

BUILDING TWISTED WAVEGUIDE ACCELERATING STRUCTURES*

M. H. Awida, Y. W. Kang, S-H. Kim, S-W. Lee, ORNL, Oak Ridge, TN, 37831, U.S.A.
 J. L. Wilson, MIT Lincoln Laboratory, Boston, MA 02139, U.S.A.

Abstract

RF properties of twisted waveguide structures were investigated to show that slow-wave accelerating fields can be excited and used for acceleration of particles at various velocities lately. To build a practical accelerating cavity structure using the twisted waveguide, more development work is needed: cavity structure tuning, end wall effect of the structures, incorporating beam pipes and input power coupler, and HOM damping, etc. In this paper, the practical aspects of making a more complete accelerating structure are discussed with the results of computer simulations.

INTRODUCTION

Slowing the phase velocity of an electromagnetic wave in a low loss resonant structure to the point that matches the particle velocity is the basis for achieving particle acceleration. The properties of twisted waveguide structures were previously investigated, and it has been shown that slow-wave accelerating fields could be excited within the structure, in contrast to straight structures where the phase velocities of electromagnetic waves are faster than the speed of light [1][4][5].

Traditionally, slow wave structures were constructed by employing reactive loading such as periodic iris [2] or a dielectric load [3]. Most practical systems use the periodic corrugation of the waveguide wall. The proposed slow-wave nature of the twisted waveguide employs a wave path that is elongated by twisting the waveguide so that the fast electromagnetic wave is actually travelling along a longer spiral path while the slow particles are traveling along a straight path. Controlling the spiral path by varying the twist-rate can allow the longitudinal velocity of the electromagnetic wave to match that of the particles.

The conventional multi-cell accelerator structures (for instance TESLA type cavity) have a circular transverse cross-section that is continuously changing along the acceleration path. That non-uniform transverse cross section is usually the main reason of the high construction cost and the possibly serious trapped modes phenomena. By contrast, the twisted waveguide structure has a uniform transverse cross section over the whole acceleration path, which potentially eliminates the troubling trapped modes inside that twisted waveguide structures, and may offer better field uniformity along the axis and enhanced beam stability. Unlike the periodic coupled cavities, the dispersion relation of the twisted structures is similar to that of regular hollow waveguides.

TWISTED WAVEGUIDE DESIGN

The mainstream body design of the twisted waveguide accelerating structure basically involves selection of two key criteria, namely; the waveguide cross-section and the twist rate. These key design parameters can be optimized in accordance with the required accelerating field strength that can be translated to R/Q as a figure of merit for any accelerator structure. For selection of the twisted waveguide cross section, there is an indefinite number of choices that could fit the required accelerator performance from an RF point of view. Designing a twisted waveguide accelerator that has a longitudinal cross section that mimics the longitudinal cross section of the rotationally symmetric conventional accelerator may help greatly in the performance evaluation of the twisted waveguide accelerator.

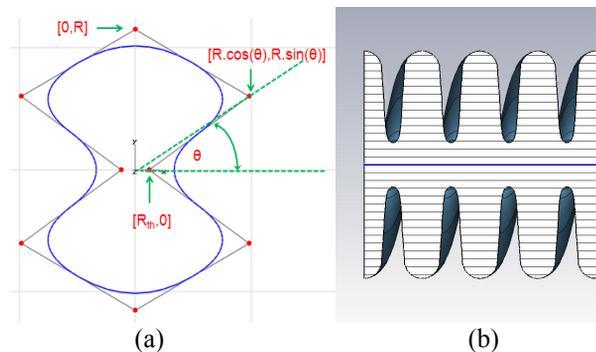
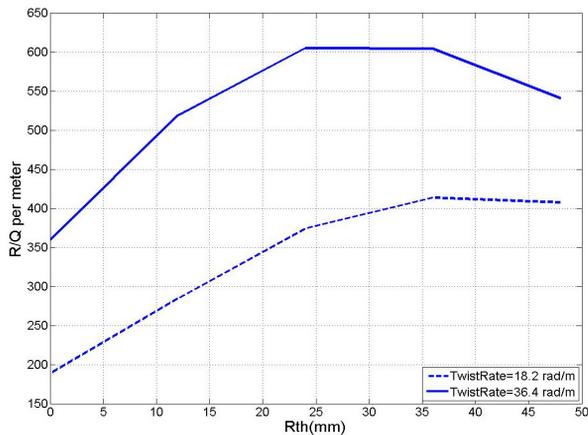


