before SLAC was constructed) showed approximately a 2 degree S-band per Meter-Atmosphere shift with atmospheric pressure. This would indicate that an atmospheric pressure change of 1/2000 atmosphere would cause an unacceptable phase shift. Static pressure shifts would be corrected by slow feedbacks, so acoustic noise provides the primary source. This pressure change corresponds to an acoustic noise level of approximately 130dB, much higher than expected. The range of frequencies of interest is probably from a few Hz to about 100Hz. Frequencies higher than this will have several wavelengths within the length of the waveguide, and lower frequencies will tend to not provide differential effects, and will be attenuated by feedback. Note that thicker wall waveguide can be used if these effects become significant.

The phase trim klystron is coupled with a -30dB coupler. This allows a maximum fast phase control of about +/-2 degrees. Noise on this klystron will have only a small effect on the output phase due to the attenuation.

Phase Jitter Measurement: In order for the feedback to operate, it is desirable to be able to measure phase jitter between the cavities on a pulse to pulse basis. We now consider the problems associated with measuring an S-band phase difference to 0.05 degrees. We assume the use of a mixer to measure the phase difference between the two cavities. The cables / waveguide from the cavities to the mixer will be subject to the same noise limitations as the power waveguide.

Typical mixers operate with input levels of approximately 0dBm, with a conversion loss of about 6dB. The required detection bandwidth is approximately 10MHz. In that bandwidth, thermal noise in a 10MHz bandwidth is -98dBm. If we allow an amplifier noise figure of 6dB, we are left with a signal to noise of 86dB. This is sufficient to detect phase shifts of 0.003 degrees.

Prototype: Although the drive and detection problems seem practical, it may still be interesting to construct a prototype system. Effects from either high power, or possibly vibrations due to water cooling, could be an issue. In addition a prototype would allow checking for unforeseen problems. A prototype using high power components, but operated at low power could be constructed first. This system could be connected to high power klystrons as a second stage test. The proposed layout of a prototype system is shown in Figure 2.