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F-87-33

NEMA STANDARDS PUBLICATION NO. MS 4

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Acoustic Noise Measurement Procedure for Diagnostic Magnetic Resonance Imaging Devices

NEMA

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION ■ 2101 L STREET, N.W., WASHINGTON, D.C. 20037

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NEMA MS*4 89 ■ 6470247 0019565 1 ■

MS 4

ACOUSTIC NOISE MEASUREMENT PROCEDURE FOR DIAGNOSTIC MAGNETIC RESONANCE IMAGING DEVICES

Published by:

National Electrical Manufacturers Association
2101 L Street, N.W.
Washington, DC 20037

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TABLE OF CONTENTS

PREAMBLE i
FOREWORD ii
INTRODUCTION ii
RATIONALE ii
SCOPE iii

SECTION 1 REFERENCED STANDARDS AND DEFINITIONS
Referenced Standards 1
Definitions 1

SECTION 2 DATA ACQUISITION PARAMETERS
Maximum Gradient Acoustic Noise (MGAN) Method 2
Maximum Clinical Acoustic Noise (MCAN) Method 2

SECTION 3 METHODS OF MEASUREMENT
Test Hardware 4
Hardware Set-Up 4
MGAN Measurement 4
MCAN Measurement 5

SECTION 4 RESULTS 6

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Preamble

This is one of a series of test standards developed by the medical diagnostic industry for the measurement of parameters governing the safety of Magnetic Resonance(MR) Imaging systems. These test standards are intended for the use of equipment manufacturers, prospective purchasers, and users alike.

Manufacturers are permitted to use these standards for the determination of system performance specifications. This standardization of performance specifications is of benefit to the prospective equipment purchaser, and the parameters supplied with each NEMA measurement serve as a guide to those factors which can influence the measurement. These standards can also serve as reference procedures for acceptance testing and periodic quality assurance.

It must be recognized, however, that not all test standards lend themselves to measurement at the installation site. Some test standards require instrumentation better suited to factory measurements, while others require the facilities of an instrumentation laboratory to assure stable test conditions necessary for reliable measurements.

The NEMA test procedures shall be carried out using the normal clinical operating mode of the system. For example, standard calibration procedures and standard reconstruction processes shall be used. No modifications to alter test results shall be used unless otherwise specified in these standards.

The NEMA Technical Committee of the MR Section has identified a set of key magnetic resonance safety parameters. This standard describes the measurement of one of these parameters.

Equivalence

It is intended and expected that manufacturers or others who claim compliance with these NEMA standard test procedures for the determination of safety parameters shall have carried out the tests in accordance with the procedures specified in the published standards.

In those cases where it is impossible or impractical to follow the literal prescription of a NEMA test procedure, a complete description of any deviation from the published procedure must be included with any measurement claimed to be equivalent to the NEMA standard. The validity or equivalence of the modified procedure will be determined by each reader.

Uncertainty of the Measurements

The measurement uncertainty of the safety parameter determined using this standard is to be reported, together with the value of the parameter. Justification for the claimed uncertainty limits shall also be provided by a listing and discussion of sources and magnitudes of error.

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Foreword

Unless otherwise noted, this NEMA Standards Publication has been approved as a NEMA Standard. It describes the test conditions and parameters which ensure that worst case acoustic noise levels are measured. It determines the maximum sound pressure level that a particular magnet/gradient system combination produces when using pulsed waveforms. In the absence of specific guidelines for sound level exposure with MR imaging equipment, this procedure references the OSHA guidelines for acoustic noise exposure and the IEC standards for sound level meters.[1]

Introduction

Current passing through a wire placed in a magnetic field will generate a force orthogonal to both the direction of the field and current. Acoustic noise in MR imaging is caused by motion of the gradient coils and attached structures when current is passed through the coils. When this happens a pulsatile noise or "tapping" is audible to the patient.

The loudest noise that can be generated at a given static magnetic field strength will occur when pulsed waveforms, consisting of maximum amplitude and minimum rise time transitions, are applied simultaneously to all three gradient axes. This is not a likely condition for most clinical imaging sequences but is representative of a worst case and is defined as the Maximum Gradient Acoustic Noise (MGAN) of the system. For clinical imaging conditions the worst case acoustic noise occurs with pulse sequences using high gradient current duty cycles and high gradient current amplitudes and is defined as the Maximum Clinical Acoustic Noise (MCAN) of the system.

