SLAC-PUB-15229

S-BAND LOADS FOR SLAC LINAC*

A. Krasnykh, F.-J. Decker, SLAC National Accelerator Lab, Menlo Park, CA 94025, USA
R. LeClair, INTA Technologies, Santa Clara, CA 95051, USA

Abstract

The S-Band loads on the current SLAC linac RF system were designed, in some cases, 40+ years ago to terminate 2-3 MW peak power into a thin layer of coated Kanthal material as the high power absorber [1]. The technology of the load design was based on a flame-sprayed Kanthal wire method onto a base material. During SLAC linac upgrades, the 24 MW peak klystrons were replaced by 5045 klystrons with 65+ MW peak output power. Additionally, SLED cavities were introduced and as a result, the peak power in the current RF setup has increased up to 240 MW peak. The problem of reliable RF peak power termination and RF load lifetime required a careful study and adequate solution. Results of our studies and three designs of S-Band RF load for the present SLAC RF linac system is discussed. These designs are based on the use of low conductivity materials.

INTRODUCTION

The original RF system setup of the SLAC linac (see Fig. 1) was based on an array of 24 MW peak klystrons [1].

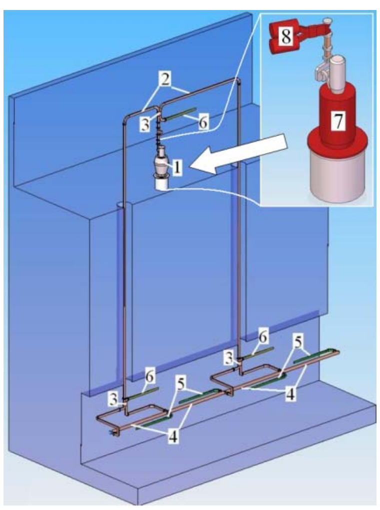


Fig.1 Original RF setup of the SLAC linac; 1 is XK-5 Klystron, 2 is WR284 Waveguide Branches, 3 is Power Dividers, 4 is Accelerating Sections, 5 is High Power RF Loads, 6 – Low Power RF Loads

Each RF station is equipped with a XK-5 klystron (1), feeding two branches of WR284 waveguide (2) and three 3dB power splitters (3) to supply four 10ft travelling wave accelerating sections (4). The residual klystron power after passing through the accelerator structure is absorbed by four high power loads (5). Three low power RF loads (6) absorb any mismatched (reflected) RF power. 240 such stations were in service of the original SLAC linac.

A high energy physics program (to reach 50 GeV output beam energy) was initiated and completed at the end of 1980 [2]. The original XK-5 klystrons were replaced by 5045 series klystrons with a 50 MW peak (subsequent production improvements the output power reached 65+ MW peak). SLED cavities were also introduced into the RF system thereby increasing the beam energy by a factor 1.7. The present typical RF setup is depicted in Fig. 1 where the new RF components (5045 klystron (7) and the SLED assembly (8)) are shown in right corner. A white arrow shows the location of the upgrade.

The residual power termination performance of the RF loads was not a concern during many years of service. For example, there were not any problems when the linac is used as the PEP-II injector. The RF absorption performance only became an item of concern after analyses of the LCLS RF phase stability issues [3].

It was found that the RF amplitude and phase of the reflected signals are unstable. It was shown also that these RF instabilities are associated with the processes inside of the load vacuum envelope. A detail of the RF structure layout that helps illustrate the high power load problem is shown in Fig.2.

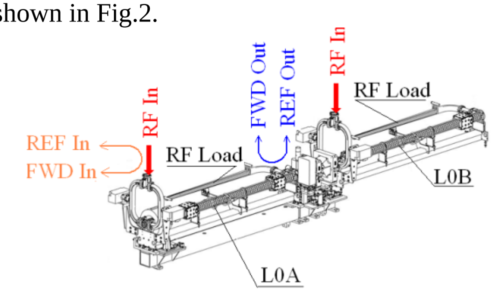


Fig. 2

These two stations are working with detuned SLED cavities. The input and output couplers are employed for the monitoring of forward (FWD In and FWD Out) and reflection (REF In and REF Out) signals. The waveforms of these signals are shown in Fig. 3.

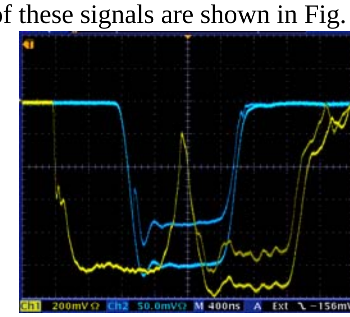


Fig. 3

Ch1 (yellow trace) shows the reflection power from the input of the accelerating structure. Ch2 (blue trace) shows the reflection signal from the output of the accelerating structure. One can see that the amplitude of the reflection signal from the input of the accelerating structure (the Ch1 trace) is stable in the beginning of the RF pulse, and after approximately 1600 nsec the amplitude is jumping

* Work supported by the U.S. Department of Energy under contract number DE-AC02-76SF00515 and SBIR grant number DE-SC0007661

Presented to The XXVI Linear Accelerator Conferece (LINAC12)
Tel-Aviv, Isreal, August 9-14, 2012

between two stages. This is clear from the Ch2 trace, which corresponds to the signal from the output coupler on the end of the accelerating structure that has been terminated by the high power RF load.

