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# Quantification and Mapping of Geometric Distortion for Special Applications



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*Quantification and Mapping of Geometric Distortion for Special Applications*

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## Preamble

This is one of a series of test standards developed by the medical diagnostic imaging industry for the measurement of performance parameters governing image quality of magnetic resonance (MR) imaging (MRI) systems. These test standards are intended for the use of equipment manufacturers, testing houses, 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. The parameters supplied with each NEMA measurement serve as a guide to those factors that 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 ensure stable test conditions necessary for reliable measurements.

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

The NEMA Magnetic Resonance Section has identified a set of key magnetic resonance image quality parameters. This standards publication describes the measurement of one of these parameters.

### *Equivalence*

It is intended and expected that manufacturers and others who claim compliance with these NEMA standard test procedures for the determination of image quality 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 equivalent to the NEMA standard. The validity or equivalence of the modified procedure will be determined by the reader.

### *Uncertainty of the Measurements*

The measurement uncertainty of the image quality parameter determined using this standards publication 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.

## Foreword

This standards publication is classified as a NEMA standard unless otherwise noted. It describes a method for evaluating the geometric distortion characteristics throughout a specified imaging volume of a Magnetic Resonance Imaging (MRI) system. The equipment contribution to geometric distortion in MRI systems is largely due to imperfections of the main magnetic field and the spatially encoding gradient subsystem. In addition, the object to be imaged by the MRI system may also induce magnetic field distortions that geometrically distort the image representation of the object to a lesser or greater extent than the MRI system imperfections, depending upon the object and scanning parameters. Since geometric distortion is spatially variable, it is important to understand the spatial distribution of error when MR images are used quantitatively.

The purpose of this procedure is to provide a standard means for measuring and reporting the geometric distortion characteristics of an MRI system. Clinically, this information is helpful in matching MR scanner characteristics to clinical requirements, when geometric accuracy is crucial (e.g. image-guided interventions.) This information is also helpful in evaluating the impact of system changes on performance, for quality control programs that seek to continually reaffirm system performance, or in demonstrating effectiveness for FDA applications.

The measurement methods have not been designed for compatibility with existing NEMA methods, but some of the methods for reporting described in this standard may be compatible with data acquired for MS 2, *Determination of Two-Dimensional Geometric Distortion in Diagnostic Magnetic Resonance Images*. Evaluations are performed on images generated using standard clinical scan protocols.

This standards publication is intended for use by MRI system manufacturers, testing houses, manufacturers of accessory equipment, and MRI end users.

This standards publication has been developed by the Magnetic Resonance Section of the National Electrical Manufacturers Association. User needs have been considered throughout the development of this publication. Proposed or recommended revisions should be submitted to:

Executive Director, Medical Imaging & Technology Alliance  
National Electrical Manufacturers Association  
1300 North 17th Street, Suite 300  
Rosslyn, VA 22209

Section approval of the standard does not necessarily imply that all section members voted for its approval or participated in its development. At the time it was approved, the section was composed of the following members:

Computer Imaging Reference Systems—Norfolk, VA  
GE Healthcare, Inc.—Milwaukee, WI  
Hitachi Medical Systems America, Inc.—Twinsburg, OH  
Indipacern Corp.—Toronto, Ontario  
Philips Healthcare—Bothell, WA  
Siemens Healthcare, Inc.—Malvern, PA  
Toshiba America Medical Systems—Tustin, CA

## Rationale

Magnetic Resonance (MR) image formation is based, in part, on the ability to impose varying magnetic field strengths at different locations within the imaging volume. These magnetic field variations change the precession frequency of the nuclei being imaged and are the basis of the MR image spatial localization process. The linear relationship of precession frequency with magnetic field strength permits the determination of signal source location. Any mechanism that distorts the magnetic field will, therefore, introduce a spatial location error in the final image.

The dominant equipment error sources are the inhomogeneity of the main magnetic field and the nonlinear characteristics of the spatially encoding gradient magnetic fields. In addition, the objects to be imaged may also alter the magnetic field, thus creating spatial errors that may exceed the hardware-induced errors in certain situations. As the accuracy of spatial information in MR images becomes more important, e.g., for image guided procedures, quantification of tumor position and volume, co-registration of images from different modalities, it becomes necessary to quantify these errors. For example, the geometric accuracy of spatial information is important for image-guided procedures when the intervention is not based on real-time MR image guidance. Spatial geometric accuracy is also important if the MR images are being used to guide external beam radiation treatment planning because it is important to size the radiation beams appropriately and direct the radiation accurately. Additionally, if treatment progression is quantified by volume measurements, it is important to understand how geometric distortion changes the perceived volume. Lastly, co-registration of images from other modalities with MR images improves with decreased geometric distortion in the MR image.

This standard also has secondary benefits, such as quantifying the degree of gradient non-linearity and its impact on various quantitative measures, such as Apparent Diffusion Coefficient (ADC) measurements, where gradient non-linearity may introduce undesirable spatial non-uniformities in ADC images, and phase contrast MRI, where gradient non-linearities introduce flow velocity errors. Another secondary benefit of this standard is the ability to visualize the homogeneity of the main field by imaging the test phantom at extremely low imaging bandwidths when gradient non-linearity errors are dominated by main field inhomogeneity errors.

## Scope

This standards publication defines test methods for measuring the absolute spatial variation of geometric accuracy within MR images. This standard presents the absolute geometric accuracy as a map, graph, or table throughout the imaging region rather than as simple figures of merit such as average or worst case error. Specifying both the acquisition and data presentation methods is the key function of this standard because the results are not easily reduced to a few simple figures of merit; the results are spatial in nature. This standard deals exclusively with absolute error measurements because it is assumed the end user will need geometric distortion error measurements in absolute versus relative terms.

While the intent of this standard is to quantify equipment induced geometric errors only, the phantom used for these measurements will also introduce some geometric errors. It is not possible to remove the phantom-induced errors within the scope of this standard, and this standard assumes that the measured errors are exclusively equipment errors. Therefore, it is necessary for the user of this standard to be able to differentiate between geometric errors due to the MR imaging system and errors that arise from measuring geometric distortion with a test object. The user should attempt to estimate the error the phantom introduces for the specific test conditions used.

This standard also recognizes that these measurements are ideally performed with three-dimensional acquisitions and large volume phantoms, but the cost, weight, and size of the required phantom may be prohibitive in certain situations. Therefore, this standard permits the use of a substantially two-dimensional phantom in conjunction with a set of two-dimensional image acquisitions in different orientations. It is recognized that the use of a two-dimensional phantom will fundamentally undersample the three-dimensional spatial error map.

These procedures could also be helpful in evaluating the impact of system changes on performance, for quality control programs that seek to continually reaffirm system performance, or in demonstrating effectiveness for FDA applications. However, this standard does not supersede NEMA MS 2 *Determination of Two-Dimensional Geometric Distortion in Diagnostic Magnetic Resonance Images*. MS 2 is designed to produce simple figures of merit that describe basic geometric distortions, or image field of view errors, that could arise from imaging gradient amplitude scaling errors.