Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

Analysis of the MRI driving sound in case of gradient magnet field controlled by the original sequence

Kenji Muto (1), Kazuo Yagi (2), Jun'ichi Hata (2),

Guoyue Chen (3) and Kunihiko Takano (4)

(1) Shibaura Institute of Technology, Department of Electrical Communication, Koto-ku, Tokyo, Japan
(2) Tokyo Metropolitan University, Division of Radiological Sciences, Arakawa-ku, Tokyo, Japan
(3) Akita Prefectual University, Course of Electronics and Information Systems, Yurihonjo, Akita, Japan
(4) Tokyo Metropolitan College of Industrial Technology, Arakawa-ku, Tokyo, Japan

PACS: 43.50.Cb, 43.58.Fm

ABSTRACT

MRI equipment is important for medical diagnosis. The driving sound is loud, and the noise levels exceed 100dB. It is unpleasant for patients. The operation of the gradient magnetic field for imaging generates the loud sound. The gradient magnetic field of the equipment of high magnetic field is generated with the coil of three orthogonal axles. Many researches only show the sound driven by the synthesized the gradient magnetic field of three axles. In this paper, the characteristic of the sound by the operation of the gradient magnetic field only of one axle by the self-made sequence is shown. The measurement equipment is Signa Horizon LX 1.5T of GE Yokogawa medical systems. This equipment has the performance of the static magnet field of 1.5 teslas, gradient magnetic field of 22mT/m, and slew rate of 77T/m/ms. In this measurement, the gradient magnetic field is controlled without the radio frequency pulse that generates the noise signal. The sound is measured near the center in the bore of the equipment. In this measurement, the strength of the gradient magnetic field was changed, and the linearity between the sound pressures was clarified.

INTRODUCTION

Recently, the MRI examination is a necessary examination in the medical diagnosis. The MRI equipment makes the distribution image of the proton in the body by using the nuclear magnetic resonance phenomenon. At the examination, subject is put in the strong magnetic field, the radio frequency pulse is irradiated repeatedly for the nuclear magnetic resonance, and the nuclear magnetic-resonance signal is sampled. The gradient magnetic field is made by three orthogonal gradient coils for tomographic image. At this time, electric current switching generates the Lorentz's force, and the force generates the loud sound. The driving sound exceeds 100dB sometimes [1 - 6]. The sound pressure level or the frequency characteristic changes variously by the imaging sequence. We reported measurement results of sound pressure level of some 1.5T whole body MRI equipments. Figure 1 shows whole body MRI equipment at examination. The report shows distribution of equivalent continuous A-weighted sound pressure level of five kinds of sequences on the examination table. It was shown that driving sound level was large at the center and edge of the gantry, and it was large between 500 and 2000 Hz.

In Japan, the 3T MRI equipment for the whole body was approved in 2005, and driving sound of 3T becomes loud sound than the MRI equipment of 1.5T. Some researches point out the problem that driving sound influences the subject [7]. Many results by researchers, including us, had analyzed general driving sounds. These are the analyses that three gradient magnetic field coils in the magnetostatic field were operating, in other words, these are the analyses that amount of the gradient magnetic fields were changing to get the tomographic image.

In this paper, we show the measurement result of driving sound in case that the strength of the gradient magnetic field of three axes has controlled by the original sequence. That was the sound in case that the one axis of gradient magnetic

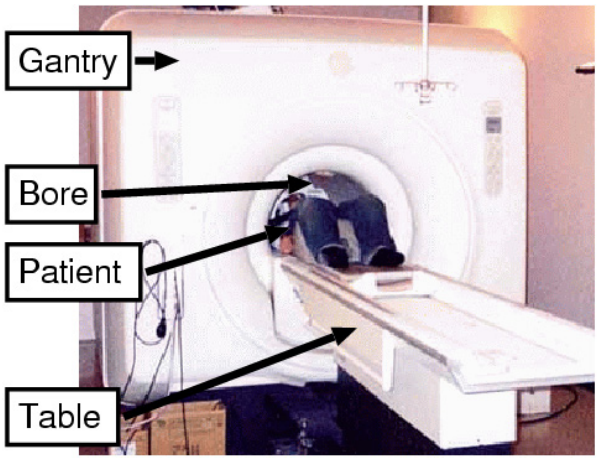

Figure 1. Subject in MRI equipment.

