MagNET TEST OBJECTS

Instructions for use

Version 4 July 2006

Introduction

This instruction leaflet contains instructions for positioning and imaging the MagNET test object set and analysing the images obtained.

We advise that the test objects are stored in the upright position (i.e. filling screws on top) in order to avoid any unnecessary stresses on the Perspex. An air bubble has been intentionally left in each test object to allow for compression and expansion of the fluid during transit. Avoid over-tightening the filling screws to avoid damage to the o-rings- they should only be ‘finger-tight’.

A certain amount of fluid loss over time is to be expected. Should you, however, require any fluid to ‘top up’ the test objects at any date in the future, please do not hesitate to contact MagNET.

Contents

1. FLOOD FIELD TEST OBJECT

The standard flood field test object is shown in Figure 1. For MRI systems below 1.5 T it can be used for both signal-to-noise ratio and uniformity tests. In this case it is filled with a paramagnetic solution (1.66 grams $NiCl_2$/litre) and loaded with NaCl and H_2SO4 so that the head RF coil quality factor with the phantom in place is approximately equal to the coil quality factor with a human head.

At 1.5 T dielectric resonance effects can begin to perturb the uniformity profiles in water-based phantoms. For this reason MagNET recommend that a separate oil-filled flood field is used for uniformity measurements particularly if a comparison is being made with MagNET evaluation data. Above 1.5 T dielectric effects significantly interfere with both signal-to-noise and uniformity measurements in water-based phantoms. The oil-filled flood phantom can also be used for signal-to-noise ratio measurements at higher fields however it will not load the RF coil appropriately. For 3 T systems a dedicated oil-filled flood field and loading annulus can be used for signal-to-noise ratio and uniformity measurements. The 3 T flood field is placed inside the annulus and used in exactly the same way as the standard test object. The annulus contains $MnCl_2$ to alter the relaxation parameters and make it invisible in images and NaCl to provide appropriate loading.

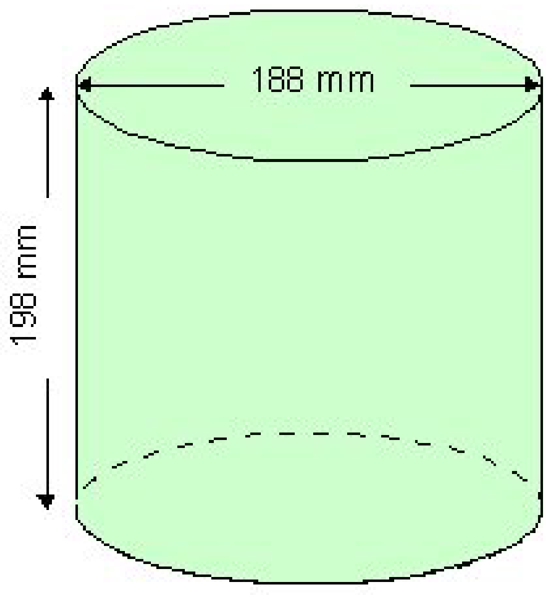


Figure 1: Flood field test object with internal dimensions. The 3T flood field has an internal diameter of 162 mm.

POSITIONING TEST OBJECT: Position the test object in the centre of the coil. Figure 2 shows the position of the phantom and imaging slice (blue line) in all three imaging planes.

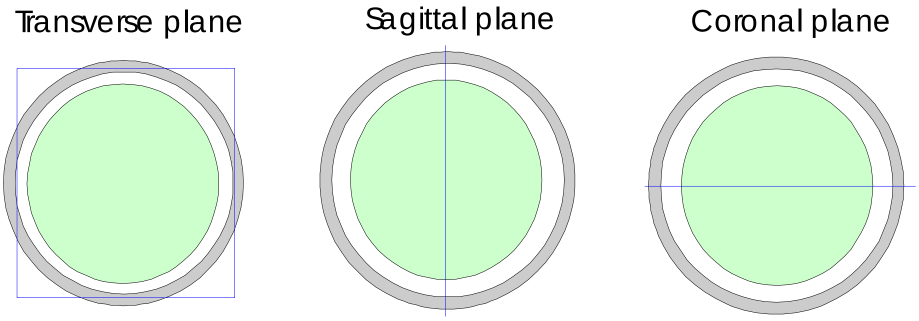


Figure 2: Position of phantom in the head coil for all three imaging planes

SCANNING PARAMETERS: The standard MagNET imaging protocol is as follows:

Signal-to-Noise Ratio and Uniformity	
Sequence	SE
Plane	TRA, SAG, COR
TE (ms)	30
TR (ms)	1000
NSA	1
FOV (mm)	250
Matrix (PE x FE)	256 x 256
Slice width (mm)	5
Scan time (min:sec)	4:16

1.1 SIGNAL-TO-NOISE RATIO TEST

The image SNR value obtained on a system is influenced by many factors. Example system factors are:

- Main magnetic field strength B_0.
- Design of the radiofrequency receive and transmit systems.
- Choice of sequence and imaging parameters.

ANALYSIS: The following steps should be taken for a comparative signal-to-noise ratio to be measured:

- Measure the signal.
- Measure the noise.
- Calculate the signal to noise ratio.

MEASURE THE SIGNAL: Create five regions of interest (ROI) of size 20 x 20 pixels on one of the flood field images as shown in Figure 3 (ROIs 1-5). Measure the mean pixel value in each ROI. Take the signal as this value averaged over all five regions (*S*).

