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POWER REDUCTION BY CHANGING THE DESIGN PARTICLE PHASE*

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The side-coupled linac at the Clinton P. Anderson Meson Physics Facility (LAMPF) at the Los Alamos National Laboratory operates at a design phase of -30 degrees, except for the first few modules, which have design phases tapering from -36 to -30 degrees in order to increase the acceptance. (Design phase for this stepped-beta structure is equivalent to synchronous phase. The rf amplitude is proportional to the secant of the design phase, and thus a module operated at -36 degrees has a higher amplitude than one operated at -30 degrees.) Calculations with the GROPE and SIMALAC codes indicate that the longitudinal and transverse beam characteristics would be little affected if the design phase of the downstream end of the linac was gradually ramped to -20 or -15 degrees, thus lowering the rf amplitude for this part of the linac. Experimental tests of this mode of operation are described, and the expected power savings are discussed.

Introduction

The LAMPF 805-MHz linac is used to accelerate H+ and H- beams from 100 to 800 MeV. It is a side-coupled structure consisting of 104 tanks coupled in fours or twos to form 44 modules. (The modules are numbered from 5 to 48.) It is a stepped-beta structure in that within each tank, the cell length is constant. The original design specified a design phase of -30 degrees, meaning that the accelerated particles cross the cell centers 30 degrees before the peak of the rf field on the average. When the 805-MHz linac was operated this way, it was difficult to capture all of the beam exiting from the drift-tube linac upstream, and it was decided to increase the acceptance of the 805-MHz linac. This was done by increasing the design phase of the first module to -36 degrees and letting the design phase decrease in 0.5 degree steps until -30 was reached, continuing with -30 degrees through the rest of the linac as before. This did improve the performance of the machine.

Currently two major thrusts of investigation are in progress with the aim of further improving the capability and performance of the 805-MHz linac. One is to see if power can be saved by reducing the acceptance of the downstream end of the linac. The other aims to better measure and control the transverse behavior of the beam while maintaining satisfactory longitudinal performance so that high intensity beams of both H+ and H- can be accelerated. (Currently only the H+ has high intensity, up to 600 microamperes average current.) This paper will discuss only the investigation of whether power can be saved and related matters.

Figure 1 shows that the phase spread along the linac remains about constant or shrinks slightly approaching the downstream end. At the same time, as one approaches the downstream end of the linac, the acceptance of the remaining portion of the linac increases. This suggests that the acceptance of the downstream end of the machine is

MOD	NG	WAVG	PHASE PROFILE(80 DEG)
5	500	113.06	......XXXXXXXXX.....
6	500	125.93	.......XXXXXXXXX....
7	500	139.61	...../XXXXXXXXX.....
8	500	153.28	......XXXXXXXXXX....
9	500	167.96	.....XXXXXXXXXX.....
10	500	182.06	......XXXXXXXXXX....
11	500	196.66	.....XXXXXXXXXX.....
12	500	211.30	......XXXXXXXXXX....
13	500	226.55	........XXXXX/X/....
14	500	241.29	....XXXXXXXXXXX.....
15	500	256.62	......XXXXXXXXX.....
16	500	271.67	........XXXXX/X/....
17	500	286.85	.....XXXXXXXXX/.....
18	500	302.56	.......XXXXXXXX.....
19	500	318.55	........XXXXXXX//X..
20	500	334.33	......XXXXXXXXX/....
21	500	350.28	....X///XXXXX.......
22	500	366.15	....../XXXXXXXX.....
23	500	382.19	........XXXXX///X...
24	500	397.80	......XXXXXXXX......
25	500	414.20	..../X.XXXXXXX......
26	500	430.62	.......XXXXXXXX.....
27	500	447.29	........XXXXX//.X...
28	500	463.83	.......XXXXXXX/.....
29	500	480.19	......X/XXXXX.......
30	500	496.55	....../XXXXXXXX.....
31	500	513.46	........XXXXXXX/....
32	500	530.35	.......XXXXXXX/./X..
33	500	547.01	.......XXXXXXX./....
34	500	564.11	......XXXXXXX.......
35	500	581.49	...../XXXXXXXX......
36	500	598.31	........XXXXXXX.....
37	500	615.12	........XXXXXX.X....
38	500	631.63	.......XXXXXXX.X/...
39	500	648.32	.......XXXXXX/......
40	500	665.31	......X/XXXXX/......
41	500	682.12	...../X.XXXXXX......
42	500	699.17	......../XXXXXX.....
43	500	716.33	........XXXXXXX/....
44	500	733.56	.......XXXXXXX.X/...
45	500	750.13	.......XXXXXXX./....
46	500	766.41	....../XXXXXX.......
47	500	782.84	......X/XXXXXX......
48	500	799.70	....../XXXXXXX......

Fig. 1. Phase spread relative to design particle phase along the 805-MHz linac. NG is the number of particles, and WAVG is their average energy (MeV).

