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Visualization of Automotive Power Seat Slide Motor Noise

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Advancing the Technology and Practice of Noise Control Engineering

Visualization of Automotive Power Seat Slide Motor Noise

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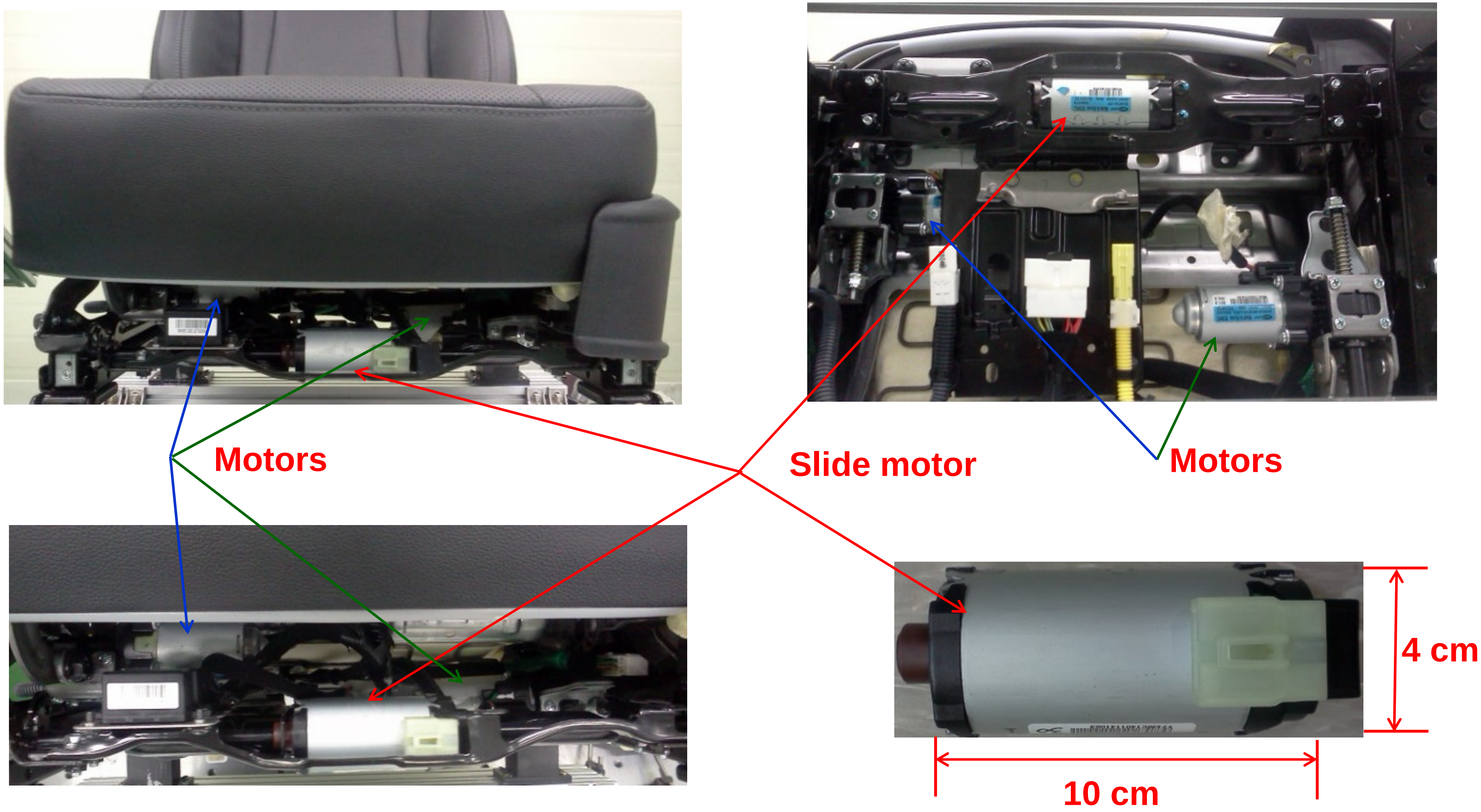
Automotive Power Seat Motors

Front view

Bottom view



Power seat with three motors
(Some other power seats have four motors)

INTRODUCTION

- Automotive power seat slide motor
  - Power seats have different but similarly shaped motors
  - Relatively compact in size, similar to small cylinder
  - Noise sources of motor are closely spaced: e.g., motor shell, bearings, and brushes
  - Span wide frequency range: e.g., 592 Hz ~ 8 kHz
  - Limited position for reference measurement
- Statistically Optimized Nearfield Acoustical Hologrpahy
  - High resolution and no truncation effects
  - Multi-reference acoustical holographic procedure
  - Cylindrical surfaces

Visualization of Power Seat Motor Noise

- SONAH formulation (1)

- The sound pressure, $p(\mathbf{r})$, can be expressed as linear combination of the measured sound pressure $p(\mathbf{r}_n)$,

$$p(\mathbf{r}) \approx \sum_{n=1}^{N} c_n(\mathbf{r})\, p(\mathrm{r}_n)$$

- If a good representation of the sound field can be obtained by using a finite subset of wave functions, the coefficients c_n can be determined.

$$\Phi_{Km}(\mathbf{r}) \approx \sum_{n=1}^{N} c_n(\mathbf{r})\, \Phi_{Km}(\mathrm{r}_n), \qquad m = 1 \ \ldots \ M$$

Visualization of Power Seat Motor Noise

- SONAH formulation (2)

$$p(r,\phi,z) = \frac{1}{(2\pi)^2} \sum_{m=-\infty}^{m=\infty} \int_{-\infty}^{\infty} P_m(r_h, k_z) \Phi_{\mathrm{Km}} \, dk_z$$

- Defining wave function,

$$\Phi_{Km} \equiv 2\pi \frac{H_m^{(1)}(k_r r)}{H_m^{(1)}(k_r r_h)} e^{im\phi} e^{ik_z z},$$

where:

$$k_r = \begin{cases} \sqrt{k^2 - k_z^2} & \text{for} \quad |k| \geq |k_z| \\ i\sqrt{k_z^2 - k^2} & \text{for} \quad |k| < |k_z| \end{cases}$$

Visualization of Power Seat Motor Noise

- SONAH formulation (3)

$$\mathbf{A} \equiv \left[\Phi_{\mathrm{K}q,m}(\mathbf{r}_{h,j}) \right] \quad , \quad \boldsymbol{\alpha}(\mathbf{r}) \equiv \left[\Phi_{\mathrm{K}q,m}(\mathbf{r}) \right] \quad , \quad \mathbf{c}(\mathbf{r}) \equiv \left[c_j(\mathbf{r}) \right].$$

- Estimated pressure $p(\mathbf{r})$ is,

$$p(\mathbf{r}) \approx \sum_{n=1}^{N} c_n(\mathbf{r}) p(\mathbf{r}_n) = \mathrm{p}^T \mathrm{c}(\mathbf{r}) = \mathrm{p}^T \left(\mathrm{A}^+ \mathrm{A} + \theta^2 \mathrm{I} \right)^{-1} \mathrm{A}^+ \alpha(\mathbf{r})$$

where, $\mathbf{p}^T$ is measured pressure vector at $\mathbf{r}_n$

- Estimated normal particle velocity $u_z(\mathbf{r})$ is,

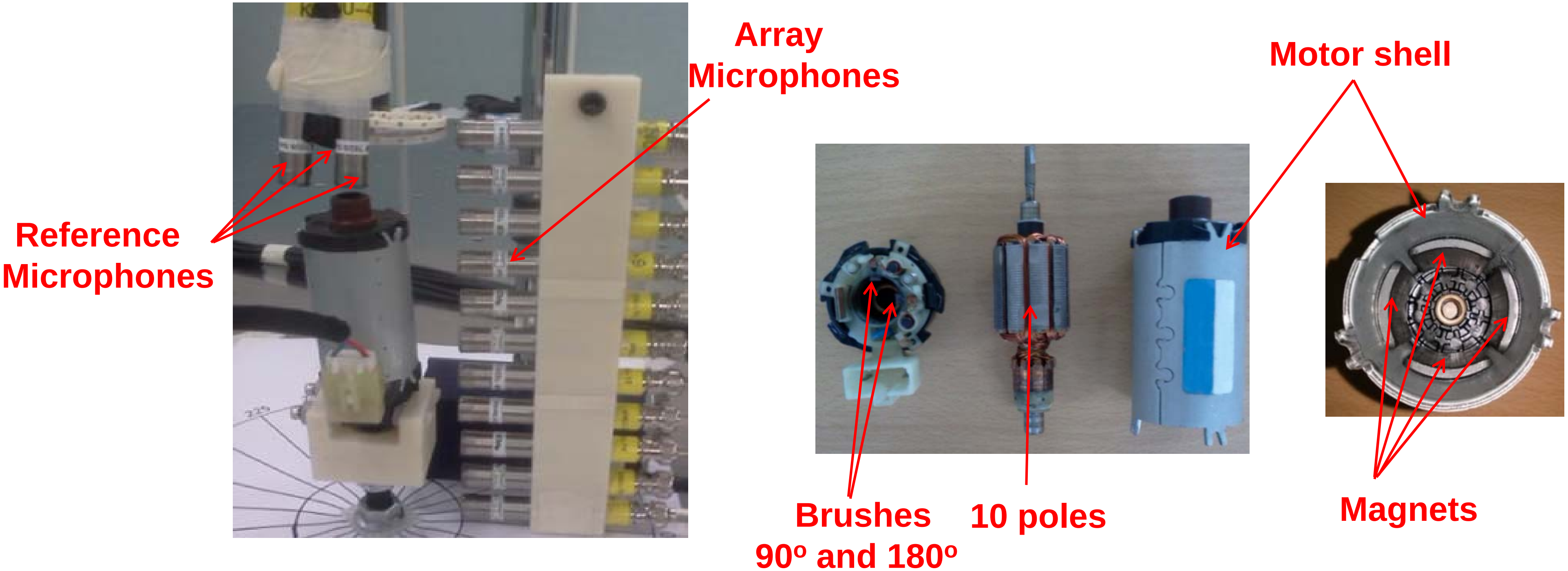
$$u_z(\mathbf{r}) \approx \mathrm{p}^T \left(\mathrm{A}^+ \mathrm{A} + \theta^2 \mathrm{I} \right)^{-1} \mathrm{A}^+ \beta(\mathbf{r})$$