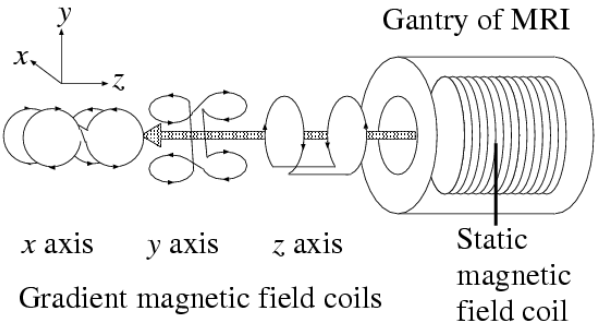

Figure 2. Gradient magnetic field coils in MRI equipment.

field was driving and the others of gradient magnetic field were not driving. It shows the result of analyzing the axis dependency of the measured driving sound. It is expected that this becomes basic to estimate an actual driving sound from the imaging sequence.

MEASUREMENT OF SOUND PRESSURE AT SINGLE GRADIENT MAGNETIC FIELD OPERATING BY ORIGINAL IMAGING SEQUENCE

The examination part of subject such as head and body is inserted in the center of the gantry for the MRI examination. Figure 2 shows a structure that three gradient magnetic field coils are inserted at the center of the MRI equipment [8]. A strong magnetostatic field and three gradient magnetic fields of the x axis, y axis and z axis are generated in the center of the gantry. These gradient magnetic field coils are operated for examination imaging usually. The sound when the coils operated for examination imaging was shown by many researchers.

This research shows the sound when a coil operated for examination imaging. This section shows the measurement conditions of driving sound which is using an original sequence at this center of the gantry. The original sequence that we developed is able to operate the one gradient magnetic field coil. This sequence is able to control all axes such as the x axis, the y axis, and the z axis. In this experiment, RF (radio frequency) pulse was not radiated for avoidance of the influence of microphone noise. The MRI equipment utilized to develop is Signa Horizon LX 1.5T of GE Yokogawa Medical Systems. The ability of this equipment is a magnetostatic field of 1.5 teslas, a gradient magnetic field of 22mT/s, and a slew rate of 77mT/m/ms.

If the gradient magnetic field is given only once by one gradient magnetic field coil, one pulse sound is generated. The pulse is generated every second, and 16 pulses are measured. In this experiment, the change of the strength and the axis of the gradient magnetic field were given. The sound pressure in case of the strength of the gradient magnetic field of 100-58% (100, 93, 87, 81, 76, 66, and 58%) was measured. The magnetostatic field is generated by utilizing the superconductive coil, and the superconductive coil is keeped cold. Therefore, driving sound of the cooling pump is always generated in the examination room, and it becomes the background noise in this measurement.

There is a problem to cut out the pulse shape in the measured signal because the background noise is large to the size of the pulse. It is necessary to evaluate the pulse to gradient magnetic field strength in a big background noise. Here, it proposes a method utilizing the difference value between the integral value of the signal including the pulse and the integral value of background noise. Let PT be amount of sound evaluation of this measurement,

$$PT = \frac{1}{N}\sqrt{\int_T p^2(t)\,dt - \int_T {p_b}^2(t)\,dt}\ . \qquad (1)$$

where, $p_b(t)$ is sound pressure of measured signal of background noise, $p(t)$ is sound pressure of measured signal of pulse, N is the number of pulse, T is the length of signals.

Because the magnetic material is pulled to MRI equipment of high magnetic field, measurement tools including magnetic material can not be utilized in MRI examination room. Or, there is a possibility of the mis-operation because of the gradient magnetic field. In the measurement, 11-030 of AZDEN was utilized as non-magnetism electret condenser microphone (ECM) [2], and AT-MA2 of audio Technica was utilized as microphone amplifier. NC-72 (114dB, 250Hz) and DA-20 (48000Hz sampling frequency) of RION was utilized as sound calibrator (pistonphone) and digital recorder.

