MRI In SPACE—Dr. Jaroslaw Wosik, UH research associate professor, and his research team are developing small MRI systems that can fit into the International Space Station to to study effects of a zero-gravity environment upon body tissue and to determine the effectiveness of measures taken in flight to counter muscle atrophy that results from minimal muscle tension in a zero-gravity environment.

Compact MRI Systems for Long-Duration Space Flights

Abstract— People are accustomed to MRI examinations for the assessment of body damage or to monitor body activity in a defensive mode before disastrous illness occurs. One prepares for an examination by being rolled into a cavernous machine that takes images of the anatomy slice by slice, the images pieced together later for medical analysis. Astronauts in space, however, do not have ready access to an MRI, nor does the International Space Station have available area for housing a large MRI device. To solve the problem, UH researchers are developing small MRI systems that can operate during space flights to document changes in the astronauts' muscle volume and to assess the effectiveness of techniques for preventing the atrophy of muscles in an environment free of gravity. They have developed a high-temperature superconducting (HTS) coil that may prove useful in a small low-field MRI system for imaging small human parts, such as a wrist, an elbow, and a foot, capable of reporting results without delay.

Development of a small Magnetic Resonance Imaging (MRI) system has been identified by the Science Working Group of the Human Research Facility on the International Space Station (ISS) as one of the most desired new research tools scheduled for use during long-duration changes in muscle volume for assessing the effectiveness of in-flight muscle atrophy countermeasures. The development of effective musculoskeletal countermeasures is one of the critical problems to be solved to accomplish the prolonged microgravity exposures required for a potential future Mars expedition.

The small MRI system has to operate at a low magnetic field utilizing either a permanent magnet or air coils. Unfortunately, low–field MRI systems suffer from small signal-to-noise ratio (SNR) since the signal is proportional to the dc magnetic field. The random noise in an MR system is caused by ohmic losses in the receiving circuit. The loss in the receiving circuit has two sources: the ohmic losses in the rf coil itself and the eddy-current losses in the sample (body), which are inductively coupled to the rf coil. Fortunately, at low magnetic fields, the losses in the rf coil dominate; thus they can be significantly reduced by using high-temperature superconducting (HTS) coils as sensors. HTS sensors increase the signal-to-noise ratio in MR measurements by essentially eliminating the noise contributed by the resistance of the sensor, which is ordinarily the dominant loss term in low-field imaging.[1] Using HTS coil at low field will provide nearly an order of magnitude increase in SNR as compared to a normal copper coil.

During the last year, we have achieved significant progress in analyzing, understanding, and improving MRI images acquired at low-field systems. Based on the above experience and findings, we have developed a HTS coil for low-field MRI system. This coil was integrated with the cryostat, which fits into a gap of the permanent low-field magnet. The performance test of our coils

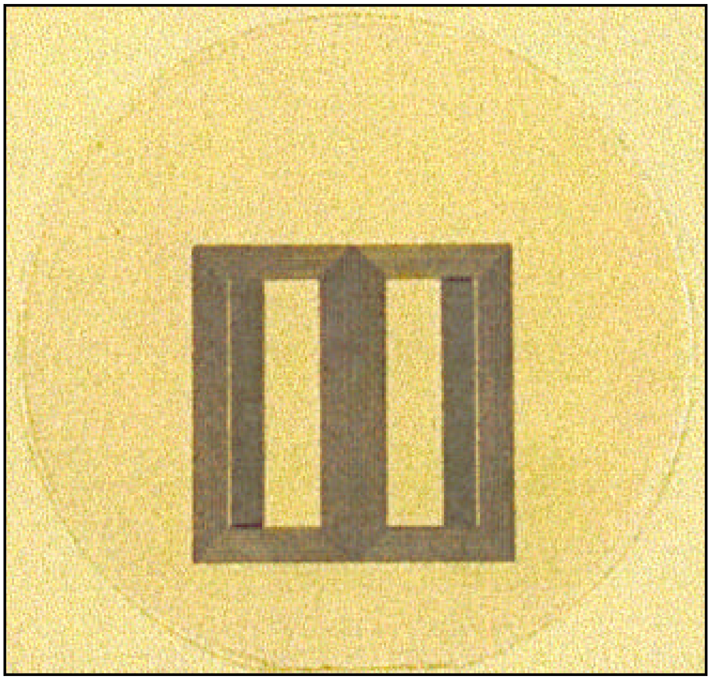

Figure 1. Butterfly 3-in. diameter probe

was carried out in the low-field MRI system developed by our collaborators from Texas A&M in College Station (Prof. Steven Wright). During this work, we have also refined an integration of optimized superconducting coils with a plastic continuous gas flow cryostat developed in our laboratory for this experiment.[2]

Current work concentrates on the development of a multi-coil system in order to increase the field-of-view required for practical applications of a low-field system.

There are two approaches to increasing the field of view of a probe: one is achieved by switching among multiple coils,[3] which are specially arranged to minimize their mutual inductance, and the other, first demonstrated by Roemer,[4] uses simultaneous acquisition of signals from de-coupled receiver coils which are similar to that of the previous case. The second approach is analogous to the phased array radar and offers SNR and resolution of a small surface coil over the field-of-view normally associated with volume coils with no increase in imaging time. We will employ such an approach in our design consisting of two pairs of coils. At this stage of the project, we have started with designing and optimizing a single coil. Figure 1 shows the final design of such coil resonating at 9.2 MHz.