where, $\mathbf{A}^+ \boldsymbol{\beta}(\mathbf{r})$ is a correlation vector that relates measured pressure and particle velocity.

Visualization of Power Seat Motor Noise

- Power seat motor measurement

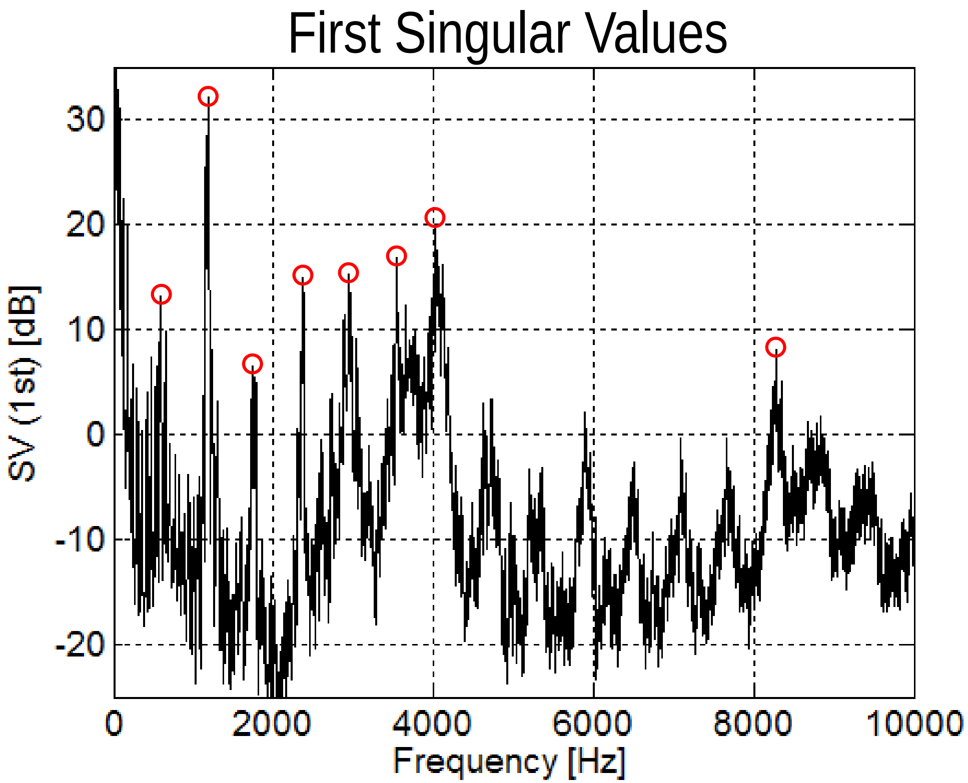
- Number of field microphones : N_z=11
- Microphone spacing in *z* direction : z_{inc}= 2 cm
- Radius of hologram : r_h = 4 cm
- Radius of motor shell : r = 2 cm
- Total aperture size : 22 cm, N_Φ=24
- Motor rotating speed : 3552 rpm (13.5V)

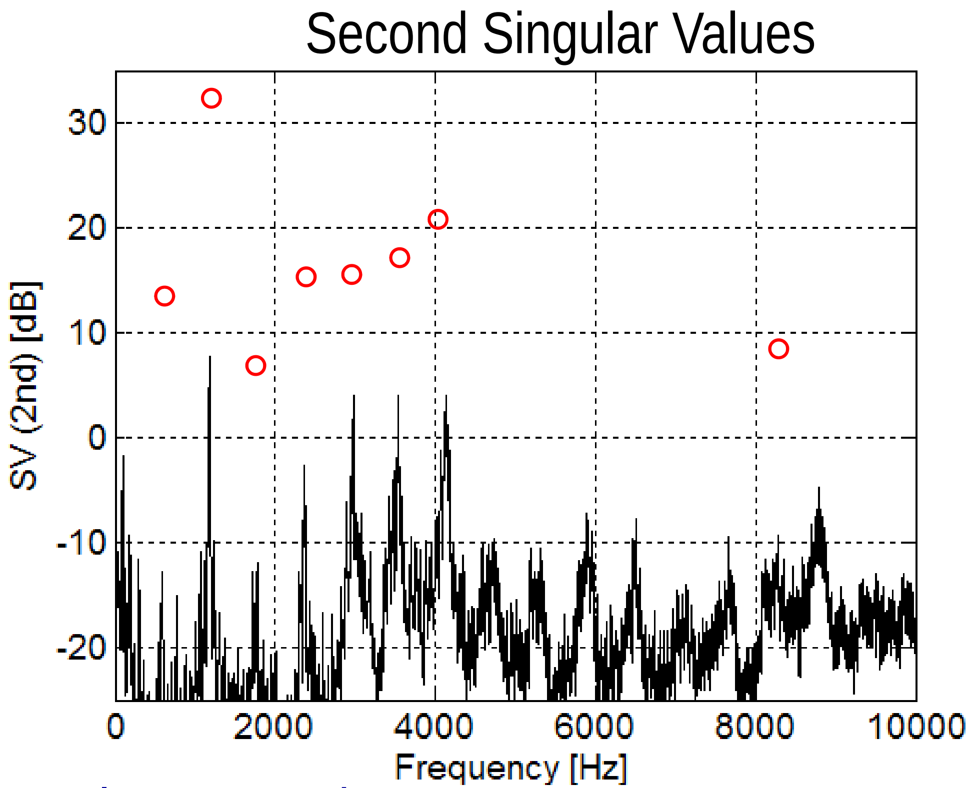


Visualization of Power Seat Motor Noise

- Power seat motor measurement result

Singular values of reference measurement





- Difference between first and second singular values > 10 dB
- First singular values are used for reconstruction
- Since the motor is rotating at 3552 Hz, and armature has ten poles, 3552/60*10=592 Hz, is brush passage frequency and the motor has two pairs of magnets, so motor housing shell is excited at 592*2=1184 Hz.

Visualization of Power Seat Motor Noise

- Power seat motor measurement result

SONAH Sound power estimate and major noise origin of motor

Frequency (Hz)	Sound power (dB) (Ref.: 10^{-12} W)	Rank	Major noise origin
592	52.0	7	Shell vibration and lower bearing
1184	86.6	1	Shell vibration
1736	47.1	8	Shell vibration
2360	55.3	6	Shell vibration
2944	67.8	2	Shell vibration and lower bearing
3536	64.8	4	Lower bearing
4032	67.5	3	Shell vibration and lower bearing
8288	61.5	5	Shell vibration and lower bearing

