HIGH VOLTAGE OPERATION OF HELICAL PULSELINE STRUCTURES FOR ION ACCELERATION*

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Abstract

To accelerate ions using a helical pulseline requires the launching of a high voltage traveling wave with a waveform determined by the beam transport physics in order to maintain stability and acceleration. This waveform is applied to the front of the helix, creating a steep voltage ramp that moves down the helix, accelerating ions over distances much longer than the ramp length. An oil dielectric helix to demonstrate ion acceleration has been designed and fabricated. Helix design parameters, high voltage issues, input coupling methods, termination methods, and pulsers are described. Waveforms from the initial characterization of the oil dielectric helix are also described.

HELIX DESCRIPTION AND PARAMETERS

The helical pulseline, or "Pulse Line Ion Accelerator" (PLIA), has the potential to become an inexpensive way to accelerate short pulse ion bunches [1]. A ramped voltage waveform is applied to a helical pulseline creating a traveling wave which produces an accelerating electric field to the ions over the length of the helix. The incoming beam energy and method of acceleration determine the required helix waveform, wave velocity, and axial length. From the wave velocity and beamline aperture constraints, the helix dimensions, dielectric material, and capacitance are chosen. The required helix inductance is then calculated. The wavespeed of the helix must increase to accommodate the continually accelerating ions. This can be achieved with multiple untapered helix sections or a single helix with characteristics tapered as a function of axial length.

DEMONSTRATION OIL DIELECTRIC HELIX

An oil dielectric helix has been constructed for tests of ion acceleration with this concept. The parameters are shown in Table 1. This pulseline will be used for initial ion beam acceleration tests on the NDCX facility [2]. A short collimated ion pulse will be used without any radial focusing. It was therefore decided to make the aperture relatively large (an 8.1 cm radius helix). A low frequency wavespeed of 2.9 x 10^6 m/s was chosen, appropriate for the entrance potassium ion energies of 200-400 keV. A range of experimental regimes are planned, such as acceleration with modest peak voltages and meter scale ramps ("snowplow mode") and higher gradient "trapping modes" [1].

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Table 1: Oil dielectric helix design parameters

wave velocity	**2.9 x 10^6 m/s**
helix radius	**8.1 cm**
ground return radius	**11.75 cm**
dielectric permittivity (oil)	**2.3**
capacitance	**344 pF/m**
inductance	**346 µH/m**
impedance	**1003 ohms**
helix pitch	**159 turns/m**
effective helix length	**1 m**

This helix is wound on a grooved acrylic winding form which has a slightly larger radius than a glass tube which isolates the oil volume from the vacuum beamline. Bellows, structural supports, and flexible seals protect the glass tube from mechanical stress which could fracture the glass. The ground return is constructed from a rolled perforated stainless steel sheet to allow air to escape the oil regions with high electric field stress. The outer housing is an acrylic tube so that all areas are visible in case of the need to locate voltage breakdowns. The ideal helix parameters must be balanced with the radial electric field, turn-to-turn electric field, and axial electric field along the inner diameter of the insulating vacuum surface. Oil is a convenient choice of dielectric for designs which may require modifications and reconfiguration. Epoxy, which is available in a variety of relative permittivities, is an attractive choice to eliminate the possibility of oil contamination of the vacuum beamline.

INPUT COUPLING METHODS

The helix is a transmission line terminated into its characteristic impedance which can typically range from hundreds of ohms to a few thousand ohms. To drive this load directly requires the full helix voltage and the associated current. In applications where the voltage on the helix may be hundreds of kV, the feedthrough used to drive the helix can become difficult. This is especially true in applications where the space between beam focusing elements must be minimized to prevent radial beam expansion. Inductive coupling, or transformer coupling, from a loosely coupled primary to the helix is a method which allows the feedthrough voltage to be a fraction of the helix voltage. Early low voltage prototypes confirmed that transformer coupling could produce step-up factors of 5-10 from the primary strap to the helix. A factor of 10 requires close coupling of the primary strap to the helix which can produce very high electric fields. For the high voltage oil helix, a configuration was chosen to produce a step-up factor of 5. The consequence of transformer coupling is that instead of driving the high impedance of the helix, one must drive a low inductive primary impedance. The current required can be tens of kA depending on the primary inductance and the pulsewidth. Waveform control may also become more difficult with the lower impedance load. Driving a magnetic core which induces an electric field on the helix is also a method to couple a waveform to the helix [1].

