Sigmaphi SHMS Magnet Project
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Third Thoughts on MQE Calculations for the SHMS Dipole Conductor

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1. Introduction

After looking at Glenn's pictures of the zig zag cuts, I have made a few more MQE calculations trying to estimate the reduction in stability coming from gaps in soldering along the centre line of the cable.

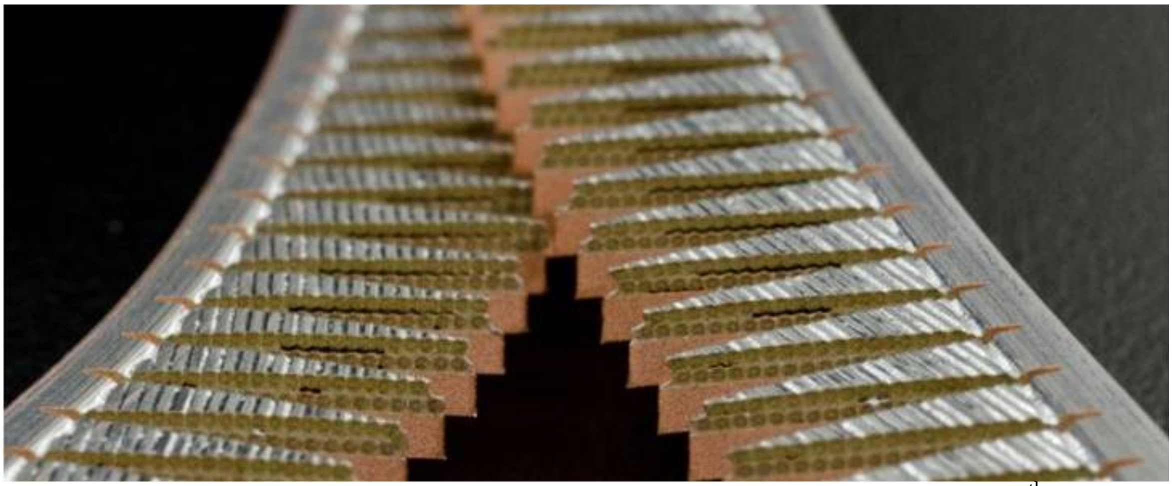

Fig 1: gaps in soldering on centre line of cable from Glenn Young email 29th Oct.

The killer blow would be for an energy pulse, say resin cracking, to hit the outer layer of cable where it is unsoldered. If the energy is large enough, the resulting resistive zone will grow until it hits the point where it is soldered to the rest of the cable. At this point, it will either collapse or, if its Ohmic heat generation is large enough, will quench the whole cable and take down the magnet.

2. Calculations

This is a complex three dimensional problem that is quite beyond my simple 1d Mathcad solver (or any fancy software that I know of). The best I can do is make a simplified model and try to get some approximate numbers. My model is sketched in Fig 2.

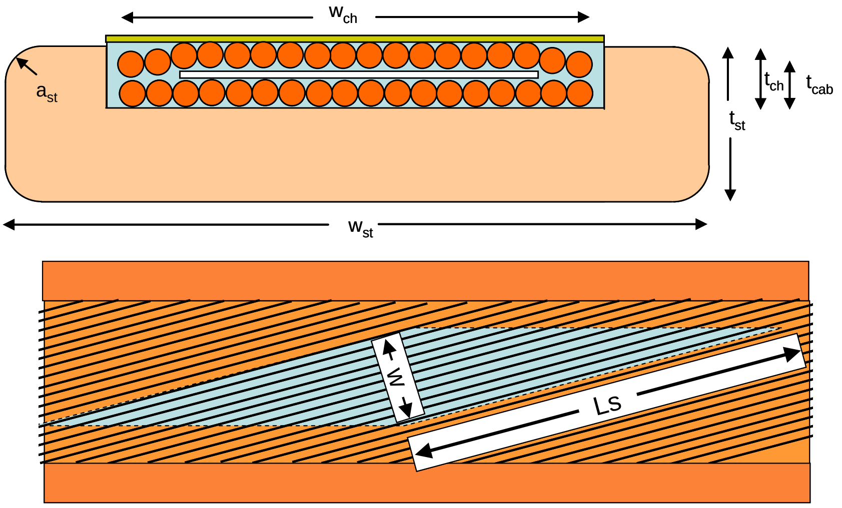

Fig 2: Model used for MQE calculations.

The unsoldered region is assumed to be a parallelogram running parallel to the wires, with a length *Ls* between the soldered ends and a width *w* perpendicular to the wires. For the Mathcad solver, I deform this parallelogram into a rectangle of length *Ls* and width *w*, assumed to be the cable width 12mm. The calculated MQEs for various values of *Ls* are presented Table 1.

Table 1: MQE for the unsoldered region as a function of *Ls*.

Ls	MQE
40mm	0.91mJ
20mm	0.91mJ
14mm	0.91mJ
12mm	0.98mJ
11.6mm	1.11mJ
11.2mm	large > 20mJ

For large gaps, the MQE is about half the value I calculated in SJD8 for a completely unsoldered cable, which is not surprising given that only half the cable is now unstuck. For pulses above this energy, the temperature rises as shown in Fig 3(a) to a steady level determined by conduction out of the ends, which are pinned at 4.2K. When *Ls* is reduced below ~ 11.4mm (which is about the size of the minimum propagating zone) the zone recovers, as shown in Fig 3(b). For Ls below 11.2mm, the zone recovers from all pulses up to 28mJ, which was the MQE I calculated for an intact cable in my report SJD7.