To determine the acoustic noise of a system either the MGAN or the MCAN shall be measured and reported. The choice of using the MGAN or the MCAN is left to the discretion of the user. Selection shall be made based on convenience.

Rationale

The sound generated by an MR system usually consists of a series of repetitive impulses. The relevant safety parameters required to characterize such a noise are the peak impulse sound pressure level (L_{peak}) and the time integral of the A-weighted sound pressure level (L_{eq}). In MR applications the peak impulse sound pressure level is dependent on the peak amplitude of the individual pulses while the time integral of the A-weighted sound pressure level is dependent on the continuous exposure to a series of such pulses. This document describes methods to measure the worst case L_{peak} and L_{eq} of an MR System.

[1] See Section 1.1.

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Scope

This NEMA Standards Publication describes two measurement procedures, Maximum Gradient Acoustic Noise (MGAN) and Maximum Clinical Acoustic Noise (MCAN).

To measure the MGAN, a trapezoidal bipolar test waveform is applied simultaneously to the X, Y and Z gradient axes. The waveform shall be defined by five variables (rise-time, fall-time, amplitude, on-time and repetition time) and shall be generated using the standard pulse sequence generation software and hardware used by the manufacturer. The generation of the test waveform is subject to the manufacturer's pulse sequence design limitations (amplitude, rise-time, fall-time and duty cycle). Within these design limitations, the rise and fall times of the test waveform shall be the minimum allowed, the amplitude shall be the maximum allowed, and the duty cycle (on time/repetition time) shall be the maximum. Further, eddy current compensation, also known as pre-emphasis, must be included since this is the mode in which the system is operated. The acoustic noise will be greater with pre-emphasis.

To measure the MCAN, the worst case clinical sequence is used. This is the sequence with the worst case combination (acoustically) of high gradient current duty cycle and gradient current amplitudes (e.g., short echo time, minimum repetition time, minimum slice thickness, minimum field of view, and oblique scan planes).

This procedure has been designed for measuring peak sound pressure levels (SPL) up to 140 dB. Above 140 dB, the use of more sophisticated equipment and methods may be required.

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SECTION 1
REFERENCED STANDARDS AND DEFINITIONS

1.1 REFERENCED STANDARDS

The following publications are adopted as indicated by reference in this standards publication. The mailing address of each referenced organization is also provided.

International Electrotechnical Commission
1, Rue de Varembe
Geneva, Switzerland

IEC 651-1979* — *Sound Level Meters*

Occupational Safety and Health Administration
Department of Labor
200 Constitution Avenue, N.W.
Washington, D.C. 20210

29CFR-1988, Part 1910.95 — *Occupational Noise Exposure*

American National Standards Institute
1430 Broadway
New York, NY 10018

ANSI S1.4-1983 — *Sound Level Meters*

1.2 DEFINITIONS

1.2.1 A-weighting

This refers to SPL frequency weighting. The ear does not respond uniformly to all frequencies. SPL measurements made with an A-weighting correspond to noise levels which are similar to those heard by the human ear (IEC 651).

1.2.2 Basic OSHA Standards

The OSHA limit for L_{peak} (unweighted) is 200 pascals (or 140 dB referenced to 20 micropascals). The OSHA limit for L_{eq} (A-weighted) for occupationally exposed individuals is 90 dBA averaged over 8 hours per 24 hour day (or 105 dBA over 1 hour). The OSHA L_{eq} standard is intended for occupational exposure and is therefore highly conservative if applied to the infrequent exposures typically encountered in MR scanning.

1.2.3 ISLM(Integrating Sound Level Meter)

The ISLM has the capability to compute the root-mean-square (rms) and the peak instantaneous value of time varying sound energy.

1.2.4 L_{eq}

L_{eq} is the rms SPL averaged over the measurement period.

1.2.5 L_{peak}

L_{peak} is the peak impulse SPL measured during the measurement period.

1.2.6 SPL(Sound Pressure Level)

The SPL is defined as ten times the common logarithm of the ratio of the square of the measured sound pressure to the square of the standard reference pressure of 20 micropascals.

*Available from ANSI, 1430 Broadway, New York, NY 10018.

