Design and Construction of a Head Probe Coil for Vocal Tract Imaging

D. Gogola, L. Valkovič, J. Přibil, T. Dermek, L. Vojtíšek, I. Frollo
Institute of Measurement Science of the Slovak Academy of Sciences,
Dubravska cesta 9, Bratislava, Slovakia

Abstract. *Magnetic resonance imaging (MRI) is nowadays a most widely use in medicine for diagnostic imaging and in research studies. At the present time many research studies follow with problematic about human vocal tract modeling. This paper is devoted to the design and optimization of head probe coil for vocal tract imaging. For the reason of requirement voice recording during measurement, this head probe coil was made and tuned for MR tomograph with field strength 0.178 T. This produces less noise like MR tomograph with stronger magnetic field.*

Keywords: probe coil, MR tomography, voice tract imaging

1. Introduction

The human vocal tract imaging is necessary for the three-dimensional modeling of human vocal tract. The three-dimensional (3D) modeling of human vocal tract is necessary for understanding the basic physical principles for the creation of human speech and voice as close to reality as possible. Such models are helpful for modeling the real clinical situation, such as influence of various inborn defects in human supraglottal spaces on speech and voice or simulations of various post surgical states in patients [1].

The human voice is made up of oscillation of vocal cords due to airflow form the lungs. Resonant frequency of the vocal cords is basic frequency of voice. While most of the acoustic energy of the human voice and speech is contained in the frequency range between 70 Hz to 5 kHz high-fidelity simulation of human voice and speech aims at producing sounds within the whole audible frequency range, i.e. 20 Hz - 20 kHz. Consequently, it is important to develop models that are able to simulate the acoustic properties of the vocal tract with a high accuracy. These models should allow simulating pathological changes or voice quality variations due to slight geometry modifications of the human supraglottal acoustic space. [2]. In previous studies it has been shown that even small changes in vocal tract geometry significantly affect the frequency above 4 kHz [1].

3D models of human glottal acoustic space during the formation vowels are acquired on the basis of magnetic resonance images.

Head probe coils are commonly produced for MR tomographs with strong magnetic field, but these systems produce a lot of unwanted acoustic noise. Because of the need of simultaneous voice recording for the vocal tract MRI, the MR tomographs with strong magnetic field cannot be used. The solutions to the acoustic noise problems are low field MR scanners, but these are not usually provided with the head/neck coils.

Therefore, in this study the focus is to develop MR receiving head coil, for a tomograph with low magnetic field, for imaging of human vocal tract.

2. Subject and Methods

For the best signal to noise ratio, receiving coil should be exactly matched to the preamplifier and tuned to the main working frequency of MR tomograph. For this reason, variable capacitors must be used [3]. Because these capacitors are part of the resonance circuit, they should be situated near be receiving coil as close as possible. This resonance circuit is placed into the main magnetic field of the MR scanner; therefore variable capacitors with ultra-low magnetic susceptibility must be used. Next requirements for capacitor for MR probes include high quality Q, high voltage, ultra-low piezoelectric effects, and high temperature stability [4]. During sample excitation by the RF pulse, the coil can induce a high voltage. For this reason, the detuning circuit was used, as a part of the resonance circuit of coil, like a protection of preamplifier, before this high voltage. For a good homogeneity in the center of the coil, as shown in Fig. 1, our probe coil was made as elliptical solenoid.

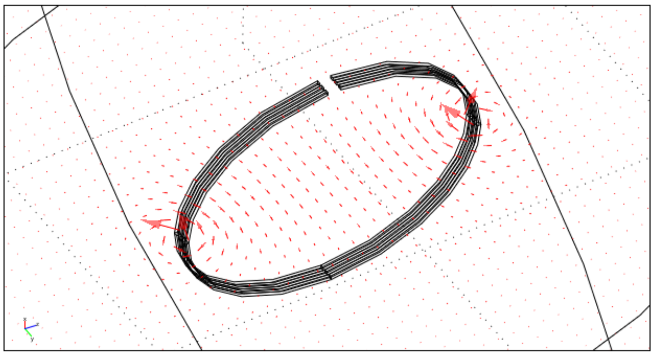

Fig.1. Magnetic flux density of a probe coil

The coil was designed and simulated in Comsol Multiphysics program (Comsol AB, Los Angeles, USA). Homogeneity of the magnetic field of coil was calculated from the simulation in the program Comsol Multiphysics. Theoretic calculation of magnetic induction, as shown in Fig.2, was made in Mathematica program.

