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**Final Report
IUT - B291527
Jan. 96 - Mar. 97**

E. Henestroza

April 23, 1996

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FINAL REPORT

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Professor Neville C. Luhmann, Jr.
Principal Investigator for IUT-B291527
Chairman of the Department of Applied Science
University of California, Davis

Work performed under IUT B²⁹¹⁵²⁷~~0921527~~ LLNL/UC Davis by Enrique Henestroza from January 5, 1996 to March 3, 1997.

- RK-CLIC Study: Scaling of the 11.424 GHz TBNLC design of a relativistic klystron two-beam accelerator to 30 GHz. In particular the design of the RF output structure to deliver 190 MW. (See attachment #1).
- TBNLC Study: Simulation of the detuning of the RF structure and analysis of the choke mode design. (See attachment #2).
- RTA Study: RTA Gun design including beam dynamics and field stress calculations. (See attachment #3).
- CLIC/CESTA Cavity Study: Design of a 35 GHz RF output structure to be used to characterize bunching from an FEL. (See attachment #4).

Enrique Henestroza
MS 47-112, LBNL
Berkeley, CA 94720

RK-CLIC RF Power Source Design

Shmuel Eylon, Steve Lidia, Enrique Henestroza, Tim Houck, Glen Westenskow, and Simon Yu

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The following note investigates scaling the 11.4-GHz TBNLC design [1] of a relativistic klystron two-beam accelerator for a 30-GHz, 50-bunch accelerator design. We will refer to this point design as the RK-CLIC. We do not expect that the design will be optimal, but offer it as a starting point for discussions. In this memo, we begin with a general description of the RK-CLIC and drive beam dynamics, discuss required changes to major components, estimate the efficiency of wall plug to microwave power, and estimate costs. To be of interest the design must be such that it:

- * Can be installed at modest cost,
- * Operate with high wall plug to rf conversion efficiency,
- * Have acceptable drive beam dynamics.

RK-CLIC

We are considering the accelerator architecture discussed during the CLIC/RK-TBA Collaboration Meeting held in January 1996 [2]. This architecture uses the CLIC "1.5" main accelerator structure (about 1.5 times longer than the initial accelerator structure considered for CLIC), where each of the main accelerating structures will require 95 MW to produce an average loaded accelerating gradient of 80 MV/m. Each structure is 0.42 m long and we have assumed that they will be placed at 0.5 m spacing. The average gradient for the linac is thus 67 MV/m. The total length of the main accelerator will be 15 km to produce 1-TeV center-of-mass energy. The group velocity of the rf in the structure is 0.082 speed-of-light.

The RK-CLIC case being considered is for 50 bunches in the high energy linac with a spacing of 20 cm between bunches. The assumed rf pulse shape desired is shown in Figure 1. The desired flat top is 33.7 ns. The 17 ns rise linear ramp in the rf fields is so the final energy of all the multibunches will be the same at the interaction region. Figure 2 is a more detailed illustration of the desired shape of the rf power and associated electric field during the 17 ns ramp. Figure 3 plots the accelerating fields as a function of position at the start of the "flat-top." The fields are low at the downstream section of the high gradient structure for the first pulse. This compensates for the reduction in the accelerating fields due to beam loading for latter pulses. Figures 2 and 3 were supplied by Lars Thorndahl.

Figure 1. Anticipated rf power pulse required for the RK-CLIC.

Figure 2. Initial ramp of the output power pulse and the electric field.

Figure 3. Accelerating gradient along the length of the high-gradient structure.

In analogy to the TBNLC, we propose that the high-gradient linac be powered by 50 RK-CLIC units. Each unit provides rf power for about 300 meters of the main linac, ($50 \text{ units} \cdot 300 \text{ m} \cdot 67 \text{ MeV/m} = 1 \text{ TeV}$), and each unit would have the major components shown in Figure 4.

Figure 4. Layout of a RK-CLIC unit showing major components.

We expect that the drive beam dynamics are very similar between the TBNLC and the RK-CLIC designs. The rf power production per meter is comparable for the two systems (190 MW/m in RK-CLIC vs. 180 MW/m in TBNLC). In the RK-CLIC design we have placed the output structures every meter, and extract sufficient power to drive two high gradient structures. A schematic of this design is shown in Figure 5.

Figure 5. Schematic of layout of RK-CLIC unit driving the high-gradient linac.

Beam dynamics issues

The beam dynamics issues which are of concern with this design are:

- Transport – the RK-CLIC will require a low emittance drive beam to allow it to pass through the small apertures in the proposed output structures.
- Longitudinal bunch stability – use of inductively detuned output structures to maintain a well bunched beam over the 300-meters output section.
- Low frequency BBU – suppression of transverse beam instabilities by the use of induction cell gaps with low transverse shunt impedance coupled with the expected energy spread (to provide Landau damping).
- High frequency BBU – spacing of the output structures at $\lambda_b/2$ spacing (“half betatron node scheme”) to suppress the instability growth.

For the RK-CLIC transport system we have assumed permanent magnet quadrupoles with:

- FODO lattice
- 33.3 cm lattice period (60° phase advance/period),
- 2 meter betatron period
- 800 G pole strength (ferrite magnets, 10th is first non-zero harmonic)
- 2.5 cm radius bore

For a 500- π -mm-mr normalized edge emittance beam, we expect the edge diameter to be 3 mm. The output cavities scaled to 30 GHz will have a beam tube diameter of 6 mm. This puts a high emphasis on production of low emittance beams. The emittance requirement could be relaxed by increasing the drive beam energy.

We have assumed that a 30-GHz chopper can be produced. For the adiabatic compression section we have assumed we can reach the same rf bunching in both the TBNLC and RK-CLIC drive beams (1120 A of rf current).

The synchrotron period (particle rotation in the rf bucket) for this case is estimated to be:

$$\lambda_s = 2\pi \left(\frac{\omega}{c} \frac{d\gamma}{\gamma^3 dz} \right)^{-1/2} = 30 \text{ meters.} \quad (1)$$

The output structures will need to be detuned to compensate for longitudinal space charge and energy spread effects. However, the shorter synchrotron wavelength and closer spacing of the output structures should make longitudinal stability easier in the RK-CLIC design.

We expect the beam dynamics for the low frequency BBU to be the same as in the TBNLC. However, we may want to lower the acceptable growth level. Calculations will need to be performed to estimate the expected energy spread for the RK-CLIC. This will allow an estimate of the effectiveness of Landau damping.

For the RK-CLIC we will be able to maintain the spacing of the output structures at one half betatron wavelengths of the focusing system. Sensitivity of the “half betatron node scheme” will need to be checked for the new system, but we do not expect a large change from that found for TBNLC.

RF output structure design

For this memo we made a direct scaling of the three-cell traveling-wave output structure that we proposed for the TBNLC. The shunt impedance has been reduced to produce the lower rf power level required for CLIC. An illustration of the proposed output structure is shown in Figure 6. The longitudinal impedance will be invariant under this direct scaling while the transverse impedance will increase with ω [3].

