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POWERED SEAT ADJUSTER NOISE CHARACTERISTICS AND ITS PSYCHOACOUSTICS ASSESSMENT

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Abstract

In order to improve the noise performance for the seat adjuster mechanism, noise and vibration measurements were conducted in both European and Australian cars for six and eight modes of the seat adjustment operations on the driver's seat. The six modes of the driver's seat operations are: both up for the front and rear seat ends, both down for the front and rear seat ends, front seat end up, front seat end down, rear seat end up and rear seat end down. The eight modes of the seat operations are: forward, backward, both up for the front and rear seat ends, both down for the front and rear seat ends, front seat end up, front seat end down, rear seat end up and rear seat end down. The noise and vibration levels, sound quality and the root causes for the noise problems have been analysed and discussed for the six and eight modes of the seat adjustment operations. The noise characteristics have been identified; the psychoacoustic parameters have been used to quantify the sound quality of the seat adjuster and the assessment results have been found to match well with subjective evaluation results.

1. INTRODUCTION

Over the last two years significant advances have been made in relating the subjective perception of vehicle sound to objective measures or metrics. Psychoacoustic parameters such as Loudness, Sharpness, Roughness, Fluctuation Strength, Tonality have been applied to evaluate sound quality of machinery [1].

A way to quantify loudness is to relate the sensation stimulus to a known standard sound by asking subjects how much louder or softer a test sound is. Sharpness is a ratio of high frequency level to overall level. Sounds can be perceived as tonal when they contain pure tones or noise with bandwidths less than 1 critical band. Roughness is generated by sounds that contain tones spaced within a critical band, amplitude modulated tones, frequency modulation and rapidly, repetitively fluctuating noise. Parameters important to roughness are degree of modulation (AM), frequency modulation index (FM) and modulation frequency. Fluctuation Strength measures the sensation of "slow moving" modulation. A good example is a pair of closely spaced tones which causes beating. Modulating sounds can cause a different hearing sensation depending upon level of modulation and rate of modulation. The standardized psychoacoustic measures of modulation fall into two different categories: Fluctuation and Roughness.

Seat adjusters are normally operated when the driver first enters the vehicle, particularly if the seat is a long way out of adjustment. This represents the worst case as there are no other sources to provide masking of the adjuster noise.

The aim in design of seat adjusters focuses on both the objective and subjective qualities dictated by the customer. The discriminating consumer also demands greater travel lengths, improved operation smoothness and stability. When working on new designs for power seat adjusters, one major issue to address would be quality of the sound developed by the mechanism.

Cerrato, G., etl [2] developed a method for analysing and predicting the sound quality of seat adjusters and described the statistical methods of analysing jury preference data. They identified a model or relationship between the objective data and subjective data using regression analysis. This model was a linear combination of a "loudness-related" metrics, a "modulation-related" metrics and a "impulsiveness-related" metrics. The seat adjuster noise character difference in one of operating modes was insufficient as to require a different coefficient for accurate evaluation. The relationship between sound metrics and vibration data was not investigated. Bernard, T., etl [3] tried to implement at the end of assembly line an automated Sound quality-based inspection system that relies exclusively on objective parameters. They concluded that the A-weighted Sound Pressure Level does not allow to judge between good and bad seat track sound quality and DC-motor RPM is an important factor which affects the perceived sound quality of the seat track.

Laux, P., etl. [4] developed a model for prediction of sound quality of power seat mechanisms. This model was based on the statistical correlation of objective popular sound quality metrics to a set of subjective data obtained using step wise regression. This resultant model showed better correlation to the subjective data than overall sound quality metrics such as Loudness, UBA, Pleasantness, etc. However the model error was larger than the population difference. There were still some components or properties of these sounds that subjects were responding to but the model was not properly accounting for. A specific experiment was then designed to test for a variety of expected common experimental errors. The data represented a valid set of subjective responses from which extensive model development of preferences relative to engineering measures can be conducted. However the population inferred can only extend to the population sampled in the study. Therefore, it could not be proven that there were any effects of presentation order on the subject's individual ratings. It was concluded that the three metrics (pleasantness, annoyance and delight) were all measuring the same subjective scale or dimension as those descriptors apply to the sound of power seat adjuster mechanisms, and an overall metric Total Subjective Quality (TSQ) was developed that averaged the results of the three.

2. EXPERIMENTAL DESCRIPTION AND TEST SET UP

In order to refine the seat adjuster noise performance, it is important to identify the noise characteristics of the seat adjuster. Three different passenger vehicles A, B, and C are instrumented and tested. A 90 kg mass was placed on the seat which simulated a human body mass. A microphone was installed at the driver's ear outboard inside the cabin to record the seat adjuster operating sound in a stationary vehicle with engine ignition off as shown in Figure 1. An accelerometer was installed at the driver's seat track outboard in the vertical direction as shown in Figure 2. The Brüel & Kjaer Pulse intelligent dynamic data acquisition and analysis system and sound card – Syntrillium Cool Edit 96 system were used to record and analyse the noise and vibration signals under all operating modes of the seat adjuster (forward, backward, both end up, both end down, front end up, front end down, rear end up and rear end down). The Head Acoustics Artemis software was used to analyse the sound quality.

