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Measurement of sound intensity of MRI driving sound in near field of MRI equipment

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ABSTRACT

Magnetic resonance imaging (MRI) equipment of high magnetic field generates loud sound of around 100 dB. The purpose of this study is sound source search of MRI driving sound for hearing protection. We reported sound source search on the patient's table of MRI equipment. This paper shows the result of sound source search of the driving sound in near field of MRI equipment. Target of MRI equipment is Signa Horizon LX 1.5T for the whole body of magnetostatic field 1.5T of GE Yokogawa Medical Systems. The objects of analysis sound are auto tuning pulses and continuous driving sound of slice positioning. Auto tuning pulses are generated at the initial of imaging sequence. Slice positioning is utilized to get an image for decide the region of diagnosis. Measurement conditions are follows. Sampling frequency is 48000 Hz, analysis by sound intensity is cross-spectral method with Fast Fourier Transform (FFT), window function is Hanning window, analysis data length by FFT is 4096 points, and analysis frequency is from 176 to 1414 Hz. The result shows that maximum of sound intensity level of the driving sound was 89.3 dB and characteristic of the vector radiated from side surface of MRI gantry. It is clear that sound source of the driving sound is radiated from side shell and bore of MRI equipment.

INTRODUCTION

Magnetic resonance imaging (MRI) examination is necessary to medical diagnosis. The MRI utilizes a technology for the distribution of imaging proton with the nuclear magnetic resonance (NMR) phenomenon. When the examination part is put in the static magnetic field, to irradiate the part with radio frequency (RF) pulse generate the NMR signal. The signal is repeatedly sampled for tomographic image.

MRI driving sound is generated by the gradient magnetic field coil for distribution imaging inside of the body during the operation of MRI equipment. Changing of the gradient magnetic field is given by switching of the gradient coil current. Loud sound at MRI driving is generated by Lorentz force by the current switching in strong static magnetic field. The sound pressure level is around 100 dB depended on MRI sequence or resolution parameter [1].

Many results of researches, including us, had analysed the driving sound. It is necessary for hearing protection to measure the MRI driving sound on the patient's table or in the bore of MRI equipment. We reported measurement result of sound intensity and noise level of the driving sound on the table inside and outside the bore [1] ~ [3]. Patients hear the direct sound from MRI equipment in addition to the reflected sound from wall of MRI examination room. Therefore, it is also necessary for research of sound on the table to measure the driving sound in near field of MRI equipment. However there is no report described driving sound in near field of MRI equipment. Then, for hearing protection is necessary to reduce the driving sound. One method for the reduction is active noise control (ANC) [4]. Because ANC actuate appropriately, it is required appropriate position of reference microphone.

The purpose of this study is sound source search of MRI driving sound in near field of MRI equipment. This paper shows the result of sound source search of the driving sound in near field of MRI equipment, which the method is sound intensity utilized cross-spectral method.

MATERIALS AND METHODS OF SOUND INTENSITY

Figure 1 shows the MRI equipment for measurement, Signa Horizon LX 1.5T for whole body of magnetostatic field 1.5T of GE Yokogawa Medical Systems. This MRI equipment has ability of magnetostatic field of 1.5T, gradient magnetic field of 22 mT/m, and slew rate of 77 mT/m/ms or less. The materials of floor and wall of the MRI examination room are linoleum and concrete. The imaging sequences of analysis sound are auto tuning pulse and slice positioning [3] of initial in examination.

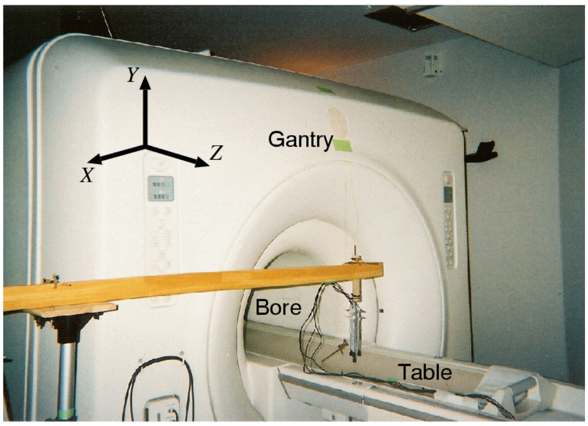

Figure 1 Sound intensity probe and MRI equipment.