Figure 6. Illustration of the TBNLC output structure scaled for the RK-CLIC.

For 360 MW of power, the maximum surface field for the TBNLC output structure is predicted to be about 75 MV/m. At 190 MW the surface field should be reduced to:

$$(190/360)^{1/2} \cdot 75 \text{ MV/m} = 55 \text{ MV/m.} \quad (2)$$

Then scaling the surface fields as $E_s \sim a^{-1}$ [4], where a is the aperture radius and, assuming a varies as λ , yields a prediction for the surface fields of 145 MV/m for the RK-CLIC output structure generating 190 MW. Experiments on relativistic klystrons at LLNL [5] indicate that traveling-wave output structures can be operated safely with surface fields of 100 MV/m for a 50-ns pulse at 11.4-GHz. Assuming that the breakdown limit for a copper structure scales approximately as the square root of the frequency [6], we expect to operate up to 160 MV/m fields without breakdown. It may also be possible to utilize SW cavities rather than TW structures in the RK-CLIC design.

The transverse impedance increases as ω , assuming the geometry is also scaled as ω [a factor of 2.6 between RK-CLIC and TBNLC]. There will also be twice as many output structures for the RK-CLIC, but with about one half the longitudinal shunt impedance of the TBNLC structures. Preliminary studies indicate that the transverse impedance for a SW cavity design may be only a third as for the TBNLC TW structure. Also, the flat top duration for the RK-CLIC design is only about 1/10 that of the TBNLC design. The convective nature of the instability may result in the

peak instability propagating out of the pulse tail. For these reasons, we expect similar transverse instabilities for the RK-CLIC as was found in the TBNLC case.

Induction Cell Design

The use of METGLAS® 2605SC in RK-CLIC is not practical because of high losses for short pulses. However, the above time scales fit the parameters for ferrite material. We cannot lower the rise time of thyatron switching, used in the TBNLC design, sufficiently to obtain a 17-ns rise time. Generally, the RK-CLIC design is more attractive for longer flat-tops (more bunches), until the cross-sectional area of the ferrite core increases such that the core volume becomes large.

We have held the induction cell voltage the same (100 kV/cell) as in the TBNLC design. The pulse length at the FWHM of the voltage waveform, τ_h , is taken as 50 ns. The amorphous material (METGLAS®) used for the TBNLC induction cell has relatively high losses for short pulses (fast rate of flux swing, $\Delta B/dt$). Instead we will assume that ferrite is used for the accelerator cores. Below a comparison is made between ferrite and amorphous material. The core design consists of a 25 cm long tube of ferrite with a 8 cm inner diameter. If we assume a ΔB of 0.65 T, then the outer diameter of the ferrite will be less than 14.2 cm, see equation (4) below. The volume of ferrite per cell will then be about $2.68 \times 10^{-3} \text{ m}^3$.

$$V_c \cdot \tau_h = A_c \cdot \Delta B, \text{ or } 10^5 \text{ Volts} \cdot 5 \times 10^{-8} \text{ s} = 7.7 \times 10^{-3} \text{ m}^2 \cdot (0.65 \text{ T}) \quad (3)$$

$$A_c = \Delta r \cdot \Delta z \Rightarrow r_o = r_i + \Delta r = 4.0 \text{ cm} + 3.1 \text{ cm} = 7.1 \text{ cm} \quad (4)$$

The energy loss per volume for CMD-5005 material for $\Delta B = 0.65 \text{ T}$ and a $\Delta B/dt$ of $0.65 \text{ T}/50 \text{ ns}$, or $13 \text{ T}/\mu\text{s}$, is estimated to be 600 J/m^3 . Thus, about 1.6 J will be lost in the ferrite per shot. The energy required for the beam is approximately 1/3 (three induction cells per output structure) of the $190 \text{ MW} \cdot 50 \text{ ns}$ or 3.17 J.

The losses associated with capacitance and stray induction for these short pulses can limit efficiency. If we assume that $C = 20 \text{ pf}$, then E_{cap} is the energy loss where $E_{\text{cap}} = C \cdot V^2/2 = 0.1 \text{ J}$. Thus, the efficiency for the cell is:

$$\eta_c = 3.17/(3.17 + 1.6 + 0.1) = 65\%. \quad (5)$$

A smaller inner radius for the core would reduce core losses, but would also reduce the beam line aperture increasing the transverse impedance of the induction cell gaps. New core materials could lead to better efficiency and lower costs. Within the limitations of core materials that we have tested, the easiest way to improve efficiency is to increase the pulse length. In Figure 7 the efficiency of induction cells for three different core materials are plotted as a function of pulse length. The voltage, inner radius, and length of the core were fixed at the RK-CLIC design values given above. Below 50 ns, the CMD-5005 ferrite is preferred material. Over 100 ns, METGLAS® alloy 2714AS begins to show improved efficiency. For very long pulses, on the order of several μs , METGLAS® alloy 2605SC can be the best choice. Doubling the pulse length will increase the core efficiency by about 8%.

An important factor in the choice of induction core material is the total volume required which then determines the core cost. Figure 8 plots the volume as a function of pulse length for the three cases used in Figure 7. The lower ΔB ferrite requires a much greater core volume to generate the desired pulse length than the METGLAS® alloys. Variations in core geometry will change the details of Figures 7 and 8, but in general more ferrite will be required than METGLAS®.

Figure 7. Induction cell efficiency (beam power/power delivered to cell) for different pulse lengths.

Figure 8. Required core volume to generate different pulse lengths.

Pulsed power system

The repetition rate of RK-CLIC will be determined by the required luminosity of the collider. With a train of 50-pulses, the CLIC design calls for a 600 Hz repetition rate. The pulsed power system proposed in the TBNLC design is not suitable at this repetition rate. We are proposing two different systems.

Magnetic switching [7] has been demonstrated at high repetition rates [8] in other experiments, and is a candidate power switching method for the RK-CLIC design. Because of the short required rf pulse length, we are proposing a magnetic pulse compression system. Figure 9 is an induction cell voltage pulse generated using a magnetic compression/switching system demonstrating that the rise time requirements can be accomplished. The picture was taken at the LLNL Accelerator Research Center during testing of SNOMAD cells in July 1990. Firing jitter was about 1 ns and energy variation over the "flat top" was about 1% during operational runs. Ability to cool the ferrite cores and the pulse power units will need design effort, but we feel that multiple kHz operation is possible with this technology.

A preliminary design for a three stage magnetic pulse compressor was performed to assist in estimating cost and efficiency. It is cheaper to limit the DC power supplies to 15-20 kV. A step-up transformer would then be needed to produce the 100 kV needed for the induction cell. A reasonable alternative solution, used in the TBNLC design, is to operate the induction cell as a transformer. The core is segmented longitudinally with each segment driven separately. This could slightly increase the total core volume and cell fabrication costs, but eliminate a separate transformer and decrease total losses. In this preliminary design, the cores are divided into four segments, each driven at 25 kV, and six cores (2-m of accelerator representing a beam-loaded impedance of 1.5 Ω) are driven by the output of one magnetic compressor. The design parameters for the magnetic compressor are given in Table 1.

