U.S. MAGNET
DEVELOPMENT
PROGRAM

How to perform reproducible and verifiable training enhancement experiments?
(Liquid impregnation)

M. Marchevsky

US Magnet Development Program
Lawrence Berkeley National Laboratory

Challenge of training enhancement experiments

- Training enhancement experiment face many complicated issues related to delivery of vibrational energy to the interior of the magnet.
- But imagine we solved them all – still, proving that the technique works will be a very difficult task since it would potentially require many magnets to be tested in order to collecting statistics… and every new magnet is different with respect to training….
- **How do we build "identical magnets" for training enhancement experiments?**

Liquid impregnation

A proposal: impregnate CCT magnets with neutral dielectric fluids that remains liquid at ambient temperature, but freezes upon cooling. This enables very fast and easy magnet assembly, and can provide multiple novel options for varying pre-stress, controlling mechanical disturbances and modifying mechanical, thermal and magnetic properties of the magnet in a unique new way.

But above all that, it would **allow to "restore" the magnet to its original state by simply warming it up to room temperature.** This creates an ideal object for repetitive training / training enhancement experiments.

Why liquid impregnation?

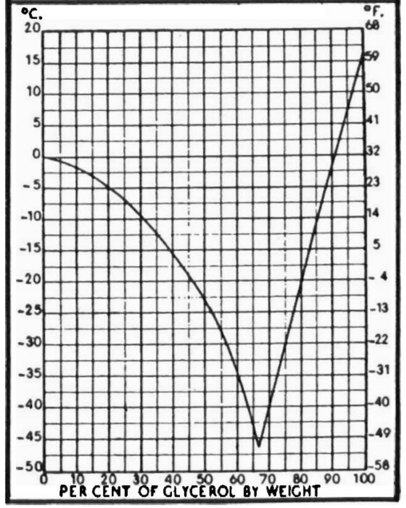
- It is very easy – fill up the magnet and you are done. No impregnation tools, no pumps, no heating – just a simple seal on the bottom side and a plug on top side for the liquid to stay contained
- It makes disassembly/re-assembly of a magnet very simple, and all parts remain completely reusable for future tests (including the cable!). This can truly speed up our fabrication/test/re-test turnaround. Coils once reacted can be re-impregnated and retested multiple times
- For the first time we will be able to fully examine, extract and study the conductor after completing the magnet test
- By tuning composition of the fluid, its volumetric change on freezing can be varied in a broad range. Incompressibility of liquids brings up a unique prospective of preloading the magnet internally just by freezing it. By pre-tuning fluid composition for the required amount of volumetric expansion the resulting pre-stress can be accomplished precisely and without use of additional tools or equipment like keys, bladders, pumps, etc.
- Fluid composition can be varied to form either a crystalline ice state or a non-crystalline glassy state upon freezing. This brings up some opportunities in terms of tuning adhesion to surfaces, eliminating localized energy releases and mitigating training behavior
- Heat capacity of ice is about a factor of 2 larger than that of epoxy – an additional benefit for reducing localized thermal perturbations
- Various kinds of soft and hard nanoparticles can be easily mixed into fluids to further tune heat capacity, magnetic or elastic properties of the frozen phase. This "mixology" may bring unique new options for magnet fabrication and operational performance improvement

What fluid to use?

Glycerin / DI water mixture

- Water is unique in a sense that it is one of very few liquids that expand upon freezing
- Glycerin (= glycerol) is an ubiquitous, inexpensive ($15/gallon), non-volatile and non-toxic organic liquid. It is often used in mixture with water to produce low-temperature freezing (antifreeze) solutions as well as a stabilizer for various organic chemistry and medical uses. The glycerin/water solution of molar fraction=0.28 (67% by weight) is an "eutectic" that never phase-separates and freezes at -45 C.
- Both glycerol and DI water are very good electrical insulators
- Viscosity of the mixture is higher than water (about 10 times higher at 60% g/w by weight). This is still an order of magnitude lower than CTD-101 epoxy. It will flow into voids easily and also wet surfaces well since glycerin is about as good as water as a solvent.
- By varying the mixture ratio its volumetric expansion upon freezing can be varied continuously between 6% (pure water) and zero at ~0.28 glycerin/water molar fraction
- At a low mole fractions the mixture can phase-separate upon freezing and form either a low-density ice or high-density ice
- At mole fraction > 0.38 the frozen substance is homogeneous and fully vitrified. An amorphous ceramic-like state is formed upon freezing

Fig. 1. Freezing Points of Glycerol-Water Solutions



Glycerin c_p ~ 0.96 mJ/g K (4.2 K)