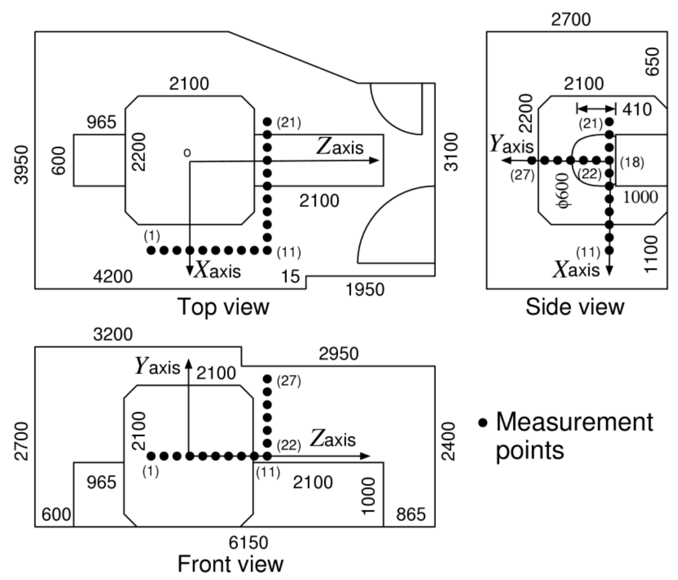

Figure 2 Size of an MRI examination room and measurement points [mm]

Table 1 Position of measurement points [mm]

No.	*x*	*y*	*z*	No.	*x*	*y*	*z*
(1)	1400	0	–600	(15)	600	0	1400
(2)	1400	0	–400	(16)	400	0	1400
(3)	1400	0	–200	(17)	200	0	1400
(4)	1400	0	0	(18)	0	0	1400
(5)	1400	0	200	(19)	–200	0	1400
(6)	1400	0	400	(20)	–400	0	1400
(7)	1400	0	600	(21)	–600	0	1400
(8)	1400	0	800	(22)	0	200	1400
(9)	1400	0	1000	(23)	0	400	1400
(10)	1400	0	1200	(24)	0	600	1400
(11)	1400	0	1400	(25)	0	800	1400
(12)	1200	0	1400	(26)	0	1000	1400
(13)	1000	0	1400	(27)	0	1200	1400
(14)	800	0	1400				

Because the MRI equipment is a high magnetic field generator, it is need to utilize the sound intensity probe made with non-magnetic microphones, aluminium, and wood [2]. This probe's microphones are electret condenser microphones (ECM). The distance between each ECM is 3cm. The probe has ability of measuring frequency of 1.5 kHz or less.

Sound intensity is a vector that the energy flow of sound of unit cross-section area per unit time, is calculated by time average of product of sound pressure and particle velocity [5] by close to two microphones. Let the sound pressure between two points be $p_1(t)$ and $p_2(t)$, the sound intensity of direction connecting the two microphones becomes as follows:

$$I(f_1, f_2) = -\frac{1}{2\pi \rho d}\int_{f_1}^{f_2} \frac{\mathrm{Im}\{G_{p_1 p_2}(f)\}}{f} df. \quad (1)$$

Where, ρ is the air density, d is the distance between two microphones, f_1 and f_2 are the analysed frequency range, and $\mathrm{Im}\{G_{p_1 p_2}(f)\}$ is the imaginary part of the cross-spectral density function of $p_1(t)$ and $p_2(t)$.