Table 1. Magnetic compressor parameters.

Stage	Time to Charge/Discharge	Gain	Switching Core / Turns	Core Efficiency
First	7.5 μ s / 1.25 μ s	6	5.843 kG - 2605SC / 20	0.983
Second	1.25 μ s / 250 ns	5	20.794 kG - 2714AS / 6	0.984
Third	250 ns / 50 ns	5	26.815 kG - 2714AS / 1	0.980

Energy storage for the third stage consists of a 0.84-m long, water-filled Blumlein line. The first two stages use Strontium-Titanate capacitors. The long charge time of the first stage allows the use of SCR's in the CRC for the initial triggering. The Blumlein line is the major expense for the magnetic compressor. A simple coaxial transmission line will lower cost, but, because of the higher charging voltage, lowers the efficiency of the third stage to about 0.92. The use of dielectric filled, high-voltage cables for the Blumlein line requires fewer cores to be driven to increase the load impedance. Thus, this configuration will have more modulator units and approximately the same total cost as water-filled Blumlein lines.

The advantage with this magnetic compressor system is that it is totally solid state. It should have high-reliability, long lifetime, good efficiency, and be capable of kHz operation. A drawback of the system is that it is difficult to adjust the voltage wave shapes to obtain different accelerating gradients. The addition of fast correction circuits interspersed in the system could be used to correct for errors. In general, such a system can achieve good results at one design parameter, but may not be flexible for other operational conditions.

A second candidate for the pulsed power system is to trigger a transmission line, e.g. a Blumlein, with a thyatron switching. Figure 10 shows a voltage pulse obtained with a thyatron switch and Blumlein line driving a resistive load. The photograph was taken in June 1989 by Lou Reginato at LBL.

Figure 9. Voltage pulse on induction cell using magnetic compression/switching. Scales are 12 kV/div and 10 ns/div.

Figure 10. Voltage pulse generated by triggering a Blumlein with a thyatron into a resistive load. Scales are 10 kV/div and 20 ns/div.

This is an attractive option due to the simplicity of the design and high relative efficiency for longer pulses. A preliminary design uses a single thyatron switching a 0.84-m long, water-filled Blumlein line to drive a single core (three segments) at 33 kV. Due to ohmic losses in the water, a CRC with solid state switches will be used to charge the Blumlein in about 1 μ s. The major concerns with thyatrons are lifetime and reliability. Depending on pulse requirements, thyatron lifetimes of 1 to 3 years at 600 Hz operation is reasonable. The figure of merit is the total charge extracted from the thyatron. If the pulse length is doubled, the repetition rate would need to be halved to keep the lifetime constant.

System efficiency

Where possible, comparable efficiencies for similar steps with conventional klystrons or the TBNLC are used. We have also tried to base estimates on values that can be obtained with current technology.

- (1) DC Power Supplies – Conventional 60 Hz 3 phase full wave rectifier with filter supplies will be used. Estimated efficiency is 93%.

- (2) Command Resonant Charging (CRC) System – A solid state CRC system will be used. Estimated efficiency is 96%.
- (3) Modulator – Power losses for magnetic pulse compression are due primarily to three components, core losses, ohmic losses in the Blumlein water, and capacitors. Losses due to the cooling system are included under auxiliary power. Core losses (efficiencies) are given in Table 1. Assuming the same ratio between the outer and middle conductors radii as between the middle and inner, the energy loss in the water can be expressed as:

$$U_L = \frac{240 \pi L V_o I_o}{\rho \sqrt{\epsilon_r}} \Delta t, \text{ where}$$

L is the length (cm) of the Blumlein, V_o/I_o is the voltage (V)/current (A) applied to the load, ρ is the water resistivity (Ω -cm), ϵ_r is relative permittivity, and Δt is the charging time. For our design, L is 84 cm, $V_o = 25$ kV, $I_o = 17$ kA, $\epsilon_r = 80$, $\rho = 8$ M Ω -cm and Δt is 250 ns for an energy loss of 0.094 J or 0.5% of the total energy transferred to the induction cell. The efficiencies of the capacitors is estimated at 98%. Total efficiency for a magnetic pulse compression modulator is 92%.

The thyatron switched modulator has three primary loss mechanisms, ohmic losses in the Blumlein line, fall time of the thyatron tube, and filament/reservoir power requirements. For our preliminary design, L is 84 cm, $V_o = 33$ kV, $I_o = 2.1$ kA, $\epsilon_r = 80$, $\rho = 8$ M Ω -cm and Δt is 1 μ s for an energy loss of 0.061 J or 1.7% of the total energy transferred to the induction cell. The efficiency of the thyatron tube will vary with the tube, but, for an estimate, we can assume a fall time of 20 ns from a hold off voltage of 33 kV with the current increasing to 2.1 kA or about 0.7 J. Note that this value is independent of pulse length. Thus the thyatron tube has an efficiency of 80% for a 50 ns pulse increasing to 95% for a 200 ns pulse. Losses for filament/reservoir power supplies are considered as auxiliary power, and are not included as part of the modular efficiency. Total efficiency for the thyatron switched modulator is 78.6% for the 50 ns pulses increasing to 93.4% for 200 ns.

- (4) Induction Cells – As described above, the cell efficiency should be about 65% for 50 ns pulses. This efficiency could be > 80% if the pulse length were increased to 200 ns. RF to beam efficiency in the high-energy linac would also increase.
- (5) Drive beam (pulse fall time) – As in the TBNLC, we plan to utilize the rise time of the current pulse. Some care needs to be taken in determining the energy loss in the fall time of the pulse. The beam transport system is not expected to transport the portion of the beam during the fall time of the voltage pulse. This small portion of the beam should be lost to wall intercept before injection into the main extraction section. A sizable amount of the energy that flows through the pulse forming network/modulator after the "flat top" portion of the drive pulse is energy stored in cell, i.e. gap capacitance and magnetic field energy. This energy loss has already been included in the losses due to the induction core. As an estimate of the energy to drive the core during the fall time, allow 300 A core current (average core current used for induction cell losses) times 20 ns fall time times one half of 100 kV or 0.3 J. This also includes the 0.1 J of gap capacitance. Thus, actual losses during the fall time not previously accounted for is only 0.2 J giving an efficiency of 94% for transfer of energy into the drive beam.

- (6) Drive beam to rf – The conversion losses of drive beam to rf power is due to losses at the front of the relativistic klystron primarily in the chopper, and residual beam power lost in the dump. This will be the same as for the TBNLC design. Thus, the efficiency should be about 90% if the RK-CLIC generates the same power as the TBNLC.
- (7) Auxiliary power – This is a miscellaneous category that accounts for losses due to systems such as cooling fluids, vacuum, thyatron tube heating/reservoir power, etc. These losses are estimated to be about 80 kW. At 600 Hz this represents an efficiency of 0.96. This efficiency could be overly optimistic with respect to thyatron heating/reservoir power losses, but should be accurate for the proposed magnetic compressor modulator.