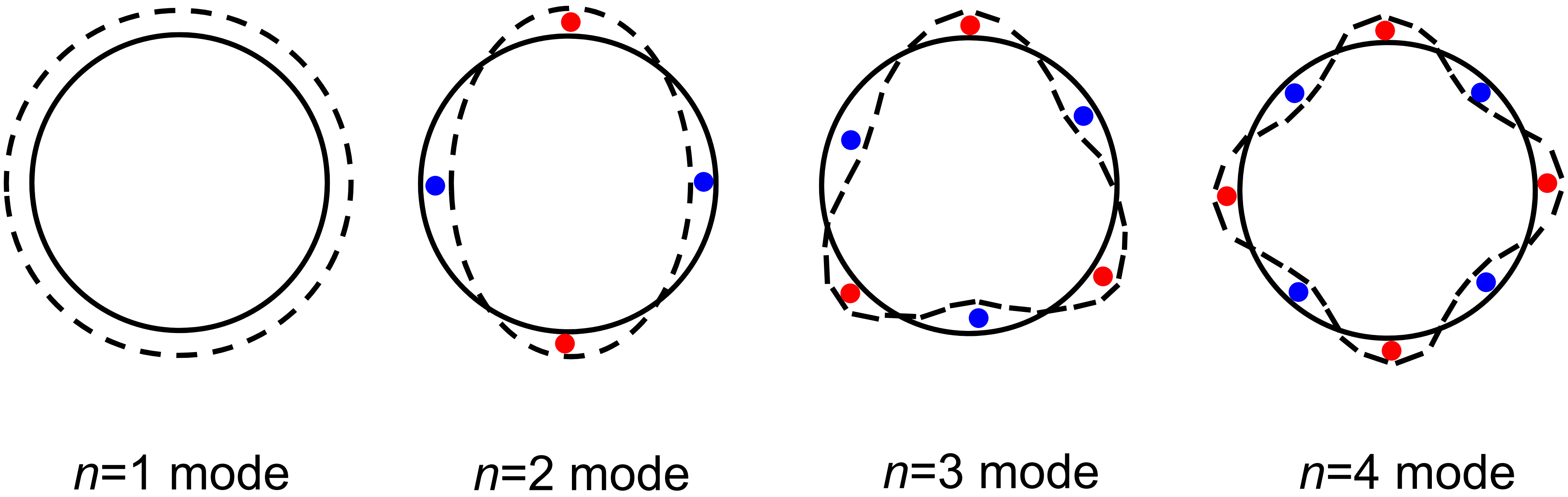
Shell vibration

Lower bearing

Visualization of Power Seat Motor Noise

- Cylindrical shell vibration

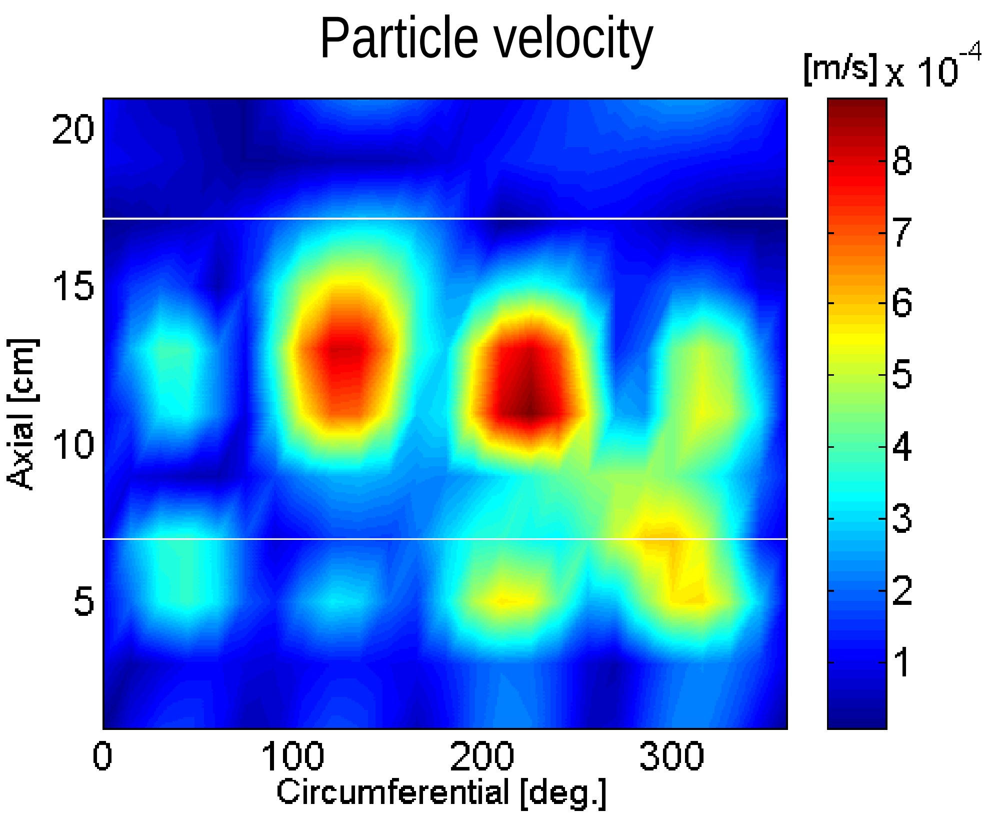
Cylindrical mode shapes

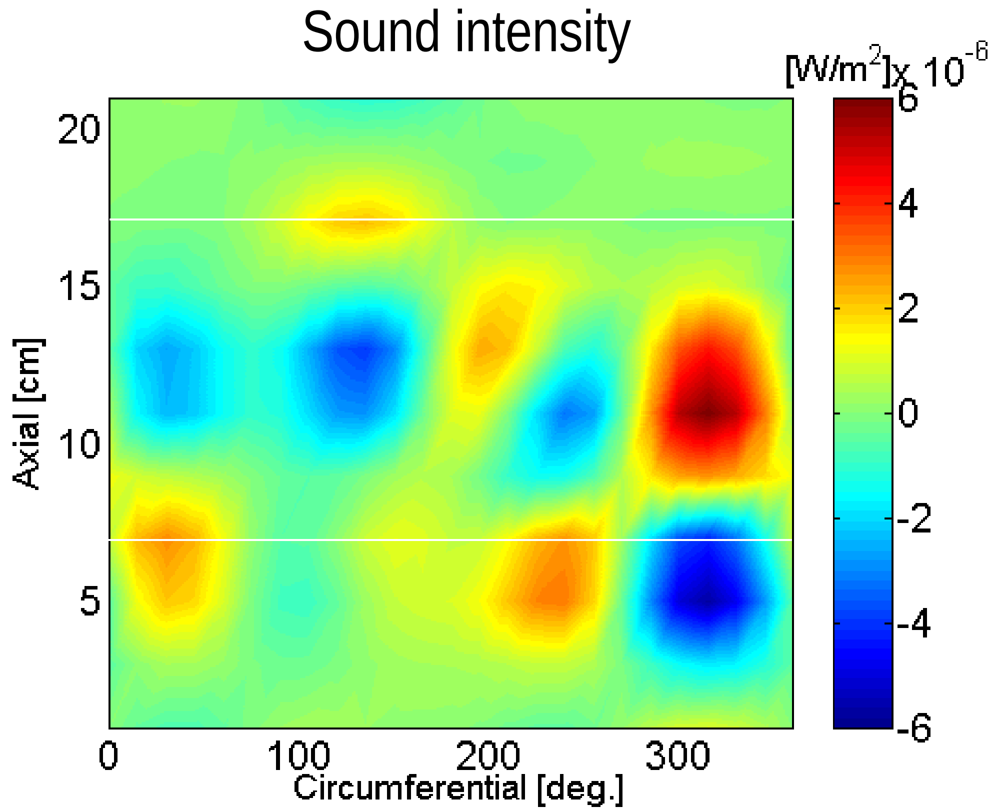


Visualization of Power Seat Motor Noise

- Power seat motor measurement result : Eight major frequencies

592 Hz





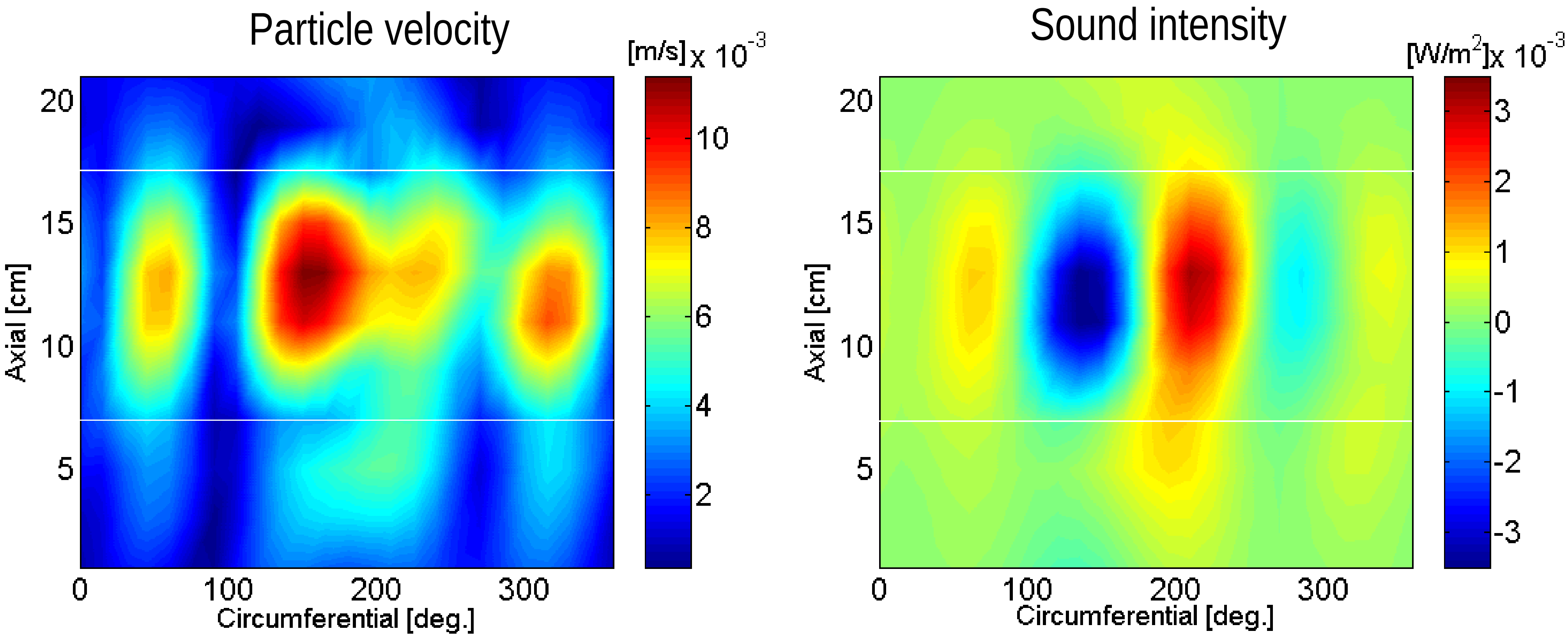
Motor shell vibration and lower bearing

Sound power: 52.0 dB (Ref.: 10^{-12} W), 7th/8 frequencies