Analysis frequency range of sound intensity is between f_1 = 176 Hz and f_2 = 1414 Hz. f_1 is the lowest frequency of octave band center frequency 250 Hz, considering that influence of noise due to the AC power source. f_2 is the highest frequency of octave band center frequency 1000 Hz, considering that

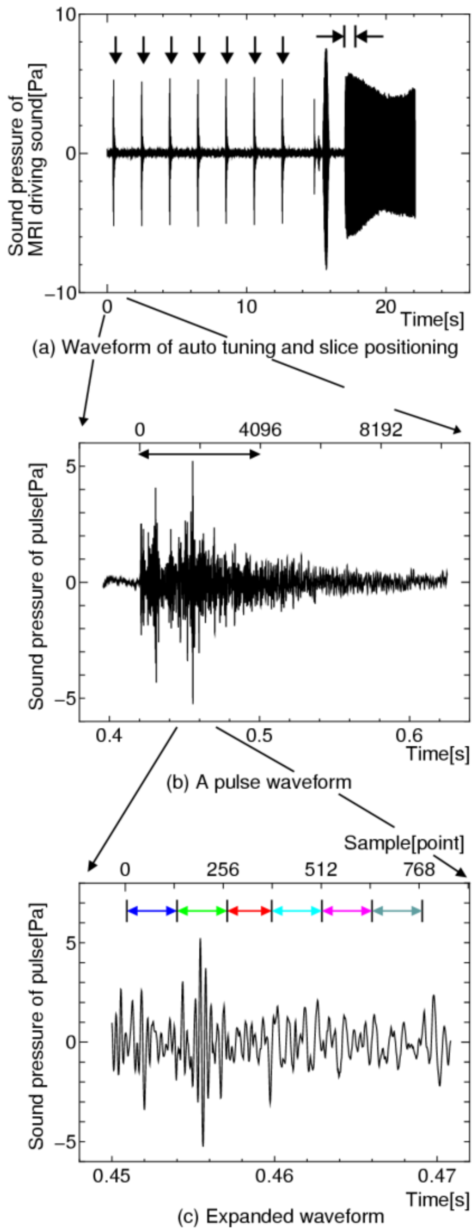

Figure 3 Example of MRI driving sound at auto tuning and slice positioning, and its analysed parts.

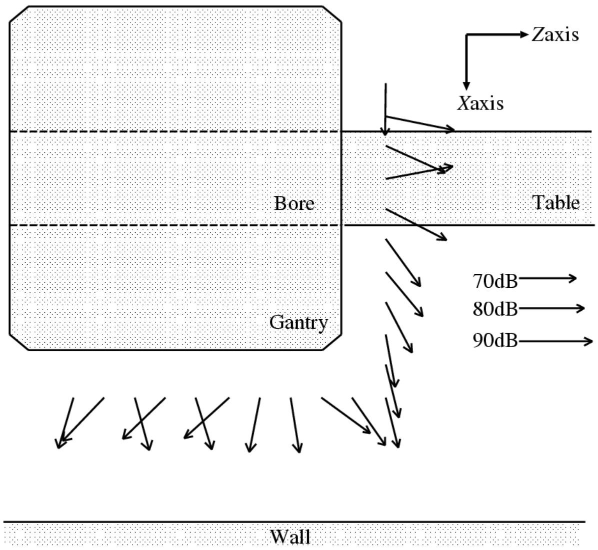

Figure 4 Result of sound intensity vectors of continuos driving sound in *xz* plane.

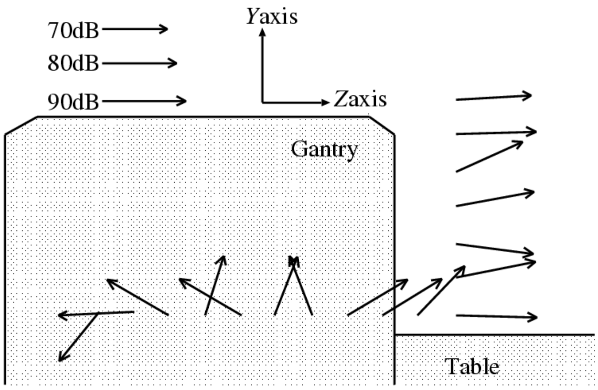

Figure 5 Result of sound intensity vectors of continuos driving sound in y*z* plane.

frequency characteristic of four microphones of sound intensity probe.

Figure 2 shows the measurement points in an MRI examination room. Let origin be the gantry center, let *z* axis be the direction of the long side of the table, let *y* axis be the direction of height of the table, let *x* axis be the orthogonal direction of *z* axis and *y* axis. Position of measurement points are decided that intervals are 200 mm in MRI examination room as Table 1.