To summarize the estimated efficiencies:

<u>Component</u>	<u>efficiency</u>
Power supplies	0.93
CRC	0.96
Modulator	0.92
Induction cells	0.65
Drive beam (fall time)	0.94
Drive beam to rf	0.9
<u>Auxiliary power</u>	<u>0.96</u>
Total efficiency	0.43

System Cost

The cost for the RK-CLIC rf power source design should be similar to that of the TBNLC with the exception of induction core material, microwave components, and some electrical components. The following cost estimate is performed for a 1 TeV c.m. system.

- (1) **Primary AC Power** – A well accepted figure for a primary power distribution substation is 200 \$/kVA. This includes all interrupters, circuit breakers, fuse disconnects, cabling and step down transformers to a 12 kV distribution. An additional 50 \$/kVA is needed for the distribution to power supplies and outlet boxes. Required power will be 190 MW/output · 300 outputs/unit · 50 units · 600 Hz · 50 ns/pulse / 0.45 efficiency or 190 MVA. The cost for the primary AC power is about 48 \$M.
- (2) **Mechanical** – The difference between mechanical costs between the RK-CLIC and TBNLC designs is primarily due to the reduced core requirements and doubling the number of output structures.

In the TBNLC the core costs were 22.5 \$M out of a total 338 \$M for mechanical systems. This represents \$5/kg · 100 kg/module · 45,000 modules. The RK-CLIC will require 13.4 kG of ferrite or 11.3 kG of METGLAS® alloy 2417AS. The price of METGLAS® alloy 2605SC used in costing the TBNLC is about \$100/kg when ordered in small amounts. In very large quantities (and in 6 inch wide ribbon) the cost of 2605SC is reduced to \$5/kg. Assuming a similar price reduction for large quantities of 2417AS, the RK-CLIC cores should cost only about 15% of the TBNLC cores, or about 3.4 \$M.

The CMD-5005 ferrite in large quantities is about \$20/kg. However this price was not based on competitive bidding and possibly could be furthered reduced.

The TBNLC rf output subsystem costs totaled 54.4 \$M. At 30 GHz, all the components are reduced in size by about a factor of three reducing the cost of material, but increasing manufacturing costs. We will assume these two effects cancel. Three scenarios are possible for the RK-CLIC. The most costly is that all components are doubled leading to twice the cost (total = 108.8 \$M). Next, due to the lower power levels, each output structure will have only one output port instead of two. The components related to the second port accounted for 28.8 \$M in the TBNLC (total = 80 \$M). The least expensive scenario is that standing wave cavities with single output structures are used and cost only a third of the TBNLC output structure. Even with twice the output structures, the total cost for cavities is less (total = 74.8 \$M). We will use the second scenario for figuring costs.

The estimated cost for RK-CLIC mechanical systems is 345 \$M.

- (3) **Control and Diagnostics** – The increased repetition rate (600 Hz), decreased ramp time (17 ns), and high rf frequency (30 GHz) is expected to result in more expensive control and diagnostic systems. A difficulty in comparing the costs for the two different system parameters is that for some components the minimum specifications are satisfactory for both systems. Thus cost doesn't change, but performance specifications are nearer to operating specifications. For other components, the desired parameters place you into the next (and perhaps much more costly) level of performance specifications. In general, the repetition rate results in minimal cost change. The higher rf frequency components are 30% more expensive and, due to the increase number of output structures, may be needed in larger quantities. The beam diagnostics acquisition, analysis, and control systems are impacted by the faster rise time and tend to be 50% more expensive. Conservatively, the Control and Diagnostics System will be about 50% more expensive for the RK-CLIC than TBNLC, or about 120 \$M.

- (4) **Electrical** – The cost for the magnetic compression modulator can be broken down as:

Component	Cost
Magnetic cores	\$800
Capacitors	\$1,200
Blumlein Line	\$4,400
Labor/Overhead	<u>\$4,000</u>

Total: \$10,400

The design of the Blumlein lines will require careful attention to tolerances possibly leading to higher fabrication costs than normally expected. The cost estimate accounted for these higher costs and is probably overly pessimistic. The use of high-voltage cables in place of the water-filled Blumlein is marginally cheaper. 7,500 modulators are needed for the full system for a total cost of 78 \$M.

The magnetic compression modulators are replacing 140 \$M in components for the TBNLC design. The remaining electrical system components are primarily dependent on average power which is about equal between the TBNLC and RK-CLIC. Thus, the cost estimate for the RK-CLIC electrical systems is 424 \$M.

The thyatron switched modulator costs approximately \$1,500 for the tube (assumed 50% reduction for large quantities), \$1,000 for the Blumlein Line (looser tolerances and smaller dimensions than for the magnetic compressor), and \$500 for Labor/Overhead for

a total of \$3,000 per induction cell. 45,000 thyatron switched modulators are needed for the full system for a total cost of 135 \$M. These modulators are only replacing 92 \$M in components for the TBNLC design. Thus the thyatron switched modulator option is not attractive for short pulses where the magnetic compression is efficient.

The estimated cost of the RK-CLIC rf power source (1 TeV c.m.):

<u>Major System</u>	Cost (\$M)
Primary AC Power	48
Mechanical	345
Control and Diagnostics	120
Electrical	<u>424</u>
Total	937

Summary

Scaling the TBNLC rf power source design to 30 GHz for CLIC looks very promising in regards to cost and efficiency, and does not reveal any "show stoppers." More detailed analysis is required to improve efficiency and cost estimates. Operational flexibility issues should also be studied. Specifically, the following tasks should be performed:

- 1) Beam interaction with rf output structures - A rf output structure design with sufficient detail to determine surface electrical fields, impedances (wakefields) and phase velocity is needed. An alternative standing-wave design should also be done. Numerical simulations of the beam dynamics (longitudinal and transverse) should then be performed to determine the expected efficiency of drive beam to rf conversion and various parameter sensitivities. This could be an iterative effort leading to an optimize output structure design.
- 2) Optimization of linac parameters for a TBA design - As described in the section on induction cells, increasing the pulse length can significantly improve efficiency. For 200 ns pulses and thyatron tube modulators the system efficiency could increase to about 54%. Pulse lengths of 300 ns may allow the replacement of the thyatron tubes with solid state switches with a significant improvement in reliability and efficiency. The initial impression is that solid state switches are prohibitively expensive, but for the vast numbers required for the RK-CLIC and innovative manufacturing techniques, the cost could be manageable. Repetition rates and accelerating gradients should also be included in the optimization studies.

