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Thermal Stabilization of Low Level RF Distribution Systems at SLAC*

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ABSTRACT

Analysis of SLC accelerator operator activity, in particular control system knob turns, indicated poor thermal stability performance of the low level RF distribution system in the SLC injector and positron production complex. Daily drifts of up to 15° S-band delay, about 30 times the tolerance, were observed. In this paper we describe the tool used to track down and quantify operator knob turn activity, the low level RF distribution stabilization systems, and some fixes used to correct the problem. In order to identify poorly performing components, a beam timing or phase monitor diagnostic has been developed. Initial results from it will be presented.

INTRODUCTION

The SLC RF distribution system has evolved from the original SLAC design. The original system consists of a main drive line running the length of the linac with couplers at the beginning of each of the 30 sectors. The portion of the RF that is coupled out of the main drive-line at the start of each sector is amplified by a sub-booster, and distributed along a sub-drive line to each of the eight klystrons. Temperature stabilization of the main and sub-drive lines is only partially effective, and diurnal phase changes correlated with temperature have been a source of instability. For SLC, temperature stabilized phase reference lines[1] have been added to each sector. These reference lines provide a reference phase to each klystron in a sector. The injector and positron production complex have been fitted with a number of these phase reference lines and a marked increase in the phase stability has been observed. However, operators must still apply diurnal phase adjustments to the electron injector and the positron capture klystrons to maintain injection of electrons and positrons into the damping rings. Two software packages; Error Log and SLC History Buffers[2] are used to help determine which RF devices require the most adjustment. Some of the phase stability problems have been traced to poor temperature stabilization of coaxial cables. A low cost coaxial cable temperature stabilization system has been developed to fix identified problems.

KNOB TURNS OVER FOUR HOUR INTERVALS

KNOB	6-10	10-14	14-18	18-22	22-2	2-6	COUNT
POSPHAS	89	105	106	105	112	70	587
NLTRPHAS	35	55	68	63	24	4	249
DR02 PH 6	12	20	20	22	30	50	154
PHSRMP	17	35	14	13	21	34	134
EP02 S 700	35	22	18	10	24	4	113
CIDM_PHAS	24	32	9	6	5	—	76
YP@NINJ	24	11	8	5	6	1	55
XP@NINJ	28	10	7	5	3	1	54
X@NINJ	20	11	8	8	5	1	53
Y@NINJ	20	9	9	5	6	1	50
EP_Y_MM	—	6	4	4	3	—	17
EPYNG_MR	—	6	4	3	3	—	16
EPXNG_MR	—	5	3	—	4	—	12
EXPV36	—	—	—	—	—	10	10
PXPV36	—	—	—	—	—	10	10
NUY@NDR	1	—	—	—	—	—	9
EP_X_MM	—	3	3	—	3	—	9
NUX@NDR	1	—	—	—	—	—	8
Y@SINJ	—	2	—	2	4	—	8
K20-4A DRV	—	—	—	—	7	—	8
XP@SINJ	—	—	1	1	4	—	7
LI11YPOSE+	—	—	—	7	—	—	7
X@SINJ	—	—	1	1	3	—	6
DR11 AM 1	—	—	2	—	—	—	6
YP@SINJ	—	—	—	1	3	—	6
NLTRENGYE-	—	—	5	—	—	—	6
DR01 AM 1	—	—	3	—	—	—	5
PHBM1V 10	—	—	—	5	—	—	5
1-1BPAU	—	—	2	—	—	—	4

Figure 1: Knob turns made by the operators over a 24 hr. period are shown above. The first six are knobs that control RF phase shifters in the electron and positron production areas. The large number of knob turns for these devices, indicates phase poor stability in the their respective RF distribution systems.

SOFTWARE TOOLS

KNOB TURNS

The SLC control system is used to control all phase shifters in the RF distribution system. An operator wishing to adjust the phase of an RF device, selects the appropriate phase shifter and assigns it to a knob. The knob is turned to adjust the phase the desired amount. A control system program called ERROR LOG creates an entry in a file each time the knob is turned. The entry consists of a time stamp, the knob name, the identification number of the control console where the knob was assigned, and the value of the device. The entries can be collected for any period of time up to a year and printed out. Figure 1 shows the knob turns for a 24 hr. period. The first six entries are phase shifters. The large number of knob turns for these devices indicate stability problems with the corresponding portions of the RF distribution systems.