SOUND INTENSITY IN NEAR FIELD OF MRI EQUIPMENT

Figure 3 shows the wave form of measurement point (18). The objects of analysis sound are auto tuning pulses and slice positioning as continuous driving sound. Auto tuning pulses are generated at the initial of imaging sequence. Slice positioning is utilized to get an image for decide the region of diagnosis. Recorder's sampling frequency is 48000 Hz for analysis.

SOUND INTENSITY OF CONTINUOUS DRIVING SOUND

In this section, it is shown that sound intensity is researched the sound in slice positioning sequence as continuous driving sound. Analysis wave forms are seven frames of non overlap from 17 s, one frame is 4096 points as shown with arrow in figure 3 (a).

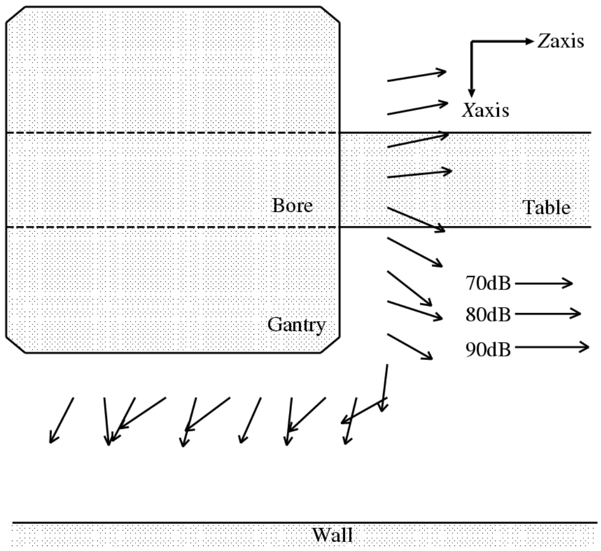

Figure 6 Result of sound intensity vectors of auto tuning pulse in *xz* plane.

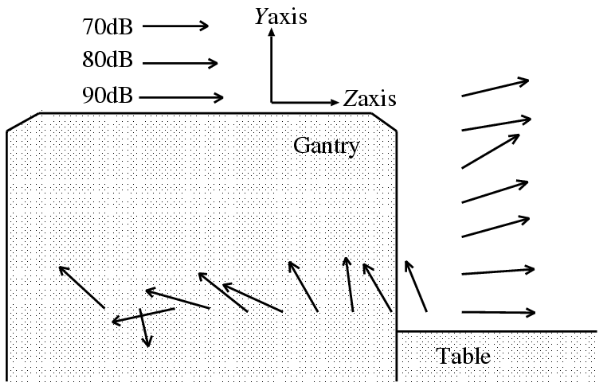

Figure 7 Result of sound intensity vectors of auto tuning pulse in *yz* plane.

The sound intensity is calculated by cross-spectral method with Fast Fourier Transform (FFT), seven times averaging on the cross-spectrum, hanning window on time domain. Figure 4 shows the sound intensity vectors in *xz* plane; figure 5 shows the sound intensity vectors in *yz* plane.

The measurements point (17) was maximum value, and the level was 89.3dB. The characteristic of the vectors radiated from side surface of MRI gantry. It is thought that the driving sound generated the whole of MRI equipment. However the vectors of measurement points (1) ~ (11) showed various direction. The cause of various directions is showed the reflection by the wall of the examination room in near measurement points (1) ~ (11).

SOUND INTENSITY OF AUTO TUNING PULSE

In this section, it is shown that the sound intensity is researched the sound in auto tuning as pulse. Analysis waveforms are seven pulses indicated arrows in figure 3 (a).
Figure 3 (b) expanded (a) is example of wave form as one frame is 4096 points. Center of the analysis wave form is peak of pulse. The sound intensity is calculated by the same method with the previous subsection. Figure 6 shows the sound intensity vectors in *xz* plane; Figure 7 shows the sound intensity vectors in *yz* plane. Measurement point (16) was maximum value, and the level was 80.5 dB. The vectors were the same Characteristic as the sound intensity vector of continuous driving sound. It is thought that the driving sound generated the entire equipment.