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SIMULATIONS AND COLD TEST OF AN INDUCTIVELY DETUNED RF CAVITY FOR THE RELATIVISTIC KLYSTRON TWO BEAM ACCELERATOR*

E. Henestroza, S. Eylon, J.S. Kim, T. Houck[†], G. Westenskow[†], and S. Yu^{††}
Fusion and Accelerator Research, 3146 Bunche Avenue, San Diego, CA 92122, USA

[†] Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

^{††} Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

Abstract

Electromagnetic and particle-in-cell codes in two and three dimensions were used to design inductively detuned traveling wave cavities for the Relativistic Klystron Two Beam Accelerator (RKTBA) expected to extract high RF power at 11.424 GHz for an energy upgrade (TBNLC) to the Next Linear Collider, as well as for the prototype (RTA) being built at LBNL. Previous design was based mainly on 2D calculations. We will present full 3D simulations of a three-cell traveling wave structure in two configurations (with and without a choke structure), as well as preliminary cold-test results of a model cavity assembly.

Introduction

A preliminary point design study for an rf power source based on the Relativistic Klystron Two Beam Accelerator (RKTBA) concept to extract high power at 11.424 GHz for the 1 TeV center of mass Next Linear Collider design has been presented recently by a LBNL-LLNL team [1]. The point design requires that the bunched drive-beam delivers 360 MW of rf power with an rf current of 1.15 kA (600 A DC) in each of the 150 rf extraction cavities in a 300 m long RK-TBA. To achieve this goal, and to maintain longitudinal beam stability over long distances, the extraction cavity must be inductively detuned. To maintain low surface fields to avoid breakdowns, we consider traveling-wave output structures. The frequency-domain and time-domain computations were performed using the three-dimensional electromagnetic code MAFIA [2]. Based on the simulation results an experimental, cold test, extraction cavity was fabricated and tested. Initial S-parameter measurements show good agreement with numerical calculations.

Numerical Simulations

The numerical effort for the physics design of the rf extraction cavity is based on calculations that are fully three-dimensional electromagnetic simulations of the complete cavity geometry including the output structures and the driving beam.

The favored type of simulations that we have been performing are the so-called "stiff-beam" calculations, where the beam excites the cavity to generate electromagnetic fields, but the fields do not act upon the beam. From this type of simulation we can calculate the electromagnetic fields and the wake potentials. The output power can be calculated as a function of time. The beam dynamics can be analyzed from the wake potentials by beam dynamics code simulations [3,4,5].

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The mesh size used is under one millimeter to accurately represent the cavity geometry. This type of mesh translates into a calculation involving about one million nodes. Furthermore, time steps of under 1 picosecond (dictated by the Courant condition for stable simulation) require running the calculation for several tens of thousands of time steps to simulate several tens of nanoseconds in order to have a smooth filling of the cavity and reach steady-state condition.

The beam is represented as a train of micro-pulses at the driving frequency. Each micro-pulse line-charge density shape is represented as the superposition of a constant term and three harmonics of the train frequency; this improves the numerical stability of the simulation.

The fully electromagnetic, three-dimensional code MAFIA has been the code of choice to perform all calculations. We have been using the frequency-domain as well as the time-domain modules. The alternate fully electromagnetic, three-dimensional Particle-In-Cell code ARGUS [6] has been used to cross-check the MAFIA calculations.

Traveling Wave Extraction Cavities

To avoid electrical breakdown, traveling-wave cavities are preferred over standing wave cavities since they generate lower surface electric fields for a given output power.

Present designs for the TBNLC extraction cavities evolve around traveling wave structures (TWS) with 3 cells of 8 mm inner radius; 180 MW of rf power is extracted through each of 2 separate ports in the third cell and transported via waveguides.

Fig. 1 shows a schematic of the 3-cell traveling wave output structure. A beam pipe length of 3.0 cm on each side is required to confine the electromagnetic field inside the cavity. The rf power is extracted through two WR90 waveguides attached to the last cell of the cavity.

Fig. 1. Schematic of the 3-Cell TWS. The structure is cylindrically symmetric with the exception of the two WR90 waveguides.

For this type of structure we have found a cavity design that delivers the right amount of power for the design parameters of the beam. Fig. 2 shows the calculated power as a function of time out of each WR90.

Fig. 2. Output power signal with a time-average of 180 MW per waveguide.

From the longitudinal wake potential we have found that the beam is detuned by 60° (lagging in phase). Calculations using the RKS code [3] have shown that this amount of detuning is required to obtain longitudinal beam stability for a long machine, as well as to sustain the level of output power for up to 150 structures. Fig. 3 shows the longitudinal wake and the beam profile for a detuned structure as a function of the distance from the beam-train head; in the micro-bunch frame, particles at the front lose energy and slow down, while particles at the tail gain energy, producing a bunching effect that counteracts the space charge debunching.

Fig. 3. Longitudinal wake variation over two micro-pulses showing the inductive detuning.

The peak surface electric field calculated is ≈ 75 MV/m, a field that is within the upper limit in the peak electric field that has been imposed as a constraint in the design.

Transverse beam dynamics require low shunt impedances to avoid the beam break-up instability (BBU). Even when the 3-Cell TWS has low enough transverse impedance to avoid BBU [7], further damping of the high order modes is desirable to increase the confidence for the success of the accelerator as well as to relax tolerances on other parameters.

The addition of a cylindrically symmetric choke structure [8] to the 3-cell TWS, that confines the fundamental mode of the cavity while allowing high order modes to propagate out of the structure has been evaluated numerically.

Figure 4. shows a schematic of the 3-Cell TWS with choke used in the simulation. The dimensions of the 3 cells are changed slightly to compensate for the effect of the choke structures in the resonant frequency; the output waveguides are the same as in the previous case.

Fig. 4. Schematic of the 3-Cell TWS with choke. The structure is cylindrically symmetric with the exception of the two WR90 waveguides.

It was found numerically that by a small change in the cavity dimensions, to keep the resonant frequency constant, the cavity could extract the same amount of power from the beam while maintaining the inductive detuning. Even when this design was not optimized the transverse impedance calculated decreased appreciable by the introduction of the choke.

Cold tests of the rf cavity structure

An experimental 3-cell traveling wave extraction cavity was designed and fabricated. The design is based on the results of the 3D computer simulations. Since cold tests do not present any break down or vacuum requirements the cavity mechanical design is rather simple, allowing a quick and flexible assembly of the cavity. The cavity assembly shown in Fig. 5 consists of from 1 to 5 cells and two 30 mm long end beam pipes. One of the cells contains the two extraction apertures connecting to the WR90 waveguides. The test cavity is made from brass to reduce manufacturing costs.

Cold test measurements can be used to validate the results of the electromagnetic computer calculations by measuring the frequency-dependent S-parameters of the extraction cavity. Furthermore the measurements may allow the optimization of the extraction cavity geometry by evaluating the loaded Q of the cavity.

Fig. 5 The test extraction cavity assembly schematics showing a) side-view, b) cross-section, and c) top view.

The test is performed in the LBNL Lambertson Beam Electrodynamics Laboratory using the HP 5810 RF vector network analyzer. Fig. 6 shows the test system layout. The network analyzer oscillator signal is introduced through a WR90 waveguide in one extraction aperture while the second aperture, through a WR90 waveguide, can be connected to a matched load, short, open or to the network analyzer's second channel.