HISTORY BUFFER

The SLC History Buffer is another software tool. Every three to six minutes the data returned from most devices is saved. The data can be plotted vs. time, or vs. the data from other devices. The data can be plotted for the last few minutes, or the last year. The history buffer data is used to look for correlation's between phase changes in RF devices and temperature. When the phase of a device is dependent on several parameters, including temperature, the history buffer data of the known parameters can be subtracted away revealing any remaining temperature correlation. Figure 2 shows a portion of the injector RF distribution system. The CIDM_PHAS PAD (phase and amplitude detector) provides a measurement of the phase between the injector klystron RF and SB 0 (sub-booster 0) RF. The SB 0 PAD measures phase changes made by its phase shifter. Phase changes measured by the CIDM_PHAS PAD should be due only to adjustments of the CIDM_PHAS phase shifter and the SB 0 phase shifter. Figure 3a shows history buffer readings of the CIDM_PHAS PAD. Figure 3b shows the same data after subtracting out the phase changes made by operators adjusting the CIDM_PHAS phase shifter. If the RF distribution system were perfect, the remaining phase changes should be due entirely to changes in

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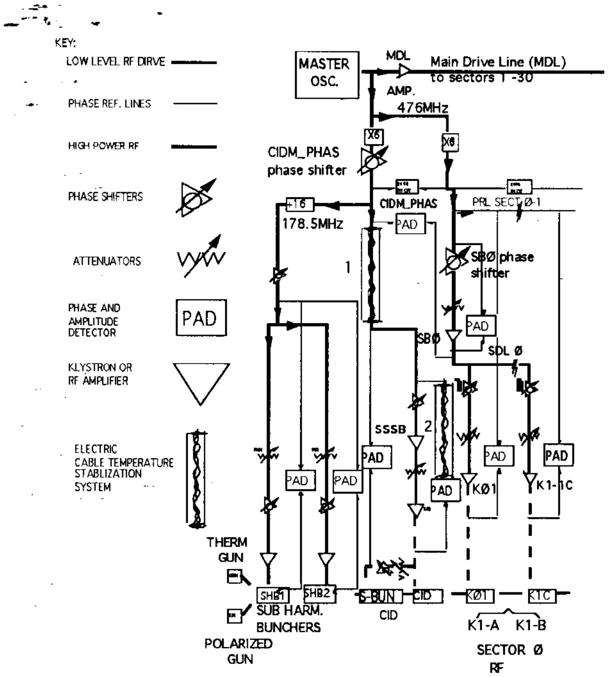

Figure 2: Electron injector RF distribution system. Operators adjust CIDM_PHAS and SB 0 phase knobs to maintain injection into the north damping ring. Two 2.5m sections of the RF distribution system have been fitted with a electric cable temperature stabilization system (shown with the numbers 1&2 above). This has improved the stability of the system.

the phase of sub-booster 0. In figure 3c, the data from the SB 0 PAD is subtracted from the data in figure 3b. A remaining diurnal phase change is clearly seen. These two sections of the RF distribution system are being investigated to determine the cause of this phase error.

PHASE REFERENCE LINE IMPROVEMENTS

An inspection of the phase reference lines in the injector revealed two 2.5 m sections and a number of smaller lengths that had no temperature stabilization. The phase reference lines are "phase stabilized" lengths of Andrews LDF4-50 coaxial cable. The phase change calculated from Andrews phase stability documentation[3], indicated that the 5m of unstabilized cable should have an S-band phase shift of 0.04 deg./ °F. For the 30°F temperature change shown in figure 4a, the 5m of unstabilized cable should contribute 1.25 degrees to the observed 8.5 deg. S-band phase change. At the end of the 1992 run these two 2.5m sections of cable were fitted with the electrical stabilization system described below. History buffer data showing the correlation between temperature and phase for the 1992 and 1993 runs are shown in figure 4. Stabilizing the 5m of cable, reduced the temperature phase correlation by 14%. This is in good agreement with the predicted change of 15% .

TEMPERATURE STABILIZATION OF COAXIAL CABLES

For SLC, the control of propagation delay in the phase reference lines has been accomplished by placing the cables inside double wall tubing with temperature-stabilized water flowing between the walls[1]. Hot and cool water are mixed so that the temperature at the pump output was kept constant. A new system that operates well above the ambient temperature and requires only the input of heat has been developed.