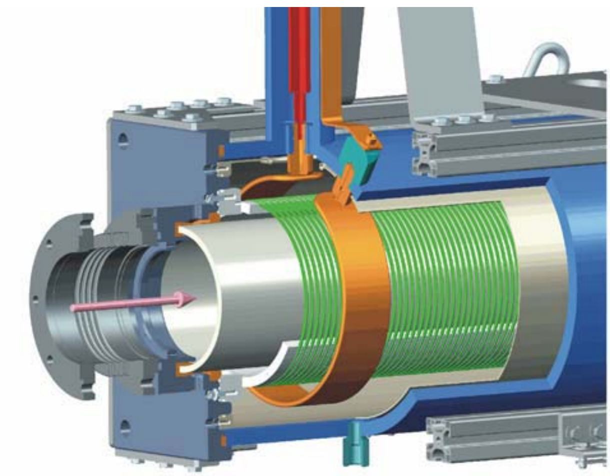

Figure 1: Transformer coupling with single turn primary strap on the oil dielectric helix.

TERMINATION IMPEDANCE

To avoid reflections which can distort the voltage waveform, the helix must be terminated into the characteristic impedance. In earlier prototype helices and low voltage models, radial and axial resistors were used. When these systems were tested, the voltage amplitude decreased at the end of the helix as the wave approached the termination. The helix inductance, and therefore the impedance, decreased in the region near the termination because mutual coupling from neighboring turns was lower at the end of the helix. To approximate the mutual inductance from later turns, a string of resistors in a spiral with a pitch similar to the helix was used on the oil dielectric helix (Figure 2). Carbon composition resistors were chosen for their availability, voltage holding, and energy dissipation. The voltage coefficient for these resistors can be significant, so it important to quantify this effect for the required range of helix voltages. This type of termination also provides a convenient diagnostic by using a tap from the resistor string as a resistive divider voltage monitor.

PULSER DESIGN

The required helix voltage waveform can often be a bipolar ramp to minimize the peak voltage. When driving the helix through transformer coupling, a capacitor which rings with the inductance of the primary strap is a convenient choice to drive the low impedance load. Although there can be a significant step-up from the primary strap to the helix, careful control of stray inductance in the pulser, cable, and feedthrough is required to minimize the peak voltage at the output of the pulser. Triggered spark gaps have been used in the initial designs because of the high peak current. By using a directly driven helix, higher impedance pulsers, and therefore lower current switches, can be used.

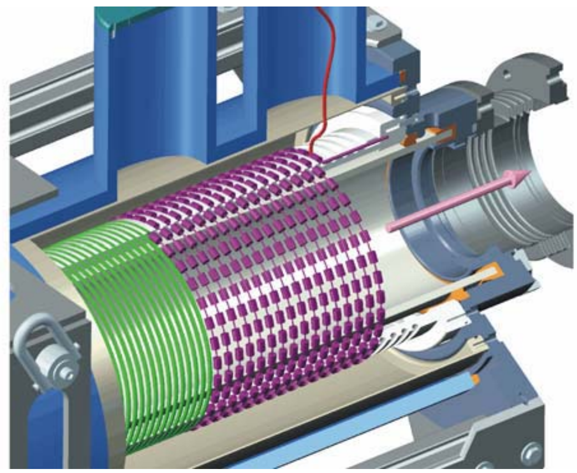

Figure 2: Termination resistor string for the oil dielectric helix.

LOW VOLTAGE DATA

After an oil dielectric helix was built, low voltage tests were used to characterize the structure before the application of oil. Small holes in the inner diameter of the acrylic winding form allowed direct measurements of voltage along the helix with a high impedance scope probe.

When using transformer coupling, there is a section of the helix which is required to buildup the voltage. This section is not an effective accelerating section of the helix but there are still axial electric field concerns on the inner diameter of the vacuum insulator. Low voltage tests in air were done to quantify the effective length of this buildup section (Figure 3). At 5 in. from the grounded drive end of the helix, the voltage was at the maximum.

To check the wave velocity and observe the effects of dispersion, a pulse generator was used through a filter to generate test waveforms at low voltage on the oil dielectric helix. Direct measurements of V(z,t) down the helix were made (Figure 4). These results were also confirmed using a B-dot loop with an integrator looking at $B_z(z,t)$. The ramp length of the test waveform violates the guidelines for low dispersion ($ka < 1$). As a result, the effect of dispersion can be seen in the increasing risetime down the transmission line which also results in a decrease in peak amplitude. Further testing with longer risetimes will provide more information on the low dispersion guideline.

After oil was added to the system, direct measurement of the helix voltage was no longer available, so a B-dot loop with an integrator looking at $B_z(z,t)$ was used to quantify the wave velocity and observe the effects of dispersion (Figure 5). The measured wave velocity was 2.8 m/s and within experimental error of the expected value of 2.9 m/s.

