SINGLE PASS COLLIDER MEMO

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TITLE: REFERENCE KLYSTRON OUTPUT PHASE VALUES FOR THE FIRST TEN LINAC SECTORS
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1.0 INTRODUCTION

The purpose of this note is to provide phase reference values for klystrons in the first ten linac sectors to be used as tentative start-up values next September and to point out the degree of long term phase stability of the klystrons as well as the possibility of implementing closed loop feedback stabilization.

2.0 HARDWARE MODIFICATIONS IMPACT

Several hardware changes are scheduled to happen in the linac first ten sectors during the summer shut-down, the most significant for our purposes are:

1. replacement of the existing sub-booster electronic phase-shifter by a new one of improved linearity.
2. installation of the modified Modulator Klystron Support Unit (MKSU) which allows for computer control of the sub-booster drive attenuator and of the electronic phase shifter.
3. installation of the new Isolator Phase-shifter Attenuator (IPHA) package for each klystron, which contains the old Fox phase-shifter and the new electronic attenuator.
4. installation of the MKSU which allows for computer control of the input drive power to the klystron and of the Fox phase-shifter position through the SLC control system.

These hardware additions and/or modifications will make all previous reference settings of the klystron phase-shifters obsolete. The only valid information will be the data derived from the Phase and Amplitude Detectors (PADs)¹. We have therefore estimated it useful to report the reference phase values for the first ten linac sectors as computed from measurements logged during the month of April 1984. It seems reasonable to attempt acceleration of a beam in the linac at start-up time next September having set up this phase configuration.

3.0 PHASE AVERAGE COMPUTATION

The phase values reported in table 1 represent averages over one month. This is strictly true for sectors 2 through 10 but not quite for the first two sectors. In fact the phase values for sectors 0 and 1 depend strongly upon the setting of the dc phase closure. The relative phase between two klystron in sectors 0 and 1 did not change by large amounts, but the reported values read by the phase detectors

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did move in the ± 180 degrees range depending on the phase closure setting. This happens because, after a major rephasing of the linac front end by the MCC operator, the phase closure setting is used to phase the first two sectors with respect to the rest of the machine. In order to eliminate this coherent drift from the phase data we have selected klystron 21 in sector 1 as the reference and computed the correction terms $\Delta\Phi^i = \Phi_{21}^i - \Phi_{21}^0$ where Φ_{21}^0 is the phase of klystron 21 on April 29, 1984, date of the last useful data logging and Φ_{21}^i is the value for day i. The correction terms $\Delta\Phi^i$ have then been added to the phase values of the other klystrons in sectors 0 and 1 for day i so that the phase averaging was done according to:

$$\bar{\Phi}_k = \frac{\sum_i^N (\Phi_k^i + \Delta\Phi^i)}{N}$$

where N is the number of phase data sets. The values $\bar{\Phi}_k$ are reported in table 1 for sectors 0 and 1. We have preferred to use the measured phase variations over time of klystron 21 in sector 1 rather than the settings of the phase closure phase-shifter which works at 476 MHz because there is no direct measurement of the phase variations introduced by this phase-shifter on the main drive line.

4.0 LONG TERM STABILITY

In order to investigate the long term phase stability of klystrons we have used the program SAMPLE to log the phase values every three hours for about one week at a time (64 data points) and we have used ERRLOG to plot the data. The long term stability of the sub-booster is critical because the effect of its variations is amplified by one sector worth of klystrons. Fig.1 shows respectively the variations of the bias voltage to the sub-booster phase-shifter in sector 5 as moved by the MCR operators (1a), the phase variations at the sub-booster output as measured by the phase detector (1b) and the difference between the two previous plots which shows the intrinsic phase stability of the sub-booster (1c). One can clearly see the daily phase variations very likely due to the temperature excursion of the cooling water.

Fig. 2a shows the phase plots for klystron 11 in sector 5 taken during the same time period. Again using the facility in ERRLOG to operate on plots, we have subtracted from the klystron output plot (2a) the sub-booster output (1b) to obtain the plot in Fig.2b which show the daily excursions of the klystron phase independently of sub-booster output phase variations. Figs 3 through 9 show the corresponding plots for the other klystrons in sector 5 which we have chosen as a typical example. Large and rapid phase variations in the plots type b are due to steering of the Fox phase shifters by the linac operators: one can see that an internal sector rephasing process has occurred at point 44 on the time axis. We found that differences exist in the long term phase stability of klystrons and we have computed standard deviations for the values of table 1 which range between 2 and 10 degrees. The klystron phase excursion are very likely caused by cooling water temperature variations; such variations were logged during the month of April and Fig.10 shows a typical plot taken at 1 h intervals. However more extensive data logging is needed to establish a quantitative relation between water temperature and klystron phase variations.

