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SLOW-WAVE CHOPPER STRUCTURES FOR NEXT GENERATION HIGH POWER PROTON DRIVERS

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A description is given of slow-wave chopper structures for the 3.0 MeV, 60 mA, H^- MEBT lines of the CERN Linac 4 and RAL Front-End Test Stand (FETS). Transmission line properties and transverse E-field uniformities for the original European Spallation Source (ESS) designs [1] have been refined by modelling electromagnetic fields in a commercial 3D finite difference time domain (FDTD) code [2]. In addition, the original compact, radiation hard, vacuum compatible designs have been simplified and reconfigured to be compatible with standard NC machining practice. Transmission line properties in the frequency and time domain, together with E-field uniformity in the axial and transverse planes, are presented.

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A description is given of slow-wave chopper structures for the 3.0 MeV, 60 mA, H^- MEBT lines of the CERN Linac 4 and RAL Front-End Test Stand (FETS). Transmission line properties and transverse E-field uniformities for the original European Spallation Source (ESS) designs [1] have been refined by modelling electromagnetic fields in a commercial 3D finite difference time domain (FDTD) code [2]. In addition, the original compact, radiation hard, vacuum compatible designs have been simplified and reconfigured to be compatible with standard NC machining practice. Transmission line properties in the frequency and time domain, together with E-field uniformity in the axial and transverse planes, are presented.

INTRODUCTION

Proton driver specifications for the next generation of spallation neutron sources, neutrino factories, and waste transmutation plants, call for more than an order of magnitude increase in beam power, typically from ~ 0.16 to ~ 5 MW [3]. For the linac-accumulator or linac-synchrotron schemes, beam loss at ring injection and extraction, and the consequent activation of components, can be minimised by a programmed population of ring longitudinal phase space, produced by ‘chopping’ the linac beam at low energy. The ‘chopper’ is required to produce precisely defined gaps in the bunched linac beam, and the chopping field must therefore rise and fall within, and be synchronous with, bunch intervals that are typically just a few nanoseconds in duration . Slow-wave (E-field) transmission line structures have demonstrated field transition times in the nanosecond regime [4, 5], and chopping schemes utilising these structures have been described [6]. The electrode structures are designed with the aid of 3D high frequency field modelling codes, where the complex geometry, extended electrical length, and the effects of inter-electrode coupling set a practical limit on the computational accuracy of broad-band properties. Speed and / or accuracy of computation, have been enhanced by identifying small repetitive structures and modelling their properties in a commercial finite difference time domain (FDTD) code.

SLOW-WAVE ELECTRODE DESIGN

The basic features and function of the proposed slow-wave electrode structures are shown in Figure 1, where partial chopping of beam bunches is avoided by ensuring that the deflecting E-field propagates at the beam bunch velocity.

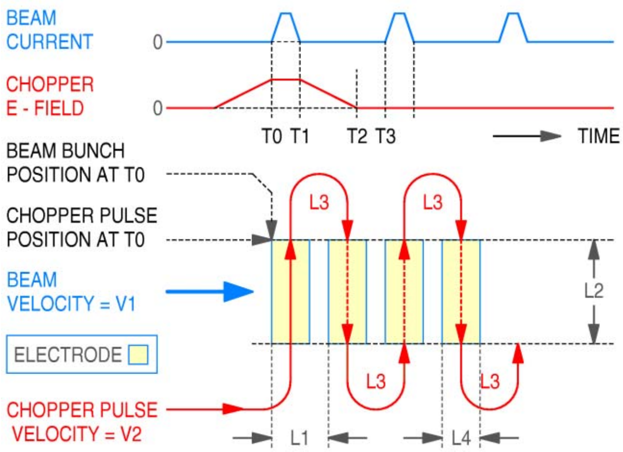

Figure 1: Slow-wave electrode design

In Figure 1:

L2 is the transverse extent of the beam.
T(L1) is the beam transit time per cell length L1.
T(L2) is the pulse transit time in vacuum for length L2.
T(L3) is the pulse transit time in delay line length L3.
L4 is the electrode width.

