A Novel Magnet Main Coil Design with Shimming Capability

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Introduction: A major constrain of MRI superconducting magnet design is the cost and it becomes increasingly important given the dynamics in global market. Shimming system, an essential subsystem in MRI magnets, is one of the areas where constant efforts have been put down to make it simpler and more cost-effective. In this paper, a novel magnet coil design scheme, which minimizes B0 inhomogeneity through micro-adjustment of main coil currents, is presented. This design could substantially reduce system cost in comparison to traditional designs such as a set of standalone shimming coils.

Method: The central idea of this design is to establish additional superconducting current loops (partial coils) within main coil windings by adding low cost switches into the circuit. The partial coils can be energized by external power supply and currents in these coils can be adjusted independently from main coils and independently between themselves. It can be demonstrated that even very small currents (<1A) in these partial coils could provide significant shimming capacity to compensate axial harmonics. A major challenge of this design is to ensure the stability of the partial superconducting coil circuits. Due to the strong mutual coupling between different coils in the system, it turns out design can be carefully selected such that the currents in partial coils are insensitive to current change in the main coils. Quench protection of these partial coils must be also considered to ensure the survival of these coils during quench events.

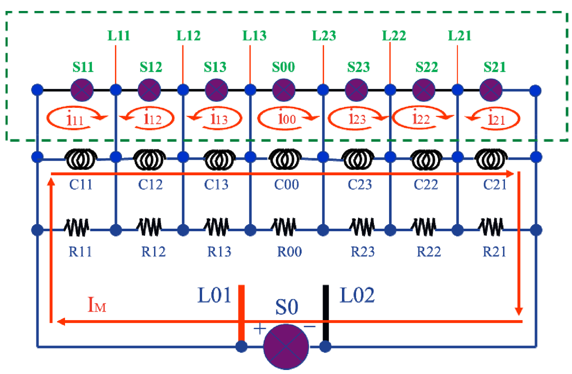

Figure 1 Diagram of 7-coil system design example

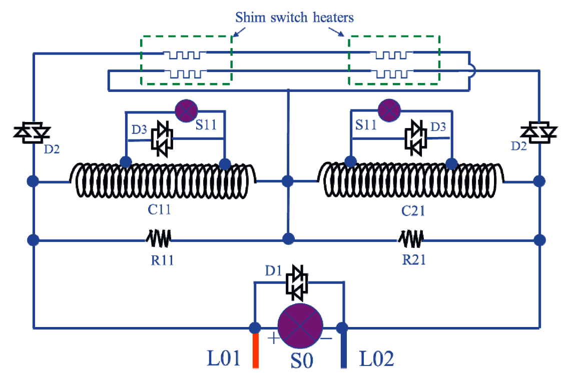

Figure 2 Quench protection design scheme

Result: The circuit diagram of a design example that consists of 7 coils C11, C12… C21 is shown in Figure 1. In additional to generate a 1.5T B0 field with an operating current at ~400A, the system is able to provide ~550 ppm and ~470 ppm (45DSV) shimming capacity for (1, 0) and (2, 0) harmonics, respectively, with just 1A current. During magnet ramping, all switches S0, S11… S21 are turned on to set superconducting switches at resistive state. The operating current can be then input through power leads L01 and L02 to ramp the magnets until 1.5T main field is obtained. Next, all switches are turned off to become superconductive thus the magnet main circuit is put in persistence mode. After the shimming currents are determined by field measurements and shimming calculations, the shim switch of the target coil is turned on while keeping the main switch S0 off. The small shim current is input through shim leads and then the shim switch is turned off. For example, if shim calculation shows it needs to add -0.15A to C13 coil, then switch S13 is turned on and current can be input through shim leads L13 (positive) and L12 (negative). The switch S13 is turned off after a stable magnetic field is attained.

As far as drift is concerned, for a standard -0.1ppm/hour B0 drift rate, the true drift rate due to introduction of partial coils is -0.1028ppm/hour. The increase is less than 0.3% and in practice can be neglected. The quench protection scheme is illustrated in Figure 2, where R11 is 0.08 Ohm, threshold voltage of diode D1, D2 and D3 is 15V, 6V and 8V, respectively, switches S1 normal state resistance is 8 Ohm. The switch resistance can be further increased if necessary. When ramp quenches start, the voltage across the quenched coil rises, once this voltage across resistor reaches 6V; D2 becomes conducting and trigs shim switches S11 to be normal, at the same time switch resistance increases to 8 Ohm. When switch S11 in normal state and current is >1A, the D3 diodes will open to allow current pass, thus protect the S11 switch during quench event. In case magnet has persistent quench, same logic applies. Coil quench voltage trigs D2, and then S11 heater fired and turned into resistive state. As quench propagated, current in the shimming loop increases, once it reaches 1A, D3 will be open and all the currents flow through D3 to prevent damaging switch S11.

Summary: A novel superconducting magnet coil design scheme, which minimizes B0 inhomogeneity through micro-adjustment of partial main coil currents, is proposed. This design concept could provide ample active shimming capacity while substantially reduces system cost in comparison with traditional designs. A design example is presented and issues such as field stability and quench protection are discussed.