PROGRESS ON MULTIPACTOR STUDIES IN DIELECTRIC-LOADED ACCELERATING STRUCTURES

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Abstract

Significant progress has been made in the development of high gradient RF driven dielectric accelerating structures (DLA). One principal effect limiting further advances in this technology is the problem of multipactor. The fraction of the power absorbed at saturation in DLA experiments was found to increase with the incident power, with more than 30% of the incident power per unit length being absorbed. We studied the possibility of multipactor mitigation by introduction of surface grooves (transverse and longitudinal) to interrupt the resonant trajectories of electrons in the multipactor discharge. Four DLA structures based on quartz tubes with transverse and longitudinal grooves of various dimensions were designed. In this paper we report simulation results and plans for high-power tests of these structures.

INTRODUCTION

As various engineering challenges (breakdown, dielectric losses, efficient rf coupling) have been overcome, the technology of high gradient RF driven or wakefield dielectric loaded structures appears increasingly attractive as a viable option for high energy accelerators. The basic RF structure is very simple - a cylindrical, dielectric tube with an axial vacuum channel is inserted into a conductive sleeve. The dielectric constant and the inner and outer radii of the dielectric tube are chosen to adjust the phase velocity of the fundamental mode at certain frequency to the beam velocity ~ c. In the application of particle acceleration, the dominant TM_{01} mode is of main interest. The problem of multipactor appears to be one major remaining effect limiting the practicality of these devices.

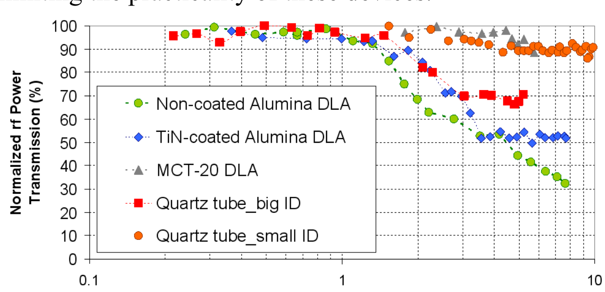

Figure 1: Summary of high power test results of dielectric loaded accelerating structures (AWA-NRL) [1].

Multipactor is an avalanche growth of secondary electrons produced in RF structures exposed to high fields. In the case of dielectric loaded accelerating structures it was observed, for example, in high power RF tests performed by the AWA-NRL collaboration (Fig. 1) [1]. A significant amount of RF power was consumed by multipactor. Moreover, multipactor stimulates breakdown and changes accelerating structure impedance.

The accelerating mode in a DLA structure possesses a significant component of the electric field normal to the dielectric-beam channel boundary. As pointed out in ref [1], the presence of both strong radial and axial electric fields leads to a new regime of single surface multipactor where only electrons emitted during a small fraction of the rf period contribute to multipactor. Saturation levels for multipactor in this regime are significantly higher than that observed for a dielectric rf window.

Analytic and numerical treatments of multipactor are challenging in part because of the nature of the secondary emission process. The secondary emission yield of electrons from a surface is a function of a number of variables, including the energy and angle of incidence of the incident electron, and the threshold energy and surface roughness of the material.

In this paper we report on progress of an experimental study of multipactor in DLA structures with modified inner surfaces.

AXIALLY (LONGITUDINALLY) GROOVED DLA STRUCTURES

Experimental studies in metal waveguides and chambers have shown multipactor reduction by making inner surface grooves along the direction of wave propagation [2-5].

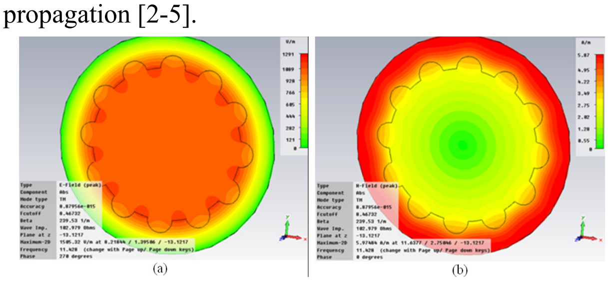

Figure 2: The magnitudes of the electric (a) and magnetic (b) fields of the TM_{01} mode in an 11.424 GHz longitudinally grooved quartz based DLA structure.

These axial grooves can partially prevent the primary electrons azimuthally hopping around the surface, and help trap the multi-generation secondary electrons in the grooves to be eventually absorbed. A similar concept can be applied to the dielectric-loaded accelerating structure. Figure 2 shows a schematic drawing of an axially grooved DLA structure and field distributions of the TM_{01} mode. The grooves are chosen to be rounded for manufacturing simplicity. Some other shapes, like rectangular, triangular or tip-rounded triangular teeth, have been studied [3]. In fact, the depth plays the most important role in multipactor reduction no matter what shapes are used [3]. However, the depth of grooves is constrained by other factors, mostly by fabrication limitations, which are particularly important considerations in a DLA structure design.