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not as critical as at the front end, and that it may be possible to decrease the rf field amplitude in the downstream end of the machine.

Expected Benefits

Figure 2 shows the present design phase and two proposed design phase configurations. Calculations show that the design phases of curves B and C would result in power savings of 5% and 8% respectively.

If one assumes that the power going into the 805-MHz linac may be reduced by 5% by such means, and if one assumes that the efficiency of the klystrons and their power supplies is approximately independent of power level, the power consumption of the 805-MHz linac facility will also be reduced 5%. If one assumes that typical operation requires 7 megawatts for the facility and that it is operated for 8 months of the year, the annual consumption of electricity by this part of LAMPF is reduced by 2000 megawatt hours. For electricity costing 30 mils per kilowatt-hour, this would mean an annual saving of $60 000.

Beam Dynamics Calculations

The analysis of a proposed design phase configuration is done in two steps. In the first step, a code named GROPE is used to optimize the longitudinal dynamics for a single particle. In the second step, the module-to-module rf phases found in step one are used in a code named SIMALAC to analyze the longitudinal or longitudinal and transverse behavior of a bunch containing up to 500 particles.

The GROPE code was written by K. R. Crandall. It analyzes progressively larger sections of the linac, finding the optimum beam phase and energy at the entrance and exit, first considering individual tanks, then individual modules, and finally the whole linac. Input to the code includes design phases for each module and lengths and spacings for each tank. Output includes module-to-module phases and various parameters needed to set the amplitudes and phases of the modules of the accelerator (where amplitude and phase cannot be measured directly to the required precision).

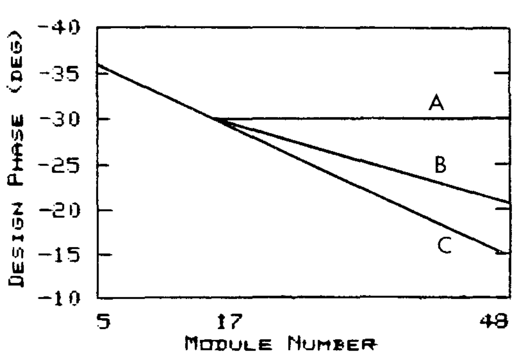

Fig. 2. Present design phase configuration (A) and two proposed configurations (B and C).

The SIMALAC code was developed by K. R. Crandall and G. R. Swain to trace particle trajectories through the 805-MHz linac. When one is simulating both longitudinal and transverse motion, the effects of misalignments, earth's field, and certain quadrupole magnet imperfections may be included.

Calculations for the cases shown in Fig. 2 indicate that the longitudinal and transverse behavior is not greatly affected by tapering the design phase to -20 or -15 degrees at the downstream end of the machine.

Experimental Results

Configuration C of Fig. 2 was tried on LAMPF on the accelerator development period of 24 August 1981. A series of time-of-flight measurements called the delta-t procedure is used to set the rf amplitude and phase of the linac modules.[1] With only a few minor adjustments after the delta-t procedure was completed, a beam of 6 milliamperes peak, 230 microamperes average current was achieved. Some beam spill was seen along the linac, but it was thought that the spill could have been reduced with further intuitive minor adjustments.

On 30 August 1981 this configuration was tried again during the tuneup for the following production cycle. This time, there was spill for a broad spectrum of energies along the machine, and no simple intuitive adjustment could be found which would reduce the spill. The operators returned to configuration A for production.

Future Investigations

The experimental tests on reducing the rf amplitude at the downstream end of the 805-MHz linac indicate that configuration C of Fig. 2 is just beyond the limit of what is practical for this linac. It is planned to test a configuration such as B which is intermediate between the present production configuration (A) and that tested in August (C).

Further beam dynamics calculations with SIMALAC have failed to indicate specifically why configuration C is not satisfactory, but a new area for investigation was suggested: longitudinal matching. Profiles showing the energy spread of the beam relative to the design energy, as shown in Fig. 3, did not change in overall character as one changed from one of the design phase configurations to another. However, it may be observed that there is an abrupt increase in energy spread near module 13. Calculations indicated that in theory, one can reduce this jump in the energy spread by adjusting the design phases in this region of the linac. An example of

