Using MR Thermometry to Monitor the Frozen Effect in High-Temperature Superconducting RF Coil System

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Introduction

High-temperature superconducting RF coil (HTSC) has been proposed to have the capacity to improve the signal-to-noise ratio (SNR) because of its non-resistive property [1;2]. For maintaining the working temperature at 77K, liquid nitrogen (LN_2) was usually used to cool the HTSC and filled in the special dewar fabricated by thermal insulated materials [3]. However, the thermal insulation cannot be totally implemented due to the manufacture error or the incomplete extraction of the vacuum layer. In in-vivo studies, the sample might be frozen due to the incomplete thermal insulation and it may lead to unsuccessful outcome or even dangerous situation in some human experiments. In this work, MR thermometry using water proton resonance frequency (PRF) method was integrated into the HTSC experiment to monitor the frozen effect and the capacity of the MR thermometry in HTSC experiment was evaluated by the correlation with the absolute temperature measurement [4].

Materials and Methods

For maintaining the temperature at 77K, LN_2 must be filled in a thermal insulated dewar to cool the HTSC. Fiberglass material was used to fabricate the LN_2 container and a vacuum layer was designed at the middle layer to provide the better thermal insulation. HTSC was built with the commercial HTS tape ($Bi_2Sr_2Ca_2Cu_3O_x$, Bi2223, Innova Superconductor Technology Co., Ltd., Beijiang, P. R. China), which has the advantages of flexible wiring size and easy fabrication [5]. HTSC was wounded into a circular shape and in series with a high-Q ceramic non-magnetic capacitor (American Technical Ceramics, NY, USA) to constitute a LC resonant loop centered at 125.3 MHz. Another copper loop in series with a trimmer capacitor was used to tune, match and pick-up the HTSC and positioned between the HTSC and the sample.

MR experiment was performed on a 3T MRI system (Bruker Biospin, Germany) and the body gradient system with the bore of diameter 60 cm was used. An agar phantom was placed under the dewar. For recording the absolute temperature change, an optic-fiber thermoprobe was fixed in the surface of the phantom and the temperature was recorded every minute during experiment. One horizontal slice at 4 cm below the sample surface was imaged to provide the information of the temporal temperature change inside it. To reconstruct the temperature mapping, MR proton resonance frequency (PRF) method was performed at 10 minutes after the phantom was positioned in the center of the magnet. Conventional gradient echo sequence with spoiled gradient was used to acquire the phase data and the scanning frequency was 1 scan/minute. TR/TE = 21.7/7 msec was set to provide enough temporal resolution and the matrix = 128 x 128 leads to the temporal resolution = 2 sec/scan. The flip angle was 15°. Single slice with thickness = 5 mm and FOV = 15 x 15 cm^2 were used to cover the desired location. Total of 20 scans were acquired to reconstruct the temporal temperature change. Phase images were reconstructed to map the temperature change using the PRF method. The phase image acquired at first time point was used as the reference phase and the phase difference at each time point can be derived by subtracting the phase with the reference. Fitting the correlation of temperature difference (ΔT) and the phase difference (ΔP) can derive PRF thermal coefficient.

Results

The experiment setup was shown in figure 1 and the fabricated dewar, the agar phantom and the optic-fiber thermo-probe were indicated by the black, blue and yellow arrows, respectively. HTSC was put inside the dewar to maintain the working temperature at 77K. At the beginning of the experiment, the measured temperature was 22ºC. After localization and acquiring conventional T1 and T2 images in ten minutes, gradient echo sequence was repeated to acquire the phase data for temperature mapping. During the measurement, the temperature in the surface of the sample was decreased from 11.5ºC to 6ºC. The phase difference image of each time point was shown in figure 2 and ΔP increased as ΔT increased. Figure 3 shows that the measured data of ΔP and ΔT (blue line), and the polynomial fitting curve was plotted in red line. The linear fitting curve was $\Delta P = 0.1181\Delta T - 0.0039$, and the PRF thermal coefficient was then derived as 0.1181 rad/ºC. With this relationship, temperature change can be derived by measuring the phase change during HTSC experiment.

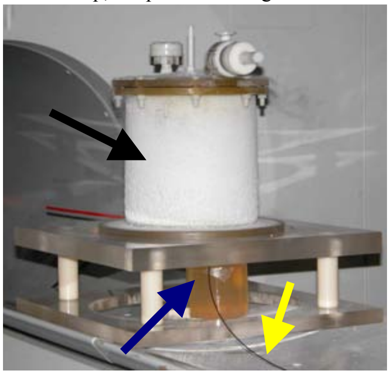

Figure 1. Experiment setup of the HTSC system. Dewar: black arrow; Agar phantom: blue arrow; Thermoprobe: yellow arrow.

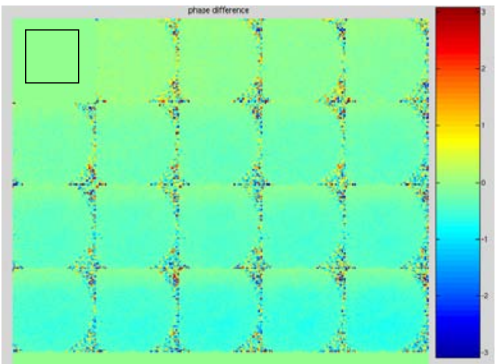

Figure 2. Phase difference images at 20 different time points (0 ~ 19 minutes, from left-top to right-bottom). The colorbar was ranged from $-\pi$ to π. The black region-of-interest in the first time point was used to calculate the mean phase difference at each time point.

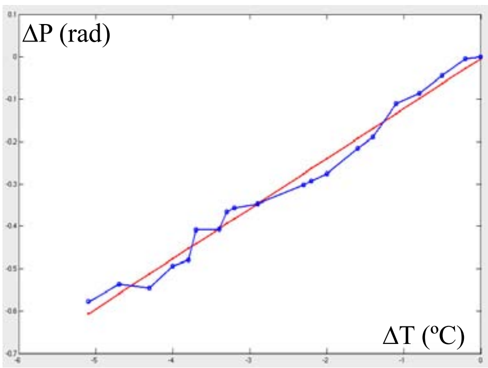

Figure 3. ΔP v.s ΔT. The measured ΔP and ΔT were plotted in blue curve and the fitting curve was in the red one. The PRF thermal coefficient was calculated as 0.1181 rad/ºC.

Conclusions

Thermal insulation of the LN_2 dewar is an important issue in HTSC system for in-vivo studies. MR PRF thermometry can help us evaluate if the fabricated dewar can maintain the working temperature at 77K and also prevent the frozen effect of the sample. Moreover, using HTS RF coil to probe the temperature change is much more sensitive than using the conventional copper coil because of the improved SNR. In this study, the PRF method was applied to provide temperature information of the HTSC system and proved to highly correlate with the measured temperature. In further work, monitoring procedures using the MR thermometry should be integrated into the in-vivo experiment with the HTSC system to keep the coil cooling and prevent the sample freezing.

Reference

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