Visualization of Power Seat Motor Noise

- Power seat motor measurement result : Eight major frequencies

1184 Hz



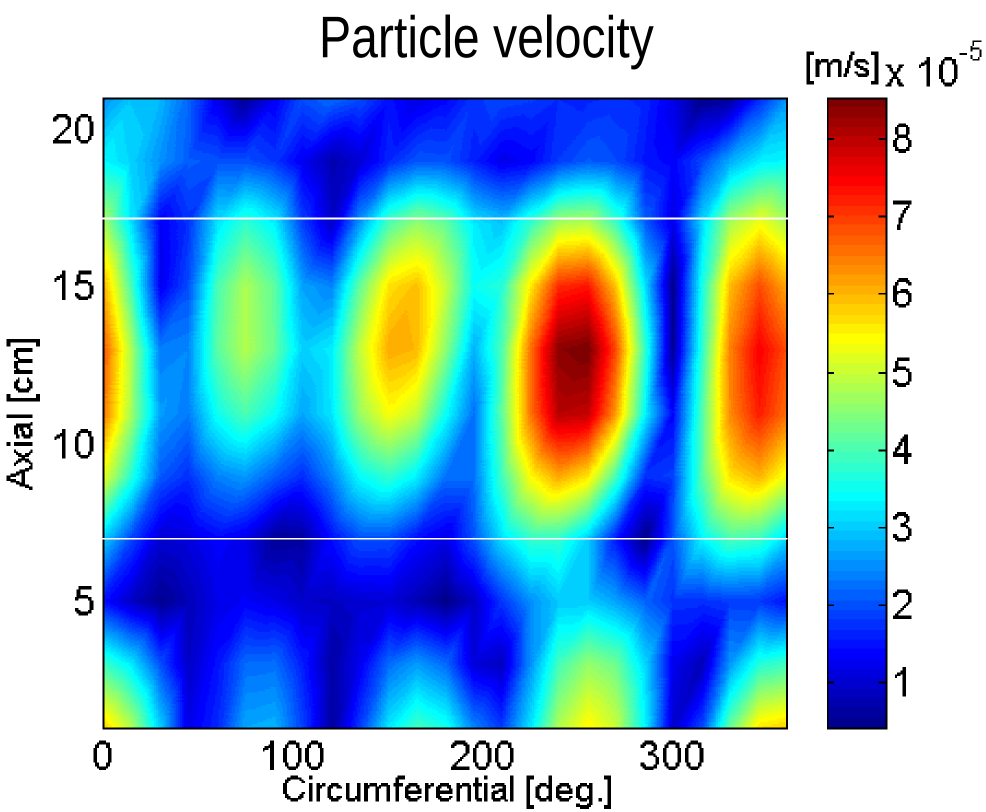
Motor shell vibration (n=2 mode) and lower bearing

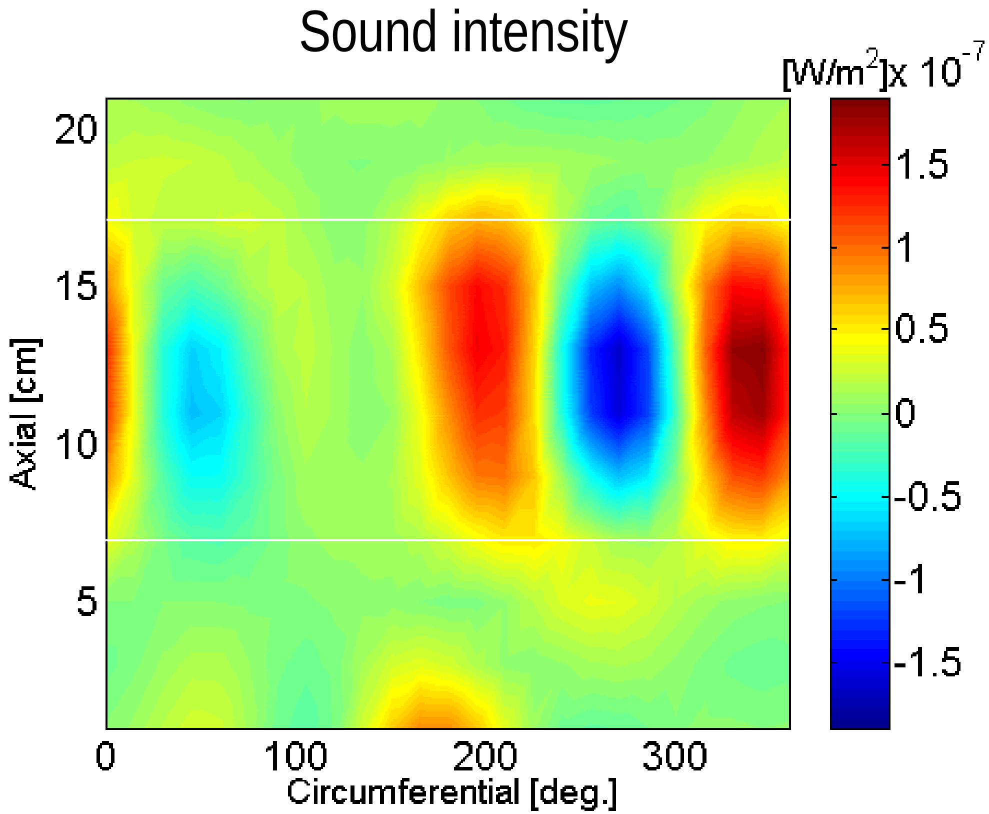
Sound power: 86.6 dB (Ref.: 10^{-12} W), 1st/8 frequencies

Visualization of Power Seat Motor Noise

- Power seat motor measurement result : Eight major frequencies

1736 Hz





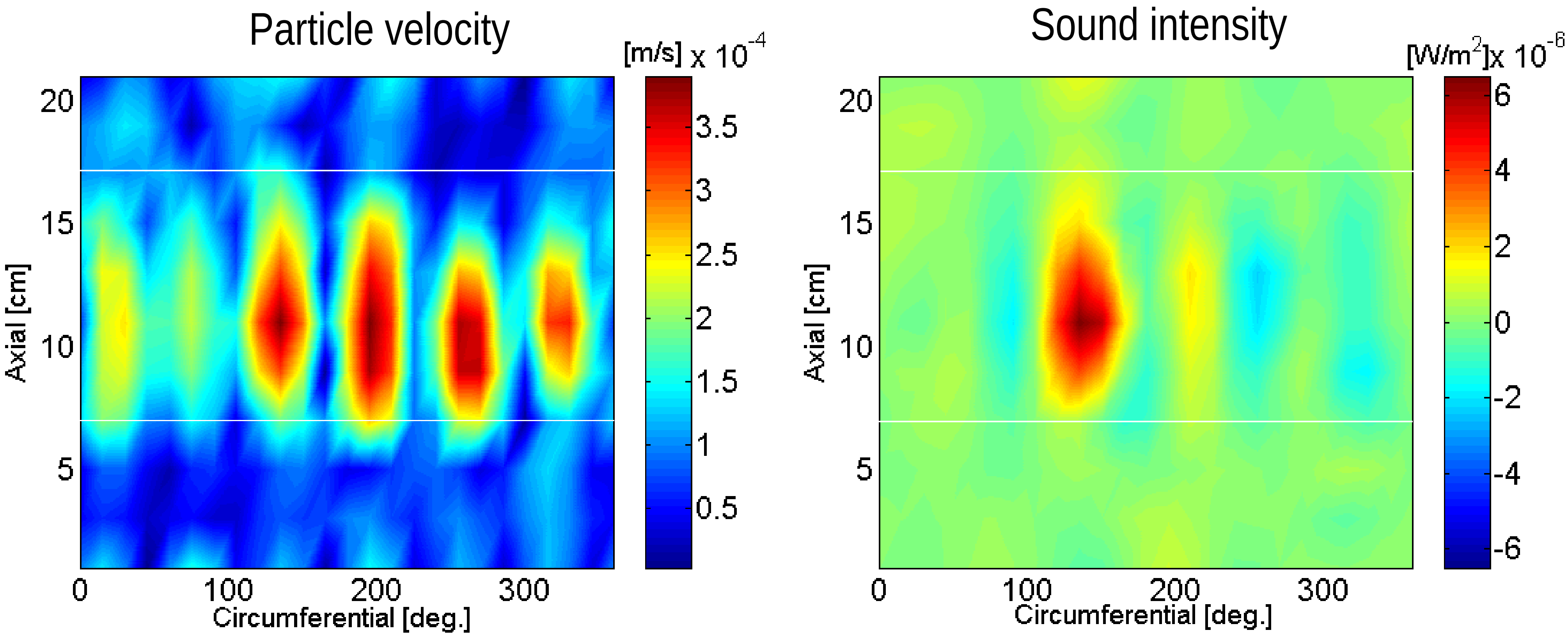
Motor shell vibration (*n*=2 mode)

