Vibro-acoustic Characterization of Gradient Induced Noise in a 7T MRI Scanner

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Synopsis

The vibro-acoustic behavior of a head-only Gradient Coil Assembly (GCA) installed in a 7T MRI scanner has been investigated. Various sound and vibration measurements were made and Frequency Response Functions (FRF) in the [20-4000] Hz range were derived from the system acoustic response at the isocenter of the bore. Linear swept sine input signals were used for each gradient coil. The system linearity was ensured and thus the loud gradient-induced noise of some EPI sequences could be predicted using a Finite Impulse Response (FIR) filter based model derived from the identified impulse responses. This study is a first step toward the design of an advanced Active Noise Cancellation (ANC) system which would use such a FIR filter as a model of the primary noise path. It also provided a suitable predictive tool of the gradient induced acoustic noise (spectra and levels). Moreover the vibration measurements were very helpful to get more insight about the acoustic radiation process of this vibrating structure.

Introduction

The GCA is subject to Lorentz forces when strong currents flow through its windings and the induced vibrations depend on both the gradient pulse sequence spectra and the ability of the windings to transmit these forces to the structure. Then the acoustic waves radiated by the structure vary with the geometry of the bore and the radiation efficiency of the vibration eigenmodes [1]. The objective of this work is to get more insight in these complex phenomenon through the analysis of acoustic and vibration data and the conception of a predictive model of the noise induced by an MRI sequence.

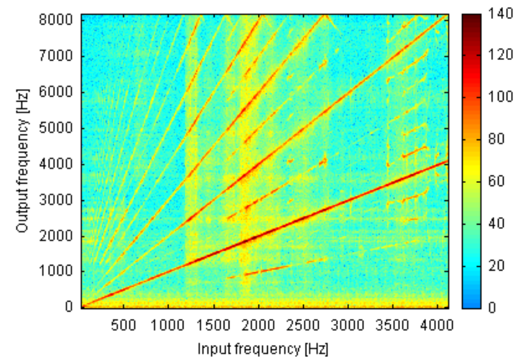

Figure 1 : Spectrogram of a microphone output signal

Method

A Brüel & Kjær 4188 microphone equipped with a random incidence corrector and connected to a B.&K. 2238 Sound Level Meter was placed at the isocenter of a Siemens AC88 GCA in a 7T MRI scanner system. At the same time a PCB 357B11 accelerometer connected to a B.&K. 2635 charge amplifier was fixed on one edge of the GCA in the radial direction. The outputs of the SLM and charge amplifier were connected to a National Instrument 4472 acquisition card, and so were the three remote signals of the X, Y and Z gradient coils. In a first time, a specific swept sine sequence was run for each gradient and the derived input and output spectra were used to compute the corresponding acoustic FRF. The vibration signal was used to obtain the related vibration spectra and spectrograms. Then a typical EPI sequence was run and the acoustic signal recorded for the same position with the aim of being able to evaluate the reliability of the predictive model. All signals were sampled at 65536 Hz (and then low-pass filtered below 4000 Hz when needed). The impulse response of each gradient were computed from the FRF and the corresponding models were built using 8196 coefficients FIR filters. The convolution of these truncated impulse response with the gradient input signals of the EPI sequence provided us with an estimation of the acoustic noise generated by this EPI sequence.

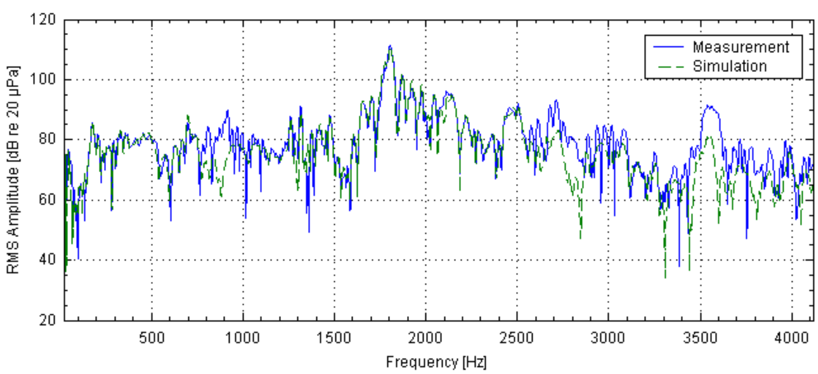

Figure 2: Acoustic response spectrum at the isocenter of the bore (EPI sequence)

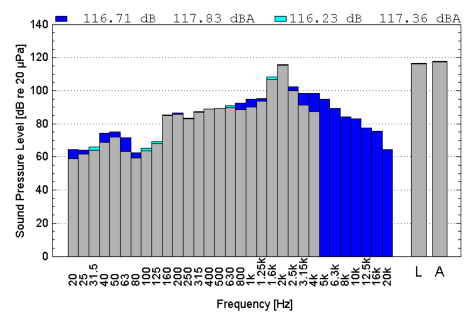

Figure 3 : 1/3rd octave analysis of the acoustic response presented on fig. (2). Measurement (blue) and Estimation (gray)

Results and Conclusion

The spectrogram of the response to a linear swept sine signal gives an idea of the degree of non-linearity of a system as shown on fig.(1). It can be seen that some sub-harmonics appear slightly below 2000 Hz for this particular gradient coil (Y gradient, which is also the readout gradient of the EPI sequence considered here). However this effect is not sufficiently important to distort the good simulation result in the same frequency region (see figure 2). The simulation spectrum on figure (2) was computed from the estimated time waveform derived from our model. The model can be considered to be relatively accurate as the overall sound pressure level differ by only less than 0.5 dB (fig. 3), although signals above 4 kHz were not included in the model. The confrontation of the measured acoustic and vibration spectra also clearly showed that not every vibration mode radiate sound with the same efficiency. The combined use of this analysis and our prediction tool can lead to a relevant optimization process which would consist of designing sequences that would not excite the highly radiating vibration modes while eventually allowing some others to respond fully. In a future work we will also take advantage of these results to develop an ANC system which would include such a model based on FIR filters.

References

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