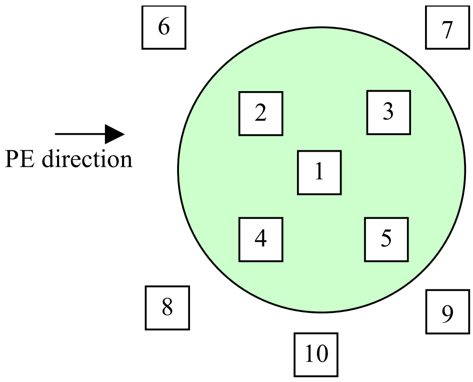


Figure 3: SNR regions of interest in flood field test object

MEASURE THE NOISE: Create five ROI's of size 20 x 20 pixels in the image background, selecting regions free from ghosting, avoiding phase-encoding direction (ROIs 6-10, Figure 3). Take the mean of the five standard deviation (SD) values for the ROI's in the background. Calculate the noise (*N*) using:

$$N = SD/0.655$$

CALCULATE THE SIGNAL TO NOISE RATIO: The signal-to-noise ratio (SNR) is calculated as average mean pixel value over the average standard deviation:

$$SNR = S\,/\,N$$

RESULTS: Results can be presented as shown below:

ROI	*Mean Pixel Value*	*ROI*	*SD*
1 2 3 4 5		6 7 8 9 10	
MEAN (S)		MEAN / 0.655 (N)	
S/N			

For comparison with MagNET report data the Normalised Signal-to-Noise Ratio (NSNR) is then calculated as:

Bandwidth normalisation Coil-loading normalisation

$$NSNR = \frac{\sqrt{BW}}{\sqrt{BW_{nom}}} \cdot \frac{1}{\Delta x \Delta y \Delta z} \cdot \frac{1}{\sqrt{N_{pe}\; TR\;\; NSA}} \cdot \sqrt{\frac{Q_{head}}{Q_{test\ object}}}$$

Voxel correction Scan-time correction

The nominal bandwidth BW_{nom} is (±) 30 kHz. For the MagNET loaded flood field test object the coil loading normalisation factor should be approximately equal to 1. TR is in units of seconds whilst the voxel dimensions, Δx, Δy and Δz should be in units of centimetres.

1.2 UNIFORMITY TEST

Factors that affect fractional uniformity are:

- RF Resonator design and set up affecting RF Homogeneity
- Magnetic Field Homogeneity
- Eddy Current Correction

The coil design plays a fundamental role in the determination of uniformity therefore the results must be viewed with this in mind.

ANALYSIS: The uniformity is evaluated in the horizontal and vertical directions on each image.
There are three steps in evaluating uniformity:

- Establish the range in which the signal should lie
- Obtain a uniformity profile.
- Calculate the fraction of the signal from the profile that lies in the range.

ESTABLISH RANGE: Create a region of interest (ROI) (20x20) at the centre of the flood field image (region 1 in Figure 3). Calculate the mean value in the ROI (i.e. the average pixel value). Evaluate the range for uniformity as the "mean value + 10%".

OBTAIN PROFILE: A horizontal or vertical profile, ten pixels wide, is the equivalent of ten separate line profiles. Centre this wide profile on the flood field image. Average the ten lines to create one profile and use the pixel intensities for the following calculation.

CALCULATE FRACTIONAL UNIFORMITY: Define a region over which to calculate the fractional uniformity. Choosing a region 160 mm in length and centred on the centre pixel (see Figure 4) will avoid any ringing at the profile edges which should not contribute to uniformity measurements. Calculate the number of pixels with intensities lying within the range evaluated in step one ('Establish range').

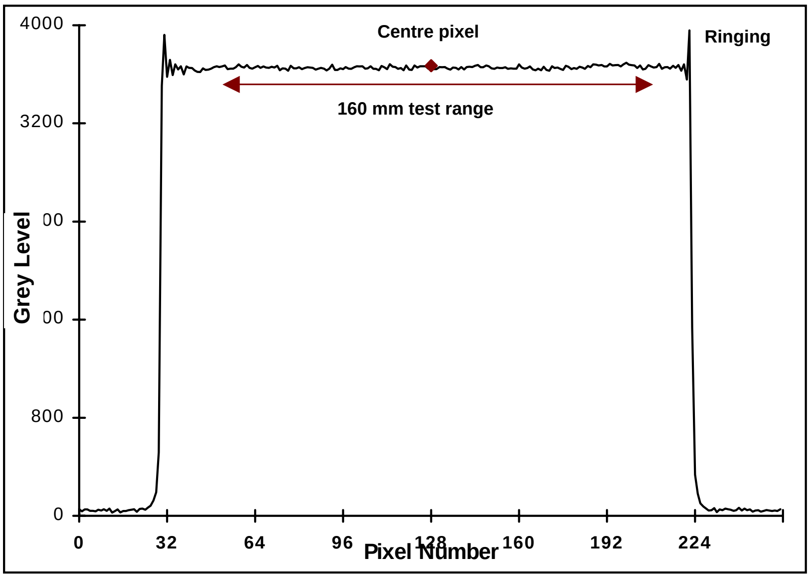


Figure 4: Measurement of fractional uniformity

The fractional uniformity for the 160 mm test range is evaluated as follows:

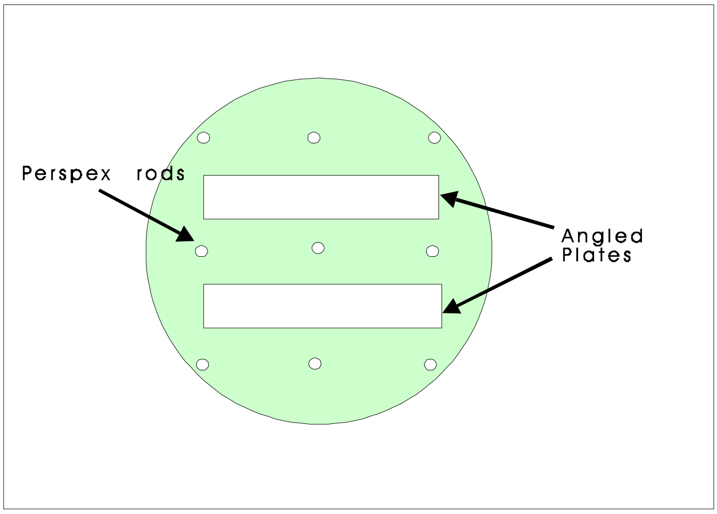
$$Fractional\ Uniformity = \frac{\text{No of pixels in range}}{\text{Total no of pixels}}$$

