SHUNT IMPEDANCE STUDIES IN THE ISIS LINAC

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Abstract

The ISIS linac consists of four DTL tanks that accelerate a 50 pps, 20 mA H^- beam up to 70 MeV before injecting it into an 800 MeV synchrotron. Over the last decades, the linac has proved to be a stable and reliable injector for ISIS, which is a significant achievement considering that two of the tanks are more than 50 years old. At the time the machine was designed, the limited computing power available and the absence of 3D electromagnetic (EM) simulation codes, made the creation of a linac optimized for power efficiency almost impossible, so from this point of view, the ISIS linac is quite simple by today's standards. In this paper, we make a shunt impedance comparison study using the power consumption data collected from ISIS and the results obtained when simulating each of the four DTL tanks with 2D and 3D EM codes. The comparison will allow us to check the accuracy of our simulation codes and models and to assess their relative performance. It is particularly important to benchmark these codes against real data, in preparation for their use in the design of a proposed new linac, which will replace the currently aging ISIS injector [1].

THE ISIS INJECTOR

The ISIS facility at Rutherford Appleton Laboratory (RAL), has been the world leading pulsed neutron source for over two decades, delivering neutrons for users from all over the world and proving to be a very stable and reliable machine. It consists of a 70 MeV H^- injector, an 800 MeV synchrotron and two target stations [2]. The injector starts with an H^- ion source, followed by a low energy beam transport line and a 665 keV RFQ operating at 202.5 MHz. The energy is then raised to 70 MeV by four Drift Tube Linac (DTL) tanks. Tanks 2 and 3 were built in the 1950s for the RAL Proton Linear Accelerator [3] and have been in operation ever since, while tanks 1 and 4 were built in the 1970s originally intended for the Nimrod accelerator, but first used in ISIS. A layout of the DTL section of the linac can be seen in Figure 1 and a list of parameters is given in Table 1.

Table 1: ISIS Linac Parameters

Energy	70.4	MeV
Frequency	202.5	MHz
Pulse Length	200 – 250	μs
Peak Current	25	mA
Repetition Rate	50	Hz
Total Length	55	m
Duty Cycle	1 – 1.25	%

ELECTROMAGNETIC MODELLING

The choice of accelerating structures is essential for every linac. In ISIS, the DTL structure is used for the entire length of the linac with small geometry variations between the tanks. The synchronous phase is kept constant at -30° in the four tanks, while the accelerating gradient varies: 1.6 – 2.2 MV/m in tank 1, 2.45 – 2. 55 MV/m in tank 2, 2.3 – 2.4 MV/m in tank 3 and 2.6 MV/m in tank 4. The geometry of a single DTL cell is very simple and it is not fully optimised for power efficiency resulting in a longer linac structure. In modern linac designs, the overall length of every tank is reduced by choosing a higher accelerating gradient and synchronous phase, optimising the cell geometry and by increasing the transit time factor by shortening the cell gap lengths [4].

The figure of merit which will be used to characterize the accelerating cavities is the effective shunt impedance per unit length, ZT^2, which is a measure of the effectiveness of producing an axial voltage V_0 for a given power dissipated, P [5]:

$$ZT^2 = \frac{(E_0T)^2}{P/L}$$

T – transit time factor
$E_0 = V_0/L$ – average axial electric field
L – cell length