A resonant circuit is created by sandwiching a dielectric (sapphire) between two faces of the planar coils in order to achieve capacitive coupling. The resonant frequency depends on spacing between patterns; thus, the coil can be designed for desired frequency by selecting a thickness of the dielectric and/or number of turns in the pattern. Such a probe consists of patterned, double-sided YBCO films deposited on 3-in. $LaAlO_3$ or sapphire substrates. Standard positive photoresist and a wet etching process were used for fabrication of the coils. We used inductive coupling, thus eliminating any need for an ohmic contact. YBCO films were obtained from Forschungszentrum in Karlsruhe in Germany in the framework of collaboration with Drs. F. Ratzel and J. Geerk.

In order to optimize coil performance such as field of view, we calculated distribution of the signal-to-noise ratio along two different cross-sectional planes in the cylindrical phantom (simulating body) placed next to the coil. Calculations were done for different coil dimensions, as shown in Fig. 2. This figure illustrates the depth and width at which each coil can "see."

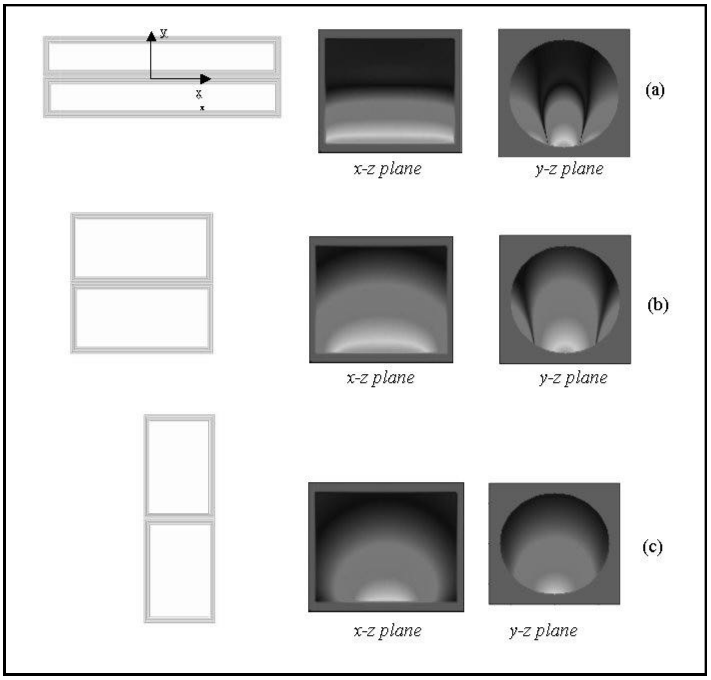

Figure 2. Images calculated from Biot-Savart law SNR in *x-z* and *y-z* planes of the cylindrical phantom placed next to the coil. Different ratios were selected for coil linear dimensions.

In (a), the FOV is very narrow and the coil does not "see" very deeply into the body. In (b) for the square-shape coil, we find that the coil can "see" more widely and deeper, and we have high SNR in the middle part near the surface of the sample (spine of mouse). In (c), the coil can "see" a very wide are, but a bit shallower than (b). It also it has a smaller SNR in the middle part near the surface of the sample. From this observation, we understand that for spine images and to get deeper images in the middle part of the sample, it is better to use square coils.

Using simulation shown above, we have optimized a single coil design, that enables us to design and fabricate one pair of coils in order to increase the field of view of the probe while making it more uniform. Two double-sided superconducting YBCO films, 3-in. in diameter, deposited on sapphire substrates, were used to develop an MRI probe with such uniform and enhanced field-of-view. In Fig. 3 such a probe consisting of two coils, is drawn for computer simulation. The cylinder represents a body. A coupling loop is also shown.

This design can be used for imaging small animals or small human parts, such as the wrist, elbow or even a foot. The results, showing significant increase of SNR for HTS coils, demonstrate that such 3-in. coils might be practical while used at low field strengths of 0.2 Tesla in small MRI systems.

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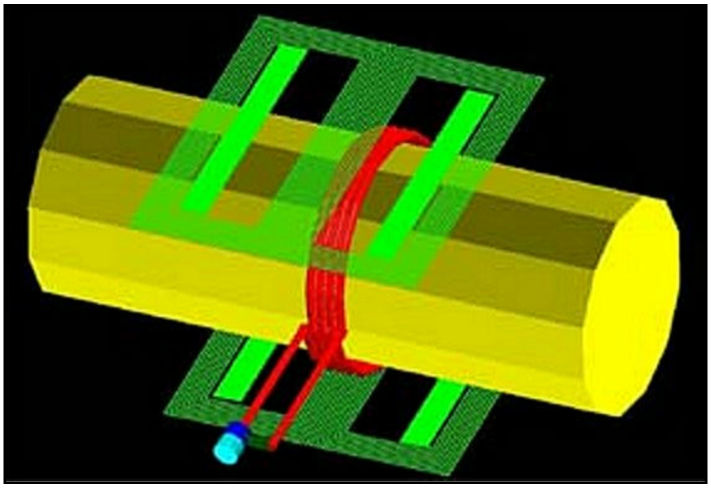

Figure 3. Two-coils (array) are shown on both sides of the cylinder together with a coupling.

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