RESULTS: Results can be presented as shown below:

	Transverse	Sagittal	Coronal	Mean ±SD
X-direction Y-direction Z-direction				

2. GEOMETRIC/SLICE WIDTH TEST OBJECT

The geometric/slice width test object is shown in Figure 5. The test object contains nine Perspex 5 mm rods and two angled 1 mm thickness glass plates. For systems up to 1.5 T it is filled with a paramagnetic solution (0.7 grams $CuSO_4$/litre distilled water, pH 2). For 3 T systems we recommend the phantom is filled with mineral oil to avoid any possibility of dielectric effects interfering with the slice width measurements.



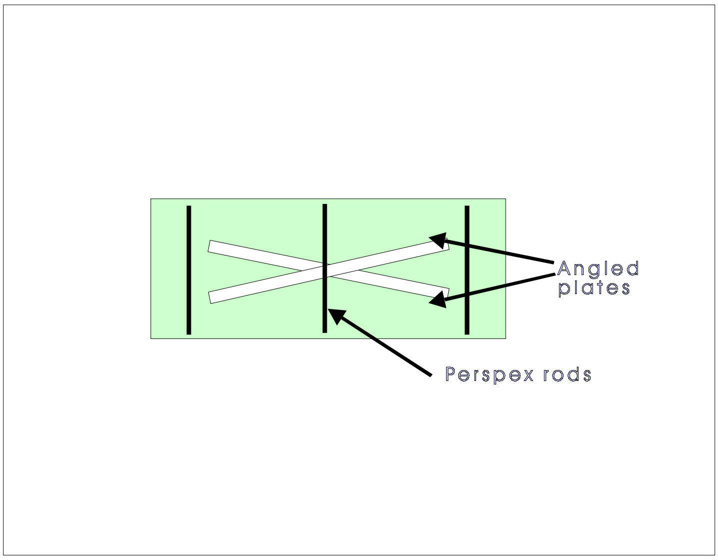


Figure 5: Plan view of geometric test object (top) and elevated views of geometric test object (bottom).

POSITIONING TEST OBJECT: Careful positioning of this test object is paramount in achieving the results required. Position the test object in the desired plane, in the centre of the coil. Figure 6 shows the position of the phantom in all three imaging planes. A single slice should be placed through the angled glass plates as shown by the blue line in Figure 7.

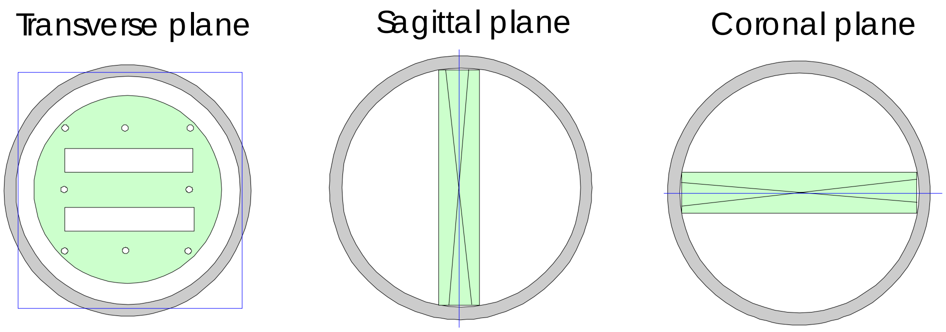


Figure 6: Position of phantom in the head coil for all three imaging planes when acquiring a transverse slice

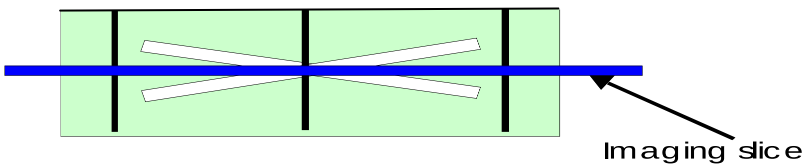


Figure 7: Slice selection

SCANNING PARAMETERS: The standard MagNET imaging protocol is as follows:

Geometric linearity/distortion and slice width	
Sequence	SE
Plane	TRA, SAG, COR
TE (ms)	30
TR (ms)	1000
NSA	1
FOV (mm)	256*
Matrix (PE x FE)	256 x 256
Slice width (mm)	5
Scan time (min:sec)	4:16

* This FOV is chosen to give a pixel dimension of 1 mm. If a FOV of 256 is not available, use 250 mm instead (generating a pixel dimension of 0.98 mm)

2.1 GEOMETRIC LINEARITY AND DISTORTION TEST

Distortion arises as a result of:

- field inhomogeneity
- gradient misadjustment
- sampling irregularity

ANALYSIS: For geometric linearity and distortion the distances (centre-to-centre) between the Perspex rods in the geometric test object are measured. Figure 8 shows the position of the three horizontal and three vertical measurements in the test object.
Six distances from the positions are measured as shown in Figure 4.

