A 26 GHz DIELECTRIC BASED WAKEFIELD POWER EXTRACTOR*

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Abstract

High frequency, high power rf sources are needed for many applications in particle accelerators, communications, radar, etc. We have developed a 26GHz high power rf source based on the extraction of wakefields from a relativistic electron beam. The extractor is designed to couple out rf power generated from a high charge electron bunch train traversing a dielectric loaded waveguide. Using a 20nC bunch train (bunch length of 1.5 mm) at the Argonne Wakefield Accelerator (AWA) facility, we expect to obtain a steady 26GHz output power of 148 MW. The extractor has been fabricated and bench tested along with a 26GHz power detector. The device has been installed at the AWA beamline and beam measurements are forthcoming.

WAKEFIELD POWER EXTRACTOR

Wakefield effects are very important considerations for accelerator design because they are the major source of beam instabilities such as bunch lengthening, head-tail turbulence and emittance growth. However, the wakefield energy generated by a charged particle beam also can be used to accelerate an appropriately phased trailing beam or can be extracted by a high efficiency RF coupler working as a high power RF source. Generally, the RF packet generated by a single particle bunch lasts a few nanoseconds. A properly spaced bunch train can stack the RF pulses from each bunch so that both the pulse length and amplitude are increased [1]. Due to the ease with which the RF power characteristics can be changed by manipulating the decelerator and its drive bunch, this scheme may overcome some of the limitations of other conventional high-power RF systems at frequencies above X-band and power levels beyond a few hundred megawatts.

A 26GHZ DIELECTRIC BASED WAKEFIELD POWER EXTRACTOR

Efficient RF power generation first requires the drive bunch energy to be efficiently coupled into the desired decelerator mode (typically TM_{01}) and then, that the RF output coupler efficiently extracts this power to the output waveguide. Because of its simplicity and other potential advantages, the use of dielectric-loaded waveguide as part of an RF power extractor has been investigated and tested [1-3]. We have recently developed a 26GHz dielectric based wakefield power extractor [4]. The estimated RF power that can be achieved in this device is 148MW using a 20nC bunch at AWA facility.

The major parameters for both the fundamental decelerating mode (TM_{01}) and the deflecting mode (HEM_{11}) of the 26GHz dielectric-based wakefield power extractor are presented in [4]. The wakefield signal excited by the beam will propagate along the structure with its group velocity, and will be extracted through an output coupler to a WR-34 rectangular waveguide. An optimized coupling slot and chamber can implement high efficiency conversion between the fundamental TM_{01} mode in the dielectric-loaded circular waveguide and the dominant TE_{10} mode in the rectangular waveguide within the operating frequency range, and simultaneously maintain a low transmission of the HEM_{11} deflecting mode. Figure 1 shows the final output coupler design of the dielectric-based 26GHz power extractor. One tuning pin is used in this design. The output RF power is propagated out to a standard WR34 rectangular waveguide through a tapered transition. In general, the dual port design can heavily suppress the coupling out of the dipole mode. However, in this proof of principle experiment, we selected a single port scheme that can significantly reduce the complexity of the fabrication work while maintaining a significantly damped coupling of the dipole mode as well. The simulation shows that ~600MHz bandwidth can be achieved with a ~97% RF power transfer efficiency. A key contribution to this large bandwidth is the slightly bigger diameter of the empty waveguide between the dielectric-loaded decelerator and the rectangular waveguide. This broadband simulation result also provides a very good mechanical tolerance in the next stage engineering design. In addition, in the simulation, the fundamental transverse mode, HEM_{11} is damped to < -20dB over the full range of the passband.