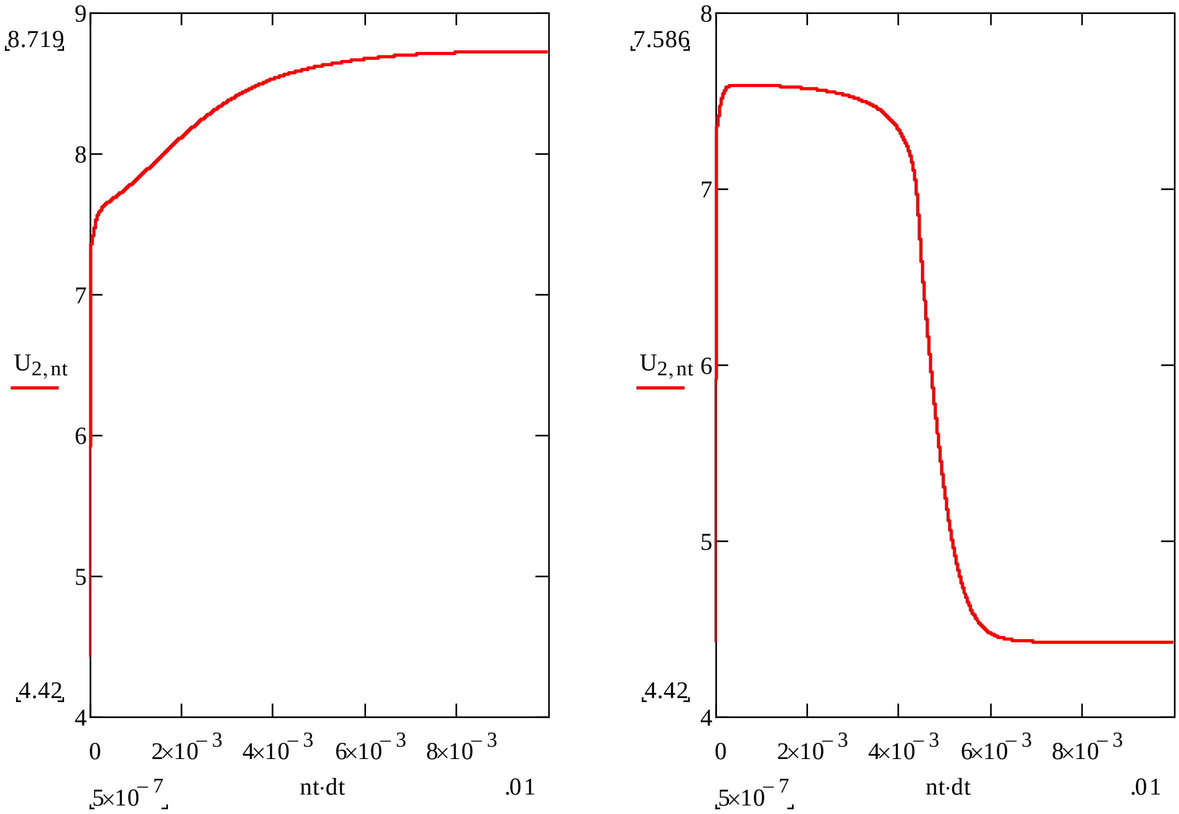

Fig 3: Temperature at centre of zone after a pulses of 1.1mJ with Ls = 11.6mm and with Ls = 12mm.

3. Concluding Remarks.

My model is crude and approximate, but nevertheless I feel it should give a good general indication of the likely response of this conductor to energy disturbances in the coil. For gaps in the soldering > 12mm, the outer layer will be quenched by an energy pulse of ~ 1mJ. Although the temperature does not rise without limit following this quench, the affected region will generated continuous Ohmic heating which, in a fully impregnated winding, will raise the surrounding temperature until it causes a quench. For gaps in soldering < 10mm the outer layer of cable will recover from all energy pulses less than the MQE of a solid conductor.

So it seems likely that gaps in the soldering > 12mm will reduce the MQE from ~ 28mJ to ~ 1mJ – a substantial reduction in stability.

I have never had much confidence in our ability to calculate *ab initio* what the disturbance in any magnet system might be. Instead, I prefer to compare MQEs with other magnets whose training performance is already known. Table 2, reproduced from my report SJD7, presents some MQEs from other magnets, with the bottom row scaled to compare with SHMS dipole.

Table 2: Calculated MQEs for Some Existing Magnets.

magnet	SHMS RRR=100	Grenoble Hybrid	MRI magnet	CLAS Torus	LHC dipole
peak field	5.45T	8.5T	6.09T	3.5T	8.4T
operating current	3419A	1330A	461A	3790A	11500A
MQE (mJ)	28mJ	1.7mJ	0.25mJ	44mJ	1.5mJ
MQE scaled to JLD current and field (mJ)	28mJ	2.9mJ	1.7mJ	63mJ	0.3mJ

It may be seen that, with large solder gaps we are less stable than MRI solenoids, but more stable than the LHC dipole. However, it is a common experience that, all other things being equal, solenoids suffer much less training than dipoles – yet the MRI solenoids do train. LHC dipoles suffered lots of training and needed a decade of development of ~ 50 prototypes to get the mechanical preload adequate for acceptable training.

So I do think that reduced stability coming from the gaps in soldering is likely to cause serious training problems – maybe even a failure to achieve design field. My recommendation would be to find an inspection technique which could detect the gaps reject sections where the solder gaps exceed 10mm length.