Sound power: 47.1 dB (Ref.: 10^{-12} W), 8th/8 frequencies

Visualization of Power Seat Motor Noise

- Power seat motor measurement result : Eight major frequencies

2360 Hz



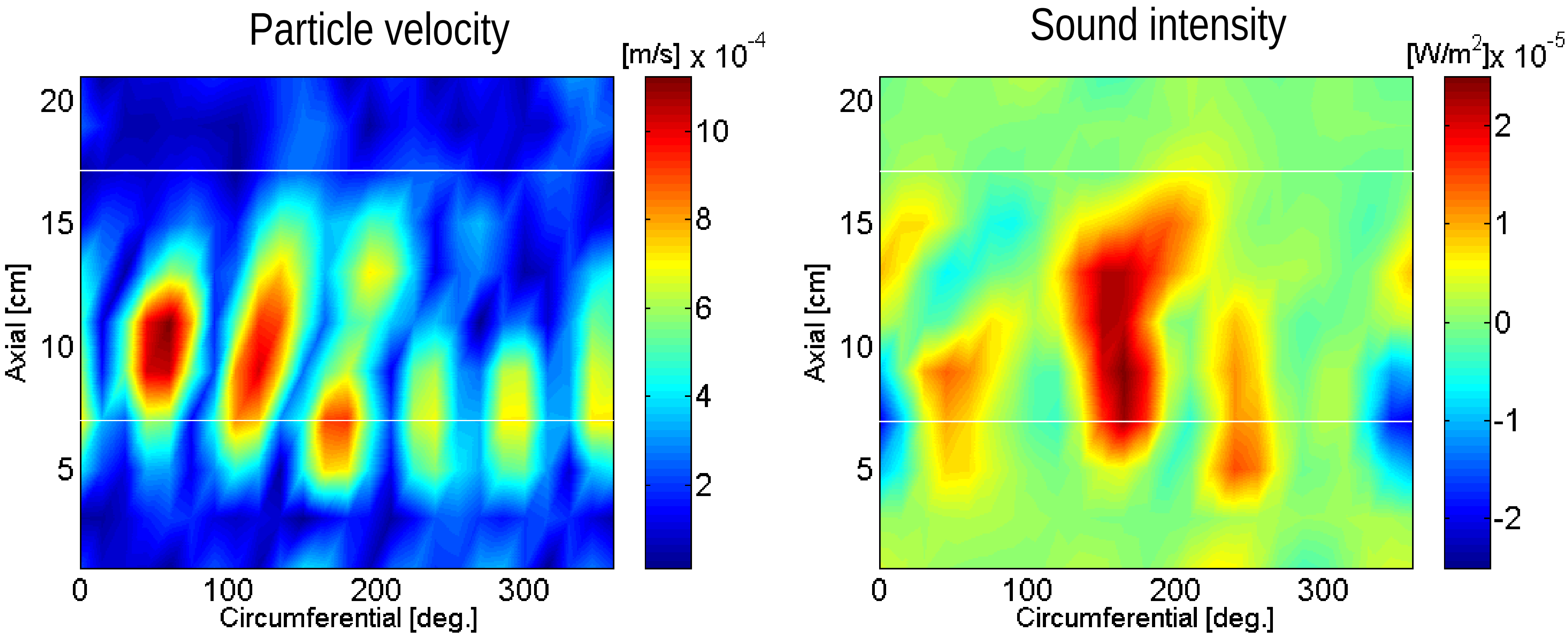
Motor shell vibration (*n*=3 mode)

Sound power: 55.3 dB (Ref.: 10^{-12} W), 6th/8 frequencies

Visualization of Power Seat Motor Noise

- Power seat motor measurement result : Eight major frequencies

2944 Hz



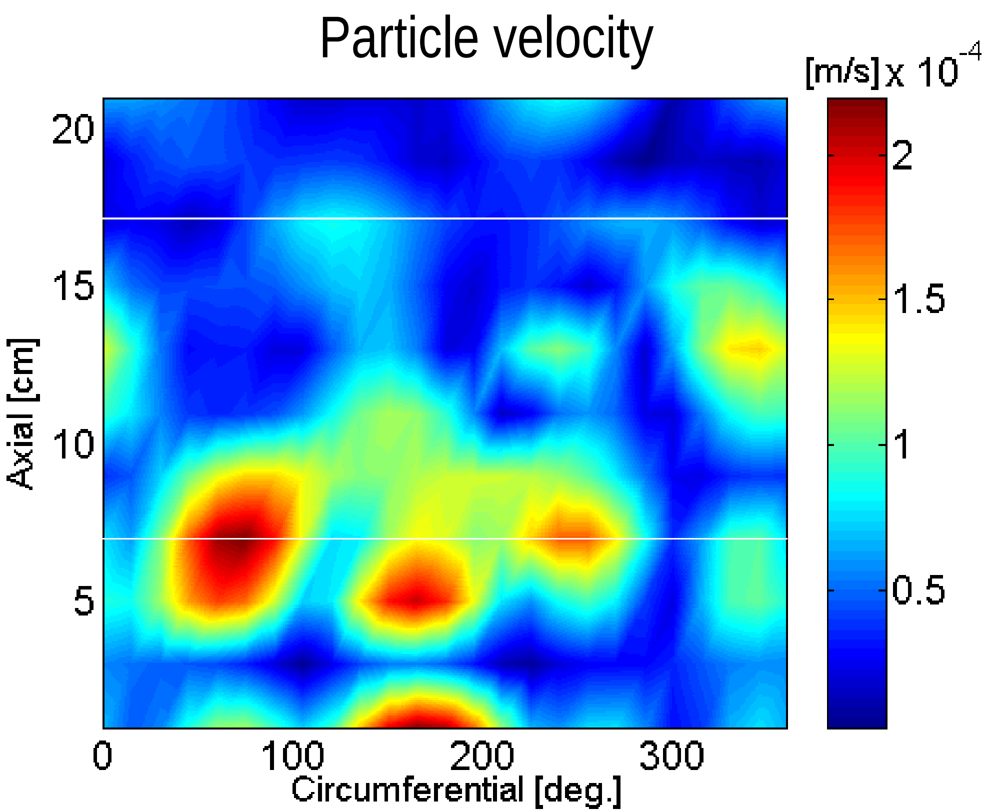
Motor shell vibration (*n*=3 mode) and lower bearing

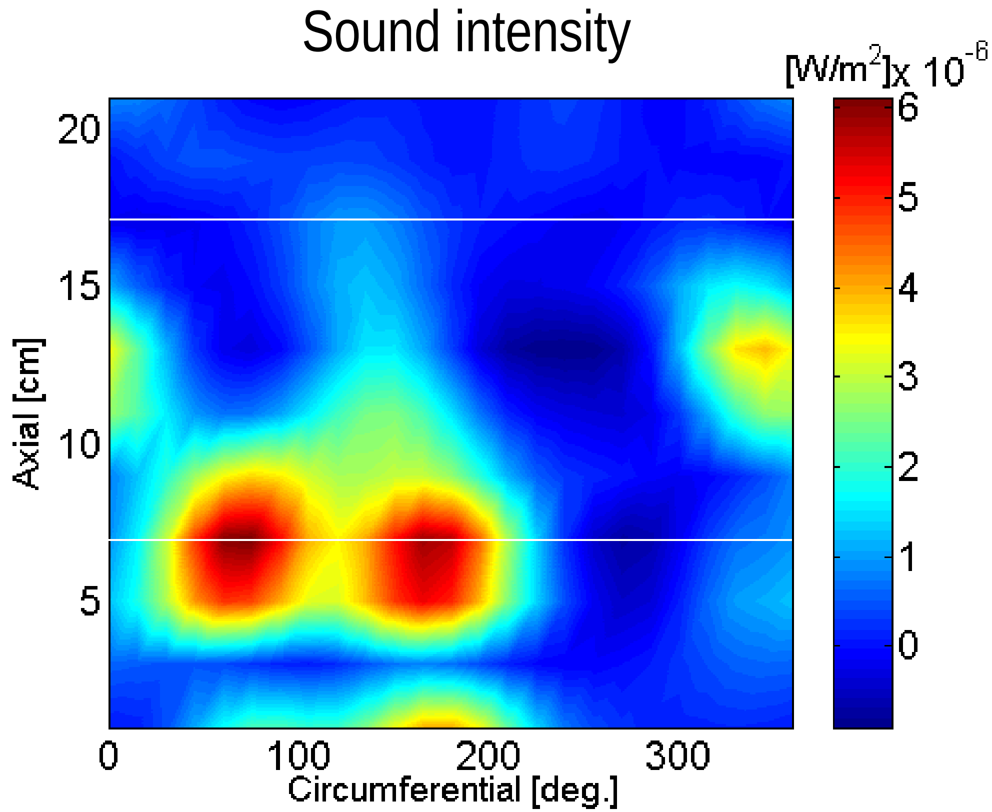
Sound power: 67.8 dB (Ref.: 10^{-12} W), 2nd/8 frequencies