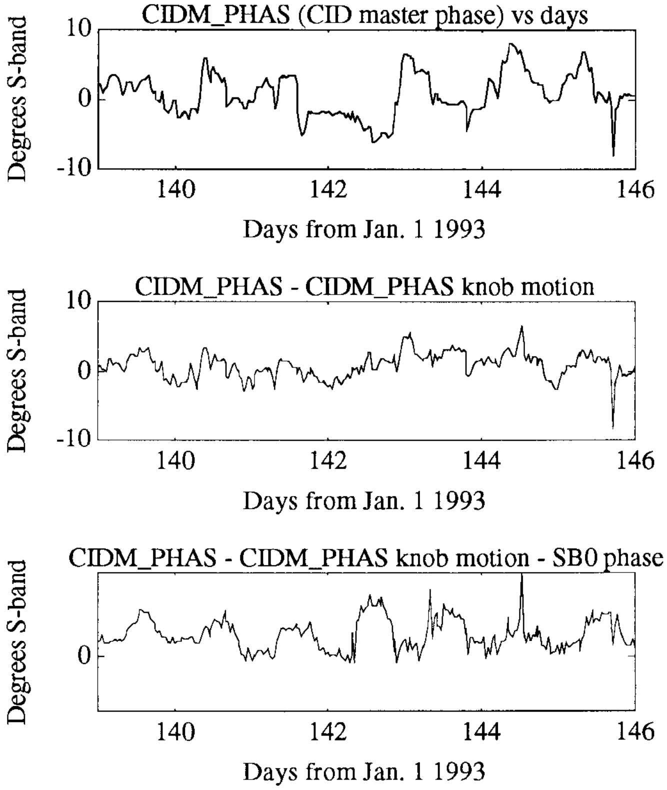

Figure 3: Figure 3a (Top) is history buffer data from CIDM_PHAS PAD. Figure 3b (middle) is CIDM_PHAS PAD data minus CIDM_PHAS knob turns. Figure 3c (bottom) is data from figure 3b minus SB 0 PAD data. The remaining diurnal phase variations indicate temperature instabilities is the low level RF distribution system.

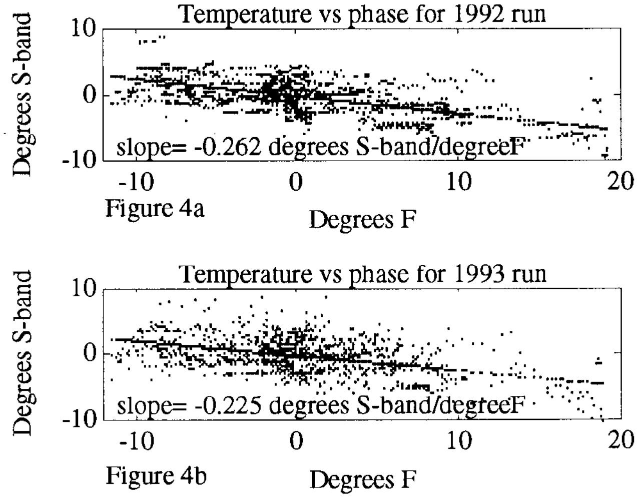

Figure 4: Figure 4a shows the temperature phase correlation between the injector air temperature and CIDM_PHAS PAD readings for the 1992 run. Two electric cable temperature stabilization systems were added (see figure 2) before the 1993 run. Figure 4b shows the resultant 14% reduction in the temperature phase correlation.

In this scheme, control of the propagation delay of coaxial cables is accomplished by maintaining an average cable temperature. If the temperature drops in a section of cable producing a decrease in propagation delay, the entire cable temperature is raised slightly to produce an increase in delay that cancels the original change. A sensor described below measures the cable's average temperature. Heater tapes are used to heat the cable to its operating point and produce the small temperature changes which control its propagation delay. The coaxial cables, the sensor, and heater tapes are covered with semi-rigid foam insulation. A cut away drawing of the system is shown in figure 5.

Measuring the average temperature of the cable with a single sensor distributed over the entire cable was determined to be more effective and less costly than many discrete sensors. A distributed RTD (resistance temperature detector) running the length of the cable was developed. A prototype sensor was constructed by sandwiching eight strands of 36 gauge enameled copper wire between two pieces of flexible cloth backed tape. The number and gauge of the strands can be varied so that when connected in series and in parallel, the resistance is 100 ohms at 0 °C. Minco Corp. manufactures distributed RTDs and can supply units up to 80ft. in length.