Vehicle A had a high subjective rating for the seat adjuster noise, Vehicle B had a medium high subjective rating for the seat adjuster noise, and Vehicle C had a low subjective rating for the seat adjuster noise.

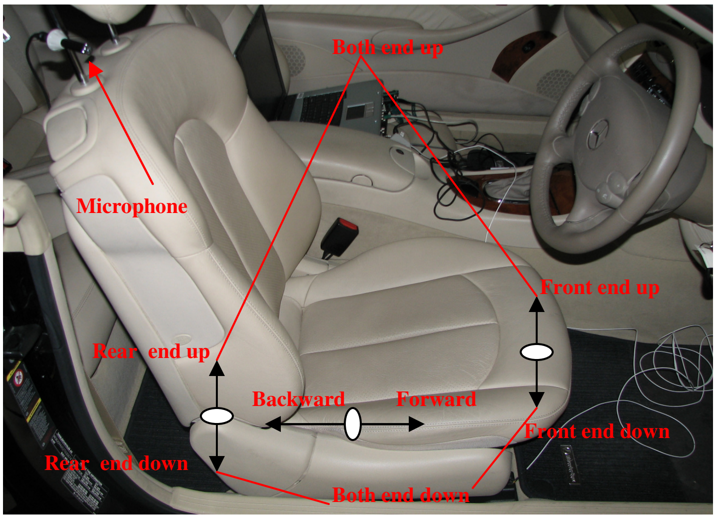

Figure 1 Positions of the microphone.

3. TESTING RESULTS AND DISCUSSIONS

Table 1 show the noise at the operating mode of **the both end up** for Vehicle **C** has the worst sound quality and the noise at the operating mode of **the front end down** for Vehicle **A** has the best sound quality. Table 2 shows the maximum noise and vibration levels are **57.7** dB(A) and **0.165** m/s^2 at the operating mode of **the backward** for Vehicle **C**. The minimum noise and vibration levels are **48.9** dB(A) and **0.0024** m/s^2 at the operating mode of **the front end down** for Vehicle **A**. The maximum and minimum Loudness correspond to the maximum and minimum sound pressure levels which occurred at the same operating modes of the same vehicles. The maximum Loudness is 34.1 soneGF at the operating mode of the backward for Vehicle C. The minimum Loudness is 14.9 soneGF at the operating mode of the **front end down** for Vehicle **A** as shown in Table 1.

It is noted from Tables 1 and 2 that the overall sound pressure level more than 55 dB(A) had bad sound quality. The operating modes of the seat adjuster with bad sound quality were: **the both end up**, the front end up and the backward for Vehicle C. Therefore if the SPL target for the seat adjuster mechanism design is set as 50 dB(A), and if the design targets of the loudness, the fluctuation strength, the roughness for the seat adjuster noise are 25.2 soneGF, 0.0697 vacil, 3.18 asper, Vehicles A meets the design targets, Vehicle B nearly meets the targets and Vehicle C does not meet the targets.

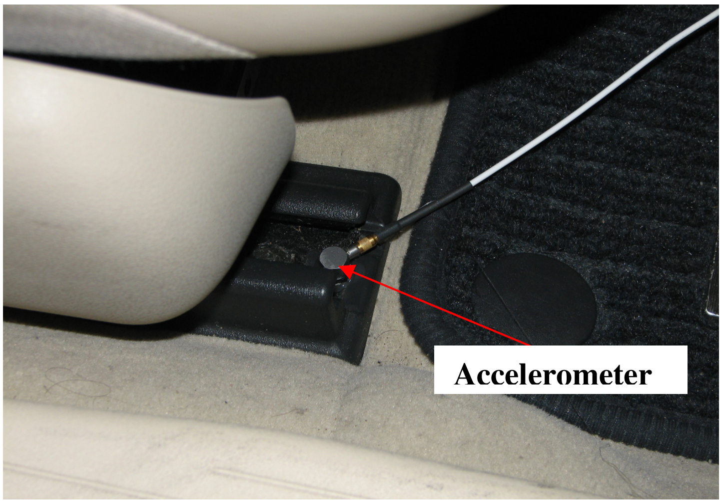

Figure 2 Positions of the accelerometer

Table 1 Sound quality evaluation for the seat adjuster mechanism of Vehicles A, B, and C.