ANALYSIS OF RELATION BETWEEN GRADIENT MAGNETIC FIELD STRENGTH AND SOUND PRESSURE OF DRIVING PULSE BY ORIGINAL SEQUENCE

There are the gradient magnetic fields of three axes with orthogonal x, y, and z axis in the MRI equipment, and the gradient magnetic field coil of single axis is operated by our original sequence in the measurement of the driving sound.

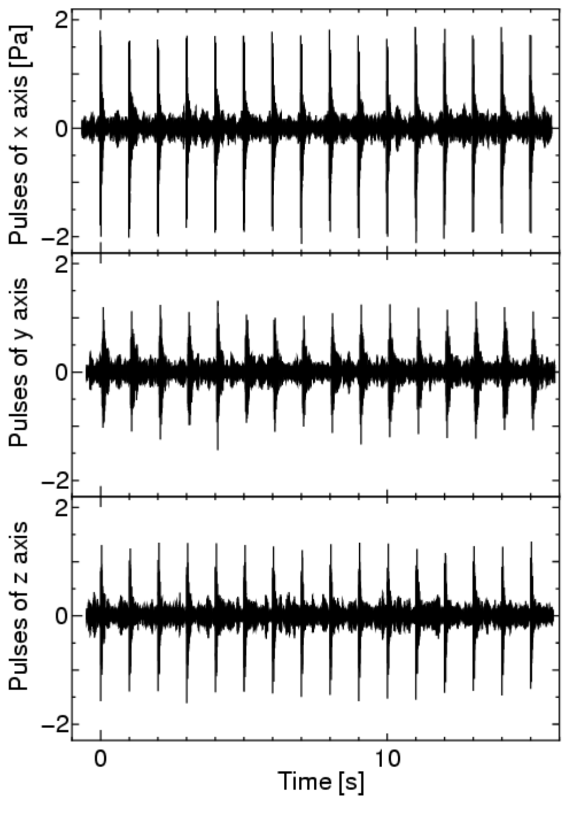

Figure 3. Pulses of each axes of the gradient magnetic coil driving.

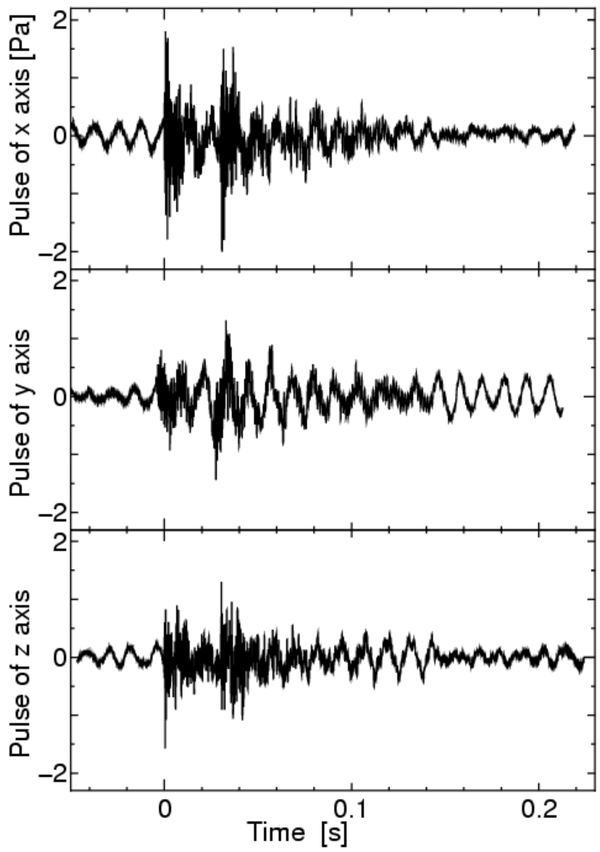

Figure 4. Expanded waveform of the pulse in the waveform of figure 3.

The center of the gantry bore of the MRI equipment was decided as origin of coordinates. The antenna for head examination and a cylindrical phantom as the subject were utilized in the bore center. The phantom is a pseudo-object of human body with the sulfuric acid nickel solution which shape is circular cylinder. The driving sound was measured near the center where probe did not touch phantom. The measurement point is from the center in the direction of the table extension axis (z axis) to 10, 20 and 30cm. The original sequence we made actuated the single gradient magnetic field at small time (30ms) per second, and the driving sound by this sequence was measured. Figure 3 shows the measured pulse in the case that the strength of gradient magnetic field was 100% and the measuring position was 20cm from the center, and it shows 16 pulses were generated at equal intervals in 16 seconds. Figure 4 shows the expanded waveform of the pulse in the waveform of figure 3. Two pulses in the figure show that the gradient magnetic field is turned on and turned off.

