Analysis of Vibration into the Scanning Area of the Open-air NMR Imager Working with a Weak Magnetic Field

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Abstract. *The paper analyzes of spectral properties of an acoustical noise produced by mechanical vibration of the gradient coils during scanning in the open-air Magnetic resonance imaging equipment working with a weak magnetic field up to 0.2 T. This vibration signal exhibits harmonic character, so it is suitable to analyze its properties in the spectral domain. Mapping of intensity distribution of the vibration signal is also described in this paper. Obtained results of spectral analysis will be used to suppression of a negative influence to the quality of resulting MR images of the thin layer samples tested in this device.*

Keywords: Acoustic Vibration and Noise, Spectral Analysis, NMR Imaging

1. Introduction

Magnetic resonance imaging (MRI) devices working with a weak magnetic field are used for non-invasive MR scanning of different parts of a human body in clinical practice as well as for testing of biomedical or agriculture samples. This type of MRI equipment can be also applied for analyzing of weak magnetic materials (belonging to diamagnetic and paramagnetic materials) [1] and for testing of widely used body implants or dental casting alloys. The MRI device consists of a gradient coil system that produces three orthogonal linear fields for spatial encoding of a scanned object. The noise is produced by these gradient coils due to rapidly changing Lorentz forces during fast switching inside the weak static field B_0 environment [2]. It results in significant mechanical pulses that cause secondary vibration in the MR scanning area and can also be induced to vibration of tested samples inserted in the MRI device. By this way induced vibrations can have a negative influence to the quality of resulting MR images (blur effect) especially when the thin layer samples are tested. In this case the vibration originated from a gradient coil causes movement of the tested sample lying on the undulating surface of a water solution. Due to its harmonic nature the produced vibration signal [3] can be generally treated as a voiced speech signal and it can be analyzed using similar methods as those used for spectral speech analysis [4].

The paper is focused on measurement and calculation of 3D maps of the vibration signal sensed at bottom plastic holder of the MRI equipment scanning area, where the gradient coil system is arranged. Determination and evaluation of the main spectral parameters of recorded vibration signals for basic types of 3D scanning sequences implemented in the MRI device was performed. The main motivation of our work was to obtain statistical results of spectral parameters of the vibration signal, which can be used to devise sharpening and reduction of the motion effect in the MR pictures of thin layer samples and phantoms.

2. Method of Analysis of the Vibration Signal Spectral Properties

Spectral analysis of the vibration signal is performed in the following way: from the input samples (after segmentation and weighting by a Hamming window with the length w_L) the absolute value of the N_{FFT} points fast Fourier transform $|S(k)|$ and the power spectrum $P(k)$ is calculated − see the block diagram in Fig. 1. The harmonics-to-noise ratio (HNR) provides an indication of the overall periodicity of the speech signal [5]. Specifically, it quantifies the ratio between the periodic and aperiodic components in the signal. The HNR expressed in [dB] is computed as

$$HNR = 10\log_{10}\left(\frac{\sum_{k=N_{FB}LO}^{N_{FFT}/2}\left|S(k)\right|^2}{\sum_{k=N_{FB}HI}^{N_{FFT}/2}\left|S(k)\right|^2}\right), \quad N_{FB} = \frac{f_{\max FB}\ N_{FFT}}{f_s}, \qquad (1)$$

where summation index N_{FB} depends on the chosen frequency band, f_s is used sampling frequency, and f_{maxFB} is the maximum frequency of the band. Determined spectrum portion of harmonic amplitudes is summed from low frequencies corresponding to the index $N_{FB}LO$ (10 ÷ 70 Hz); the noise portion is calculated from high frequencies corresponding to the index $N_{FB}HI$ (1500 ÷ 4500 Hz). The spectral centroid (SC) is a centre of gravity of the power spectrum and represents an average frequency weighted by the values of the normalized energy of each frequency component in the spectrum. The spectral flatness measure (SFM) can be used to determine the degree of periodicity in the signal. This spectral feature can be calculated as a ratio of the geometric and the arithmetic mean values of the power spectrum. The spectral entropy is a measure of spectral distribution. It quantifies a degree of randomness of spectral probability density represented by normalized frequency components of the spectrum. All mentioned spectral properties − SC in [Hz], SFM, and Shannon spectral entropy (SHE) were calculated using following formulas [5]