The result of the activity inside of the RF load is also clearly seen in Fig. 4).

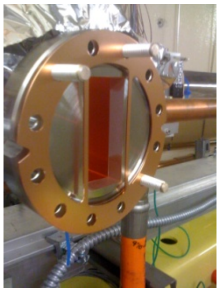


Fig. 4

When the RF load was disassembled from the accelerating structure, a gray layer on a flange of the output coupler and waveguide wall could be seen. This gray area consisted of deposited particles that were created inside of the high power RF load and transported by a pumping gradient to the end of the accelerating structure. Due to coupler directivity limitation (approx. -25 dB) the RF instability can be seen on the FWD RF signal of many SLAC RF stations. We have no data on the lifetime of the original high power RF loads. Independently we tested dozen available (spare) original RF loads. The instability of the high power RF termination has been identified in all tested loads.

RESULTS OF STUDY

There was unsuccessful attempt to find (in national and world wide) vendors to purchase the needed vacuum load from industry. Two dry load designs were tested. One high power load was designed in BINP (Novosibirsk, Russia) and another S-Band dry load manufacturer was Nihon Koshuha Co. (NKC, Japan). The BINP load design does not meet the "*dry*" SLAC specification (i.e. with water leak proof) because the only brazing layer is the vacuum-water interface. It is not acceptable for 2 mile SLAC linac. The NKC loads cost and acceptance yield are not acceptable for SLAC (we tested five loads and only two were accepted).

Results of SLAC Effort

The results above required find alternative solution for our linac within SLAC budget limitations. We are now working with a small business company that was granted a Phase I SBIRs to develop new S-Band RF loads for the SLAC linac. This work is being performed under a Cooperative Research and Development Agreement (CRADA) to design and build the RF load based on low conductive materials as a high power RF absorber. According to the CRADA, the high power load design will be performed by SLAC personnel. INTA will be a responsible for the technology and manufacting methodologies. Working together under the DoE SBIR support, the problem of high power RF load could be solved for the next 50 year linac service. A more detail decryption of SLAC RF load design will be published at SLAC.

The following RF load concepts are under consideration by INTA and SLAC:

1. RF load design based on SiGraSiC group of composite materials.
2. RF load based on the bulk Kanthal APMT extruded tubing
3. RF load based on the plasma deposition of ferritic FeCrAl alloy

1. *Result of the RF load design based on SiGraSiC material*

This is a rather new family of the carbon-carbon conductive materials and their composites. We contacted HITCO Carbon Composites, Inc. and realized that the manufacturing process allows us to tailor the conductivity based upon the constituents to some extent. The material they provided for evaluation purposes was based upon low DC conductivity applications using short fiber reinforcement. The short fiber reinforced materials are similar to the materials used for high performance braking operations. SiGraSiC samples are tested under a capability to handle a peak current up 200A, to be acceptable for a high vacuum. A conductivity of the SiGraSiC material allows employing the wire electric discharge machining process for a desired shape. A surface of SiGraSiC can be metalized. Samples of this material was tested in a broadband power range (mW <P< 10 kW) range power. A design of the high power 3dB attenuator with SiGraSiC insertions was made and a prototype of the attenuator has been tested at 8 kW peak RF level. The 3dB prototype attenuator is shown in Fig. 5 at test stand. Two black 12 inch insertions at H-planes of WR284 waveguide are made from SiGraSiC blocks.

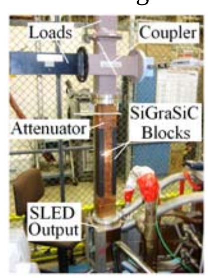


Fig. 5 a)

Fig. 5 b) shows input and output waveform of the RF power. White and red traces are the input and transmitted RF power though a device. We did not see any RF absorber degradations at kilowatt power levels.

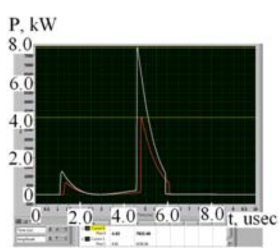


Fig. 5 b)

Attenuation rate with a special SiGraSiC shape is approx. 10 dB/m. A load (that possesses 10 dB one-way-pass attenuation) will require two SiGraSiC blocks of a 40 inch length each. The technology of vacuum and heat transfer issues is under consideration.

2. *Result of the RF load design based on the bulk APTM Kanthal extruded tubing*

The Kanthal material is preferable because of its reasonable low electric conductivity, its stability under high temperature, and its good vacuum properties. Our discussion with experts from Kanthal indicated that a rectangular waveguide from the Kanthal material will require design of special extruded tooling and a significant upgrade in technology. However extruded "cylindrical" tubing made from bulk Kanthal material is readily available. A proposed RF load concept is shown in Fig. 6.