Fig. 6. The cold test setup layout

The cavity S-parameters are measured for cases when the second extraction aperture is terminated with a short, open, and a matched load. Fig. 7 shows an example of a frequency dependent S11 measurement in agreement with MAFIA calculations. The frequency shift, and the difference in the loaded Q, between the calculated and measured S11 behavior is probably due to the resolution of the calculation. The final tuning of the system can be done by readjusting the dimensions of the cavity using the above measuring procedure.

Future plans include the extension of the measurement system to frequency perturbation techniques using moveable dielectric rods or beads inside the cavity structure to evaluate the R/Q and the electric field variation along the cavity.

Fig. 7. Comparison between measured and calculated frequency dependent S11 for the 3 cell cavity with two 15x4mm exit apertures. The second extraction aperture is terminated with a matched load.

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RTA gun layout

24 induction cells will be used to produce 1 MV across a narrow cathode-anode gap. Each core will be driven at 14 kV.

and is now undergoing testing. We will shift focus in the second section in order to discuss some recent work on extending the RK-TBA concept to higher energy and higher frequency colliders.

RTA³ PROTOTYPE RF POWER SOURCE

Construction of the RTA, a prototype of the proposed TBNLC RF power source subunits [6], has started at LBNL. Details of the RTA design has been presented elsewhere [7, 8]. Here, we describe the 1-MV, 1.2-kA induction electron gun and the pulsed power system for the gun.

Induction Electron Gun

An illustration of the 1-MV, 1.2-kA induction electron source, referred to as the gun, is shown in Figure 1. The cores are segmented radially to reduce the individual aspect ($\Delta r/\Delta z$) ratios with each driven separately at about 14 kV. The lower aspect ratio reduces the variation in core impedance during the voltage pulse simplifying the pulse forming network (PFN) design. We chose a constant radius design for the cathode-side cells. This design increased the METGLAS® core volume by about 10%, but the added cost was recovered in reduced insulator and fabrication costs. Figure 2 is a photograph of the completed cathode-half of the gun undergoing initial pulsed power tests. Currently, the cathode-half gun is being used to test various insulator configurations. The test results will be incorporated into the RTA's induction accelerator design.

FIGURE 1. Illustration of the RTA gun, a 1.2-kA, 1-MeV induction electron source.

FIGURE 2. Photograph of the assembled cathode-half of gun. The cathode will be located within the pumping spool. Flange for the anode-half of gun is blanked off.

A novel feature of the gun design is the insulator. We are doing high voltage testing with a single, 30 cm ID, PYREX® tube for the insulator with no intermediate electrodes. Average gradient along the insulator at the operating voltage of 500 kV is about 5.1 kV/cm. Maximum fields at the triple points, intersection of insulator, vacuum, and metal, is less than 3.5 kV/cm. Maximum surface fields in the cathode half of the gun are about 85 kV/cm. The rationale for using PYREX® is to explore methods of reducing the costs of induction injectors. PYREX® is significantly less expensive than ceramic, and additional savings are realized by avoiding intermediate electrodes. Since there is additional risk associated with this approach, our design allows for the addition of intermediate electrodes and/or substitution of a ceramic insulator with minimal impact to schedule or expense. However, the initial high-voltage tests on the cathode-side insulator are encouraging.

Pulsed Power System

The pulsed power system will consist of a 20-kV Energy Storage Bank Charging Power Supply, 3-kJ Energy Storage Bank, two Command Resonant Charging Chassis, 24 Switched Pulse Forming Networks, and four Induction Core Reset Pulsers. A photograph of one PFN is shown in Figure 3. Each PFN will drive a single 3-core induction cell. A sample pulse is shown in Figure 4.

FIGURE 3. Photograph of single PFN used for driving a gun induction cell. The PFN is comprised of multiple LC stages charged to about 28 kV and uses thyatron switching.

FIGURE 4. Oscilloscope trace of pulsed power pulse applied to induction cell. Top trace is voltage (10 kV/div) and middle trace is current (4 kA/div). Time scale : 100 ns/div.

Segmenting the core in the induction cell and driving the individual core segments avoids a high-voltage step-up transformer. This reduces the developmental effort needed to achieve a "good" flattop pulse (minimal energy variation) and improves the efficiency of the overall pulsed power system. Our system of low-voltage PFNs driving multiple core induction cells is similar to the system envisioned for the extraction section in the TBNLC design. For the core material, we choose METGLAS® alloy 2605SC instead of the 2714AS, the preferred material for the TBNLC, due to the larger inner diameter gun cores. In the RTA gun configuration, the larger flux swing of 2605SC was of greater importance than the lower loss per unit volume of 2714AS. The RTA extraction section will use 2714AS to permit an accurate measurement of the pulsed power system efficiency expected for the TBNLC.

An area of concern is the consistency of the METGLAS® cores. Several core materials were tested at the RTA Test Facility [9] to establish a data base for design studies. However, this testing did not address the issue of consistency between cores of the same material. We now have a data base including the 38 cores of METGLAS® alloy 2605SC used in the construction of the cathode-half of the gun. Figure 5 shows the energy loss per unit volume for these cores at a flux swing rate, dB/dt , of 5 T/ μ s. The cores used 20 μ m thick 2605SC layers with mylar insulation and achieved an average packing fraction of 76%, minimum of 72% and maximum of 78%. The cores had a radial thickness of 5.8 cm with an inner radius of 19 cm, 27 cm, or 35 cm. The small, medium, and large cores in Figure 5 refer to the different inner radii. The three horizontal lines represent the average loss per volume for the respective core sizes. The smaller the core radius, the higher the loss per volume, as shown in the figure. However, total loss per core for the 38 cores was approximately the same with no significant dependence on core size.

FIGURE 5. Test results for the METGLAS® alloy 2605SC cores.

The standard deviation in loss per volume for the small and medium cores was 14% and the large core was 29%. However, by matching the cores, the standard deviation for a three core cell was reduced to 4%. If the core losses vary sufficiently, it becomes necessary to tailor individual PFNs to adjust for the different cell loads. For a large relativistic klystron, matching cell cores should permit acceptable loss variation.

HIGHER-ENERGY, HIGHER-FREQUENCY COLLIDERS

We are currently evaluating possible designs for a 5-TeV-scale collider [10], based on operating frequencies higher than 11.424 GHz. We propose the use of high current, high power beams in the main collider linacs, while loosening some of the stringent parameters in the final focus section. The accelerating structure in the main linacs must of necessity be heavily damped, as well as detuned to allow for fast roll-off of the short-range wakefields. This damped, detuned two-beam accelerator we dub the DD-TBA.

Interaction Point Physics

Requirements of high average luminosity, a usable level of beamstrahlung induced energy spread, and a low background of high energy photons lead to tradeoffs between beam power and beam quality. The definition of terms and a comprehensive review of the relevant IP physics in a linear collider can be found in Wilson's article [11], Palmer [12], and Irwin [13].