Signal to noise ratio (SNR) and contrast to noise ratio (CNR) were calculated from the image which was produced with our coil.

The magnetic field Bz of a simple circular coil can be calculated using equation (1), [5] :

$$Bz = \frac{ElipticK[k] + \dfrac{ElipticE[k]\left(R_1^2 - r^2 - (z - z_1)^2\right)}{(R_1 - r)^2 + (z - z_1)^2}}{\sqrt{(z - z_1)^2 + (R_1 + r)^2}}, \quad \text{where} \quad k = \frac{4R_1 r}{(R_1 + r)^2 + (z - z_1)^2}. \tag{1}$$

Where $R_1 = 0.09$ [m] is a radius of coil, r denotes a variable in radius direction, z is variable in z direction, $z_1 = 0.007$ [m] is distance of each wire loop.

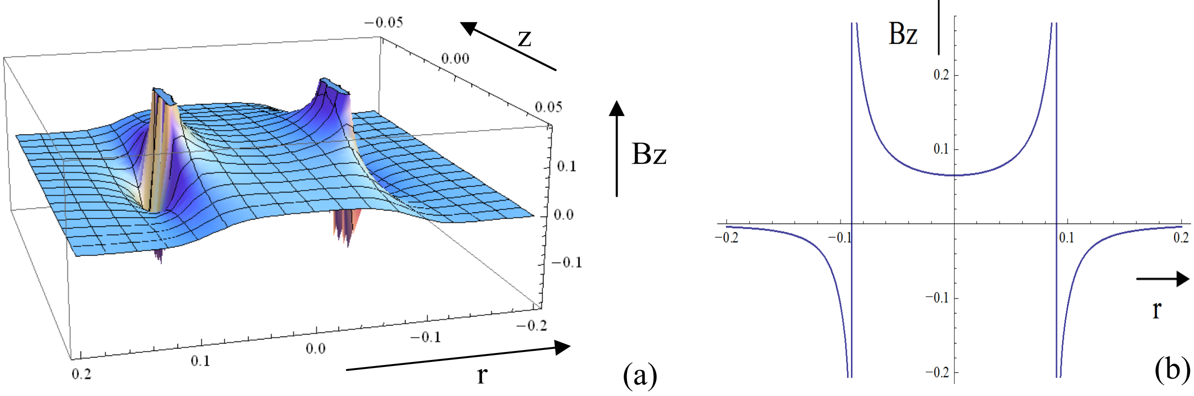

Fig.2. Image of magnetic field induction, in 3D (a) and in plane z = 0 (b)

The induction of magnetic field B_1 in center of solenoid coil is described by the equation (2), [4]:

$$B_1 = \frac{\mu_0 n I}{2h\sqrt{1+4\left(\frac{r}{h}\right)^2}} \tag{2}$$

where
μ_0 - permeability of free space, n - number of turns, I - electric current, h - high of coil and r - radius of coil.

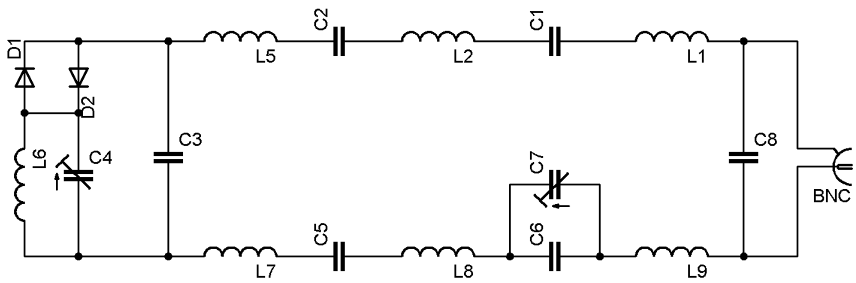

Fig.3. Equivalent circuit of head probe coil, with detuning (protection) circuit on the left side.

This coil is created by the three turns of wire with diameter 2.5mm. Loop diameter is 22cm. Each thread is divided into two parts, which are connected by the capacitors, as shown in equivalent circuit of Fig. 3.