For the generalised slow wave structure:
Maximum value for L1 = V1 (T3 - T1) / 2 (1)
Minimum Value for L1 = L2 (V1/ V2)
T(L1) = L1/V1 = T(L2) + T(L3)

The relationships for field (E), and transverse displacement (x), where q is the electronic charge, ν is the beam velocity, m_0 is the rest mass, z is the effective electrode length, θ is the required deflection angle, V is the deflecting potential, and d is the electrode gap, are given by:

$$E = \tan\theta \cdot m_0 \cdot \frac{\nu^2}{q \cdot z}, \qquad E = \frac{V}{d}, \qquad x = \frac{q \cdot E \cdot z^2}{2 \cdot m_0 \cdot \nu^2}$$

Inspection shows that for given values of m_0, ν, and V, large θ and x are obtained when z is large and d is small. An additional and important design constraint is that the inter-electrode gap shown as L1 - L4 in Figure 1 must be made significant, or alternatively a thin grounded shield must be inserted between adjacent strips, if pulse distortion due to inter-electrode coupling is to be minimised. In either case, for a given overall structure length, the effective electrode length (z) will therefore be maximised, by setting L1 to the value shown in (1), above, and maximising the strip-line width, L4.

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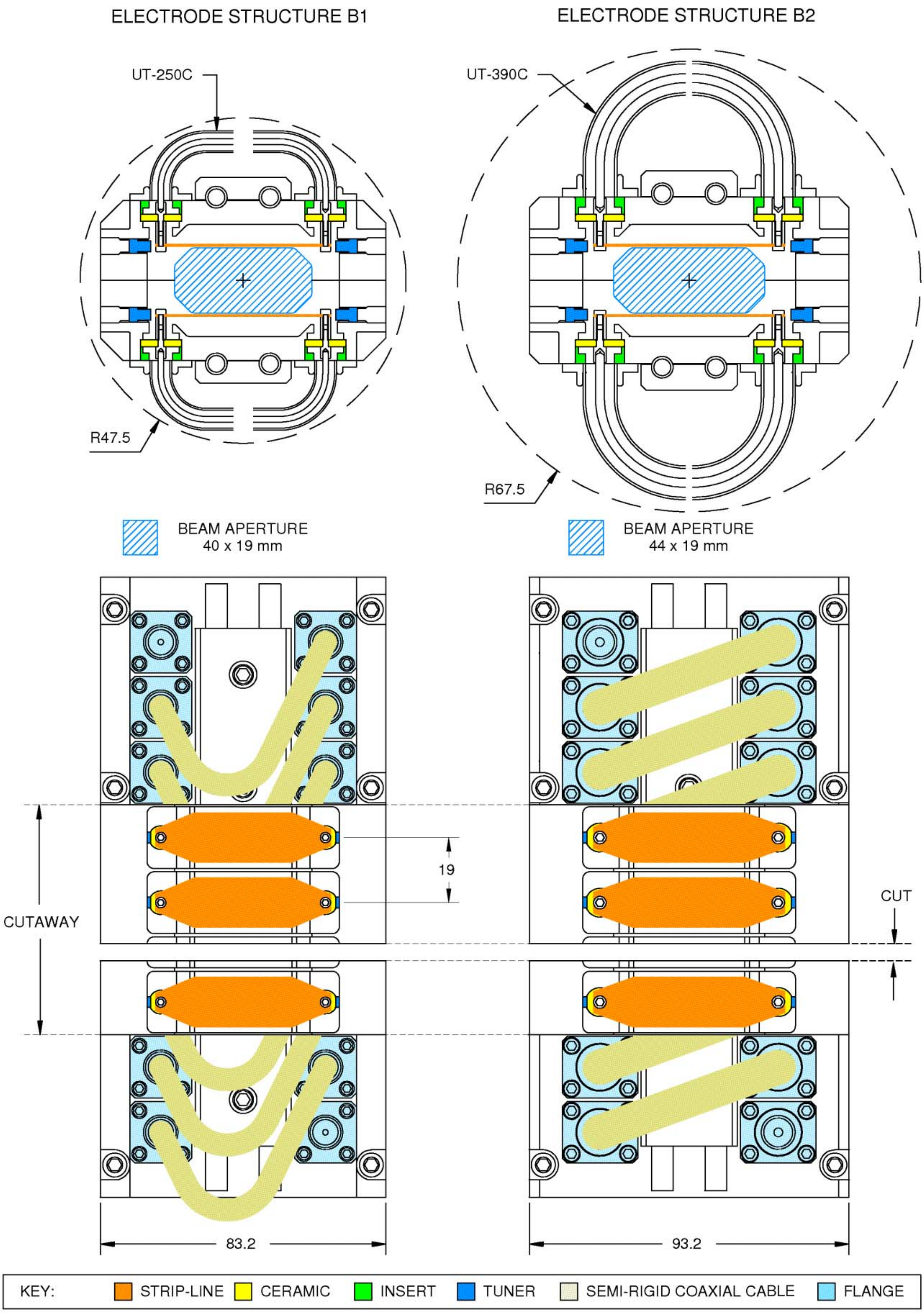

Figure 2: Electrode structures B1 and B2

ELECTRODE STRUCTURES

Electrode structure B1 for the CERN Linac 4 [7], and B2 for the RAL FETS [8], are shown in Figure 2. Key parameters, for these designs are listed in Table 1.