Figure 5 shows the technique of evaluation value in equation (1) utilizing the difference between the integral value of measured pulses squared including background noise and the integral value of background noise squared. Because the pulse is hidden in the background noise, the average is important of accuracy in the case of small value of gradient magnetic field strength.

In the case of changing the gradient magnetic field strength (100, 93, 87, 81, 76, 66, and 58%) was measured each 16 times. Figure 6 shows the relation between the gradient magnetic field strength and the amount of sound evaluation located at 10cm from th egantry center. Regression lines of the measurement results show as follows,

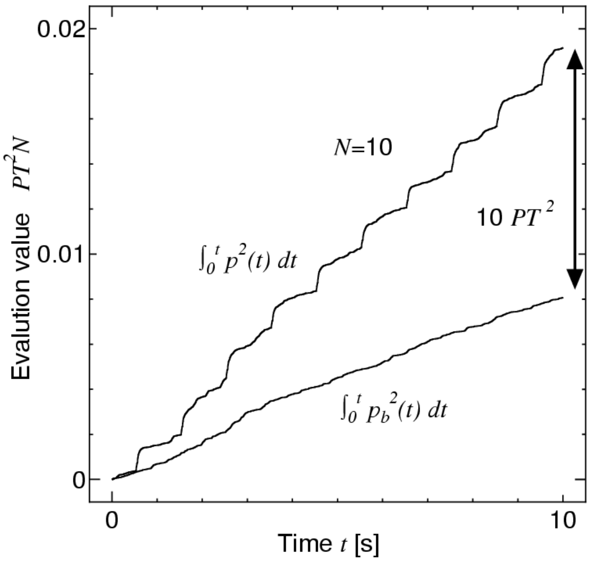

Figure 5. Technique of evaluation in equation (1) utilizing the difference value between the integral value of the signal measured including the pulse and the integral value of background noise.

$$PT_{x,10} = 0.000325\, g_{x,10},$$
$$PT_{y,10} = 0.000303\, g_{y,10}, \qquad (2)$$
$$PT_{z,10} = 0.000215\, g_{z,10}.$$

Where, $g_{x,10}$ is the strength of gradient magnetic field of x axis at 10cm from the gantry center.

Figure 7 shows the relation between the gradient magnetic field strength and the amount of sound evaluation located at 20cm from the gantry center. Regression lines of the measurement results show as follows,

$$PT_{x,20} = 0.000331\, g_{x,20},$$
$$PT_{y,20} = 0.000303\, g_{y,20}, \qquad (3)$$
$$PT_{z,20} = 0.000236\, g_{z,20}.$$

Figure 8 shows the relation between the gradient magnetic field strength and the amount of sound evaluation located at 30cm from the gantry center. Regression lines of the measurement results show as follows,

$$PT_{x,30} = 0.000329\, g_{x,30},$$
$$PT_{y,30} = 0.000310\, g_{y,30}, \qquad (4)$$
$$PT_{z,30} = 0.000269\, g_{z,30}.$$

Where, $g_{z,30}$ is the strength of the gradient magnetic field of z axis at 30cm from the gantry center.

The evaluation of regression line of the pulse of y axis and z axis had a significant difference ($p < 0.05$) in the case of each measurement point. The relation of the structure was corresponding to relation of the sound of the gradient magnetic field coil of the z axis different from the sound of the gradient magnetic field coil of the other axes.