Figure 1: (a) Parameterized twisted waveguide cross-section using spline. This can result (b) a multi-cell cavity like longitudinal cross section of a twisted waveguide.

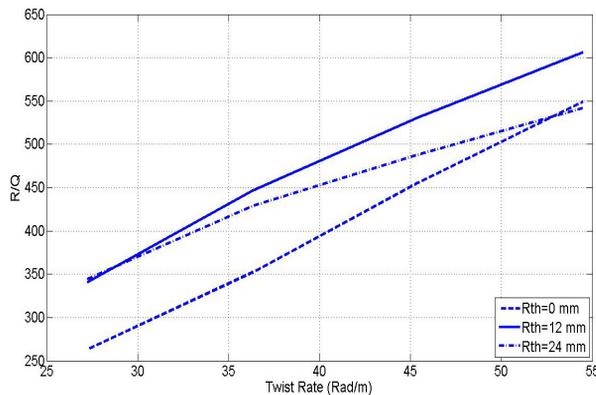
The authors in [4], [5] showed that how the transversal and the longitudinal cross-sections are related in the twisted waveguides and that certain designs can result the longitudinal cross sections similar to the cross sections of commonly used conventional corrugated cavities. One of the designs they used was similar to the one in Fig.1 (a) that reflects a TESLA style longitudinal cross section shown in Fig. 1(b). The cross section elegantly provides the smoothness required for a superconducting accelerator structure. Although further optimization will be inevitable, in an effort to standardize the transverse cross section and make it easy transferable in the particle accelerators community, we have used a spline curve shown in Fig. 1(a). There are only three parameters needed to fully define the cross section, namely: R defines the outer circle passes by the outer spline control points, θ defines the angle of the side points, and R_{th} which determines the opening distance of the inner spline control points.

* ORNL is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy.

The proposed spline-based definition was employed in the design of a 1.3GHz twisted waveguide accelerator for electron acceleration ($\beta_g=1$) which is 1.038 m in length. The proposed 1.3GHz twisted waveguide accelerator corresponds to the well-known 9-cell Tesla accelerator for the international linear collider. To achieve the design goals a parametric study was carried out using CST microwave studio [6]. As a first step, one third of the whole 1.038 m structure was used in the investigation, and the R/Q per meter was calculated based on the CST full EM simulation versus the throat distance R_{th} for two different twist rates namely; 18.2 and 36.4 rad/m.



(a)



(b)

Figure 2: R/Q parametric study (a) R/Q per meter of the one third accelerator structure versus R_{th} (b) R/Q versus twist rate for the twisted waveguide structure with flat end-wall.

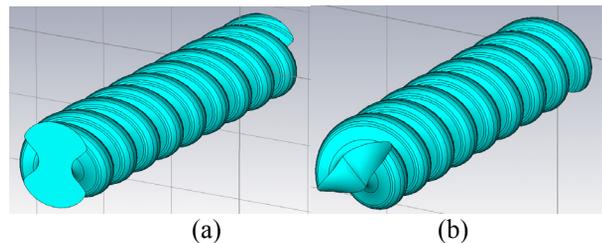
As shown in Fig. 2(a), it is clear that increasing R_{th} will increase the R/Q value up to a certain point where the R/Q will saturate and decreases back again. This saturation throat distance obviously moved from about 35 mm to 25 mm when the twist rate doubled from 18.2 rad/m to 36.4 rad/m as shown in Fig. 2(a).