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SECTION 2
DATA ACQUISITION PARAMETERS

2.1 MAXIMUM GRADIENT ACOUSTIC NOISE (MGAN) METHOD

The following parameters must be reported for the MGAN method per Section 4 (see Figure 2-1):

Parameter	Dimension
B_o (static field strength)	tesla
Gradient pulse amplitude (A_{+max} A_{-max})	millitesla/meter
Rise and fall times (r_1, r_2, r_3 and r_4)	microseconds
Gradient pulse on-time (X)	milliseconds
Gradient pulse repetition time (TR)	milliseconds
Meter response time *	–

2.2 MAXIMUM CLINICAL ACOUSTIC NOISE (MCAN) METHOD

The following parameters must be reported for the MCAN Method per Section 4:

Parameter	Dimensions
B_o (static field strength)	tesla
Sequence type/name	–
Repetition time	milliseconds
Echo time(s)	milliseconds
# slices	–
Slice thickness	millimeters
Field of view	millimeters
Data acquisition matrix size	–
Scan plane	–
Meter response time *	–

*For short integration periods (10 seconds or less), the different responses of a FAST and SLOW network can produce slightly different levels of L_{eq}; this discrepancy will "average out" and disappear after 20 seconds of integration. It is recommended that a FAST meter response time (125 milliseconds time constant per IEC 651) be used for the measurement. However a SLOW meter response time (1000 milliseconds time constant per IEC 651) can be used for integration periods greater than 20 seconds. (This note has been approved as Authorized Engineering Information.)

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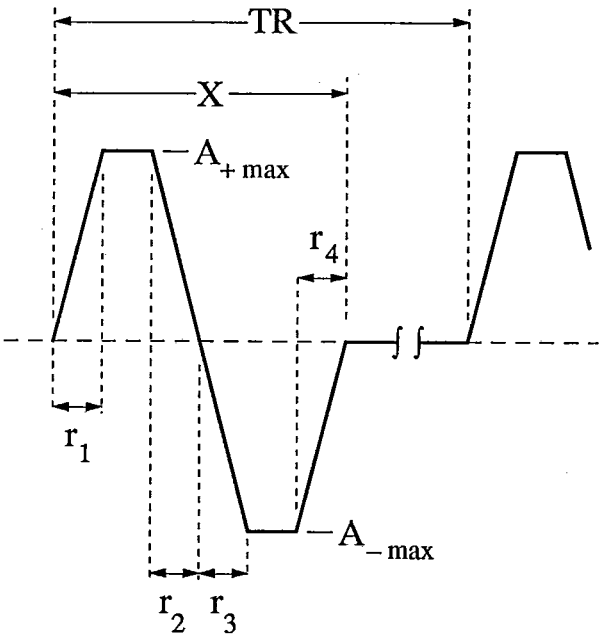


Figure 2-1
MAXIMUM AMPLITUDE BIPOLAR GRADIENT AMPLIFIER INPUT WAVEFORM (WITHOUT PRE-EMPHASIS)

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SECTION 3
METHODS OF MEASUREMENT

3.1 TEST HARDWARE

1. ISLM – An integrating sound level meter that meets ANSI Standard S1.4 Type 0 or 1 or IEC Standard 651 Type 0 or 1 is required.
2. Microphone – The microphone must be omnidirectional and insensitive to magnetic fields or calibrated to account for the magnetic field.
3. Extension cable – A microphone extension cable is required.

3.2 HARDWARE SETUP

1. The ISLM with the extension cable is calibrated using a sound level standard.
2. Without a patient on the patient table, position the microphone at magnet isocenter and aim it in a direction orthogonal to the patient axis and in a horizontal plane.
3. Using the microphone extension cable, the ISLM is placed sufficiently far from the magnet isocenter to be in a fringe field of less than 10 gauss. Care must be taken to ensure that environmental effects (e.g., pulsed gradient fields, EMI, etc.) are compensated for or avoided.

3.3 MGAN MEASUREMENT

1. Set up the equipment as described in 3.2.
2. It is recommended that the RF amplifier be switched into the "off" position prior to the start of this procedure. (This sentence has been approved as Authorized Engineering Information.)
3. Measure the ambient A-weighted L_{eq} using the following ISLM settings:
   detector – rms
   time weighting – FAST or SLOW
   frequency weighting – A-weighting
   measurement period – ≥20 seconds.
4. Begin simultaneous pulsing of the gradients using the maximum amplitude bipolar gradient waveform (Figure 2-1). The transition times – r_1, r_2, r_3, and r_4 – shall be the minimum that the system is capable of generating. The amplitudes, A_{+max} and A_{-max}, shall be the maximum gradient strength that can be generated by the system under normal gradient operating conditions. The on-time of the pulse, X, shall be the minimum that will allow the current waveform to attain the maximum current demanded by the pulse. The repeat time, TR, shall be the shortest allowed by the system gradient duty cycle limits.