Heat for the system is provided by self-regulating heater tapes manufactured by Raychem Corp. This product consists of two parallel conductors with a resistive material between them. As the temperature of the tape increases the resistance of the material between the conductors also increases reducing the current flow through the tape. This self regulating feature prevents thermal runaway in the event of a temperature controller malfunction. This product has an output of 32.8 watts/m at 10 °C. As the temperature of the cable is raised to its normal operating point of about 43 °C, the output of the heater tape falls to 12 watts/m. A double helix of this material is wrapped around the cable assembly with a pitch of one revolution/m, giving a total of 24 watts/m for both heater tapes. The insulating foam jacket has an inside diameter of 7.6cm and a wall thickness of 2.5cm. Using the foam's R value of 5.2 and a maximum temperature differential of 50 °C, the heat loss through the insulation is 20 watts/m.[4] The distributed RTD is connected to a standard temperature controller whose setpoint is adjusted above the highest expected air temperature. The controller applies power to the heater tapes to increase the average temperature of the coaxial cable. After the average temperature of the cable reaches the setpoint, the power is cycled on and off by the controller to keep the temperature constant.

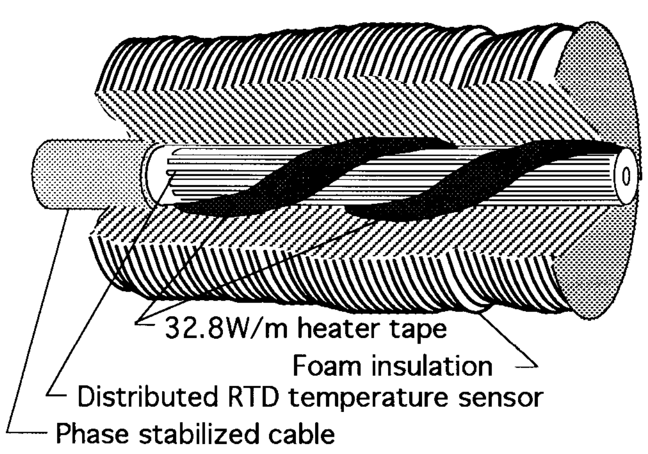

Figure 5: Cut away of a section of temperature stabilized cable. The distributed RTD (resistance temperature detector) runs the length of the cable and is connected to a temperature controller which then measures the average temperature of the cable. The controller cycles power to the heater tapes to maintain this temperature.

PERFORMANCE OF STABILIZED COAXIAL CABLES

The performance of the temperature stabilized cable was evaluated by measuring its propagation delay. A TDR (time domain reflectometer) was connected to a 10 meter piece of temperature controlled cable and the round trip travel time of the pulse was measured over several day/night periods. Results of this test are shown in figure 6. The calculated temperature change of the cable while the temperature stabilization system was functioning is about +/-0.35 °C. This is based on the 20m path length of the TDR pulse, the 0.042ps/m °C temperature coefficient for the cable and the 0.3ps propagation delay change observed in figure 6. Tests on other pieces of stabilized cable have indicated that the temperature controller used is affected by the temperature variations in the klystron gallery. Tests with other controllers are planned for the future.

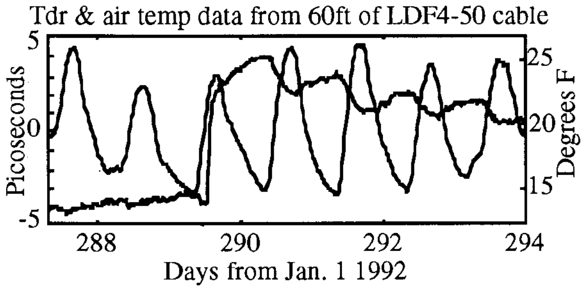

Figure 6: TDR (time domain reflectometry) data of temperature stabilized cable, along with outside air temperature. While the temperature stabilization system was active, the change propagation delay of the 20m cable was 0.3ps. The system was turned off around noon on day 289.

CONCLUSIONS

Software tools have been developed to help locate and quantify stability problems in the SLC low level distribution system. Knob turn software has identified the systems that show the greatest instability and History Buffers have been used to demonstrate the magnitude of the temperature phase correlation's. Initial installations of electric cable temperature stabilization systems have proved to be reliable and effective at maintaining the average temperature of the cables at +/-0.35 °C

ACKNOWLEDGMENTS

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