It is worth noting that the R/Q values calculated from the one third structure simulation are a little bit higher than what we expect for the whole 1.038 structure because of the flat end wall high field effects. That is why we have considered secondly the whole 1.038 m accelerator; the R/Q of the whole structure was calculated

with respect to the twist rate for different values of R_{th} . The obtained results are shown in Fig. 2(b) indicating that while the $R_{th}=24$ mm results in higher R/Q at twist rates lower than 27 rad/m, it produces smaller R/Q at higher twist rates. Clearly, choosing $R_{th}=12$ mm is better at high twist rates, and an R/Q of over than 600 was obtained for a twist rate of 54 rad/m; however higher twist rates are expected to produce higher R/Q values if needed.

REALISTIC TWISTED ACCELERATING STRUCTURE

Building a realistic twisted waveguide accelerator at 1.3 GHz for electrons acceleration has been investigated taking into account the practical aspects of the accelerator implementation, namely end wall effects, incorporation of beam pipes, and the input power coupling.



(a)

(b)

Figure 3: Comparison between the different end wall topologies: (a) Flat end walls. (b) Twisted end walls.

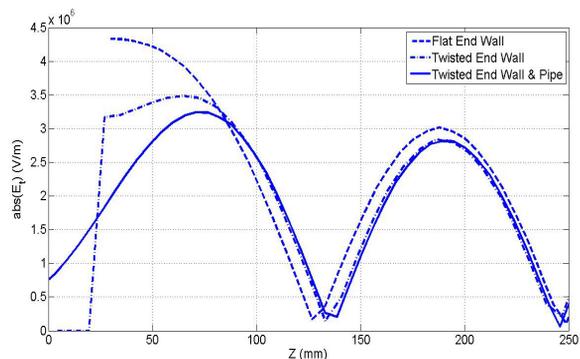


Figure 4: Comparison between the different end walls in terms of induced absolute value for the electric field.

End Wall Effects

Practically, the accelerating structure is required to have a uniform peak electric field on the accelerator axis to avoid any beam instabilities. Previously, a pair of simple flat end walls, shown in Fig. 3(a) was considered in the investigation of a twisted waveguide accelerator at 2.8 GHz. However, the flat end wall exhibits an obvious field distortion since the walls are not orthogonal to the anticipated twisted TM mode fields. Consequently, electric field strength at the end wall boundaries can be greater than that is expected inside the uniform accelerator structure [4][5]. To that end, a more practical end wall design that potentially solves this problem can be employed as shown in Fig. 3(b). The twisted end wall is obtained by generating a surface that lies on a twisted

plane in the twisted coordinate [4][5] that is also perpendicular to the E-field spiral end-path. A comparison between the end wall induced electric fields is shown in Fig. 4. The flat end wall exhibits an end total electric field of about 45% higher than that field inside the mainstream accelerator body. On the other hand, introducing the twisted end walls successfully decreases the end wall fields to be about 20% higher than the mainstream body field as shown in Fig. 4.