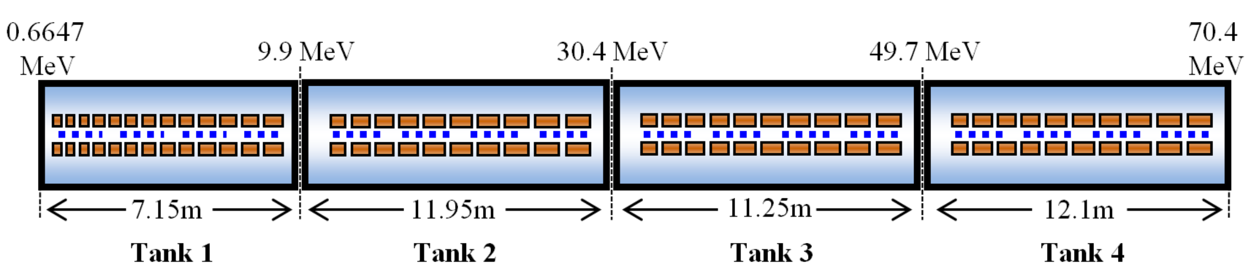
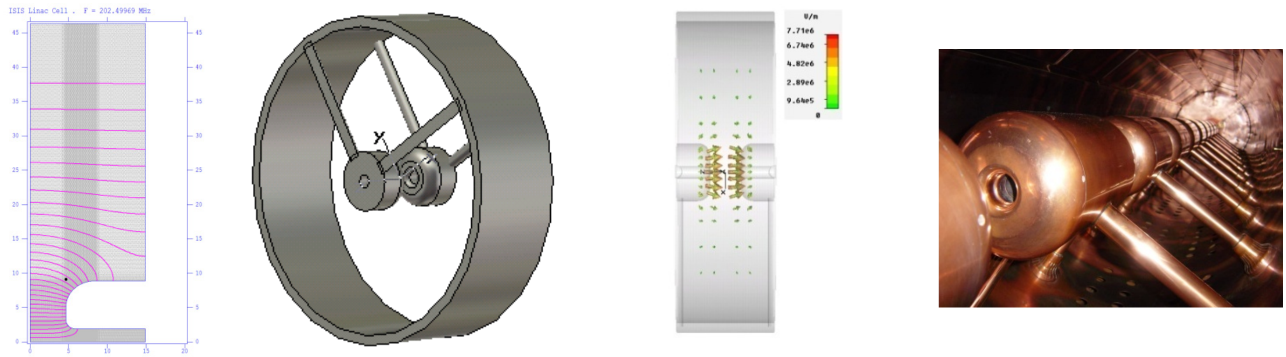


Figure 1: Layout of the DTL section of the ISIS Linac.



a. b. c. d.

Figure 2: DTL cell operating at 20 MeV and 202.5 MHz. a) 2D Superfish model. b) 3D cell geometry in Microwave Studio. c) Electric field vectors. d) Tank 3 of the ISIS linac.

The 2D Model

Using the exact cell dimensions as in the ISIS linac, an accurate 2D model of the four DTL tanks has been prepared using Superfish, a tool used widely by linac designers [6]. The code evaluates RF cavities with cylindrical symmetry, but it can make corrections to take into account the effect of the stems, or the end plates on frequency and shunt impedance. A model of a single accelerating cell operating at 20 MeV can be seen in Figure 2a, while Table 2 details the input parameters for each individual tank.

The 3D Model

The 148 cells have also been modelled in CST Microwave Studio [7], a 3D EM code normally used in linac design for problems that lack cylindrical symmetry, like the effect of tuners, post-couplers, stems, vacuum pumping ports, etc. but also to check the results calculated by the 2D codes. The geometrical model of a single cell can be seen in Figure 2b, and 2c, together with the electric field vectors as computed by Microwave Studio while Figure 2d is a picture inside tank 3.

RESULTS

In Figure 3 the evolution of the effective shunt impedance per unit length along the linac is presented as predicted by the two models. The agreement between the two codes is reasonably good, although the 3D results seem to be more sensitive to the choice of mesh. As it can be seen, Microwave Studio predicts a constantly higher shunt impedance than Superfish in each of the four DTL tanks by up to 6%, although the two curves follow a very similar path. A big jump in shunt impedance can be seen at the transition between the tanks, due to the effects of the end plates, but also a lower average value in tanks 2 and 3. This is due to the fact that these tanks being quite old have been designed and built with an emphasis on reliability rather than power efficiency. Tanks 1 and 4 being of a later generation have a slightly different cell geometry and a higher shunt impedance indicating a different design approach.

Table 2: DTL Main Parameters

		Tank 1	**Tank 2**	**Tank3**	**Tank4**
Input Energy	MeV	0.6647	9.90	30.4	49.7
Output Energy	MeV	9.90	30.4	49.7	70.4
Accelerating Gradient (E_0)	MV/m	1.6 – 2.2	2.45 – 2. 55	2.3 – 2.4	2.6
Synchronous Phase	Deg	-30	-30	-30	-30
Max. Surface Electric Field	Kilpatrick	0.67	0.81	0.84	0.87
Number of Cells		56	41	27	24
Tank Diameter	cm	93.4	92.71	81.28	88
Drift Tube Diameter	cm	18	17.78	17.78	16
Aperture Diameter	cm	2.5	3.81	3.81	3
Stems/Cell		1	2	2	1
Total Length	m	7.15	11.95	11.25	12.1