- three horizontal 1-3, 4-5, 6-8
- three vertical 1-6, 2-7, 3-8

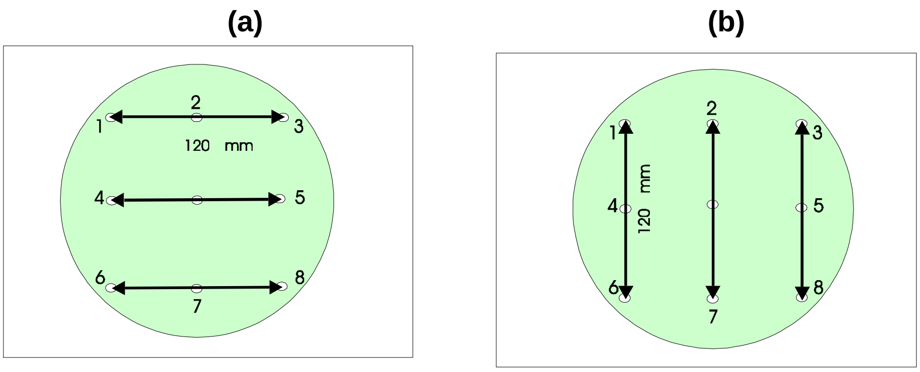


Figure 8: a) Horizontal and b) vertical measurements

The **geometric linearity** is calculated by finding the error between the measured distance and the actual distance. Errors should be less than ± 1 mm. Subtract the actual distance from the measured distance for each of the six measurements to obtain the linearity error.

The **geometric distortion** is given by the variation in the errors between the measured distances and actual distance. The coefficient of variation, CV, is used to characterise the displacement measurements and is defined as:

$$CV = \frac{standard\ deviation}{mean}\ 100\%$$

Calculate the coefficient of variation for the errors calculated above. The standard deviation off all the values measured can be calculated by using a spreadsheet package such as Microsoft Excel. The lower the coefficient of variation, the lower the in-plane geometric distortion and the better the fidelity.

RESULTS: Values should be recorded. One way of presenting the results is shown below:

Horizontal Measurements:

Line	*Measured distance in mm*	*Error*
1-3 4-5 6-8		**Mean** **SD** **CV**

Vertical Measurements:

Line	*Measured distance in mm*	*Error*
1-6 2-7 3-8		**Mean** **SD** **CV**

2.2 SLICE WIDTH TEST

The factors affecting slice profile and slice width are:

- RF pulse shape
- Magnetic Field Homogeneity
- Gradient Linearity, Gain
- Eddy current correction

If the slice width measurements are not accurate, loss of image SNR or resolution may occur.

ANALYSIS: Using the manufacturer analysis tools, create a profile across one of the plates in the image (as shown by the blue lines in Figure 9 below).

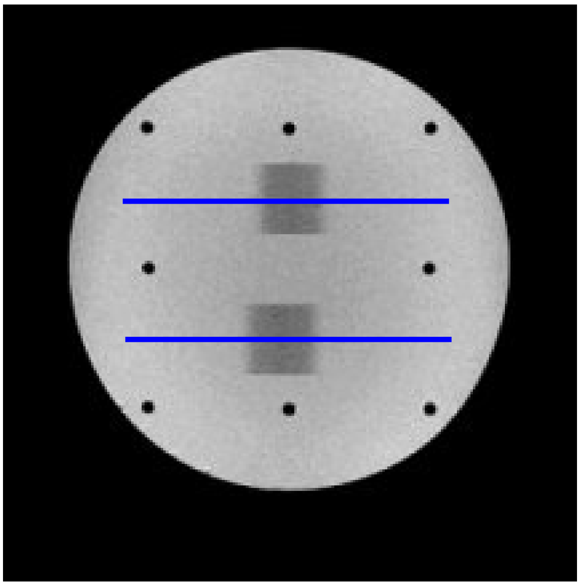


Figure 9: Position of profiles through plates in image

Measure the full-width-at-half-maximum (FWHM) as shown in Figure 10 below.

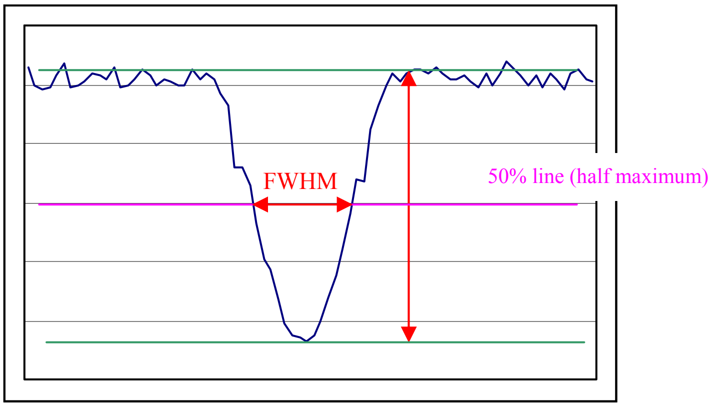


Figure 10: Full-width-at-half-maximum measurement

Repeat this for the second plate in the image. The slice width can be calculated using the following formula:

Slice width = FWHM/Stretch factor

For this test object, the angle of the plates is 11.3°, giving a stretch factor of 5. The slice width error should be less than ± 10% of the nominal slice width (i.e. for a 5 mm slice width, values should fall in the range 4.5 mm to 5.5 mm)

RESULTS: Values should be recorded. Results may be presented as in the example shown below:

Plate	*Slice width in mm*
1	
2	
	Mean

3. RESOLUTION TEST OBJECT

The resolution test object is shown in Figure 11. The test object contains a square angled Perspex block and four sets of parallel glass plates. It is filled with a paramagnetic solution (0.7 grams $CuSO_4$/litre distilled water, pH 2).