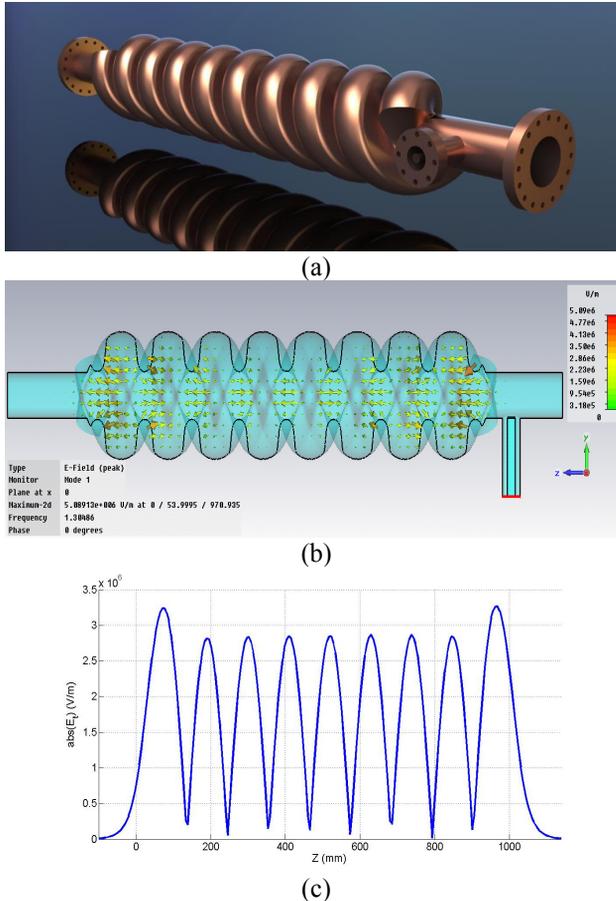


Figure 5: (a) An artist’s rendering of an example design of the twisted waveguide accelerating structure with a coupler for 1.3 GHz. (b) E-field vectors, (c) accelerating field distribution

Beam Pipe Incorporation

A beam pipe of 45 mm radius was considered in the realistic twisted waveguide implementation. The beam pipe will help more to achieve the required field uniformity along the accelerator axis. As shown in Fig. 4, the twisted end walls with the pipe will get the end fields to be within 10% higher than the mainstream accelerator electric field.

Input Power Coupler Design

To consider building a more complete and realistic accelerating structure, it was necessary to consider the input coupler design. In this example prototype, a coaxial feed was added as shown in Fig. 5(a) with inner conductor

of 19 mm diameter and outer conductor of 43.6 mm in diameter. The position of the coaxial feed along the beam pipe and the depth of the inner core conductor inside the beam pipe were adjusted to achieve external quality factor of $1.26e7$. The simulated electric field vectors inside the prototype obtained using CST are shown in Fig. 5(b), while the absolute value of the acceleration longitudinal electric field is shown in Fig. 5(c). Table I summarizes the different parameters from simulations of the proposed prototype.

Table 1: Calculated Parameters of The Prototype

f_0	1.3 GHz
Twist Rate	27.2 rad/m
R/Q	270
E_{peak}/E_{acc}	1.76
B_{peak}/E_{acc}	4.25
Q_{ext}	$1.26e7$

CONCLUSION

The practical aspects of implementing a 1.3GHz twisted waveguide accelerator for electrons have been considered by imposing the novel twisted end wall configuration, along with incorporation of the beam pipe and the input power coupler. The end wall topology that has been proposed was to offer more uniform field distribution by avoiding the high electric field effect. The beam pipes and the input power coupler could be added and functional as in the conventional accelerating structures.

REFERENCES

- [1] Y. W. Kang, “Twisted waveguide accelerating structure,” presented at the 9th Adv. Accelerator Concepts Workshop, Aug. 2000.
- [2] R. P. Borghi, A. L. Eldredge, G. A. Loew, and R. B. Neal, “Design and fabrication of the accelerating structure for the Stanford two-mile accelerator,” Academic press, New York, vol. 1.
- [3] C. Jing, W. Gai, J. Power, R. Konency, S. Gold, W. Liu, and A. Kinhead, “High-power RF tests on X-band dielectric-loaded accelerating structures,” IEEE Transactions on Plasma Science, vol. 33, no. 4, pp.1155-1160, Aug. 2005
- [4] J. Wilson, C. Wang, A. Fathy, and Y. Kang, “Analysis of rapidly twisted hollow waveguides,” IEEE Transactions on Microwave Theory and Techniques, Vol 57, no. 1, pp.130-139, Jan. 2009.
- [5] J. Wilson, A. Fathy, Y. Kang, and C. Wang, “Applications of twisted hollow waveguides as accelerating structures,” IEEE Transactions on Nuclear Sciences, accepted for publications.
- [6] “CST Microwave Studio 2009 User’s Manual,” CST Ltd., Darmstadt, Germany, 2009.