Table 1: Slow-wave structure parameters

		B1	B2	
Beam velocity	ν	2.390e7		m.s^{-1}
Mechanical length		2 x 450	450	mm
Electrode to beam axis gap	d	10.0		mm
Beam aperture		19.0		mm
Deflection potential (±)	V	0.650	1.4	kV
Coverage factor (centre/edge)		81/79	82/81	%
Characteristic impedance	Zo	~ 50		Ω
No. of sections		23		
Section delay	T(L1)	0.7949		ns
Total structure delay		18.28		ns
Pulse transition time (10-90, 90 –10%)		≤ 2.0		ns
Structure bandwidth		0 - 500		MHz
Section pitch	L1	19.0		mm
Strip-line width	L4	14		mm
Strip-line thickness		0.5		mm

The helical transmission line structures consist of strip-line sections near the beam axis, linked by sections of semi-rigid coaxial cable (delay lines). Each capacitively compensated strip-line to coaxial transition can be adjusted to compensate for manufacturing tolerances. Inter-electrode ground planes minimise frequency dependent dispersion, and conduct heat generated by stray beam particles to the water cooled backplane.

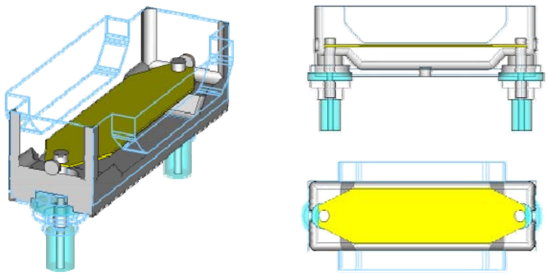

Figure 3: Sub-structure B1 / 3D high frequency model

Sub-structure models as shown in Figure 3 have been developed in a 3D high frequency finite element code [2]. Simulated S-parameters, as shown in Figure 4, indicate that the characteristics of the complete structure will meet with the RAL and CERN fast chopper requirements.

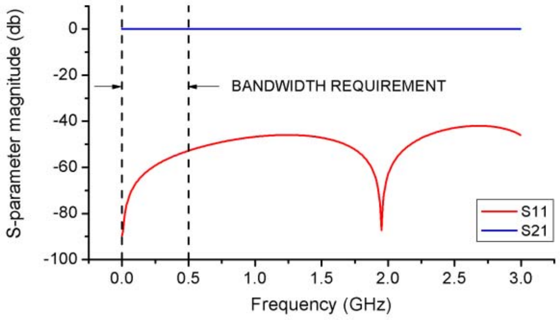

Figure 4: Sub-structure B1 / S-parameters

E-FIELD UNIFORMITY

The magnitude of the deflecting E-field in axial and transverse planes has been modelled in a static 3D E-M code [2]. A plot of the z-integral of 'on-axis' field as a function of transverse position, as shown in Figure 5, indicates that the so called 'coverage factor' for both structures should be ~ 80% of the 'parallel plate' value.

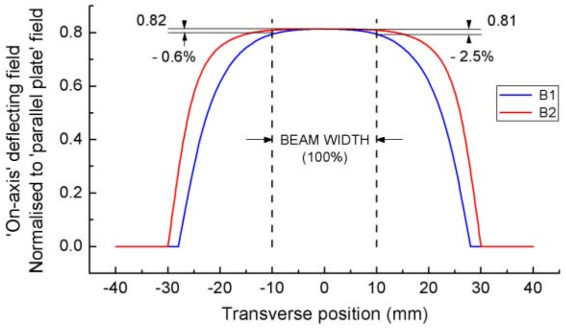

Figure 5: Transverse field distribution

SUMMARY

Slow-wave electrode design concepts for the ESS 2.5 MeV MEBT chopper are being developed to meet the requirements of the RAL FETS, and CERN linac 4, 3.0 MeV fast choppers. Simulated transmission line properties of modular sub-structures are encouraging, and good progress is being made with the detailed mechanical design, in preparation for the manufacture and test of representative prototype sub-assemblies.

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