5.0 CLOSED LOOP FEEDBACK

The installation of the MKSU and of the new IPHIAs in the first ten sectors of the linac will permit the implementation of closed loop phase stabilization. In this scheme the phase information is

read from the phase and amplitude detectors already operational and the phase correction is done by means of the electronic phase-shifter for the sub-boosters and the Fox phase shifters for the klystrons. The loops are closed through software which resides either in the VAX or in the local micro. The task of the surveillance program is to compare the actual phase value, averaged over several pulses, against the desired one and then decide whether it is within tolerance. In the negative case the program takes action and trims the phase to the desired value. When a sub-booster drifts in phase, all the klystrons in the sector follow the drift. If one is to avoid conflicts among the various phase loops, one has to assign tighter tolerances to the sub-booster phase loop with respect to the ones for the klystrons. Typically one would set the sub-booster phase tolerance to 1 degree and the one for the klystrons to 2 or 3 degrees. Moreover, when an operator wants to move the phase of one whole sector by changing the desired phase value of the sub-booster and then trimming the phase, the klystron phase loops should not fight this action by turning the Fox phase shifters to keep their output phase constant. A simple way to avoid this conflict is to use the difference between the klystron and sub-booster phases as the reference for the closed loop.

In this case if one shifts the sub-booster phase from Φ_{SB} to $\Phi_{SB} + \Delta\Phi$ then each klystron in the sector will undergo a phase shift from Φ_u to $\Phi_u + \Delta\Phi$ but the difference $\Phi_u - \Phi_{SB} = \Phi_u + \Delta\Phi - \Phi_{SB} - \Delta\Phi$ will stay the same and therefore the klystron phase loop will remain inactive. One problem with this scheme is caused by the non-linearity of the nulling phase-shifter in the phase detector. A 20 degrees phase shift in the sub-booster output may be reported as 19 or 21 degrees at the klystron according to the phase value at which the klystron sits. However, should this effect prove to be troublesome, one can introduce an accurate polynomial approximation of the PAD phase-shifter characteristic and thus minimize the effect.

6.0 PHASE CONFIGURATIONS

The set of phase reference values for the klystron phase loops ($\Phi_u - \Phi_{SB}$) should not vary by any large amount over time because they represent the ideal phase setting for each klystron within a sector. Indeed one of the major tasks after start-up will be to understand what influences the stability of these reference values. At any rate, when a consistent set has been found, it should not change significantly with time and the table of values should be stored as reference for each sector. However, any significant change in the electrical length of the main drive line as detected by the interferometer will dictated a correction to be applied to the desired phase value of each sub-booster proportionally to its distance from sector 0. This steering of the sub-booster phases will have no impact on the klystron phase loop reference values for the reasons discussed in the previous paragraph; the sub-booster phase-shifters settings will change presumably according to a slow modulation of 24 h period. The average (over 24 h) desired sub-booster phase values for one particular beam will constitute the phase configuration for that beam. This constitutes a set of some 30 values to be stored in the VAX memory for each configuration.

7.0 BEAM PHASE REFERENCE

The closed feedback loops mentioned in the previous paragraphs can be implemented in the first ten liuac sectors very rapidly after start-up. One more loop which is highly desirable and which

will presumably be implemented at a later stage makes use of the beam induced phase measurement, a device which is still being experimented with. It consists of a modified version of the phase and amplitude detector which measures the phase of the signal induced by the beam in a passive resonant cavity with respect to the stabilized reference line. The obvious way to use the beam induced phase information assuming that one such device gets installed in every linac sector, is to lock the phase of the sub-booster in the next sector (the resonant cavity being located at the end of each sector) to the beam phase averaged over several pulses. Once the sub-boosters are phase locked to the beam and each klystron is phase locked to its sub-booster, it should be possible to have a much smoother operation of the linac or, in the worst case, it should be possible to investigate the causes of long term beam instabilities under much clearer conditions.

8.0 ACKNOWLEDGMENTS

The SAMPLE program was written by Fabrizio Gagliardi. Nancy Spencer has introduced in ERRLOG the facilities to perform arithmetic operations on graphs. Nan Phinney has supplied the data on water temperature excursions.

9.0 REFERENCES

- ¹ "A Microprocessor Controlled Phase Measurement System for 2856 MHz Pulses", J. D. Fox, H. D. Schwarz, SLAC PUB 2302.

