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Acoustic Noise Reduction in MRI – A Review

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Abstract

Magnetic Resonance Imaging is a powerful scanning tool used for various medical applications. The images obtained from MRI scanning are so more accurate and are with high resolution than the traditional CT scanning. Every technology has its own advantages and drawbacks. The drawback owing to MRI scanning is the extreme high level of noise produced by the scanning tool. The alternate current which is used to generate the pulse sequence causes the gradient coil, one of the prime component of MRI to vibrate. This vibration produces the noise level of about 120 dB, which is very crucial for the patient to forbear. As a result, this becomes a trauma for the pediatric and geriatric and also for the persons who are feeble and weak hearted. Furthermore, the scanning itself additionally impinges anxiety, fear, stress , increased blood pressure and psychological distress. Hence there arises the need to reduce this generated acoustic noise to a considerable level, which can be tolerated by the persons. In view of this, there are lot many techniques available for acoustic noise reduction. This paper presents the various techniques used for noise reduction, the achieved noise level reduction, their advantages and disadvantages.

Keywords: Acoustic Noise Reduction, ANC, Gradient Coil, PNC

1. Introduction

The concept of Magnetic Resonance Imaging was conceived in Dr. Damadian in the year 1969. In the succeeding year, he identified the signal difference between the normal tissue and abnormal one. In the year 1971, he proposed voxel to voxel scanning method and gradient coil scanning method. In the year 1974, Garroway and his team introduced 3D scanning method. I the next year, Kumar and Welti introduced Phase coding method. The first scan image of the human body was obtained in the year 1977 by Dr.Damadian and his co workers, Goldsmith using voxel to voxel scanning method. The scanning took five hours to complete the process. On the other side, Peter Mansfield improved the mathematics behind MRI and developed Echo-Planar Imaging(EPI) technique , which helped in producing images in seconds. In 1980, the first commercial MRI machine came into existence. Figure 1 shows the first MRI machine. With the aid of advancements in Digital Signal Processing, Ljunggren and Twig introduced k- space method to improve the quality of the image. Later in the year 1993, functional MRI (fMRI) of the brain was introduced . In 2000s cardiac MRI, Body MRI, fetal imaging and fMRI were further developed.

2. Acoustic Noise Generation

The principal components of MRI machine are: a) A static magnet, which produces strong magnetic field b) Gradient coil c) RF coil used to point the magnetic field to a particular desired location of the body. Out of the main components, it is the Gradient coil which is solely responsible for the generation of such high level of acoustic noise. Refer Figure 2.When the alternating current is passed through the gradient coil, it acts on the magnetic field which is present inside the chamber

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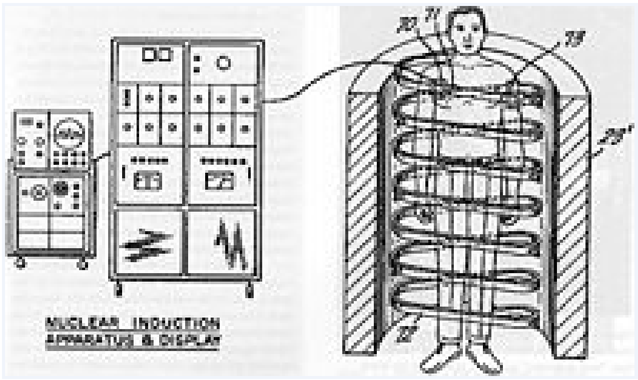

Figure 1. Damadian's First MRI machine.

