

Test Method for Unification and Luxury of Operating Interior Electric Curtain Noise

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With the rapid expansion of vehicle interior electrification, such as VIP theater mode operating rear door curtains, rear glass curtains, and roll blinds simultaneously, operating sound quality has become a critical element defining premium brand sensibility. Analysis of past customer claims revealed that approximately 21% of electric curtain complaints stemmed from operating noise dissatisfaction, specifically rail ascending and descending noise and flap closure impact noise. Previous structural investigations identified motor-curtain assembly resonances in the 540 to 620 Hz and 810 Hz package tray bands, as well as motor harmonic tone matching with door trims around 540 to 550 Hz, as primary noise contributors. Moving beyond individual structural fixes, this study establishes a systematic statistical framework to ensure operating noise unity across interior electric components, enhance luxury sound quality through high-frequency reduction, and set quantitative standards for premium brand differentiation.

Eight candidate psychoacoustic and physical acoustic scales were selected, including Sound Pressure in dBA, Loudness in sone, Sharpness in acum, Roughness in asper, Tonality, Major Frequency in Hz, Frequency Rate of Change, and 1/3rd Octave Band spectra. To guarantee measurement reproducibility across EV and ICE powertrains, test conditions were standardized at 13.5V DC in an Engine OFF and ACC ON state, eliminating background noise discrepancies of 5 to 10 dBA observed in ICE testing. Subjective evaluation database entries were compiled from 30 participants evaluating 225 test items on a 10-point Likert scale.

Linear regression analysis demonstrated high statistical significance for rear glass electric curtains, yielding an emotional score equation of $-0.5218 \times \text{Sound Pressure} + 30.85$ with $r = -0.969$ and $p < 0.001$, and a Loudness equation of $-1.1230 \times \text{Loudness} + 11.98$ with $r = -0.960$ and $p < 0.001$. Similarly, rear door electric curtain Loudness yielded $-1.4770 \times \text{Loudness} + 13.55$ with $r = -0.960$ and $p < 0.001$, while roll blind Loudness yielded $-1.0670 \times \text{Loudness} + 11.53$ with $r = -0.951$ and $p < 0.001$. Other parameters such as Sharpness and Roughness exhibited lower statistical correlation. Analysis of Variance results confirmed significant variance between vehicle groups, proving that Sound Pressure and Loudness are the primary governing factors for customer preference. Regarding tone unity, reducing overall sound pressure and loudness levels was found to be more effective than matching specific identical frequencies across components, leading to a 1/3rd Octave Band slope guideline.

Development guidelines were defined based on Likert preference targets: 5.0 points (Average, top 65%) for general vehicles and 7.0 points (Quiet, top 35%) for luxury vehicles. Slope guidelines for the 1/3rd Octave Band and motor frequency deviation rate standards were established to secure tone unity and operating uniformity. Verification on a flagship luxury SUV initially yielded an emotional score of 5.4 points. By implementing targeted engineering actions, including adding rubber dampers to panel attachment areas, optimizing controller motor frequency, and adjusting gear dimensions, the vehicle achieved the target score of 7.0 points. Specifically, 100 Hz booming noise was suppressed using rubber dampers, 1 kHz high-frequency motor noise was eliminated via controller frequency tuning, and the motor frequency deviation rate (initially 5.5% UP and 8.7% DOWN) was brought within 5% to eliminate descending noise unpleasantness.

A standardized 13.5V DC evaluation mode was established to eliminate background noise discrepancies and secure measurement reproducibility across EV and ICE platforms. Regression analysis and Analysis of Variance confirmed Loudness and Sound Pressure as the primary physical metrics governing customer emotional perception. Quantitative guidelines were established, setting a luxury target score of 7.0 points, 1/3rd Octave Band slope limits for tone unity, and motor frequency deviation standards. Application to a flagship SUV successfully improved its emotional operating noise score from 5.4 to 7.0 points. Future efforts will expand these criteria into an AI-driven predictive noise design system for all moving interior components.