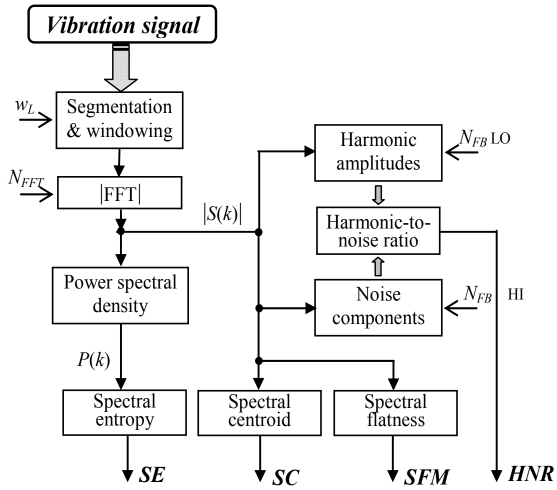

Fig. 1. Block diagram of spectral analysis of the vibration signal.

$$SC = \frac{\sum_{k=1}^{N_{FB}} k\left|S(k)\right|^2}{\sum_{k=1}^{N_{FB}}\left|S(k)\right|^2}\cdot\frac{f_s}{N_{FFT}}, \qquad SFM = \frac{\left[\prod_{k=1}^{N_{FB}}\left|S(k)\right|^2\right]^{\frac{2}{N_{FFT}}}}{\frac{2}{N_{FFT}}\sum_{k=1}^{N_{FB}}\left|S(k)\right|^2}, \qquad SHE = -\sum_{k=1}^{N_{FB}} P(k)\log_2 P(k)\,. \qquad (2)$$

3. Experiments and Results

Our experiments with mapping of produced vibrations and analyzing of spectral properties of the vibration signal were performed in the open-air 0.178 T imaginer E-scan Esaote OPERA [6]. To prevent an interaction with the stationary magnetic field B_0 in the MRI scanning area, the vibration sensor must be totally free of ferromagnetic materials. In praxis, the piezo-electric sensors for contact measurement of vibrations on surfaces were often used. The standardized vibration sensors or accelerometers designed for professional measurement usually consist of cover sleeve from metal or ferromagnetic materials, so it is impossible to measure their usage in the MRI device. Because we principally engaged in the frequency range of <10 Hz÷5 kHz> [4] we finally decided to use the vibration sensor primary designed for sensing of musical instruments − contrabass. This sensor consists of the active piezo-electric element mounted on the circular 1“ target of brass. Tested MRI equipment has

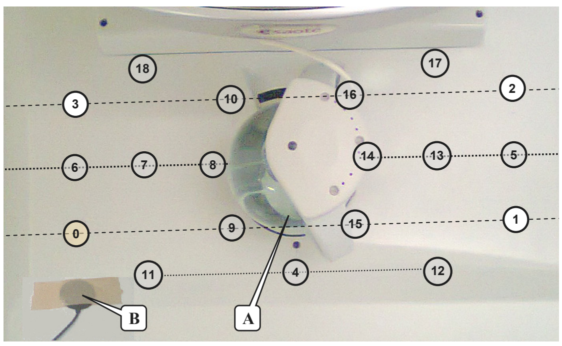

Fig. 2. Photo of distribution of 19 measuring points on the bottom scan plate of the MRI: RF knee coil with a water phantom (A), piezo-electric vibration sensor (B).