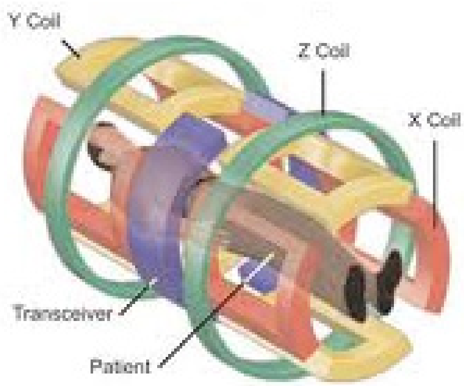

Figure 2. MRI scanner gradient magnets.

and as a result, Lorentz force is produced. This force tend to act upon the gradient coil, leading to vibration[1]. The vibration causes such a high level of acoustic noise, which is manifested as loud tapping, squeaking, chirping or knocking. The intensity of the acoustic noise can be varied by the parameters of the gradient current. In addition, acoustic noise id also dependent on MRI hardware, construction, surrounding environment, patient's position within the bore and size of the patient. Furthermore, the intensity of the acoustic noise also depends on the type of gradient pulse sequence. The related experiments report that Echo Planar Imaging (EPI) results in a much high level of acoustic noise compared to Fast Spin Echoing technique. Moreover, the amount of applied static magnetic field also impacts on the intensity of acoustic noise. Shellock in this paper reports that noise level of 114 dB is produced for 1.5 Tesla magnetic field. Later Hattori in this paper reported noise level of 126-131 dB is produced for 3 Tesla magnetic field.

3. Acoustic Noise Reduction

There are two general techniques used for acoustic noise reduction: Passive Noise Control (PNC) and Active Noise Control (ANC). Passive Noise Control involves the use of earplugs or headphones. This helps in reduction of noise level from 10 to 30 dB. But PNC has its own limitations.1) Earplugs are big in size for to be well accommodated in the ear canal of adolescence and infants. 2) Usage of earplugs dampens the verbal communication between the patient and operator, which creates a feeling of panic to the patients. 3) PNC provides non uniform noise attenuation. High frequencies are well attenuated .The size of the earplug needs to be raised further in order to obtain the equal attenuation of lower frequencies, which is highly impossible.

The alternative to Passive Noise Control is the Active Noise Control (ANC), which involves the adoption of Destructive Interference .Refer Fig 3. An Anti-Noise signal is generated in accordance with the actual acoustic noise and made to sum up with the generated noise, so as nullify the noise signal. There are two techniques in ANC: Feedback technique and Feedforward technique. Feedback technique actually dampens the source of noise, whereas Feedforward technique approaches the destination to nullify the noise signal.

Quietness factor can be determined by the expression $QF = RT_a / RT_o$, where RT_a is the Rise Time of the Anti noise pulse sequence and RT_o is the Rise Time of the original pulse sequence[2].

4. Comparison of Various Techniques used for Acoustic Noise Reduction in MRI

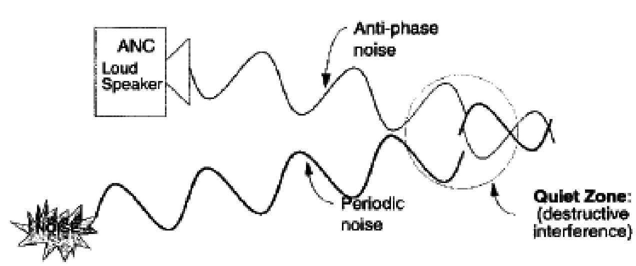

Figure 3. Destructive Interference.