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5. Using the MAX HOLD function (or equivalent), measure the unweighted L_{peak} using the following ISLM settings:

detector – peak
time weighting – N/A
frequency weighting – no weighting
measurement period – ≥20 seconds.

6. Measure the A-weighted L_{eq} using the following ISLM settings:

detector – rms
time weighting – FAST or SLOW
frequency weighting – A-weighting
measurement period – ≥20 seconds.

7. For the A-weighted ambient, unweighted L_{peak}, and A-weighted L_{eq}, a single measurement shall be made at magnet isocenter.

3.4 MCAN MEASUREMENT

1. Set up the equipment as described in 3.2.
2. It is recommended that the RF amplifier be switched into the "off" position prior to the start of this procedure. (This sentence has been approved as Authorized Engineering Information.)
3. Measure the ambient A-weighted L_{eq} using the following ISLM settings:

detector – rms
time weighting – FAST or SLOW
frequency weighting – A-weighting
measurement period – ≥20 seconds.

4. Select a protocol from each major sequence type and maximize the following parameters:

gradient current transitions per unit time (e.g., minimum TR, minimum TE, maximum number of slices)
gradient current amplitude (e.g., minimum slice thickness, minimum FOV, minimum rise-time).

5. Initiate the clinical sequence determined from step 4 above.
6. Using the MAX HOLD function (or equivalent), measure the unweighted L_{peak} using the following ISLM settings:

detector – peak
time weighting – N/A
frequency weighting – no weighting
measurement period – sufficient to include the maximum peak SPL.

7. Measure the A-weighted L_{eq} using the following ISLM settings:

detector – rms
time weighting – FAST or SLOW
frequency weighting – A-weighting
measurement period – scan time.*

8. Using other slice orientations (including oblique), repeat steps 4 through 7 as needed to obtain the worst case SPL.
9. If unsure of the effect of a given scan parameter on SPL, repeat steps 4 through 8 as required, selecting the extreme settings for the parameter in question.
10. For the A-weighted ambient, unweighted L_{peak}, and A-weighted L_{eq}, a single measurement shall be made at magnet isocenter.

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*The L_{eq} acoustic noise measurement period must begin after the start of the MR scan and must end prior to scan completion. If the acoustic noise varies during the MR scan, then the measurement period must include the maximum SPL.

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SECTION 4
RESULTS

4.1 Reporting Results

1. State method used (MGAN or MCAN).
2. State the measured values for Ambient (dBA), L_{peak} (dB) and L_{eq} (dBA).
3. State the measurement periods (seconds).
4. List data acquisition parameters of 2.1 or 2.2 as appropriate.
5. List other relevant scan parameters and meter settings required to ensure repeatability.

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NEMA STANDARDIZATION

The purpose of NEMA Standards, their classification and status, are set forth in certain clauses of the NEMA *Standardization Policies and Procedures* manual and are referenced below.

Purpose of Standards

National Electrical Manufacturers Association standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist purchasers in selecting and obtaining the proper product for their particular needs. Existence of a National Electrical Manufacturers Association standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard.

(Standardization Policies and Procedures, p. 1)

Definition of a Standard

A standard of the National Electrical Manufacturers Association defines a product, process, or procedure with reference to one or more of the following: nomenclature, composition, construction, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Standardization Policies and Procedures, p. 2)

Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the Standards Publication may be capable of otherwise equivalent performance.

(Standardization Policies and Procedures, p.8)

Categories of Standards

National Electrical Manufacturers Association Standards are of two classes:

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture, which standard has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon;
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote thereon.

(Standardization Policies and Procedures, pp. 7 & 16)

Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote on the standard.

(Standardization Policies and Procedures, pp. 7 & 16)

Official Standards Proposal

An Official Standards Proposal is an official draft of a proposed standard which is formally recommended to an outside organization(s) for consideration, comment, and/or approval, and which has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon.

(Standardization Policies and Procedures, pp. 7 & 16)

Identification of Status

Standards in NEMA Standards Publications are identified in the foreword or following each standard as "NEMA Standard" or "Suggested Standard for Future Design." These indicate the status of the standard. These words are followed by a date which indicates when the standard was adopted in its present form by the Association.

The material identified as "Authorized Engineering Information" and "Official Standards Proposal" is designated similarly.

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