The whole power extractor is designed to be machined in three parts: dielectric-loaded waveguide, coupler block, and downstream beam channel (doubling as an RF cutoff for the 26GHz signal). After machining the three parts are brazed together with the flanges at the three open ends. The standard CF flange uses a knife edge and copper ring (gasket) to seal the vacuum and the center area always has a gap where they connect together. This gap has a choke effect for the RF signal and it may lead to an breakdown in the high power RF transport. Therefore, we specially designed a flange and corresponding gasket for the RF output port so that the high power RF signal can be transmitted without an RF discontinuity while maintaining high vacuum (see Fig.2). This flange is a unisex design. In addition to the knife edge it has a

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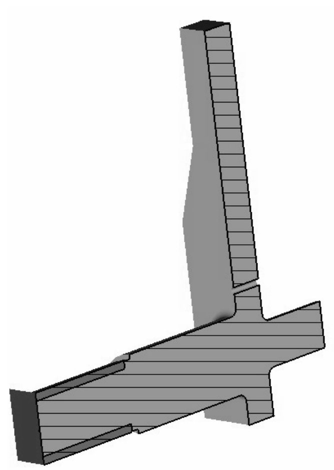

Figure 1: Cross sectional view of the final output coupler design for our proposed 26 GHz dielectric based RF power extractor, modeled using CST Microwave Studio®.

protruding rectangular lip which presses against the lip of the connected flange through a copper gasket. The gasket used for this flange is not a regular copper ring but a copper disk with a rectangular opening at the center. In order to ensure both openings from gasket and flange are well aligned in the installation, a locating post is also designed on the flange to maintain the orientation of the copper gasket (not shown in Fig. 2).

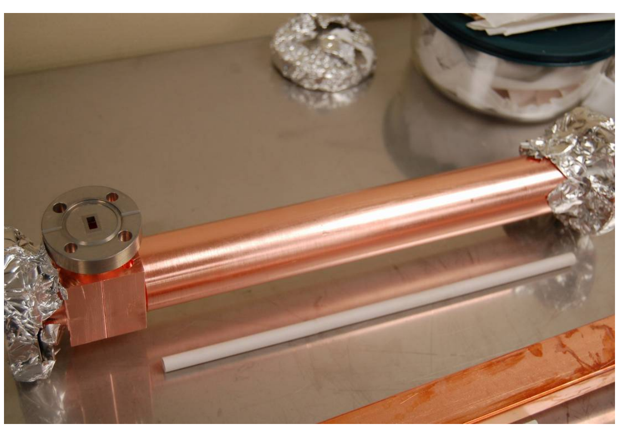

Figure 2: Fabricated 26GHz dielectric-based wakefield power extractor and dielectric (consisting of three 10-cm long dielectric tubes) prior to loading.

To evaluate the performance of the 26GHz wakefield power extractor after the machining and assembling process was complete we performed RF bench measurements. In the bench test, a TEM-TM_{01} mode launcher was designed to convert the TEM mode to the TM_{01} mode for the dielectric-loaded waveguide. The mode launcher consists of a center pin with a disc on the tip, and a grounded copper plug inserted into the copper sleeve. The simulated RF power transmission of this mode launcher is 97% in the 25–27GHz range. The bandwidth of the mode launcher is much wider than that of the RF output coupler, thus the insertion loss of the mode launcher is negligible. At the output port of the power extractor, a vacuum RF flange is used to connect to the WR34 waveguide. In the bench test, a commercial WR34 waveguide-coax adapter is used to convert the TE_{10} mode to the TEM mode for the output cable. The S-parameters of the combined mode-launcher and power-extractor system were measured, with the results plotted in Fig. 3. The system has a measured insertion loss S_{21} = -2.3dB at 26GHz. By subtraction of the loss from the adaptor (0.5dB), the loss due to the power extractor is 1.8dB corresponding to a power coupling efficiency of 66%, without considering the mismatch between the output coupler to adaptor. The theoretical loss, based on the copper losses at 26GHz and the loss tangent of the dielectric tube, is 1dB or 80%. The difference between the measurement and theoretical values may result from resonances caused by multiple reflections from the joints of the three dielectric tube segments. The reflection coefficient S_{11} in Fig. 4 shows this effect. In the actual beam test setup, the dielectric tubes will be compressed firmly by a copper plug at the upstream end that is expected to reduce these joint reflections and improve the overall RF transmission.