The NLC [14] klystron-based collider designs have exhibited overall wall plug to beam efficiencies around 10%. In order to hold down total power

consumption, a heavy burden is usually placed on generating and maintaining higher quality beams, keeping the beam power at lower levels. In this DD-TBA collider design, the net efficiency can be 50% or more. In this scheme, we choose instead to operate with much higher beam power in order to relax some of the constraints and challenges at the final focus. Various proposed schemes, and their IP parameter sets are listed in Table I. The parameters of the 1-TeV NLC case are included for comparison.

For the DD-TBA design we have allowed for both a larger beam spot size and normalized emittance, while keeping γ and δ_B at moderate values. The range of γ considered in the various designs spans an order of magnitude. The physics of high ($\gg 1$) γ interactions is still not understood, so placing any upper limit is somewhat premature. Also, the issue of energy resolution in the detector systems must be addressed before an upper limit on δ_B can be imposed as a design constraint. However, in a reasonable 5-TeV collider design, it is very difficult to achieve an energy spread below 10%.

Table 1. Comparison of linear collider IP parameters.

	Palmer [12]	Irwin [13]	Wilson [11]	DD-TBA**	NLC
E_{cm} (TeV)	5.0	5.0	5.0	5.0	1.0
$L(10^{30} \text{ cm}^{-2} \text{ s}^{-1})$	2.5	2.5	2.5	2.5	0.11
$N(10^{10})$	0.31	0.03	0.44	0.25	1.1
$f_{rep} n_b (\text{kHz})^\#$	12.7	330	5.6	71	12.6
$\sigma_y (\text{nm})$	0.2	0.1	0.1	0.4	5.1
R	136	156*	700	180	49
$\sigma_z (\text{mm})$	20	27*	20	20	150
$\epsilon_{ny} (\text{nm})$	1.5	3.3	1	4	110
D_y	7.3	7	7	2	7.6
H_D	2	1.4*	1.1*	2	1.4
γ	21	4*	28	7.8	0.29
$\delta_B (\%)$	27	10*	20	15.5	12.6
$P_{beam} (\text{MW})$	54	40	18	72	7.9

* These parameters are not given explicitly by the authors, but have been derived from scaling relationships.

** We have used a value of A_y equal to 0.10.

f_{rep} is the pulse train repetition frequency; n_b is the number of bunches per train.

This loosening of beam quality does not come without its price. The RK power source is most efficient when generating long RF pulses (100's to 1000's of ns). Efficient use of that pulse means that we must use bunch trains that span it. To achieve the required luminosity, we must also pack the bunches tightly together. The current DD-TBA design uses trains of 4761 0.4-nC bunches with a separation of 2 RF wavelengths. This gives a large DC current of 6.01 A during the pulse, which has a repetition rate of 10 Hz.

High Gradient Structures

The transport and acceleration of such large current beams necessitates a hard study of the high gradient structures. The introduction by Wilson [15] provides an in-depth discussion of the pertinent physics. Once an average current is chosen, the structure design becomes a tradeoff between accelerating gradient and RF to beam power conversion efficiency. We adopt an approach that uses heavy beam loading to boost efficiency, while maintaining relatively high loaded accelerating gradients. The linac structures are designed to have high efficiency in transfer of RF power to beam power (~80%), with high input RF power (400 MW/structure). The structure parameters are listed in Table 2.

The transverse wakefields in this structure are quite severe due to the large current. By using heavily damped structures we can produce designs with low dipole mode Q's. This can significantly damp wakefield levels generated by a bunch at a given point in the structure by the time the next bunch arrives.

Table 2. Linac structure parameters.

Frequency	30 GHz	Idc	6.01 A
β_{group}	0.10	Input power	400 MW
a/λ	0.214	Peak gradient	244 MV/m
r/Q	23.7 k Ω /m	Average gradient	126 MV/m
Q	4425	Power into beam	316 MW
Fill time	14 ns	Power into walls	80 MW
τ	0.298	Structures per m	2

Relativistic Klystron Source

The relativistic klystron power source design is similar to the proposed TBNLC. For this design, each unit would power 600 high gradient structures, so that each linac arm would require 79 DD-TBA units.

Each DD-TBA consists of a 3.5-kA, 5.0-MeV injector, a beam modulation unit, an adiabatic capture section to bunch and accelerate the beam, the main RF extraction section, and an afterburner section to extract power from the beam while decelerating it prior to the dump. At the entrance to the main extraction section, the beam has an average energy of 25 MeV and carries 3150 A of RF current with 1750 A of DC current. Each relativistic klystron has 300 extraction sections to power 600 high gradient structures. The ultimate efficiency of the relativistic klystron is limited by the number of extraction sections the beam can pass through before succumbing to beam breakup (BBU) instabilities. Careful attention must then be paid to transport and stability.

Transport and Beam Stability

Permanent magnet quadrupoles are employed to provide a magnetic FODO lattice. The lattice has a 0.33 m period with a 60° phase advance per period,

giving a 2 m betatron period. The quadrupole magnets are ferrites with an 800 G poletip field, 1.0 cm bore radius, and 0.48 occupancy factor. For a normalized edge emittance of 2000π mm-mrad, the equilibrium beam edge radius will be about 2.0 mm.

Two severe transverse instabilities have been identified in the RK-TBA. One is a low frequency mode associated with the induction modules, and the other is a high frequency mode due to the RF extraction structures. Similar instabilities will exist in this design, but at higher frequencies. Simple scaling arguments [16] imply that the high frequency instability growth rate in this design could be a factor of 4 higher than in the TBNLC design, while the low frequency instability rate could be 10 times higher, if left uncorrected.

Beam energy spread should result in effective Landau damping to counter the low frequency instability. Transport of the beam depends upon the ferrite permanent magnet quadrupoles. Increasing the poletip field of the magnets will also increase the quadrupole gradient. Alternatively, we can increase the bore of the beam pipe as well as induction gaps, while increasing the poletip field at fixed beam energy, and maintain the same betatron period. Thus, we can decrease the transverse impedance due to the induction gaps, and hence the low frequency instability growth rate.

The higher frequency mode is more severe. Our solution is to place the extraction structures at half-betatron wavelengths, on the nodes. The growth rate should be similarly depressed as in the betatron node scheme for the TBNLC [3]. Field error tolerances in the quadrupoles become an issue, since this instability is sensitive to the details of the focusing lattice with respect to the positions of the RF output structures.

Another beam dynamic issue related to the induction cell is the extraction of RF power from the modulated beam. Power is absorbed by various materials in the cell and reduces efficiency. Techniques for lowering the longitudinal impedance of the cell at 30 GHz, therefore minimizing power loss in the output structures, is an active area of study.

The idler cavities in the adiabatic capture section and the extraction structures in the main section are detuned from synchronism at 30 GHz. This compensates for bunch lengthening effects, and provides longitudinal focusing. The synchrotron oscillation, induced by the power extraction and reacceleration, has a period of 91 m.