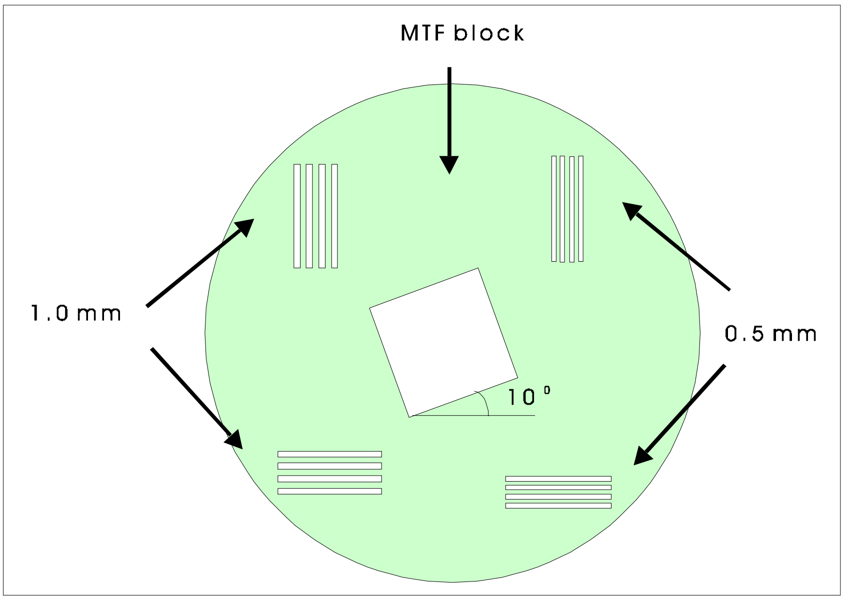


Figure 11: Plan view of resolution test object.

POSITIONING TEST OBJECT: Position the test object in the desired plane, in the centre of the coil. Figure 12 shows the position of the phantom in all three imaging planes. Use pilot scans to verify accurate positioning.

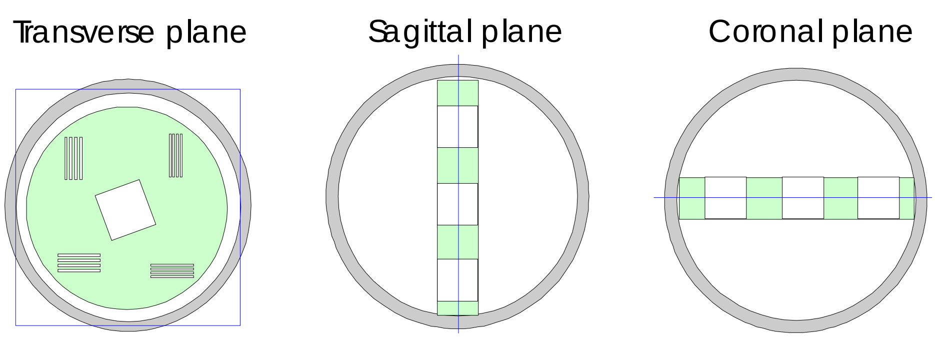


Figure 12: Position of phantom in the head coil for all three imaging planes

SCANNING PARAMETERS: The standard MagNET imaging protocol is as follows:

Spatial resolution	
Sequence	SE
Plane	TRA, SAG, COR
TE (ms)	30
TR (ms)	1000
NSA	1
FOV (mm)	250
Matrix (PE x FE)	256 x 256
	512 x 512
Slice width (mm)	5
Scan time (min:sec)	4:16
	8:32

2.3 RESOLUTION (MTF METHOD)

ANALYSIS: The primary means of quantifying spatial resolution is by calculating the modulation transfer function (MTF) from the edges of the Perspex block angled at 10° to the horizontal and vertical. Resolution measurements are made in both phase encoding and frequency encoding direction for each image plane. Figure 13 shows the principle steps for this (for further details refer to Judy PF, Med Phys, 1976 Jul-Aug; 3(4): 233-6).

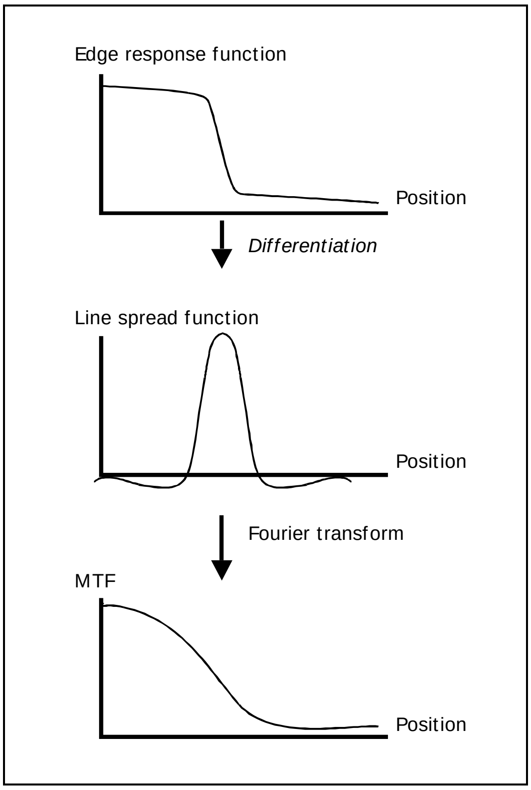


Figure 13: Evaluation of MTF from edge response function

3.2 RESOLUTION (PARALLEL BAR METHOD)

ANALYSIS: MagNET resolution test object consists of sets of plates with two known thickness and separation: 1.0 mm and 0.5 mm. Both phase encode and frequency encode directions can be assessed with a single image.

To assess resolution a line profile is drawn through the bars. The 50% intensity line is used to determine to what degree the bars are resolved as shown in Figure 15 .