AZIMUTHALLY (TRANSVERSELY) GROOVED DLA STRUCTURES

In order to disturb the resonant electrons along the dielectric surface, we can also cut azimuthal grooves on the inner surface of dielectric tube (Fig 3.).

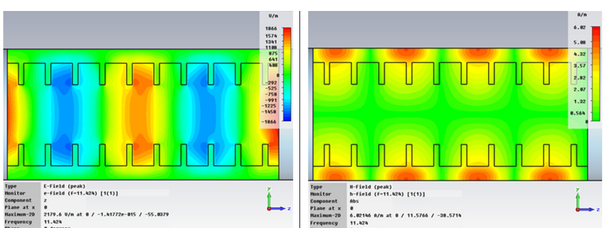

Figure 3: The magnitudes of the electric (a) and magnetic (b) fields of the TM_{01} mode in an 11.424 GHz transversely grooved quartz based DLA structure.

Table 1 shows the accelerating parameters of structures that have been designed and built. We can see that the R/Q of azimuthally–grooved structures increases and the shunt impedances are higher than that of a smooth surface. This is in itself a very interesting effect. Traditional DLA structures made of smooth ceramic tubes have lower shunt impedance than metallic structures of comparable accelerating properties. Obviously, in this case altering the dielectric surface helps to recover the decrease in shunt impedance.

Table 1. Accelerating Parameters Comparison

	v_{group} % c	Q	r/Q (Ω/m)
Smooth	38.6 %	6795	3658
Transverse 1	40.1 %	7410	3917
Transverse 2	39.2 %	7730	3841
Longitudinal 1	40.8 %	7761	5411
Longitudinal 2	38.6 %	7543	4268

DESIGN AND MANUFACTURING OF DLA STRUCTURES WITH GROOVES

Since observation of multipactor in dielectric loaded accelerating structures several simplified models were developed [1, 6 - 8]. Full 3D simulations started to be available recently in commercial software packages. These solvers are currently being benchmarked by the accelerator community [9 - 11]. The mainstream application at this moment is multipactor studies in superconducting structures. Multipactor in DLA structures can be simulated, but we found that results were sensitive to the mesh density and seed patterns. We also observed particles trapped inside dielectric subdomains. Simulation using CST (Fig. 4) shows a comparison of the growth in the electron population in the case of smooth and grooved tubes. We observe that saturation occurs much earlier than in the smooth tube case.

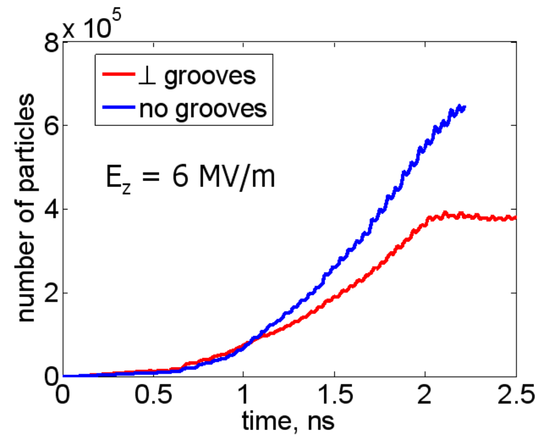

Figure 4: Comparison of the multipactor development for a smooth tube vs. a tube with transverse grooves.

Multipactor saturation occurs when DC field from the electron cloud of emitted secondary electrons compensates the RF field. The structure with transverse grooves prevents the cloud from dispersing longitudinally facilitating early saturation of multipactor.

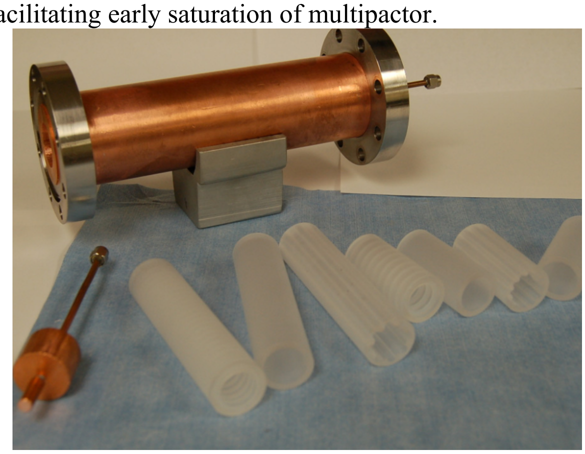

Figure 5: Example of manufactured quartz tubes: longitudinal and transverse grooves, various lengths, smooth tubes. Waveguide and mode launchers for bench test.

