A 100 GeV SLAC Linac *

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Introduction

The SLAC beam energy can be increased from the current 50 GeV to 100 GeV, if we change the operating frequency from the present 2856 MHz to 11424 MHz, using technology developed for the NLC. We replace the power distribution system with a proposed NLC distribution system as shown in Fig. 1. The four 3 meter s-band 820 nS fill time accelerator sections are replaced by six 2 meter x-band 120 nS fill time sections. Thus the accelerator length per klystron retains the same length, 12 meters. The 4050 65MW-3.5 μ S klystrons are replaced by 75MW-1.5 μ S permanent magnet klystrons developed here and in Japan. The present input to the klystrons would be multiplied by a factor of 4 and possibly amplified. The SLED [1] cavities have to be replaced. The increase in beam voltage is due to the higher elastance to group velocity ratio, higher compression ratio and higher unloaded to external Q ratio of the new SLED cavities. The average power input is reduced because of the narrower klystron pulse width and because the klystron electro-magnets are replaced by permanent magnets.

Comparison at Steady State

Define the gradient, $E_g = 1/L_s \int_0^{L_s} E(z, t) dz$. The steady state no-load gradient is [2]

$$E_{gs} = \sqrt{\eta_s s T_f P_s / L_s} = \sqrt{\eta_s s P_s / v_{ga}}. \quad \text{For CG : } \eta_s = (1 - e^{-2\tau}) / 2\tau \quad (1)$$

$$\tau = T_f / T_a, \quad T_a = Q_a / \pi f_0, \quad P_s = P_k / N_{spk} \quad .$$

*Work supported by the Department of Energy, contract DE-AC03-76SF00515.

Fig. 1. Present (top) and proposed (bottom) rf power distribution to the accelerator sections

Here, η_s is the section efficiency, s is the elastance/m, T_f is the fill time, P_s is the power into the section and L_s is the section length, P_k is the klystron output power, N_{spk} is the number of sections per klystron, τ is the section attenuation in nepers, Q_a is the section quality factor, and f_0 is the operating frequency. A comparison of the current and new accelerator section parameters are shown below.

f_0	T_f	Q_a	L_s	s	v_{g0}/c	v_{gL}/c	τ
MHz	μS		m	$M\Omega\mu\text{S}^{-1}\text{m}^{-1}$			neper
2856	0.82	13000	3.01	74	.0204	.0066	.55
11424	0.12	7500	2	850	.110	.0366	.57

The new section is a modified NLC design [3]. For better comparison we have assumed constant gradient.

Substituting the SLAC section parameters and using $P_k=55$ MW, $N_{spk} = 4$, in eq. (1), we have $E_{gs} = 12.9$ MV/m. Using the new section parameters and $P_k = 65$ MW $N_{spk} = 6$, we have $E_{gs} = 18.10$ MV/m, a 40% increase.

SLED at 11424 MHz

Changing to 11424 MHz, in addition to increasing the steady state no-load gradient, also increases the maximum SLEDed gradient E_{gm} to E_{gs} ratio, the SLED gain, S_g . Because the compressed pulse is narrower we have a higher compression ratio. As for the same diameter the cylinder loss decreases with frequency we can have a higher Q_0 with a small diameter and long cavity. Thus the SLED cavity Q_0 increases, which lowers the dissipated energy, thereby increasing S_g .

Define S_{gn} as the ratio of the new SLED gains to the current SLED gain. The power gain $S_{pg} = S_g^2$ and the SLED efficiency $\eta_{sg} = S_{pg}/C_r$.

Fig. 2 shows the SLED fields for the current SLED. Fig. 3 shows the SLED fields for SLED at 11424 MHz with $C_r=.72/.12=6$. and $Q_0=300000$. Figures 4 and 5 are the SLED fields at 11424 MHz with $Q_0 = 300000$ and $C_r=1.20/.12=10$ and $C_r=1.50/.12=12.5$, respectively.

The SLAC beam energy, V_{nl} divided by E_{gm} , is $50/20.9=2.39$ GeV/(MV/m). Thus the maximum SLEDed gradient and the beam energy are:

$$E_{gm} = S_g E_{gs} \text{ [MV/m]}, \quad V_{nl} = 2.39 E_{gm} \text{ [Gev]} \quad . \quad (2)$$

Fig. 2. Emitted field, E_e , Reflected field, E_r and Stored Energy, U_s vs time. Current SLED .
 $S_g=1.618$ $S_{gn}=1$ $S_{pg}=2.618$ $\eta_{sg}=61.3 \%$

Fig. 3. Emitted field, E_e , Reflected field, E_r and Stored Energy, U_s vs time. 11424 MHz SLED .
 $S_g=1.944$ $S_{gn}=1.202$ $S_{pg}=3.779$ $\eta_{sg}=63 \%$

Fig. 4. Emitted field, E_e , Reflected field, E_r and Stored Energy, U_s vs time. 11424 MHz SLED .
 $S_g = 2.205$ $S_{gn} = 1.363$ $S_{pg} = 4.861$ $\eta_{sg} = 48.6 \%$

Fig. 5. Emitted field, E_e , Reflected field, E_r and Stored Energy, U_s vs time. 11424 MHz SLED .
 $S_g = 2.29$ $S_{gn} = 1.415$ $S_{pg} = 5.243$ $\eta_{sg} = 41.9 \%$

The current (first line), and the new SLED and Linac parameters are shown below for comparison. We use the section parameters and input powers given above.

Q_0	Q_e	T_k μS	C_r	S_g	S_{gn}	E_{gm} MV/m	V_{nl} GeV
100000	20000	3.50	4.27	1.618	1	21.0	50.0
300000	12500	0.72	6	1.944	1.202	35.2	84.2
300000	18000	1.20	10	2.205	1.363	40.0	95.5
300000	20000	1.50	12.5	2.290	1.415	41.5	99.2
500000	20000	1.50	12.5	2.326	1.435	42.2	101

The increase in beam energy when we replace the present system with 11424 GHz system depends on our choice of the compression ratio, which determines the klystron pulse width. At $T_k = 0.72 \mu S$ the beam energy increases from 50 to 84.2 GeV. The average rf power is $P_k T_k f_r$ where f_r is the pulse repetition frequency. It decreases from $0.228 f_r$ kW to $0.054 f_r$ kW, a factor of 4.22. At $T_k = 1.2 \mu S$ the beam energy increases to 95.5 GeV and the average rf power decreases by a factor of 3.65. At $T_k = 1.50 \mu S$ it increases to 99.2 GeV and the average power, for the same f_r , decreases by a factor of 3. In addition to saving rf average power, about one MW of ac power is saved due to the use of permanent magnet klystrons.

A Q_0 of 300000 can be achieved with a copper cavity with D=8 cm L=141 cm, operating at 11424 MHz in the $TE_{0,1,100}$ mode. Even though many modes are possible, we assume that we will not have any problems with mode interference, because, as with SLED-II, the coupling is circularly invariant. Of course, this has to be verified experimentally.

There are two ways to increase the linac beam energy above 100 GeV. One would be to replace one klystron by two klystrons, so that one klystron feeds 3 sections, which will increase E_{gs} , E_{gm} , and V_{nl} by $\sqrt{2}$. Because the klystron pulse width is reduced, the modulator stored energy does not increase. The second uses one-time high power Q_e switching being developed for NLC, which increases the beam energy increases 27% [4]. If both are used the beam energy reaches 178 GeV.

For test purposes we could install a new 11424 MHz station in the current linac, but then only every fourth rf cycle will be effective.

References

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October 2001