For a field of view of 250 mm and a matrix 256 x 256 the pixel resolution should be 0.98 mm, therefore the 1.00 mm bars should be resolved. Similarly, with a matrix of 512 x 512 and pixel dimension of 0.49 mm, the 0.5 mm bars should be resolved. Resolution is investigated by placing an intensity profile across the line bars.

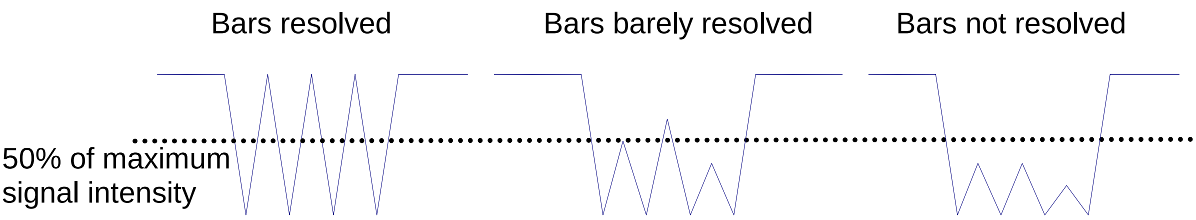


Figure 14: Visual inspection method for resolution bars.

4. SLICE POSITION TEST OBJECT

The slice position test object (Figure 15) is constructed of Perspex and is part of the MagNET Quality Assurance test object set. The test object contains two angled glass rods and four parallel glass rods. It is filled with a paramagnetic solution (0.7 grams $CuSO_4$/litre distilled water, pH 2).

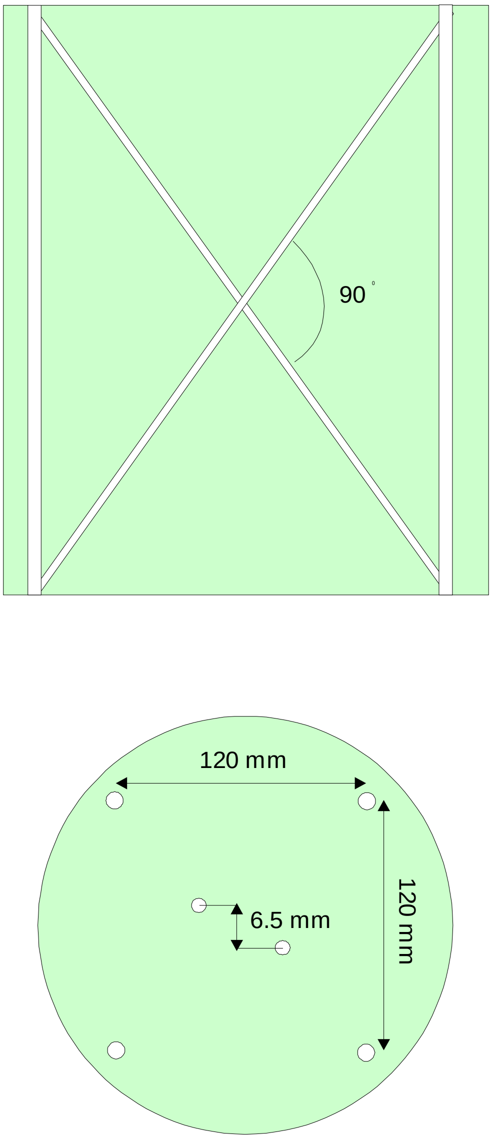


Figure 15: Side view (top) and plan view (bottom) of slice position test object.

POSITIONING TEST OBJECT: Position the test object in the desired plane, in the centre of the coil. Figure 16 shows the position of the phantom in the transverse plane.

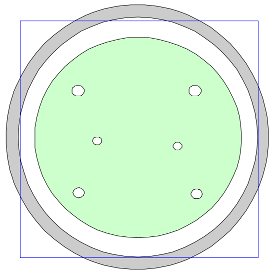


Figure 16: Position of phantom in the head coil in the transverse plane

SCANNING PARAMETERS: The standard MagNET imaging protocol is as follows:

Slice position	
Sequence	SE
Plane	TRA
TE (ms)	30
TR (ms)	System dependent
NSA	1
FOV (mm)	256*
Matrix (PE x FE)	256 x 256
Slice width (mm)	5
No of slices	65
Scan time (min:sec)	System dependent

ANALYSIS: There are three steps for analysing slice position:

- Calculate the pixel dimensions.
- Measure the rod displacement for each slice.
- Evaluate the slice position.

Each of the 65 images acquired is analysed using these steps.

* This FOV is chosen to give a pixel dimension of 1 mm. If a FOV of 256 is not available, use 250 mm instead (generating a pixel dimension of 0.98 mm)

CALCULATE THE CORRECTION FACTOR: From the image measure the horizontal (or vertical) distance of parallel rods, RDM. The physical distance of the parallel rods is 120 mm, RDA. Calculate the correction factor CF:

$$CF = RDA/RDM$$

MEASURE THE ROD DISPLACEMENT FOR EACH SLICE: Measure the distance (centre-to-centre) between the angled rods as they appear in each slice.

