Analytical and Experimental Study on a Thin-walled Gradient Coil Cylinder Model

F. Wang[1], C. K. Mechefske[1], B. Rutt[2]

[1]Mechanical Engineering, Queen's University, Kingston, Ontario, Canada, [2]Imaging Laboratory, Robarts Research Institute, London, Ontario, Canada

Introduction

Vibration modal studies [1-3] have been recently done to further the understanding of the mode shapes and acoustic characteristics of gradient coil inserts in a 4T MRI scanner. The next step to a complete understanding of gradient coil noise generation will be the building of an analytical dynamic model of the gradient coil insert and investigation of its dynamic responses. A single-winding gradient coil insert model (X or Y winding only) has been developed for this purpose. Analytical and experimental studies of the model were conducted to reveal the vibration characteristics of a gradient coil cylinder and its vibration distribution in the normal direction to the cylinder surface.

Materials and Method

Parameters of the test thin-walled cylinder model are: the length L=0.59 (m), radius R=0.18775 (m), thickness h=0.0115 (m), Young's modulus E=2.8 $\times 10^9$ Pa, Poisson's ratio 0.39, density 1200 Kg/m^3. The cylinder model was supported by two rigid columns to simulate the boundary condition of gradient coil inserts in an MRI. Love's governing equations [4] and boundary conditions for the cylinder model were established. The modal testing system used a National Instruments PXI data collector with 3 accelerometers and a hammer as shown in Figure 1. Frequency response functions (FRFs) for 480 measurement points on the model surface were collected and then processed.
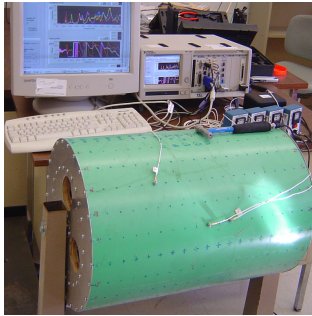
Table 1.Comparison of analytical and experimental results

Figure 1. Experimental set-up

Modes	Frequencies (Hz)			Modes	Frequencies (Hz)		
	Ana.	Exp.	Error %		Ana.	Exp.	Error %
(1,1)	500.9	N/A	N/A	(3,1)	1217.7	1328.0	-8.31
(1,2)	258.4	240.1	7.62	(3,2)	955.3	862.3	10.79
(1,3)	257.1	257.4	-0.12	(3,3)	786.1	742.6	5.86
(1,4)	413.7	422.1	-1.99	(3,4)	776.8	767.5	1.21
(1,5)	654.1	658.4	-2.02	(3,5)	919.0	915.2	0.42
(1,6)	932.9	942.9	-1.06	(3,6)	1168.5	1167.0	0.13

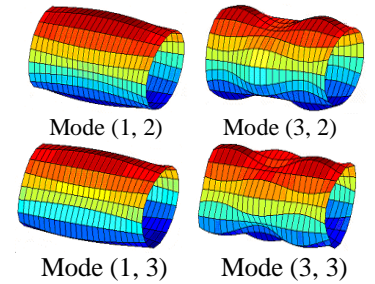Mode (1, 2)　　Mode (3, 2)

Mode (1, 3)　　Mode (3, 3)

Figure 2. Analytical modal shapes

Results

Natural frequencies and their modal series numbers for the analytical solutions with the corresponding experimental results are compared in Table 1. Except for one mode, which was not detected by experiment, the analytical natural frequencies are in close agreement with the experimental results. Some of the analytical modal shapes are shown in Figure 2. The thin-walled cylinder mode shapes are composed of two basic modal patterns - a ring modal pattern and a simply-supported beam pattern - in linear or nonlinear combinations. Two measured mode shape examples are given in Figure 3. By comparing Figure 2 and 3, it is seen that all the analytical mode shapes are exactly the same as the measured results.
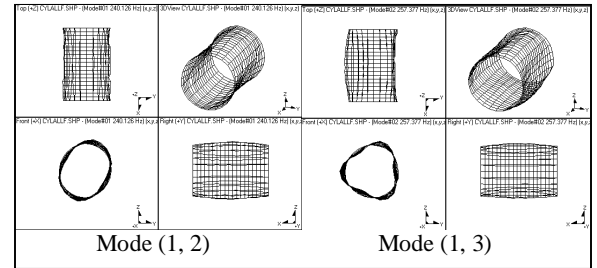

Mode (1, 2)　　　　Mode (1, 3)

Figure 3. Experimental modal shapes

Conclusions and Discussions

Experimental modal testing studies reveal the real natural frequencies and their corresponding mode shapes. The measured mode shapes and natural frequencies are in close agreement with the analytical results. The natural frequency distribution is determined by the geometrical ratio of the length to the diameter (L/D) of the cylinder and its material properties. The dynamic behaviour of the cylinder model is dominated by the linear modes, which were also partly verified by previous work [1, 2]. Analytical modal analysis is a powerful tool to predict the vibration responses and distribution on the cylinder model and could become a useful tool for the design of low-noise gradient coil inserts.

References

1. C.K. Mechefske et al. (2004) Vibration and acoustic characterization of a gradient coil insert in a 4 T MRI, J. of Vib. & Con., 10: 861-880.
2. G.Z. Yao, et al. (2003), Modal Analysis of a Gradient Coil for a 4T MRI, ISMRM, Toronto, Canada.
3. G.Z. Yao et al. (2004), Vibration Analysis and Measurement of a Gradient Coil Insert in a 4T MRI, ISMRM, Kyoto, Japan.
4. Soedel, W., 1993, Vibrations of Shells and Plates, Marcel Dekker, Inc. Second edition.