Table 1. Performance comparison

S.NO	YEAR	AUTHOR	TECHNOLOGY USED	NOISE LEVEL REDUCED	ADVANTAGES	LIMITATIONS
1	1989	[3]Goldman	Active Noise Control technique -Concept of Destructive Interference is used	14 dB noise reduction is achieved.	Attains noise reduction at lower frequencies.	Nonadaptability to the system changes and generated signal .Moreover time delay is present because of use of tube.
2	1997	[4]Pal et al.	Passive Noise Control technique – Instead of headset, piezoelectric speakers are used and implemented with FXLMS algorithm.	25 dB reduction is achieved upto 1.2 kHz frequency.	Considerable amount of noise reduction is achieved.	Only first few harmonics of the noise signal are considered
3	1997	[5]Mc Jury	ANC – Feedforward technique adapted by FUXLMS algorithm.	10-15 dB reduction is achieved upto 350 Hz.	The design works well at lower frequencies.	Only fundamental harmonics are considered. Pre recorded signals are used for the experiment.
4	1999	[6]Chen et al	ANC – Feedback technique with a cascaded neural network architecture is employed.	Approximately 19 dB noise level reduction is achieved.	Amount of time required for producing reduced noise signal is less.	Usage of pre recorded signal for the test.
5	2002	[7]Mechefske and Gris	ANC – Double feedforward circuits , headset based system and tube based system are used.	Headset based system has improved noise reduction.	Aperiodic noises can be reduced .	Headset based system prove less efficiently for the actual MRI set up.
6	2006	[8]Yuvi Kahana	Usage of optical microphones.	20dB noise reduction is achieved.	Electrical Interferences are minimized, thereby reproducing the audio waveform stable.	Larger bandwidth required.
7	2006	[9]Tesfaye Kidane	Passive Copper shielding over Z axis Gradient coil is used	13.5dB noise reduction is achieved.	Economically simple technique.	Minor error in the calculation of mutual inductance between the copper slices creates more mismatch
8	2007	[10]Kuan –Hung Cho	ANC was implemented using Filtered-x Recursive Least Square filter combined with PNC.	9.4dB with ANC and 25 dB when combined with PNC.	System design is done by non-magnetic materials and electrostatic earphone, thus ensuring stable and safety in high magnetic field.	ANC is IIR filter based. Problem arises because of non linear phase response characteristics.
9	2007	[11]Kahana	Feedforward ANC together with Opto acoustic ear defender was used.	35-50 dB reduction is achieved.	Lower frequency is considered for the test.	Only fundamental frequency components are used.

10	2012	[12]Yoshinobu	Uses Head- mounted ANC system which comprises of two optical microphone and two piezoelectric loudspeaker.	15-30 dB noise reduction is achieved.	The author has devised an novel ANC structure, allowing verbal communication also apart from the process of just noise reduction.	The obtained results are mere experimental ones and not implemented in actual MRI room. Moreover system size is large.
11	2013	[13]Ming feng	ANC with MRI compatible devices and MRI non compatible devices. Additionally, PNC with MRI compatible devices and MRI non compatible devices.	At 850 Hz, 34 dB reduction is achieved for MRI non compatible device with ANC and 30 dB for MRI compatible device.. Moreover, 25 dB for MRI non compatible device with PNC and 13 dB for MRI compatible device.	Experiment is done with both MRI compatible and non compatible devices.	Only a particular frequency range is considered for the test.
12	2014	[14]Joshua Inouye	ANC – Combination of Correlation subtraction and Spectral Noise Grating in time and frequency domain.	Noise reduction of 20 dB is achieved by Correlation subtraction and 80dB by SNG. By combing both a total of 100 dB is achieved.	Result is achieved using only one microphone and no echoing artifacts are present.	This method works well for tested periodic sequence.
13	2014	[15]Kenji	ANC – Feedforward technique by considering the location of reference microphone inside the MRI gantry.	Noise reduction of 26 dB is achieved when the reference microphone is place closer to the noise origin.	The accurate location of noise production inside the MRI tube can be identified.	The location of reference microphone have to be changed so as to obtain the origin of sound source exactly.
14	2015	[16]Hirofumi	ANC – Anti noise is predicted by Linear prediction and ANN methods and the predicted noise is subtracted from the original noise.	Error ratio of only 5% is resulted.	The time series of the noise production is predicted and managed.	Neural network have to be trained by its first captured value. It includes overhead.

5. Conclusion

This paper presents various techniques by which the acoustic noise is reduced in MRI machine, amount of noise reduced, advantages and drawbacks. It is observed that the maximum amount of 20- 30 dB noise reduction is obtained for Active Noise Control technique. Passive Noise Control well suites for higher frequencies. But results show that MRI machine produces most of its noise within the range of 400Hz- 2Khz. Hence Active Noise Control richly supports for noise reduction in this particular frequency range.

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