EVALUATE THE SLICE POSITION ERROR: Multiply distance of angled rods by corresponding correction factor CF (either vertical or horizontal depending on displacement direction). Square the measured distance and subtract the square of the rod separation (rod separation 6.5 mm). The square root of the result divided by two (to account for rod angle) is the slice position.

$$Slice\ \ position\,(measured) = \frac{\sqrt{(dis\tan ce\ \ of\ \ angled\ rods * CF)^2 - (rod\ separation)^2}}{2}$$

The correct position can be calculated from number of slices and centre-to-centre gap in imaging protocol according to:

$$Slice\ \ position\,(calculated) = (position\,of\ 1st\ slice) \pm \{(slice\,number - 1) * (slice\,thickness)\}$$

The slice position error for each slice is:

$$Error = slice\ position\ (calculated) – slice\ position\ (measured)$$

RESULTS: Results should be recorded and presented as for the example below:

Slice	Correction factor (CF)	Measured position (mm)	Calculated position (mm)	Position error (mm)
1 2 3 4 5 6 7 8 9 10 11 12 13				
			Mean	
			SD	
			Error range (max-min)	

5. SPINE TEST OBJECT

The spine test object (Figure 17) is constructed of Perspex and is part of the MagNET Quality Assurance test object set. It is filled with a paramagnetic solution (1.66 grams $NiCl_2$/litre distilled water, pH 4) and combines signal-to-noise ratio and uniformity tests. For systems above 1.5 T it can be provided filled with mineral oil. The test object is designed for use with phased array spine coils which sit flat on the patient table and typically consist of six elements along the head-foot direction.

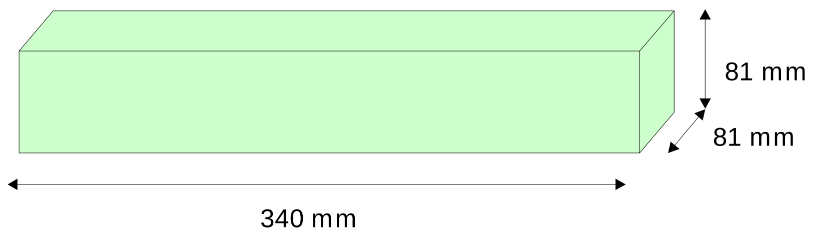


Figure 17: Spine test object with internal dimensions

POSITIONING TEST OBJECT: Two sets of identical images are acquired, the first with the phantom placed over the upper part of the coil, the second with the phantom placed over the lower part of the coil.

Position the test object centrally (left-right) on the coil over the upper set of elements (centred over element 2). Position sixteen contiguous slices over the test object in the coronal plane. Figure 2 shows the position of the phantom and imaging slices (blue lines) in the transverse plane.

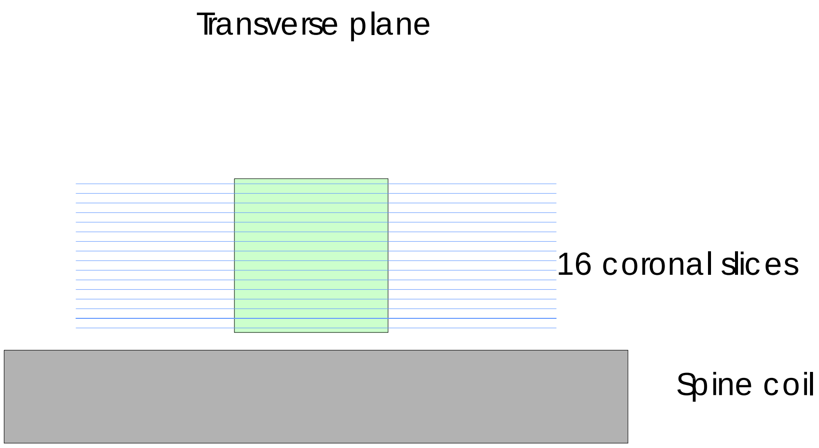


Figure 18: Position of spine phantom and slices for transverse plane

SCANNING PARAMETERS: The standard MagNET imaging protocol is as follows:

Signal-to-Noise Ratio and Uniformity	
Sequence	SE
Plane	COR
TE (ms)	30
TR (ms)	1000
NSA	1
FOV (mm)	350
Matrix (PE x FE)	256 x 256
PE Direction	HF
Slice width (mm)	5
Slice gap	0
Slices	16
Scan time (min:sec)	4:16

5.1 SIGNAL-TO-NOISE RATIO TEST

ANALYSIS: The following steps should be taken for a comparative signal-to-noise ratio to be measured:

- Measure the signal.
- Measure the noise.
- Calculate the signal to noise ratio.

MEASURE THE SIGNAL: Create one region of interest (ROI) of size 220 x 35 pixels on each of the images as shown in Figure 19 (ROI 1). Measure the mean pixel value in the ROI. Take the signal as this value (S).

MEASURE THE NOISE: Create five ROI's of size 10 x 10 pixels in the image background, selecting regions free from ghosting (ROIs 2-6, Figure 19). Take the mean of the five standard deviation (SD) values for the ROI's in the background. Calculate the noise (*N*) using:

$$N = SD/0.655$$

CALCULATE THE SIGNAL TO NOISE RATIO: The signal-to-noise ratio (SNR) is calculated as average mean pixel value over the average standard deviation:

$$SNR = S / N$$

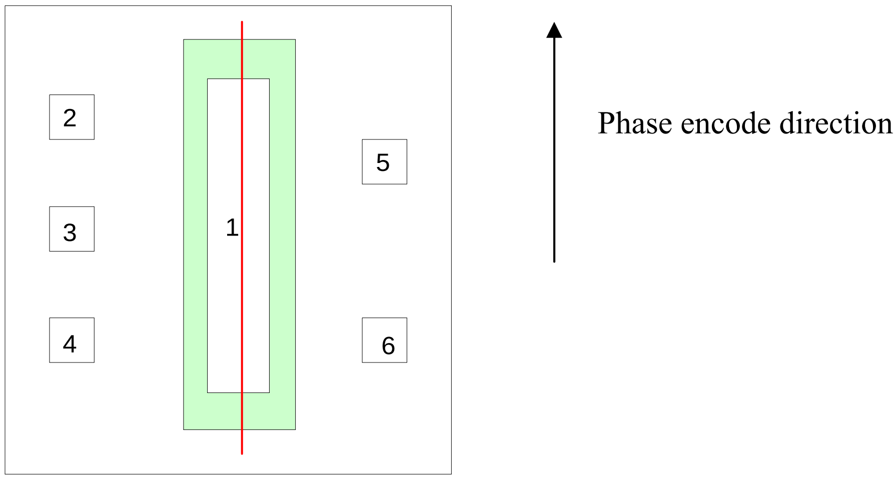


Figure 19: SNR regions of interest in spine test object and background and position of uniformity profile