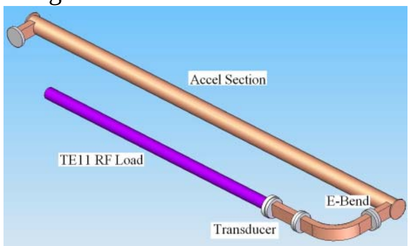
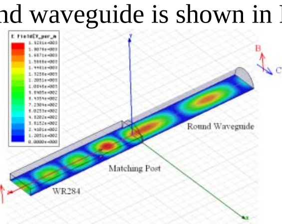


Fig. 6

The RF load based on tubing will require a mode converter (transducer) because the RF mode from the output of the accelerating section is TE10 mode. For our experiments, we selected a tube with OD=75mm and wall thickness=4.5 mm because the wave length in this waveguide would be close to the critical wave length. In this case, we would expect a high attenuation of a propagated wave.

We evaluated two types of waveguide transducers. The first one is simply a rectangular-to-round waveguide with a conductive post (see HFSS half of model on Fig. 7a) and a smooth tapering transducer from rectangular-to-round waveguide is shown in Fig. 7 b).



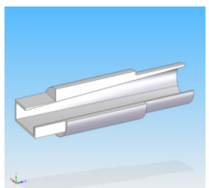


Fig. 7 a) Fig. 7 b)

A low level setup for a measurement of RF power attenuation of the APTM Kanthal extruded tube of 6 ft long is shown in Fig 8. We tested this load concept in a broadband power range too.

Fig. 8

TE11 attenuation measurements of the bulk Kanthal APMT show approximately 2-2.5 dB/m attenuation rate. It is rather low compared to the attenuation rate of the original RF load [1] where a technology of "flame-spayed" Kanthal wire onto a stainless steel base was used. That fact confirms that both (1) a component matrix of absorber and (2) a technology of matrix deposition onto base material are important phases for the RF attenuation rates.

3. *Result of the RF load design based on the plasma deposition of ferritic FeCrAl alloy*

A concept of the TE10 mode RF load can be seen from Fig. 9 where a cross section of modified WR284 waveguide is shown.

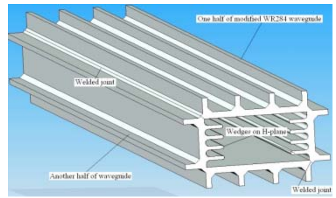


Fig. 9

The modified WR284 waveguide is formed (extruded) from two identical parts made from aluminium alloy. Two halves are a base for the RF absorber layer. Both H-planes are with four thin vanes. A FeCrAl matrix is plasma sputtered onto the halves. Both coated halves are welded and a waveguide channel is formed. The RF load prototype was designed at SLAC and made by INTA Technologies. The RF load prototype had been conditioned and tested up to 30 MW peak power. Two power meter waveforms vs. time are shown in Fig. 10. Red and Blue traces are forward and transmitted RF power.

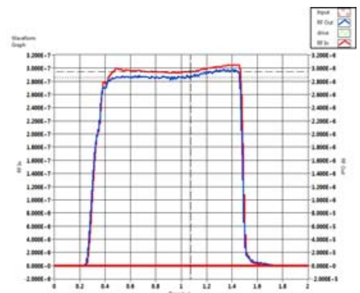


Fig. 10

One can see that: (1) the RF load prototype runs at 30MW peak and 1 usec pulse width, and (2) one-way-pass attenuation is approx. 10 dB (~5.5 dB/m). No RF power instability was detected.

CONCLUSION

There are indications that the present SLAC RF loads are near the end of their lifetime. SLAC and INTA Technology haves studied several alternatives for solving the RF load problem. The most promising results were obtained with the plasma deposition of ferritic FeCrAl alloy onto modified rectangular waveguide with vanes on H-planes. The technology achieved a 5.5 dB/m attenuation rate at 30 MW peak power and 1 usec pulse width with no evidence of breakdown activity in the vacuum envelope on the coated surfaces. We proposed a design and technology recommended for manufacture of a pilot series of the high power loads for the SLAC linac.

ACKNOWLEDGMENT

We thank Mr. R. Sviben and Mr. S. Schatz (Kanthal, SANDVIK) and Mrs. R. Hines (SiGraSiC, HITCO) for useful discussions.

REFERENCES

[1] "The Stanford Two-Mile Accelerator", p. 376-381, R. B. Neal, General Editor, 1968, W. A. Benjamin, Inc., NY Amsterdam

[2] [2] G. A. Loew, et. al., PAC 1985 Vancouver, Canada, 1985 (see also SLAC-PUB-3609)

[3] F.-J. Decker, et. al. "Indentifying Longitudinal Jitter Sources in the LCLS Linac", IPAC 2010, May 2010