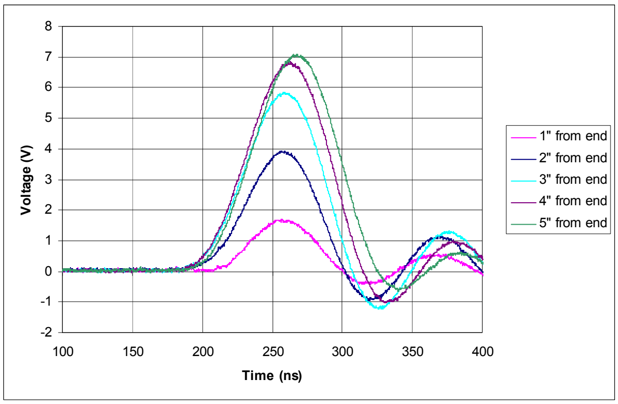

Figure 3: Buildup of helix voltage from transformer coupling with air dielectric.

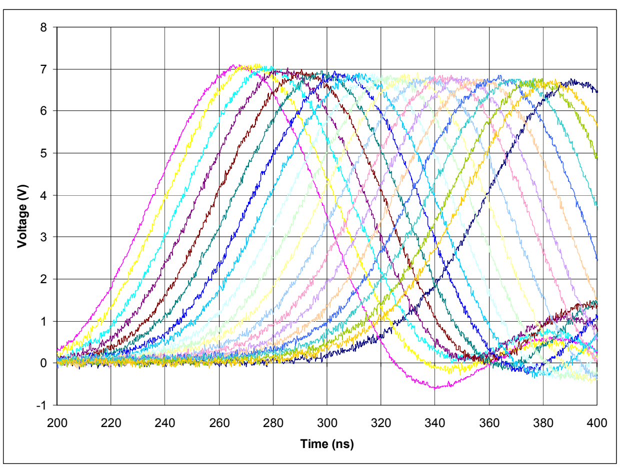

Figure 4: V(z,t) directly measured along helix at 1" intervals with air dielectric.

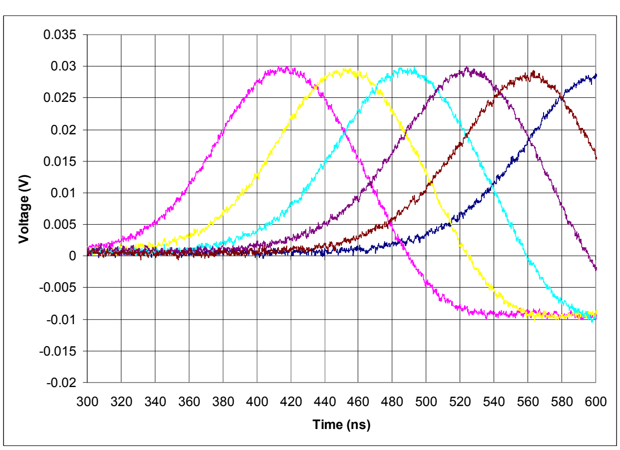

Figure 5: $B_z(z,t)$ measured at 4" intervals with a hardware integrated B-dot loop with oil dielectric.

HIGH VOLTAGE DATA

After oil was added to the helix and the structure was installed on the beamline, high voltage tests were done. A typical waveform, measured by the voltage divider at the helix termination is shown in Figure 6. The ramplength of this waveform was chosen to accelerate a 200-400 keV potassium beam. Time-of-flight techniques as well as an electrostatic energy analyzer will be used to quantify the energy gain downstream of the helix. Work is currently being done to increase the voltage amplitude and optimize the timing with the beam pulse to maximize the energy gain from the helix.

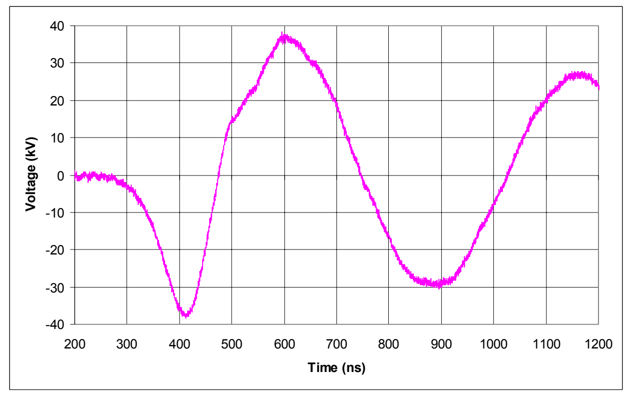

Figure 6: Initial high voltage waveform on the oil dielectric helix.

CONCLUSION

An oil dielectric helical pulseline to demonstrate ion acceleration has been designed and fabricated. Initial low voltage and high voltage measurements have been performed to characterize the structure. Acceleration experiments using a 200-400 keV potassium beam have begun and will continue for the next several months to explore the physics and engineering limits of this concept.

ACKNOWLEDGEMENTS

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[2] P. Roy, *et al.*, "Initial Results on Neutralized Drift Compression Experiments (NDCX) for High Intensity Ion Beam", these Proceedings.