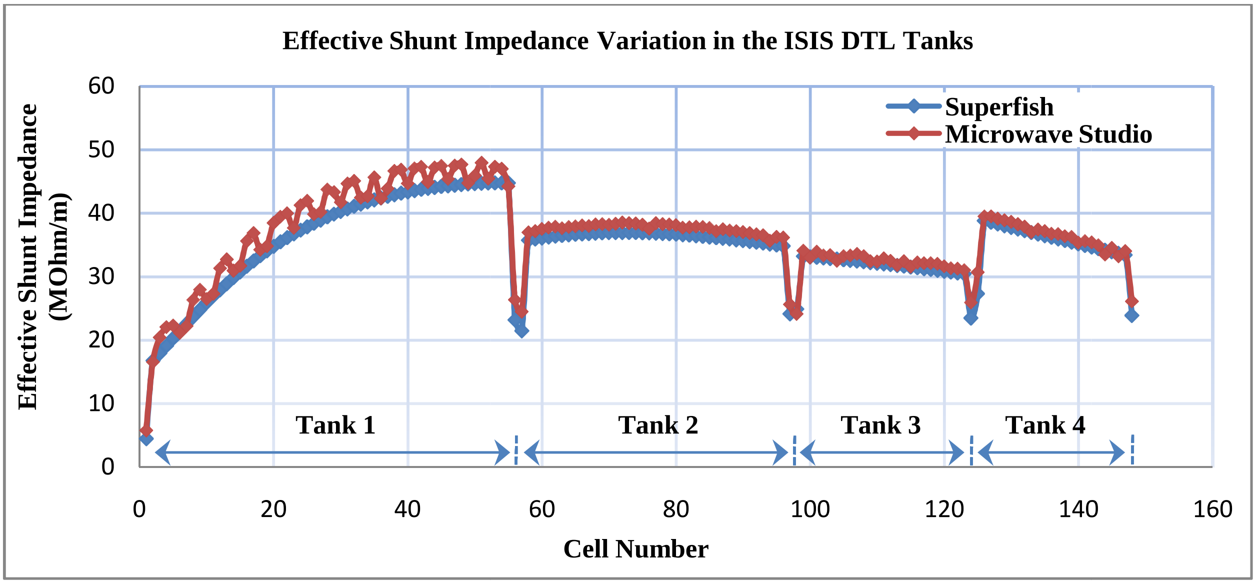


Figure 3: Effective shunt impedance variation in the ISIS DTL tanks.

However, a comparison between the shunt impedance calculated by the two models and the actual power levels measured in each of the four DTL tanks shows a mixed picture. As it can be seen in Figure 4, for tank 1, the measured power level is 0.49 MW, while Superfish and Microwave Studio predict 0.43 and 0.4 respectively, thus requiring a ~13% adjustment for Superfish and ~20% for Microwave Studio. The best agreement seems to be for tank 3 where the predicted shunt impedance has to be reduced by only ~10% for Superfish and ~12.5% for Microwave Studio. On the other hand, for tanks 2 and 4, the models overestimate the shunt impedance by a much higher fraction: 32%/37% for tank 2 and 23%/28% for tank 4. We believe that the significant disagreement between simulations and measurements for tanks 2 and 4 can be explained if we assume that these tanks are being operated at a higher electric field gradient than the design value. However, this assumption is very difficult to verify as in the current DTL setup, the electric field gradient cannon be accurately measured.

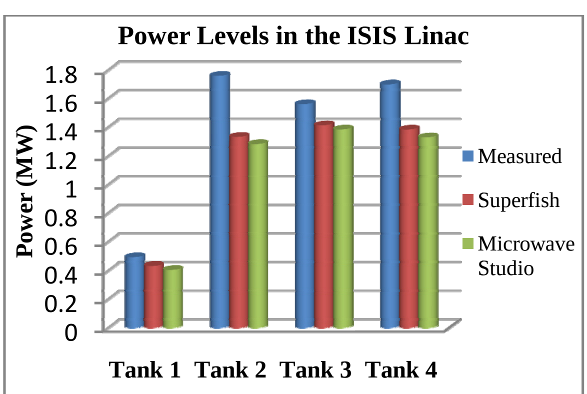


Figure 4: Power levels in the ISIS DTL tanks.

CONCLUSIONS

Two computer models for the four ISIS DTL tanks have been created and the predicted shunt impedance has been compared with the power levels measured in the ISIS linac. While the 2D and the 3D simulation codes show a good agreement throughout the linac, the actual power dissipation is constantly underestimated by an average of ~20% by Superfish and ~25% by Microwave Studio. This difference is normal, and it is due to the effects of surface imperfections, coupling holes, post-couplers, tuners and other auxiliary equipment. However, one can note a relatively high discrepancy for tanks 2 and 4, which we believe is caused by operating the tanks at a higher electric field gradient than the design value.

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