All experiments were done on the 0.178 T MR scanner Opera [6].

3. Results

The magnetic field homogeneity calculated from the simulated field was +/-4.2 ppm.

The constructed head probe coil was tuned and tested in low-field MR scanner. The measured image of volunteer is depicted in Fig.4. The SNR of the tissues surrounding the vocal tract in the measured image, as seen in Fig.5, were as follows: soft palate 26.84, tongue 22.36 and epithelium 15.36. The CNR of the tissues against the cavities was as follows: soft palate 26.45, tongue 14.96 and epithelium 21.96.

Fig.4. MR image of vocal tract with following parameters TR: 900, TE: 26, slice thickness: 5mm

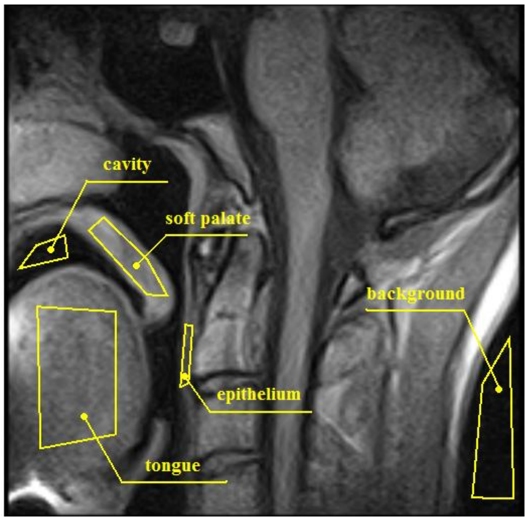

Fig.5. Image of vocal tract with described regions of interest

4. Discussion and conclusions

The prototype of receiver coil design with partitioning of turns seems to be feasible for obtaining reasonable signal to noise ratio. The calculated contrast to noise ratio of the tissues surrounding the vocal tract against the cavities was acceptable, and thus the vocal tract is in the image easily recognized.

According to design a head probe coil was made and afterwards tested in Opera ESAOTE tomograph. An image with relative high SNR (see Fig.3) can be measured with only two averages, thus in reasonably short acquisition time.

From our results it is clear that our head coil developed for low-field MR scanners is suitable for vocal tract MRI, as seen in Fig. 3. Imaging of the throat and mouth cavity in short time along with voice recording is therefore possible without enormous acoustic noise. In our case, the mouth cavity is not fully visible due to the imaging sequence restrictions (Field of View - FOV). The increase of FOV is the focus of our future developments.

This prototype of a low-field MR probe head coil has fair properties, but not yet optimal. In further research we will primarily focus on the selection of more suitable materials for the construction of the coil to increase the coil quality and thus improve the signal to noise ratio. For the same purpose will also the development of high impedance differential amplifier be part of further research.

For automatic fine-tuning and better compatibility with Opera ESAOTE system will be air variable tuning capacitor replaced by the varicap.

Acknowledgements

This work was supported by Grant Agency of the Slovak Academy of Sciences, VEGA 2/0090/11 and by State program ŠPVV no. 2003SP200280203.

References

[1] Vampola T, Horáček J, Švec G.J. FE Modeling of Human Vocal Tract Acoustica. *Acta Acustica united with Acustica*: 94, 433-447, 2008.

[2] Vampola, T., Horáček, J., Vokřál, J., and Černý, L. FE modeling of human vocal tract acoustics: Part II – Influence of velopharyngeal insufficiency on phonation of vowels", *Acta Acustica United with Acustica*, 94, 448-460, 2008.

[3] Andris P, Frollo I. Varicaps for NMR receiving coil matching and sensitivity changes. *Journal of ELECTRICAL ENGINEERING:* vol. 58, no.5, 291-293, 2007.

[4] Doty F.D. Solid State NMR Probe Design. *Encyclopedia of Magnetic Resonance*, 2007.

[5] Frollo, I.: Generation and application of gradient magnetic fields in NMR measurement and imaging. Scientific Instrumentation, 4, 1989, 2, 41-51.

[6] E-scan Opera. Image Quality and Sequences manual. 830023522 Rev. A, Esaote S.p.A., Genoa, April 2008.