a planar arrangement of the gradient sub-system consisting of parallel combination of surface coils located on the upper and bottom part of the scanning area. For mapping of distribution of the vibration on the scan area of the MRI device, the bottom plastic plate was covered by a measuring matrix consisting of 19 points (see Fig. 2), and the spherical testing phantom filled with doped water inserting in the scanning RF knee coil were used. An electric signal from the vibration sensor was directly measured by the digital oscilloscope Tektronix TDS 210. Obtained relative peak-to-peak values were subsequently recalculated to signal levels in [dBuV]. The vibration signal was parallel recorded with the help of the Behringer PODCAST STUDIO equipment connected to a separate personal computer (originally recorded at 32 kHz, resampled to 16 kHz). The whole measurement was performed for eight different types of the 3D and Hi-Res scanning sequences (often used for MR images of the thin layer magnetic materials) in four different measuring positions – see Tab. 1.

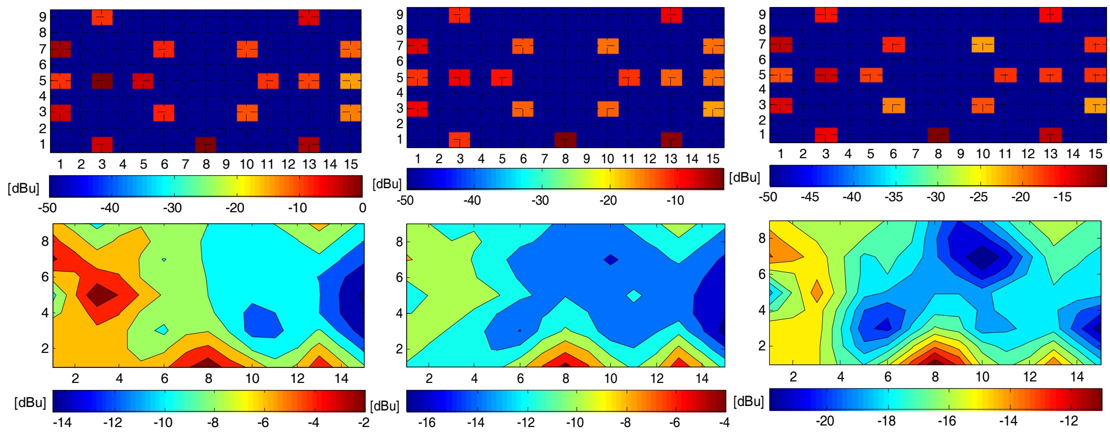

Fig. 3. Graphic representation of distribution of the vibration signal: discrete values at measuring positions of <0÷18> in the 15x9 grid (upper set) – the background level was substituted with the -50 dBuV value; calculated 2D contour map (lower set) – used scanning sequence No 1 (left), No 4 (centre), and No 8 (right).

Table 1: Parameters of tested scanning sequences together with measured vibration signal level on the basic positions (in corners of the plastic plate), and the mean values of spectral properties measured at position "0".

No	Sequence type*)	TE [ms]	TR [ms]	Signal level at positions [dBuV]**)				Mean values of spectral properties			
				0	1	2	3	HNR	SC [Hz]	SFM	SHE
1	SS 3D balanced	5	10	-4.4	-13.1	-11.6	-1.6	0.0902	876.9	0.0008	4.579
2	SSF 3D	10	40	-11.1	-18.2	-14.4	-6.4	0.1008	911.7	0.0017	5.128
3	SSF 3D rsf	10	30	-11.1	-18.8	-15.3	-6.8	0.1004	911.6	0.0018	5.115
4	SSE 3D	10	20	-8.7	-16.9	-15.1	-7.8	0.1158	945.1	0.0013	3.815
5	TURBO 3D-T1	16	40	-17.5	-21.4	-15.6	-13.6	0.1289	1012.2	0.0032	5.319
6	3D-CE	30	40	-15.3	-19.9	-19.1	-15.9	0.1181	1020.1	0.0031	5.111
7	Hi Res SE 26 HF	26	500	-13.4	-20.5	-18.0	-8.8	0.2077	1779.4	0.0675	5.606
8	Hi Res GE STIR 25	25	1000	-14.2	-21.7	-17.3	-12.9	0.2630	2091.6	0.1094	6.023