Visualization of Power Seat Motor Noise

- Power seat motor measurement result : Eight major frequencies

3536 Hz





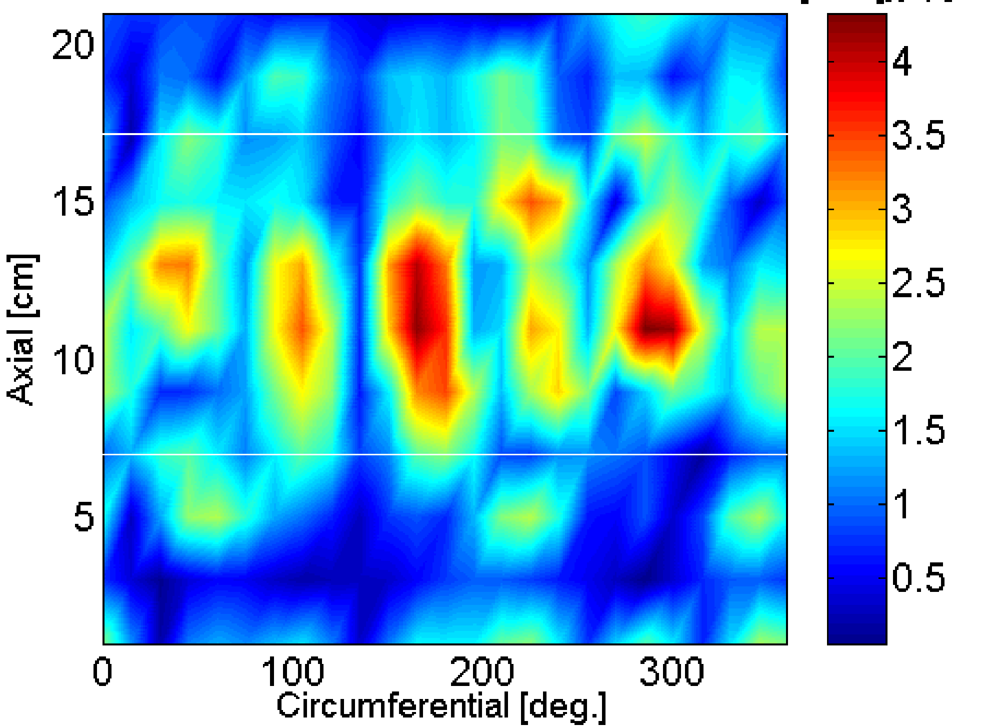
Lower bearing

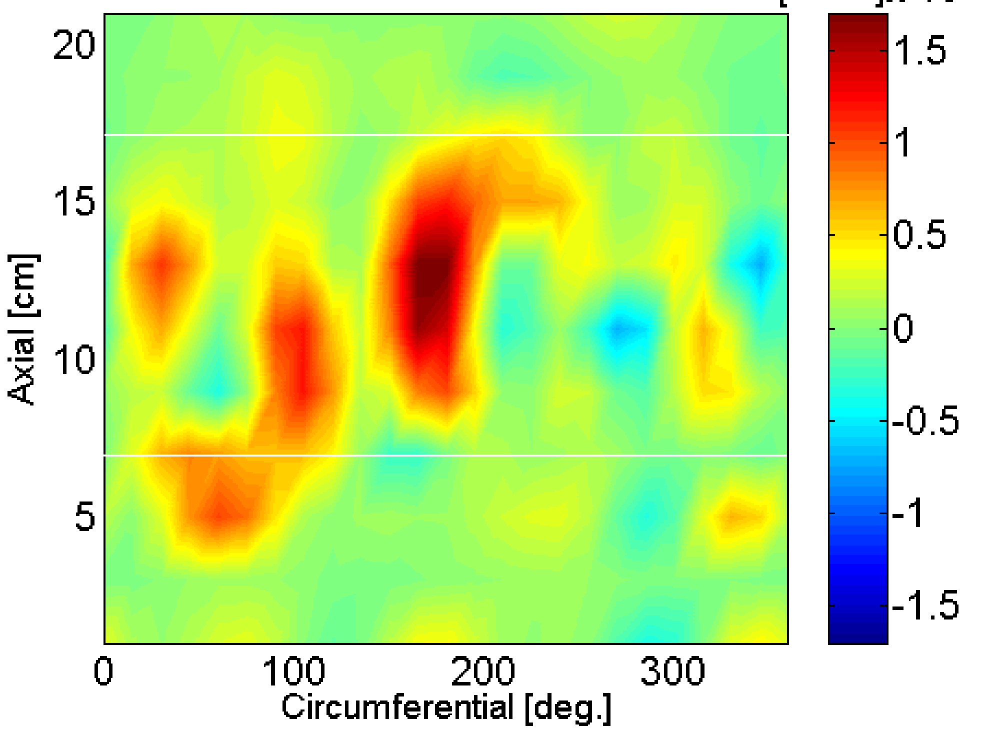
Sound power: 64.8 dB (Ref.: 10^{-12} W), 4th/8 frequencies

Visualization of Power Seat Motor Noise

- Power seat motor measurement result : Eight major frequencies

4032 Hz





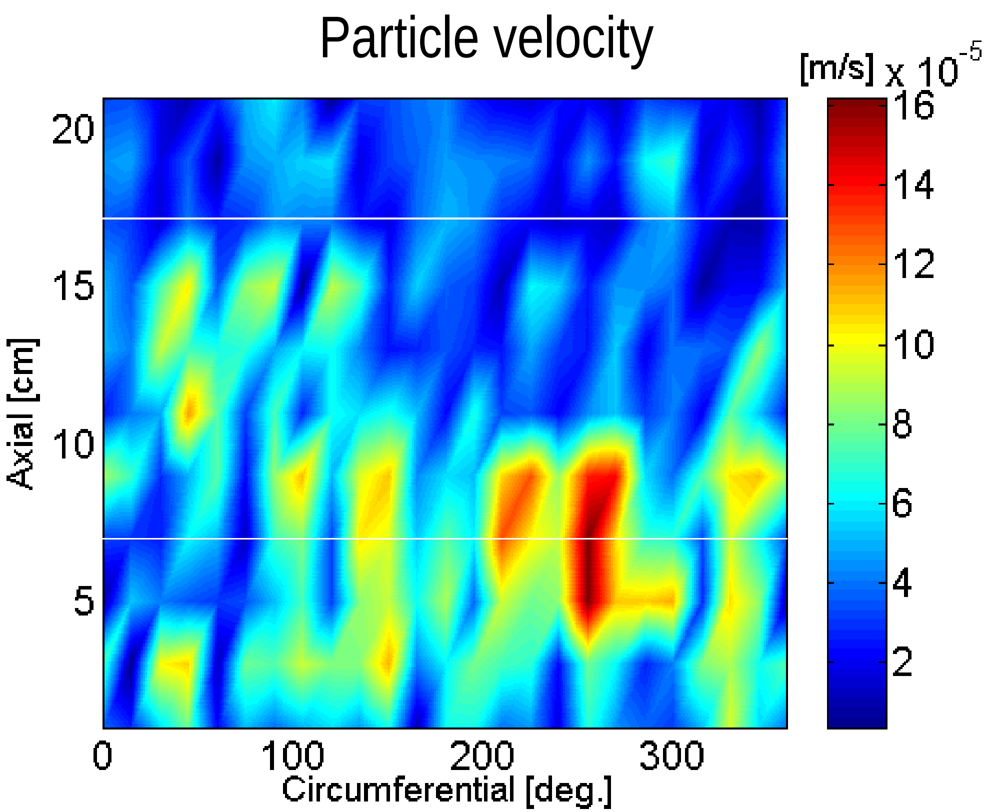
Motor shell vibration (*n*=3 mode) and lower bearing