No.	Analysis Criteria	M					Statistical group					Statistics			
		A	B	C	D	E	A	B	C	D	E	d/f1	d/f2	F	p
1	Relative Rating (1-5)	0.0	3.4	1.6	0.4	2.4	ab	a	a	ab	a	1	158	90.08	0.000
2	rise														
3	Overall														
4	operating														
5	sound														
6	1) "Noisy - Quiet" (0-10 points)	3.7	8.2	5.2	4.0	6.1	b	a	ab	ab	a	2	157	48.11	0.000
7	2) "Sharp - Heavy" (0-10 points)	4.0	6.7	5.4	4.8	5.9	ab	a	ab	ab	ab	1	157	22.06	0.000
8	3) "rough - smooth" (0-10 points)	3.6	7.7	5.9	4.4	6.8	b	a	ab	ab	a	2	157	31.15	0.000
9	4) "Messy - Harmonious" (0-10 points)	3.9	7.4	5.8	5.0	6.3	b	a	ab	ab	a	2	157	22.79	0.000
10	5) "Low-class - luxurious" (0-10 points)	3.9	7.2	5.6	4.7	6.4	b	a	ab	ab	a	2	157	26.68	0.000
11	rise														
12	Early Life														
13	1) "Noisy - Quiet" (0-10 points)	0.0	3.5	1.8	1.0	3.1	ab	a	a	ab	a	1	158	52.17	0.000
14	2) "Sharp - Heavy" (0-10 points)	3.2	8.4	5.8	4.9	7.0	b	a	ab	ab	a	2	157	72.10	0.000
15	3) "Sharp - Heavy" (0-10 points)	3.1	6.7	5.7	5.7	6.6	b	a	ab	ab	a	2	157	35.20	0.000
16	rise														
17	Midterm														
18	1) "Noisy - Quiet" (0-10 points)	0.0	3.9	1.7	0.4	2.5	ab	a	a	ab	a	1	158	85.52	0.000
19	2) "Sharp - Heavy" (0-10 points)	3.5	8.3	5.1	4.0	6.1	b	a	ab	ab	a	2	157	40.05	0.000
20	3) "Sharp - Heavy" (0-10 points)	3.8	6.6	4.8	4.8	6.1	b	a	ab	ab	a	2	157	22.13	0.000
21	4) "rough - smooth" (0-10 points)	3.3	8.0	5.2	4.0	7.0	b	a	ab	ab	a	2	157	63.34	0.000
22	5) "Low-class - luxurious" (0-10 points)	0.0	3.6	1.0	-0.5	2.1	b	a	a	ab	a	2	157	38.86	0.000
23	rise														
24	terminal														
25	period														
26	1) "Noisy - Quiet" (0-10 points)	4.3	8.7	5.3	4.0	6.6	ab	a	ab	ab	a	1	158	103.2	0.000
27	2) "Noisy - Quiet" (0-10 points)	0.0	3.6	0.5	0.5	2.8	b	a	ab	ab	a	2	157	53.06	0.000
28	3) "Sharp - Heavy" (0-10 points)	3.8	8.4	4.5	5.1	7.1	b	a	ab	ab	a	2	157	70.69	0.000
29	4) "Sharp - Heavy" (0-10 points)	4.0	7.1	4.6	5.0	6.6	ab	a	ab	ab	a	1	158	55.75	0.000
30	5) "rough - smooth" (0-10 points)	3.5	8.2	5.0	5.5	7.2	b	a	ab	ab	a	2	157	61.41	0.000
31	6) "Messy - Harmonious" (0-10 points)	3.6	7.8	4.5	5.3	7.0	b	a	ab	ab	a	2	157	40.97	0.000
32	7) "Low-class - luxurious" (0-10 points)	3.9	7.8	4.8	5.3	7.2	b	a	ab	ab	a	2	157	53.01	0.000
33	rise														
34	Early Life														
35	1) "Noisy - Quiet" (0-10 points)	0.0	3.9	0.1	0.9	3.2	ab	a	a	ab	a	1	158	94.75	0.000
36	2) "Noisy - Quiet" (0-10 points)	4.2	8.7	5.9	5.1	7.5	ab	a	b	ab	a	2	157	90.97	0.000
37	3) "Sharp - Heavy" (0-10 points)	0.0	4.0	0.7	0.6	2.6	ab	a	a	a	a	1	158	25.20	0.000
38	4) "Noisy - Quiet" (0-10 points)	3.6	8.7	4.7	4.8	6.8	b	a	ab	ab	a	2	157	84.81	0.000
39	5) "Sharp - Heavy" (0-10 points)	4.1	7.0	4.6	4.7	6.4	ab	a	ab	ab	a	1	158	60.13	0.000
40	6) "rough - smooth" (0-10 points)	3.3	8.3	4.7	5.0	7.0	b	a	ab	ab	a	2	157	67.17	0.000
41	7) "Noisy - Quiet" (0-10 points)	0.0	3.6	2.1	1.5	2.1	ab	a	a	a	a	1	158	46.21	0.000
42	8) "Noisy - Quiet" (0-10 points)	3.2	7.5	6.0	5.5	6.3	b	a	ab	ab	a	2	157	47.95	0.000
43	9) "Sharp - Heavy" (0-10 points)	3.3	7.2	5.8	5.6	6.0	b	a	ab	ab	ab	2	157	37.38	0.000

Fig.1 ANOVA Analysis Significant Factor Verification