*) Auxiliary parameters: FOV 200x200x192, 10 slices, 4 mm thick, orientation sagittal. **) Background level were -48dBuV for all sequences

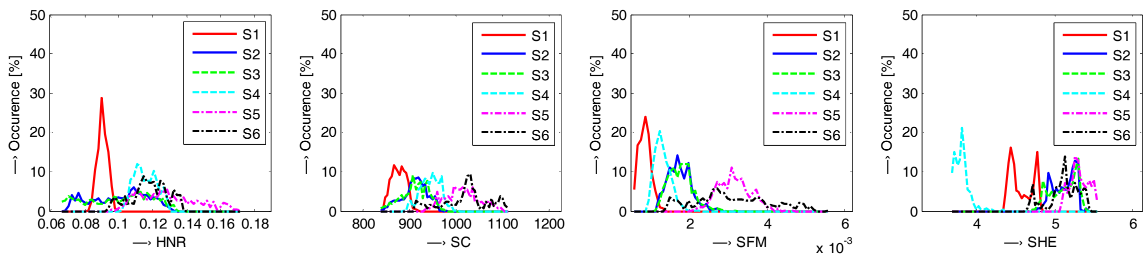

Fig. 4. Histograms of the spectral properties values measured at point "0" for the first six scanning sequences.

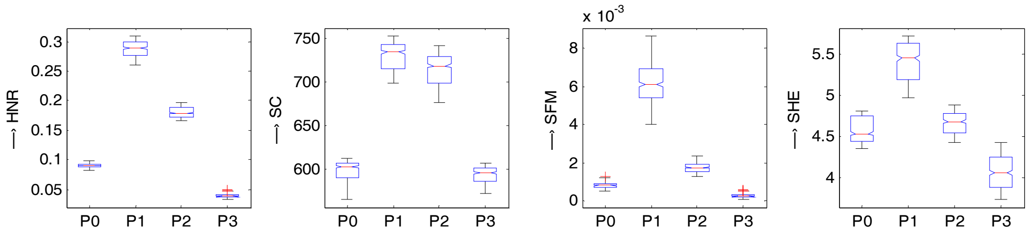

Fig. 5. Values comparison of spectral properties obtained at different measuring positions; MR sequence No 1.

4. Conclusions

Performed analysis of distribution of the vibration signal for different scanning sequences shows that the intensity on the bottom plastic plate is not consistent – see maps in Fig. 3. The maxima are located near the front edge of the scanning area and the minimum is approx. in the centre of the plate. This is a positive result instead of the fact that in the centre is placed the RF coil with the tested samples. On the other hand, not only the intensity of vibrations influences the tested thin layer samples. Realized analysis of spectral features of the vibration signal shows that different frequencies are attended – see comparison of results in Tab. 1 and graphs in Fig. 5. Obtained values of the HNR and SC parameters demonstrate that representation of the different frequencies depends first of all on the used MR sequence, and next on basic setting of the scan parameters – TE and TR time. Measurements using the scanning sequences No 2, 3 yielded similar results, because these two types differ only in the parameter TR. Given results confirm our assumption, that the TR time affects first of all the fundamental frequency of the vibration signal (like as the F0 of a speech signal [4]).

In the near future, we will to realize the mapping of the vibrations with higher precision – in more measuring points. To obtain the results in normalized vibration (pressure) level [3] our piezo-electric sensor must be calibrated with the standard one designated for this purpose. In addition, we plan to measure and analyze the time propagation delay [2] between the electrical excitation pulse of gradient coils and subsequently generated vibration wave.

Acknowledgements

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