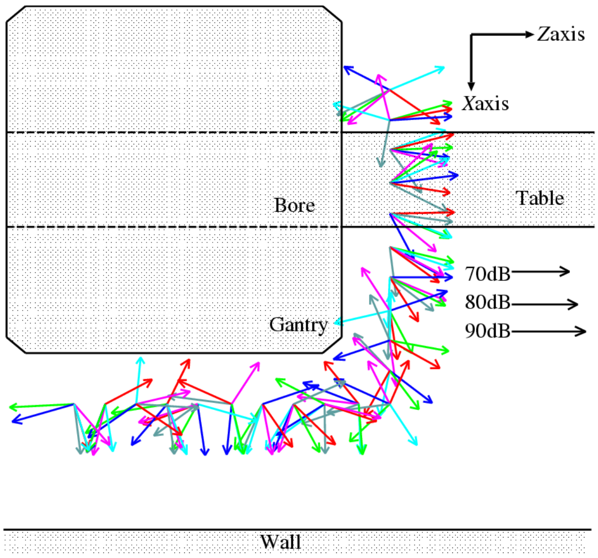

Figure 8 Result of sound intensity vectors of auto tuning pulse in *xz* plane. (six frames, 128 points)

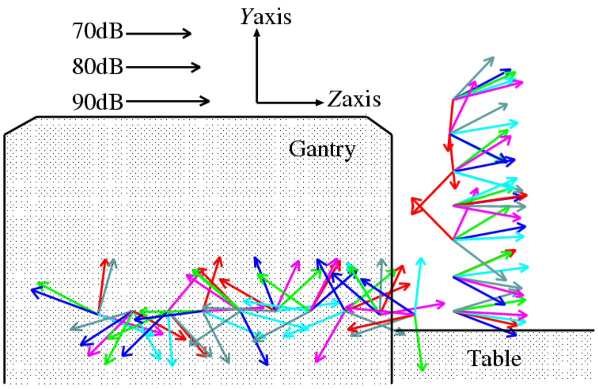

Figure 9 Result of sound intensity vectors of auto tuning pulse in *yz* plane. (six frames, 128 points)

SOUND INTENSITY FOCUSED ON THE PROPAGATED DISTANCE

By the previous subsection, analysis data length by FFT was 4096 points. Time length of a frame in this measurement was 85.3 ms, which sound data length propagated 29.5 m. Because Distance between MRI equipment and wall of the examination room in near measurement points (1) ~ (11) is 1.1 m, the analysis was included influence of reflection from the wall. It is necessary for the influence of reflection to show the sound intensity focused on the propagated distance for influence of the reflection.

Analysis wave forms are six flames of non overlap indicated arrows in figure 3 (c) as one flame is 128 points. Time length of this analysis is 2.67 ms, which sound data length propagated 0.923 m. The sound intensity is calculated by the same method with the subprevious section. Figure 8 shows the sound intensity vectors in *xz* plane (six frames), figure 9 shows the sound intensity vectors in *yz* plane (six frames). The color arrows of each the sound intensity vectors are the same color of each the arrows in figure 3 (c). Because the vectors of measurement points (1) ~ (11) indicated from the wall to the equipment, it is clear that the result included influence of the reflection. Characteristic of the vectors included influence of the reflection, but radiated from side surface of MRI gantry. The characteristic was the same result of the sound intensity of continuous driving sound and auto tuning pulse as time window is 85.3 ms.

CONCLUSIONS

The purpose of this research is analysis of MRI driving sound in near field of MRI equipment for sound source sereach. Sound intensity of the driving sound, which pulse and continuous driving sound, is measured by the sound intensity probe made with non-magnetic microphone. It is clear that the sound source of driving sound was the entire gantry by this research. Most of the result of measured vectors showed the sound was radiating from side surface of MRI gantry. In the result of measurement at the point near the wall, the measuring sound was influenced by reflected sound. it is necessary to soundproofing considered the reflection in examination room for improvement of the acoustic environment. In the future, we will research the analysis of the MRI driving sound on the table of the equipment for hearing protection.

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