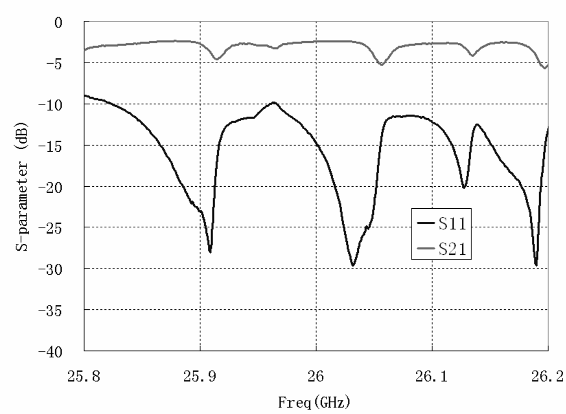

Figure 3: The measured S-parameters of the power extractor.

BEAM EXPERIMENT PREPARATION

The next step on this project is a beam experiment that will permit evaluation of the real performance of the developed structure. The beam test is planned for the AWA facility, which has the capability of producing high current bunch trains from its L-band photoinjector. The 26GHz high power RF signal from the output port of the power extractor will need to be transported to the diagnostics and requires a waveguide capable of handling at least 150MW short pulse RF. We plan to use WR34 waveguide under ultra high vacuum to convey the RF signal. Since a high power RF load at 26GHz is not available, we plan to use a long shorted end waveguide, which can provide ~15ns time delay, to replace the load in the experiment. In order to achieve an efficient vacuum pumping rate for the low pressure conductance WR34 waveguide (small size and long range) and maintain a small RF perturbation, we designed two pumping ports along the waveguide. The AWA facility is a pulsed machine. The operational repetition rate is usually less than 5Hz so that the RF wave reflected back to the power extractor will not influence the electron bunch train in the next cycle. However, a high power RF load is more favorable if the RF pulse length is increased (otherwise, we would have to use an even longer waveguide to generate an RF delay). This load has to be vacuum friendly since there is no RF window available in the high frequency range. The traditional multiple-cell all metal load is complicated to design and fabricate. Considering the low average power generated in our experiments, we choose to develop a SiC based 26GHz high power RF load. We have fabricated one 26GHz SiC based RF load (The SiC material actually used is Ceralloy 13740Y,SiC-AlN, from Ceradyne®.). Bench tests show -20dB of RF reflection has been achieved over a broad frequency band. Since the load will be used under ultra-high vacuum condition, we have brazed RF flanges to both ends of a short piece of WR34 waveguide as the housing of the SiC wedge. The load will be installed after the long waveguide in the experiment.

The major diagnostic component required to evaluate the 26 GHz RF power extractor is a 26GHz RF power detection system. Since the forward and backward RF signals will be well separated in time by tens of nanoseconds due to the use of a long WR-34 waveguide in the beam experiment, instead of a bidirectional coupler, we can then use one RF pin probe to detect the RF signal in both directions. We have developed a 26GHz RF power detector. In the design, a pair of arc slots is designed to have a small portion of RF coupled out. This specially designed coupling slot is to establish the TEM mode and suppress unwanted TE modes for the RF pin probe. The commercially available RF pin probe used in the detector can hold ultra high vacuum through the use of a 1.33” CF flange. The output end of probe is a standard 3.5mm connector. -51dB coupling coefficient at 26GHz was measured by network analyzer. Figure 4 shows the experimental setup of the structure at the AWA beamline.

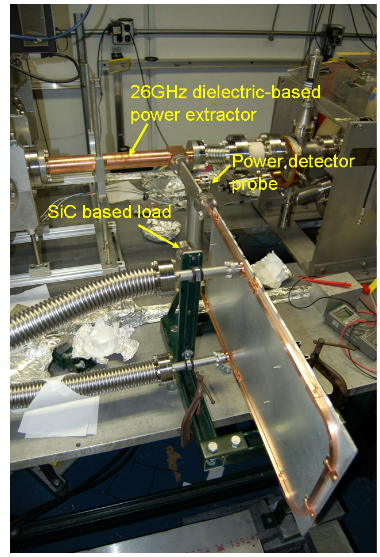

Figure 4: The finished U-shape waveguide, 26GHz RF detector, and SiC based RF load.

NEXT STEP

The structure has been pumped to the low 10^{-9} Torr. The experimental study is undergoing. A bunch train consisting of 16 bunches will be used in the test, which is able to generate 10ns flat top rf pulse. The experimental data will be reported soon.

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