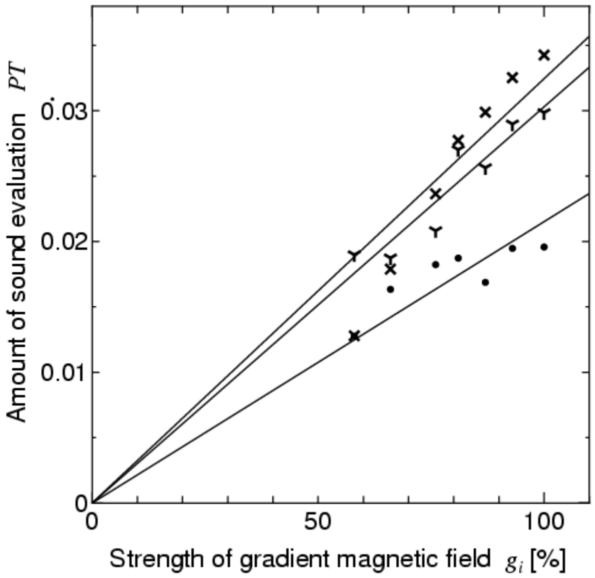

Figure 6. Relation between gradient magnetic field strength and amount of sound evaluation at 10cm from center (**X**: measurement value of x axis, **Y**: measurement value of y axis, ●: measurement value of z axis, line: regression line).

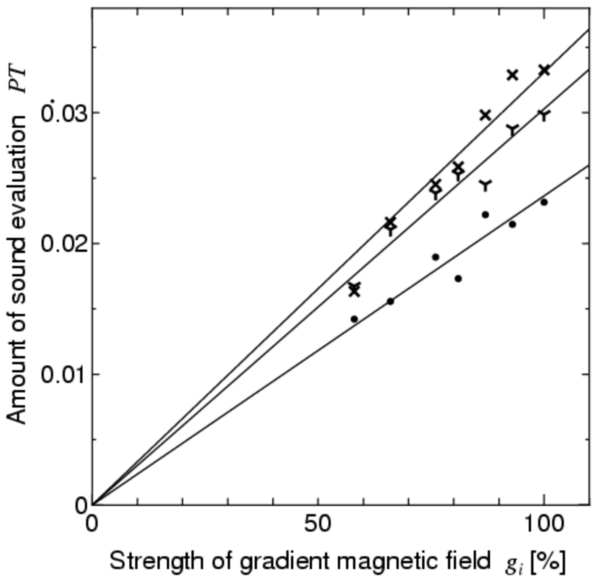

Figure 7. Relation between gradient magnetic field strength and amount of sound evaluation at 20cm from center (**X**: measurement value of x axis, **Y**: measurement value of y axis, ●: measurement value of z axis, line: regression line).

CONCLUTIONS

In case that the strength of the gradient magnetic field of three axes has controlled by the original sequence, the measurement result of driving sound was shown in this paper. It showed the result of analyzing the axis dependency of the measured driving sound. It was shown the relation linear between sound pressure and gradient magnetic field strength. The sound of the gradient magnetic field coil of z axis was different level at same strength of the gradient magnetic field driving. It related to the structure the gradient magnetic field coil of the z axis different from the gradient magnetic field coil of other axes. It is thought that the driving sound at the examination by convolution of the driving sound of the gradient magnetic field of each axis can be estimated.

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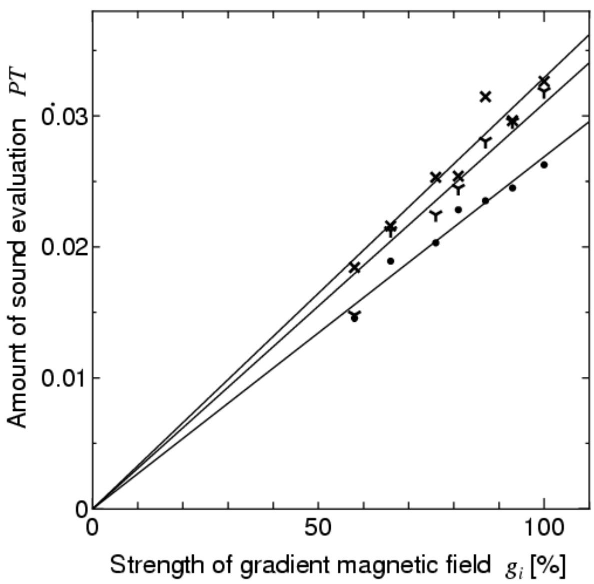

Figure 8. Relation between gradient magnetic field strength and amount of sound evaluation at 30cm from center (**X**: measurement value of x axis, **Y**: measurement value of y axis, ●: measurement value of z axis, line: regression line).