RESULTS: Results can be presented as shown below for each slice analysed:

ROI	*Mean Pixel Value*	*ROI*	*SD*
1		2 3 4 5	
MEAN (S)		MEAN / 0.655 (N)	
S/N			

5.2 UNIFORMITY TEST

ANALYSIS: The uniformity is evaluated qualitatively by obtaining uniformity profiles in the z-direction for a selection of slices. The uniformity profile position is shown by the red line in Figure 19. A typical profile is shown in Figure 20.

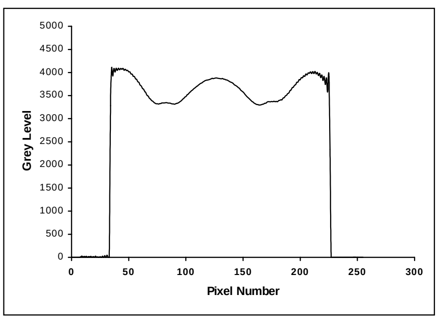


Figure 20: Typical uniformity profile for spine coil (z-direction)

6. SHOULDER TEST OBJECT

The spherical shoulder test object is shown in Figure 17. It is filled with a paramagnetic solution (1.66 grams $NiCl_2$/litre distilled water, pH 4) and combines signal-to-noise ratio and uniformity tests. The test object is designed for use with shoulder coils or other similar-sized extremity coils.

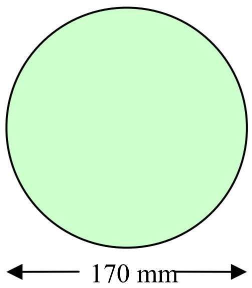


Figure 21: Shoulder test object

POSITIONING TEST OBJECT: Position the test object in the centre of the coil.

SCANNING PARAMETERS: The standard MagNET imaging protocol is as follows:

Signal-to-Noise Ratio and Uniformity	
Sequence	SE
Plane	TRA, SAG, COR
TE (ms)	30
TR (ms)	1000
NSA	1
FOV (mm)	250
Matrix (PE x FE)	256 x 256
Slice width (mm)	5
Scan time (min:sec)	4:16

6.1 SIGNAL-TO-NOISE RATIO TEST

ANALYSIS: The following steps should be taken for a comparative signal-to-noise ratio to be measured:

- Measure the signal.
- Measure the noise.
- Calculate the signal to noise ratio.

MEASURE THE SIGNAL: Create five regions of interest (ROI) of size 10 x 10 pixels on one of the flood field images as shown in Figure 3 (ROIs 1-5). Measure the mean pixel value in each ROI. Take the signal as this value averaged over all five regions (*S*).

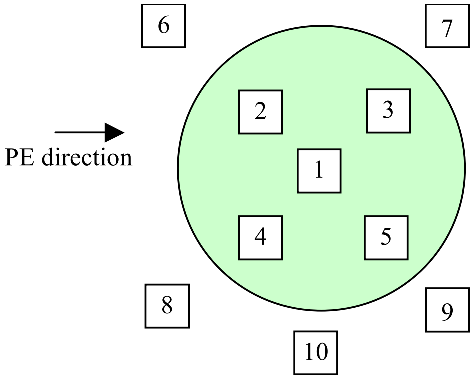


Figure 22: SNR regions of interest in flood field test object

MEASURE THE NOISE: **C**reate five ROI's of size 10 x 10 pixels in the image background, selecting regions free from ghosting (ROIs 2-6, Figure 19). Take the mean of the five standard deviation (SD) values for the ROI's in the background. Calculate the noise (*N*) using:

$$N = SD/0.655$$

CALCULATE THE SIGNAL TO NOISE RATIO: The signal-to-noise ratio (SNR) is calculated as average mean pixel value over the average standard deviation:

$$SNR = S / N$$

RESULTS: Results can be presented as shown below for each slice analysed:

ROI	*Mean Pixel Value*	*ROI*	*SD*
1		2 3 4 5	
MEAN (S)		MEAN / 0.655 (N)	
S/N			

6.2 UNIFORMITY TEST

ANALYSIS: The uniformity is evaluated qualitatively by obtaining uniformity profiles in the all three gradient directions.

7. SUGGESTED TOLERANCES FOR ACCEPTANCE TESTING

Parameter	Tolerance
Head / Body SNR	± 10% of type-test
Head / Body Uniformity	± 10% of type-test
Geometric linearity	± 1mm in measurement of 120 mm
Geometric distortion	Refer to type-test results but normally CV should be <1%
Slice width	± 10% of nominal slice width
Slice position	Refer to type-test results if available but normally mean slice position error should be < 2 mm
Resolution	± 10% of nominal pixel size (MTF method) 1 mm bars should be resolved with 0.98 mm pixel size

8. REFERENCES

IPEM Report No. 80, Quality Control in Magnetic Resonance Imaging 1998

Standardization of performance evaluation in MRI: 13 Years' experience of intersystem comparison. J. De Wilde, D. Price, J. Curran, J. Williams, R. Kitney. Concepts in Magnetic Resonance. 15(1) p. 111-116. 2002

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