	SBST	KLYS 11	KLYS 21	KLYS 31	KLYS 41	KLYS 51	KLYS 61	KLYS 71	KLYS 81
LI00	96	-22*	-14*	140*	-58*	71*			
LI01	-63	-	-110	30	-33	167	-108	138	-105
LI02	-58	-170	-70	41	-39	-11	-82	-160	170
LI03	5	-126	35	14	100	126	-117	-83	119
LI04	131	-55	22	23	98	151	-179	157	-32
LI05	-48	142	26	-40	-6	-92	-95	-30	152
LI06	-136	-147	73	-	153	117	-128	165	-74
LI07	-163	147	-17	75	80	34	50	91	-18
LI08	-96	69	-43	63	-64	58	77	-133	86
LI09 **	-	-	-	-	-	-	-	-	-
LI10	81	-121	61	53	93	-132	-38	na	na

Table 1

Phase Closure set at -130°

* in sector 0 the klystrons are called 01, 02, 11, 12, 13 resp.

** Sector 9 is not operational.

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	SBSST	KLYS15	KLYS21	KLYS31	KLYS41	KLYS51	KLYS61	KLYS71	KLYS81
I ϕ 0	96	-22*	-14*	140*	-58*	671*			
I ϕ 1	-63	-10	-110	30	-93	167	-108	138	-105
I ϕ 2	-58	-170	-70	41	-39	-11	-82	-160	170
I ϕ 3	5	-126	35	14	100	126	-117	-83	119
I ϕ 4	131	-55	22	23	98	151	-179	157	-32
I ϕ 5	-48	142	26	-40	-6	-92	-95	-30	152
I ϕ 6	-136	-147	73	-	153	117	-128	165	-74
I ϕ 7	-163	147	-17	75	80	34	50	91	-18
I ϕ 8	-96	69	-43	63	-64	58	77	-133	86
I ϕ 9	**								
I10	81	-121	61	53	93	-132	-38	ma.	ma.

PHASE CLOSURE SET AT -130°

TABLE 1

* in vector ϕ the Klystron are called $\phi_1, \phi_2, 11, 12, 13$ resp.
 ** I ϕ 9 or 9 is not specified.

FIG. 1a PHAS LI05 1 BACT FROM 2-APR-1984 11:51:12 BY 03:00:00

FIG. 1b SBST LI05 1 PHAS FROM 2-APR-1984 11:51:12 BY 03:00:00

FIG. 1c SBST LI05 1 PHAS-BA FROM 2-APR-1984 11:51:12 BY 03:00:00

FIG. 2a KLYS LI05 11 PHAS FROM 2-APR-1984 11:51:12 BY 03:00:00

FIG. 2b KLYS LI05 11 PHAS-SB FROM 2-APR-1984 11:51:12 BY 03:00:00

FIG. 3a KLYS LI05 21 PHAS FROM 2-APR-1984 11:51:12 BY 03:00:00

FIG. 3b KLYS LI05 21 PHAS-SB FROM 2-APR-1984 11:51:12 BY 03:00:00

FIG. 4a KLYS LI05 31 PHAS FROM 2-APR-1984 11:51:12 BY 03:00:00

FIG. 4b KLYS LI05 31 PHAS-SB FROM 2-APR-1984 11:51:12 BY 03:00:00

FIG. 4c KLYS LI05 41 PHAS FROM 2-APR-1984 11:51:12 BY 03:00:00

FIG. 5b KLYS LI05 41 PHAS-SB FROM 2-APR-1984 11:51:12 BY 03:00:00

Fig. 6a KLYS LI05 51 PHAS FROM 2-APR-1984 11:51:12 BY 03:00:00

Fig. 6b KLYS LI05 51 PHAS-SB FROM 2-APR-1984 11:51:12 BY 03:00:00

Fig. 6c KLYS LI05 61 PHAS FROM 2-APR-1984 11:51:12 BY 03:00:00

Fig. 6d KLYS LI05 61 PHAS-SB FROM 2-APR-1984 11:51:12 BY 03:00:00

Fig. 24 KLYS LI05 71 PHAS FROM 2-APR-1984 11:51:12 BY 03:00:00

Fig. 25 KLYS LI05 71 PHAS-SB FROM 2-APR-1984 11:51:12 BY 03:00:00

Fig. 26 KLYS LI05 81 PHAS FROM 2-APR-1984 11:51:12 BY 03:00:00

Fig. 27 KLYS LI05 81 PHAS-SB FROM 2-APR-1984 11:51:12 BY 03:00:00

FIG. 10 ASTS LI05 1 KLY9H20 FROM 20-APR-1984 17:39:41 BY 01:00:00