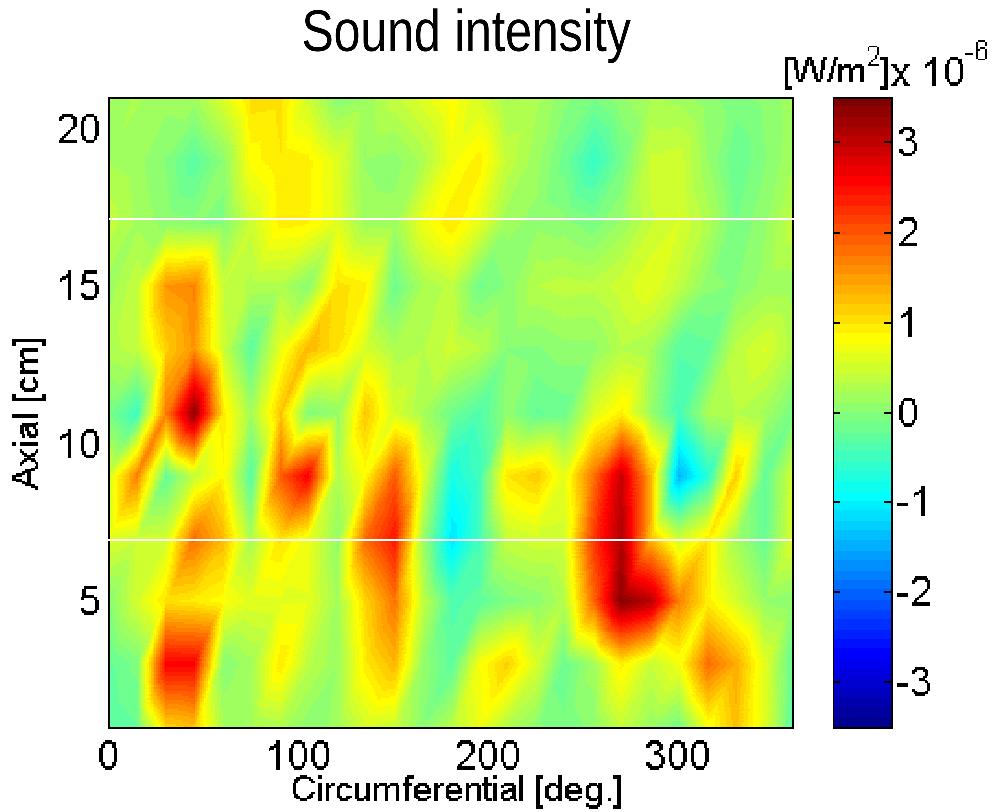
Sound power: 67.5 dB (Ref.: 10^{-12} W), 3rd/8 frequencies

Visualization of Power Seat Motor Noise

- Power seat motor measurement result : Eight major frequencies

8288 Hz





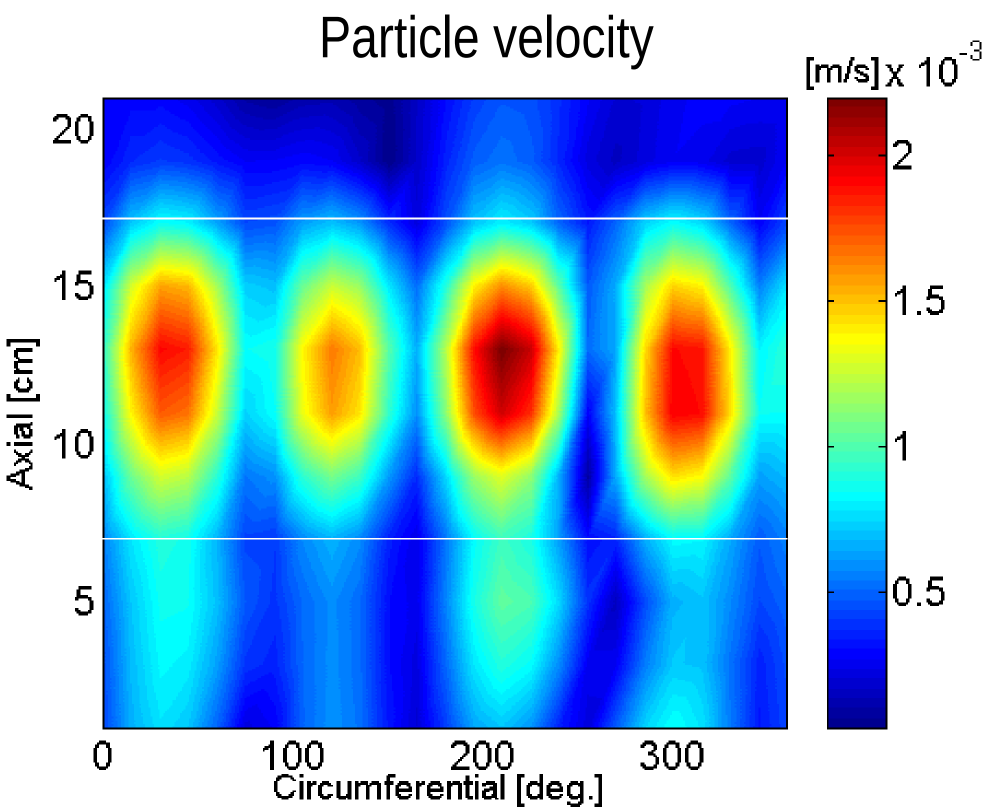
Motor shell vibration and lower bearing

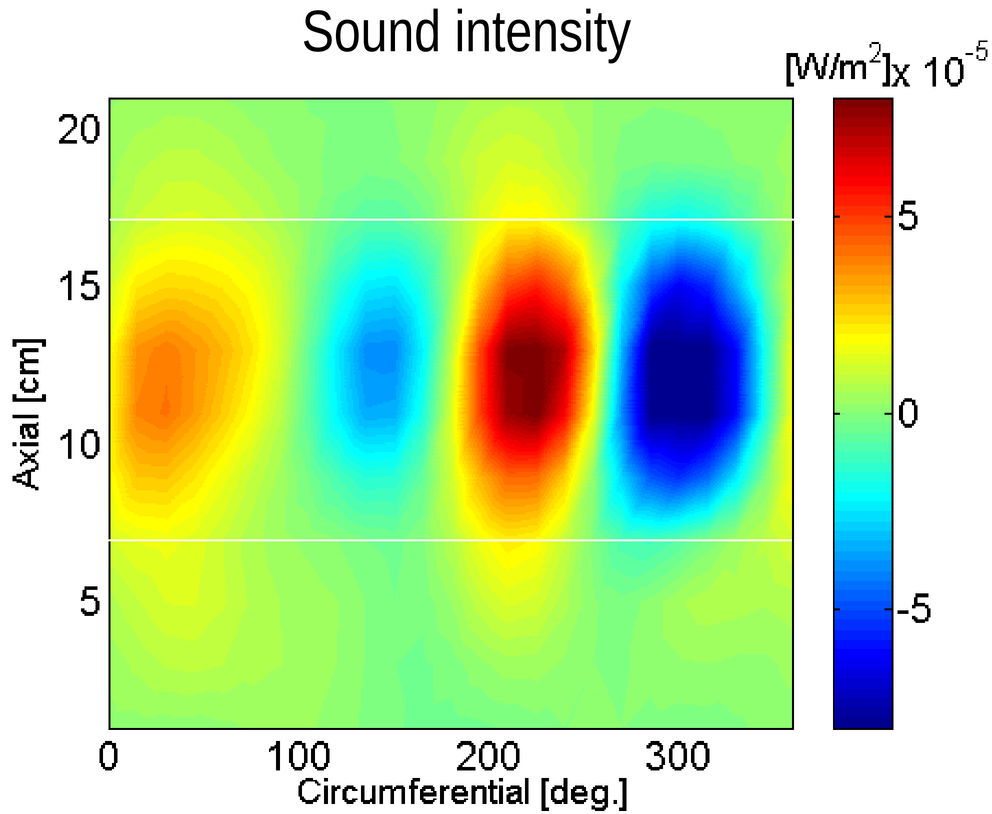
Sound power: 61.5 dB (Ref.: 10^{-12} W), 5th/8 frequencies