Based on our studies we were considering dramatic designs: high aspect ratios, large heights of grooves etc. However we faced severe limitations imposed by manufacturing process. Altogether there were 6 quartz tubes manufactured (Fig. 5): smooth, transverse and longitudinal grooves with different lengths. These tubes will be tested at least two times each: with and without TiN coating. Long tubes will be cut in half and retested. This way we will be able to cover a large parameter space of coatings, groove types and length.

All dielectric tubes are made with identical outer diameters. This way only two copper enclosures will be needed – for short tubes (50 mm) and long tubes (100 mm). The high power testing hardware is designed for a fast turnaround of the sample.

RF MATCHING DESIGN AND BENCH TEST

In a high power test the 11.424 GHz RF power comes in a ~ 200 ns pulse from the NRL magnicon facility. A reusable SLAC coupler / mode converter [12] will convert the TE_{10} mode coming from the magnicon in a rectangular waveguide into the TM_{01} mode of a cylindrical waveguide. This mode has to be matched to the TM_{01} mode inside the dielectric loaded structure. This is achieved by an intermediate transition piece between the coupler and waveguide flange with matching azimuthal bump (shown by the arrow on Figure 6). In principle, all manufactured different quartz tubes will require different transition pieces. However the manufactured quartz pieces are still quite similar to the empty tube and we found that only two different transition pieces will be required. This is due to the fact that the quartz dielectric constant is small enough (3.8) so that the RF properties of different dielectric pieces are not that different from piece to piece.

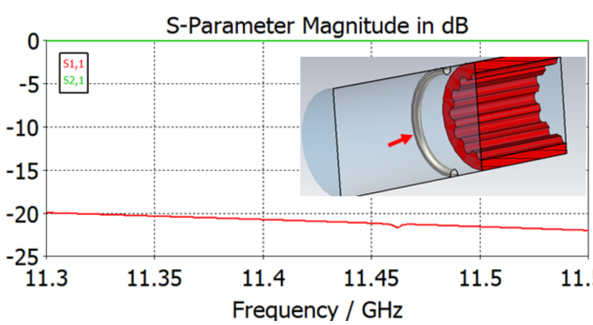

Figure 6: RF matching from an empty waveguide into waveguide loaded with a dielectric cylinder with longitudinal grooves. The metal bump position and size is optimized to provide perfect matching at 11.424 GHz for a particular tube geometry.

While the high power matching sections were being manufactured we performed a bench test using a mode launcher design that is routinely used for DLA bench measurements. The launcher was designed for this particular geometry (Fig. 5). The bench measurement was performed on various quartz tubes that had been manufactured. We used a network analyzer to record transmission / reflection (S-parameters) from the structure. Figure 7 shows the bench measurement results for the structure with transverse grooves.

Cold testing provides a description of the manufactured pieces by giving an estimate for imperfections due to manufacturing tolerances. In the measurements we observed that even though we did not use the high power couplers that are planned for the actual high power test (with matching bumps) transmission through the structures was quite acceptable. This indicates that the manufacturing errors were minor.

Figure 5 shows all the grooved and smooth quartz tubes that have been designed, manufactured, and bench tested.

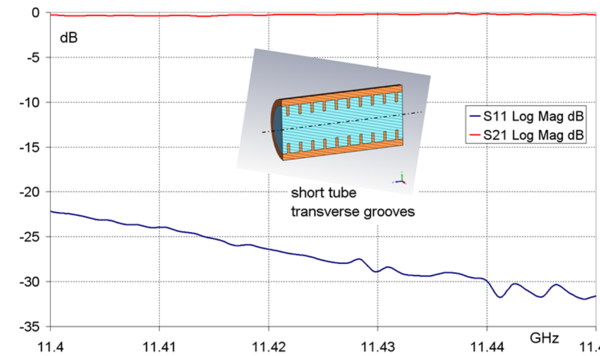

Figure 7: Bench test measurement (S-parameters) of a transverse-grooved structure.

SUMMARY

Building upon prior experimental work in this area we have designed and constructed several DLA structures with modified inner surface, using different geometrical factors (grooves). We designed and are currently manufacturing the RF coupling adaptors for high power testing to be conducted at NRL magnicon facility. An rf bench test of these 11.424 GHz dielectric structures were performed which showed, that the tubes were manufactured with minimal errors. A large space of parameters that define multipactor properties will be experimentally studied at high power. The data will be also made available for simulation benchmarking.

The overall objective for this research is a systematic study of the multipactor mitigation techniques in dielectric loaded accelerating structures using grooved dielectric tubes with combinations of TiN coating.

ACKNOWLEDGEMENTS

The work is supported by the DOE SBIR program, grant #DE-SC0004323.

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