Induction Modules

We have designed a system to provide 155 kV per induction cell, to replace the beam energy lost in the RF output structures. For our long pulse (300 ns), and assuming that we drive the core to saturation, the 2714AS material has the lowest losses, and hence the largest efficiency. For a DC current of 1750 A and voltage of 155 kV/cell, the net core efficiency is ~91%.

Travelling Wave Output Structures

We obtain a zero-order design for the 30-GHz output structures by scaling the physical dimensions from our 11.424 GHz design. The structure is initially designed to operate in the $2\pi/3$ mode, but is then detuned by 30° so that it will actually resonate in the $\pi/2$ mode when driven at 30 GHz. The structure parameters are listed in Table 3.

Table 3. Travelling wave output structure parameters.

Frequency	30 GHz	R/Q	19 W/cell
Mode	$2\pi/3^*$	Pout	801 MW
β_{group}	0.65	Max. field	344 MV/m
a/λ	0.62		

* Detuned by 30° - resonant travelling mode is $\pi/2$.

System Efficiencies

The pulse power system suitable for this design would utilize a DC power supply, a Command Resonant Charging (CRC) chassis, and thyatron switching, like the earlier TBNLC proposal. We can make predictions of the efficiency of the pulse power system based on our previous work. These estimates are listed below in Table 4. Here the drive beam fall time has been included to account for losses at the end of the voltage pulse that are dissipated in the induction cores. Drive beam to RF losses account for the beam losses at the front end of the relativistic klystron, and for beam power lost at the dump. Auxiliary power accounts for cooling and vacuum systems, etc. We include the RF to beam efficiency of the high gradient structures, and calculate the net efficiency of the RK-TBA to be ~52%.

Table 4. Power source efficiencies.

DC Power	0.93	Drive Beam Fall Time	0.94
Command Resonant Charging	0.96	Drive Beam to RF	0.93
Modulator (thyatron)	0.94	Auxiliary Power	0.98
Induction Cells	0.91	RF to High Energy Beam	0.79
Net Wall Plug to Beam			0.52

Future Collider and Power Source Studies

We are exploring techniques to modulate beams and extract power at much higher frequencies (30 GHz - 120 GHz or higher). At these frequencies, free electron lasers become good candidates for modulating beams [17]. We are currently designing inductively detuned RF extraction cavities at 30-35 GHz, to take advantage of some available beam sources. W-band (90-120 GHz) systems are also being considered in support of high-gradient structure research occurring elsewhere.

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We are working with a CLIC/CESTA group to characterize bunching from an FEL

We would like to test a high-power detuned rf structure with the CESTA beam

STANDING WAVE CESTA/RK CAVITY V-1A

VIEW A-A

UNITS ARE IN MILLIMETER

0.25 mm

R 0.050

slit width
= 4.24 mm

(Nlar/vopceek/CESTA/CESTA-SW-CAVITY... 7-Feb-97)

$f_R = 35.5269$: $df = -0.7267$: $Q = 25.6717$: $R_s = 178.906$: E.H.04.SEP.96

MAFIA

FRAME: 1 03/09/96 - 10:11:16
TYPE OF MODE 2.000000000000E+00
FCUTOFF/HZ 2.008044953600E+10
FNORM/HZ 0.000000000000E+00
SPATIAL STEP/M 2.625389024615E-04

VERSION[V321.0]

RKTBA.3D.O1.W39.1CELL.T3.2.585CM.ROUNDED.CESTA.DRC

RELATIVISTIC KLYSTRON TWO BEAM ACCELERATOR 3D CAVITY DESIGN
1MM OVERLAP : 39MM WAVEGUIDE LENGTH: 30MM PIPE : 1-CELL CAVITY
ENRIQUE HENESTROZA : 19 JANUARY 1996
MODE AMPLITUDE

P--:3.20

#1DGRAPH

ORDINATE: YHIGH_1_OUT
COMPONENT: -

FIXED COORDINATES:
DIM.....MESHLINE

ABSCISSA: GEOMTIME
[BASE OF YHIGH_1_OUT]

REFERENCE COORDINATE: T
VARY.....MESHLINE
FROM 1
TO 20000

MAFIA

FRAME: 2	03/09/96 - 10:11:16	VERSION[V321.0]	RKTBA.3D.01.W39.1CELL.T3.2.585CM.ROUNDED.CESTA.DRC
TYPE OF MODE	2.0000000000000E+00	RELATIVISTIC KLYSTRON TWO BEAM ACCELERATOR 3D CAVITY DESIGN 1MM OVERLAP : 39MM WAVEGUIDE LENGTH: 30MM PIPE : 1-CELL CAVITY ENRIQUE HENESTROZA : 19 JANUARY 1996 MODE AMPLITUDE	
FCUTOFF/HZ	2.0080449536000E+10		
FNORM/HZ	0.0000000000000E+00		
SPATIAL STEP/M	2.6253890246153E-04		

P--:3.20

#1DGRAPH

ORDINATE: YHIGH_1_OUT
COMPONENT: -

FIXED COORDINATES:
DIM.....MESHLINE

ABSCISSA: GEOMTIME
[BASE OF YHIGH_1_OUT]

REFERENCE COORDINATE: T
VARY.....MESHLINE
FROM 15000
TO 15250

MAFIA

FRAME: 7

03/09/96 - 10:11:16

VERSION[V321.0]

RKTBA.3D.01.W39.1CELL.T3.2.585CM.ROUNDED.CESTA.DRC

RELATIVISTIC KLYSTRON TWO BEAM ACCELERATOR 3D CAVITY DESIGN

1MM OVERLAP : 39MM WAVEGUIDE LENGTH: 30MM PIPE : 1-CELL CAVITY

ENRIQUE HENESTROZA : 19 JANUARY 1996

BUNCH CHARGE IN AS/M

P--:3.20

#1DGRAPH

=MULTI-CURVE=

ORDINATE: WAKEZ

[-0.800E+06, 0.800E+06]

ABSCISSA: GEOMWAKE

[0.768E+00, 0.784E+00]

ORDINATE: BUNCH

[0.000E+00, 0.100E-04]

ABSCISSA: BUCOORD

[0.768E+00, 0.784E+00]

MAFIA

FRAME: 8

03/09/96 - 10:11:16

VERSION[V321.0]

RKTBA.3D.01.W39.1CELL.T3.2.585CM.ROUNDED.CESTA.DRC

RELATIVISTIC KLYSTRON TWO BEAM ACCELERATOR 3D CAVITY DESIGN
1MM OVERLAP : 39MM WAVEGUIDE LENGTH: 30MM PIPE : 1-CELL CAVITY
ENRIQUE HENESTROZA : 19 JANUARY 1996

P--:3.20

#1DGRAPH

ORDINATE: POWFFTAM
COMPONENT: -

FIXED COORDINATES:
DIM.....MESHLINE

ABSCISSA: GEOMTIME_F_15
[BASE OF POWFFTAM]

REFERENCE COORDINATE: F
VARY.....MESHLINE
FROM 135
TO 200