MOD	NG	WAVG	ENERGY PROFILE(4MEV)
5	500	113.06	......./XXXXXX/......
6	500	126.00	.......XXXXXXX.......
7	500	139.53	......./XXXXX/.......
8	500	153.34	......./XXXXX/.......
9	500	167.91	......./XXXXX........
10	500	182.11	......./XXXXX/.......
11	500	196.59	......./XXXXX........
12	500	211.41	......./XXXXXX//.....
13	500	226.40	...///XXXXXXXXXX//...
14	500	241.34	....../XXXXXXXX......
15	500	256.75	......//XXXXX/////...
16	500	271.48	.../X/XXXXXXXXXXX//..
17	500	286.90	..../XXXXXXXXX/......
18	500	302.72	....////XXXXXX/////..
19	500	318.42	..../XXXXXXXXXXXX....
20	500	334.23	....///XXXXXX///./...
21	500	350.43	...X/XXXXXXXXXXX/....
22	500	366.22	....../XXXXXXXX///./.
23	500	381.99	..////XXXXXXXX/X///..
24	500	397.80	..../XXXXXXXXX///....
25	500	414.36	..///X/XXXXXXXXXX....
26	500	430.69	....///XXXXXXXX//////
27	500	447.10	....XXXXXXXXXXXXXX...
28	500	463.72	//////XXXXXXXX//////.
29	500	480.34	../XXXXXXXXXXXXX/....
30	500	496.76	.//////XXXXXXX/////..
31	500	513.40	....//XXXXXXXXXX/////
32	500	530.14	.../XXXXXXXXXXXXXX...
33	500	546.97	///////XXXXXXX/////..
34	500	564.22	././XXXXXXXXXXX//./..
35	500	581.67	..////XXXXXXXXXX/....
36	500	598.34	.//////XXXXXXXX/////.
37	500	614.94	..////XXXXXXXXXXX////
38	500	631.49	.../XXXXXXXXXXXXXX//.
39	500	648.30	./////XXXXXXXX/////..
40	500	665.37	/////XXXXXXXXXX///./.
41	500	682.28	/./XXXXXXXXXXXXX///..
42	500	699.22	./////XXXXXXXXXXXX/..
43	500	716.23	.//////XXXXXXXX//////
44	500	733.40	./././XXXXXXXXXXX////
45	500	749.99	.../XXXXXXXXXXXXXX/..
46	500	766.43	.////XXXXXXXXX//////.
47	500	783.00	//////XXXXXXXX//////.
48	500	799.84	////XXXXXXXXXXX///../

Fig. 3. Calulated energy spread before longitudinal matching.

MOD	NG	WAVG	ENERGY PROFILE(4MEV)
5	500	113.06	......./XXXXXX/......
6	500	126.00	.......XXXXXXX.......
7	500	139.51	......./XXXXX/.......
8	500	153.36	......./XXXXX/.......
9	500	167.89	......./XXXXX........
10	500	182.14	......./XXXXX/.......
11	500	196.57	.......XXXXXX/.......
12	500	211.39	......./XXXXX/.......
13	500	226.48	....../XXXXXXX/......
14	500	241.37	....../XXXXXXX/......
15	500	256.63	......XXXXXXXX/......
16	500	271.55	......XXXXXXXX///....
17	500	286.95	......XXXXXXXX/......
18	500	302.57	...../XXXXXXXX/......
19	500	318.46	.....//XXXXXXXX/.....
20	500	334.33	......XXXXXXXXX/.....
21	500	350.36	....///XXXXXXX//.....
22	500	366.12	...../XXXXXXXXX/.....
23	500	382.09	...../XXXXXXXXX//....
24	500	397.90	...../XXXXXXXXX/.....
25	500	414.27	....//XXXXXXXXX/.....
26	500	430.57	.....XXXXXXXXXX/.....
27	500	447.15	...../XXXXXXXXX/.....
28	500	463.85	...../XXXXXXXXXX/....
29	500	480.36	..../XXXXXXXXXXX/....
30	500	496.62	....//XXXXXXXXX/.....
31	500	513.30	.....XXXXXXXXXX//....
32	500	530.18	...../XXXXXXXXX//....
33	500	547.11	...../XXXXXXXXXX/....
34	500	564.32	..../XXXXXXXXXXX.....
35	500	581.61	....//XXXXXXXXX//....
36	500	598.18	..../XXXXXXXXXXX.....
37	500	614.83	..../XXXXXXXXXXX/....
38	500	631.51	..../XXXXXXXXXX//....
39	500	648.42	.....XXXXXXXXXX///...
40	500	665.53	..../XXXXXXXXXXX/....
41	500	682.34	..../XXXXXXXXXXX/....
42	500	699.12	...///XXXXXXXXXX/....
43	500	716.05	.../XXXXXXXXXXXX/....
44	500	733.27	..../XXXXXXXXXXX/....
45	500	749.98	..../XXXXXXXXXXX/....
46	500	766.52	..../XXXXXXXXXX///...
47	500	783.17	...//XXXXXXXXXXXX/...
48	500	800.00	...//XXXXXXXXXXXX/...

Fig. 4. Calculated energy spread after longitudinal matching.

the results is shown in Fig. 4. Of course one is limited in the amount one can adjust the design phase since if it is made too small, the admittance will be inadaquate, and if it is made too large, the klystrons will be unable to supply sufficient power. Possible areas for future investigation in this new area include seeing if the energy spread in the LAMPF 805-MHz linac exhibits any such sudden jumps, and if so, seeing if adjustments to the design phase in the vicinity can reduce them.

References

1. K. R. Crandall, "The Delta-t Tuneup Procedure for the LAMPF 805-MHz Linac," Los Alamos Scientific Laboratory Report LA-6374-MS (May 1976).