Visualization of Power Seat Motor Noise

- Power seat motor measurement result : Shell modes

1196 Hz



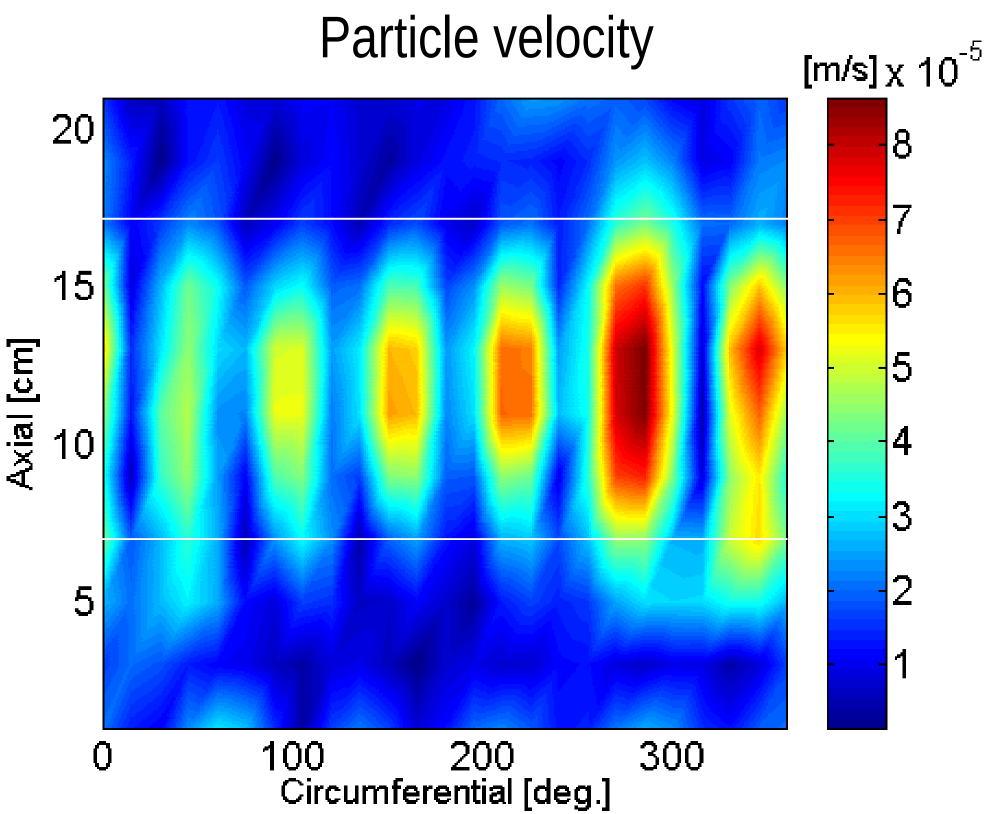


Motor shell vibration (*n*=2 mode)

Visualization of Power Seat Motor Noise

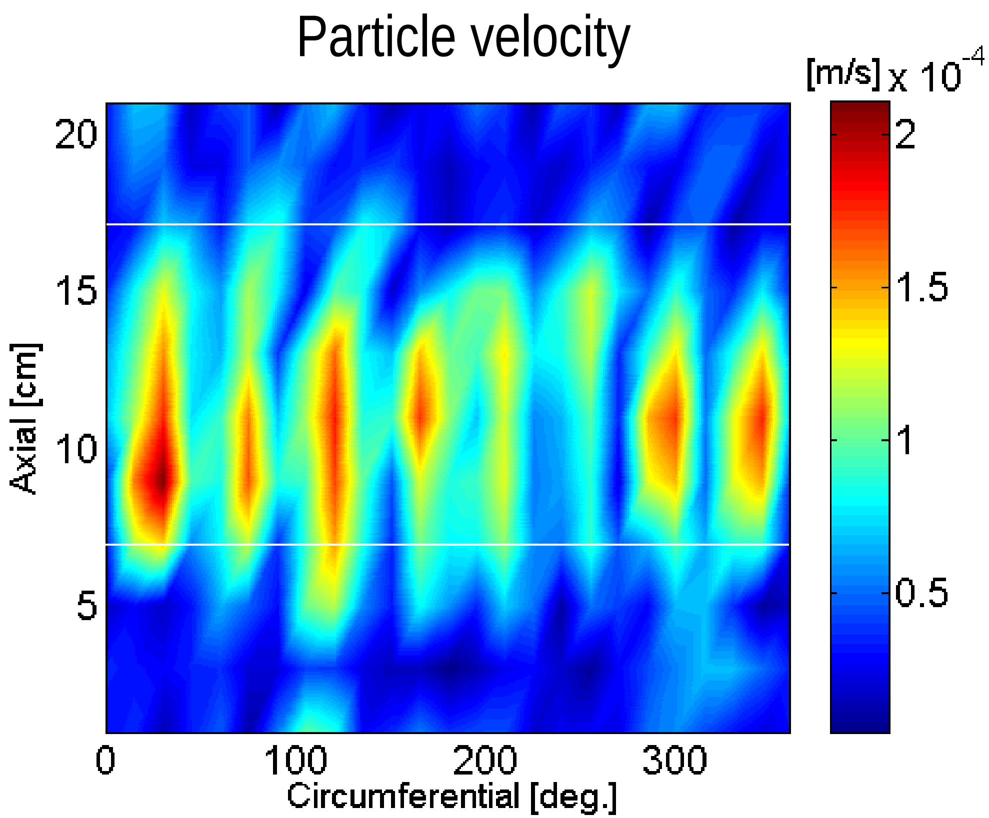
- Power seat motor measurement result : Shell modes

3100 Hz



Motor shell vibration (*n*=3 mode)

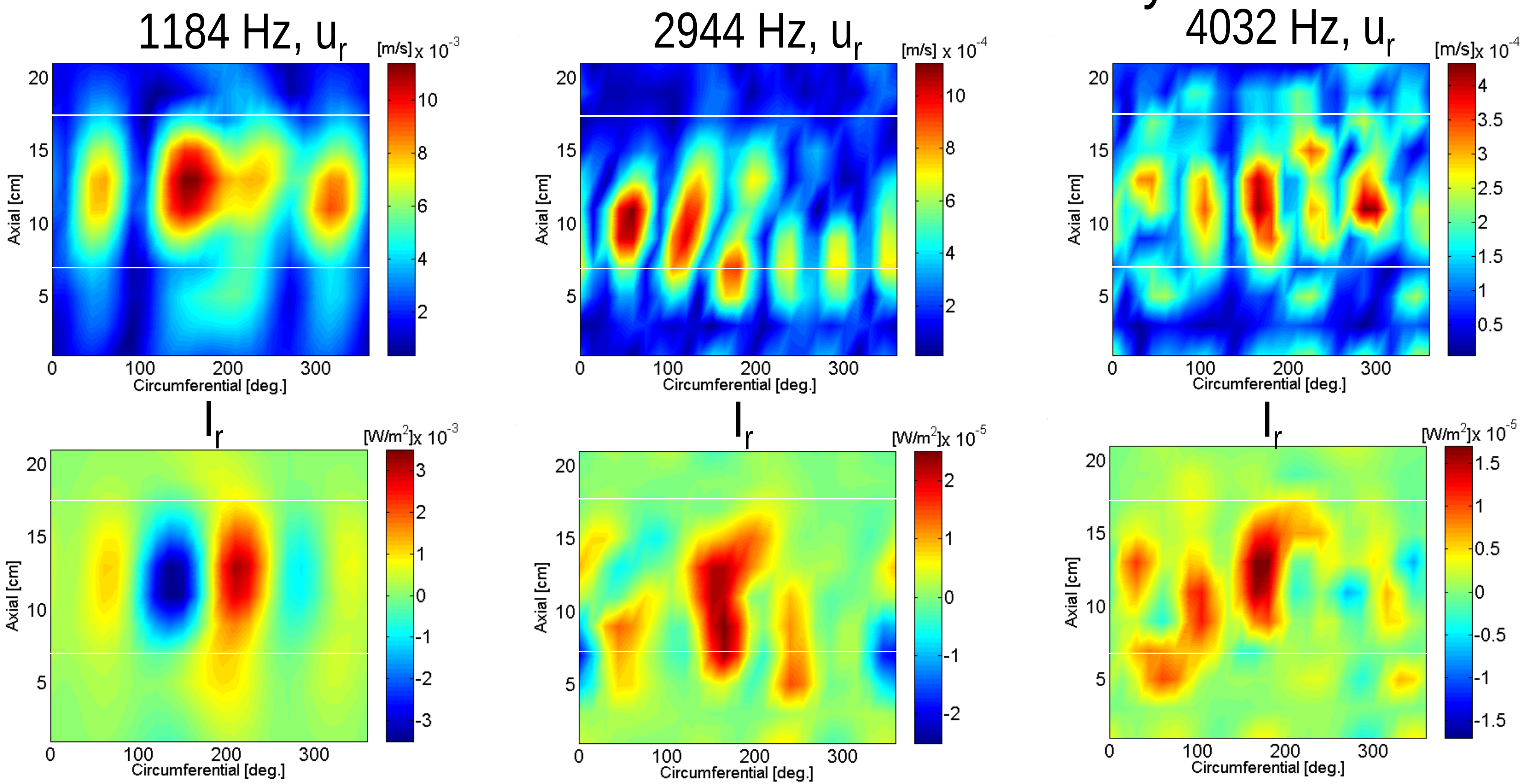
4720 Hz



Motor shell vibration (*n*=4 mode)

Visualization of Power Seat Motor Noise

- Power seat motor measurement result: Summary



Motor shell vibration, *n*=2	Motor shell vibration, *n*=3	Motor shell vibration, *n*=3
Lower bearing	Lower Bearing	Lower bearing

Visualization of Power Seat Motor Noise

- Conclusions

- Possible to visualize closely located sources on compact cylindrical machine accurately by using high resolution, multi-reference acoustical holographic procedure over a wide range of frequencies
- Sound radiation from motor shell vibration and lower bearing were clearly visualized over wide range of frequencies
- Clearly shown that sound radiation around 1184 Hz is primarily from motor shell vibration of *n*=2 mode
- Sound radiation from automotive power seat slide motor was clearly visualized, and also other power seat motors with similar geometry can be clearly visualized