Modes of Operating	Loudness (soneGF)			Fluctuation Strength (vacil)			Roughness (asper)			Sharpness (acum)			Tonality (tu)			Subjective Rating (R1-R10)		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Both End Up	17.4	20.9	33.2	0.046	0.045	0.14	1.91	2.05	4.19	2.27	2.21	2.38	0.26	0.18	0.241	9.5	9	7
Both End Down	19.7	22.8	29.4	0.067	0.065	0.060	1.75	2.27	2.64	2.26	2.19	2.43	0.35	0.27	0.204	9.5	8.5	8
For ward	N/A	27.7	26.5	N/A	0.035	0.078	N/A	1.9	2.57	N/A	1.94	2.11	N/A	0.31	0.147	N/A	8.5	8.5
Back ward	N/A	25.1	34.1	N/A	0.037	0.101	N/A	1.88	2.31	N/A	2.03	2.22	N/A	0.31	0.347	N/A	8.5	7.5
Front Up	15.7	19.7	31.8	0.048	0.062	0.069	1.89	1.92	2.28	2.32	2.23	2.38	0.34	0.41	0.355	9.5	9	7.5
Front End Down	14.9	19.8	28.2	0.047	0.052	0.065	1.71	1.92	3.03	2.47	2.27	2.35	0.25	0.39	0.288	9.5	9	8.5
Rear End Up	15.3	20.9	25.2	0.037	0.058	0.07	1.71	1.73	3.18	2.25	1.96	2.14	0.35	0.33	0.27	9	9	9
Rear End Down	15.3	21.6	27.6	0.036	0.067	0.072	1.71	1.96	3.46	2.25	2.11	2.19	0.35	0.45	0.286	9	8	8.5

Table 2 Noise and vibration levels for seat adjuster mechanism of Vehicles A, B, and C.

Benchmark Vehicles	**Vehicle A**		**Vehicle B**		**Vehicle C**	
Modes of Operating	**Total SPL dB(A)/20 upa**	**Total Vibration (m/s^2)**	**Total SPL dB(A)/20 upa**	**Total Vibration (m/s^2)**	**Total SPL dB(A) /20 upa**	**Total Vibration (m/s^2)**
Both End Up	49.2	0.0532	49.8	0.0873	55.8	0.106
Both End Down	48.9	0.0480	50.6	0.1535	50.1	0.129
FORWARD	N/A	N/A	50.6	0.2762	49.6	0.148
BACKWARD	N/A	N/A	50.1	0.1138	**57.7**	**0.165**
Front End Up	49.8	0.0273	50.3	0.0497	55.9	0.106
Front End Down	**48.9**	**0.0246**	49.6	0.1038	51.3	0.143
Rear End Up	49.9	0.0497	50.2	0.0640	49.5	0.062
Rear End Down	49.9	0.0497	49.9	0.0761	51	0.063

One of the important features of the seat adjuster sounds is their time dependent characteristics. Although nominally running at a constant speed some of seat adjuster mechanisms show significant motor speed variations with time due to friction or load variations. Figure 3 shows that the poor sound quality at the operating mode of **the both end up** was induced by high levels of the dual peak frequency modulation around 600 Hz (and 1600 Hz). Speed variation in the motor gave rise to frequency modulation of the mechanism harmonics. Figure 4 shows that the noise and vibration at the operating mode of the rear end up only had a single peak at 657 Hz, no peaks appeared around 1600 Hz, therefore no frequency modulation existed. This explains why the sound quality at the operating mode was good. It is seen from Figures 3 and 4 that the noise spectrum peaks had the same frequencies as the vibration spectrum peaks which mean the noise was structure-borne. Therefore, the poor sound quality was induced by the frequency modulation around 600 Hz (and 1600 Hz). The high sound pressure levels of the noise at the operating mode of the backward may be caused by a loud motor. Sharpness and Tonality showed very little influence on the sound quality of the seat adjuster. Figure 5 shows that the overall noise and vibration levels at the operating mode of the backward were much higher than those at the operating modes of **the both end up** and the rear end up. There was very little frequency modulation at the operating mode.

Figures 6, 7 and 8 display the modulation spectrum contour maps where the horizontal axis represents the time history; the vertical axis represents the modulation frequency in octave 1000 Hz; the colour scale represents the modulation amplitude in SPL (dB). Figure 6 shows that the noise at the operating mode of **the both end up** had the maximum level of the frequency modulation which supports the conclusion from Figure 3, that is, high levels of the dual peak frequency modulation degraded sound quality at the operating mode of **the both end up**; Figure 7 shows that the noise at the operating mode of the rear end up had the minimum level of the frequency modulation which supports the conclusion from Figure 4, that is, the noise and vibration at the operating mode of the rear end up only had a single peak, no frequency modulation existed; Figure 8 shows that the noise at the operating mode of the backward had the high levels of the noise and very low level of the frequency modulation which supports the conclusion from Figure 5, that is, the overall noise and vibration levels at the operating mode of the backward were much higher than those at the operating modes of **the both end up** and the rear end up. There was very little frequency modulation at the operating mode.

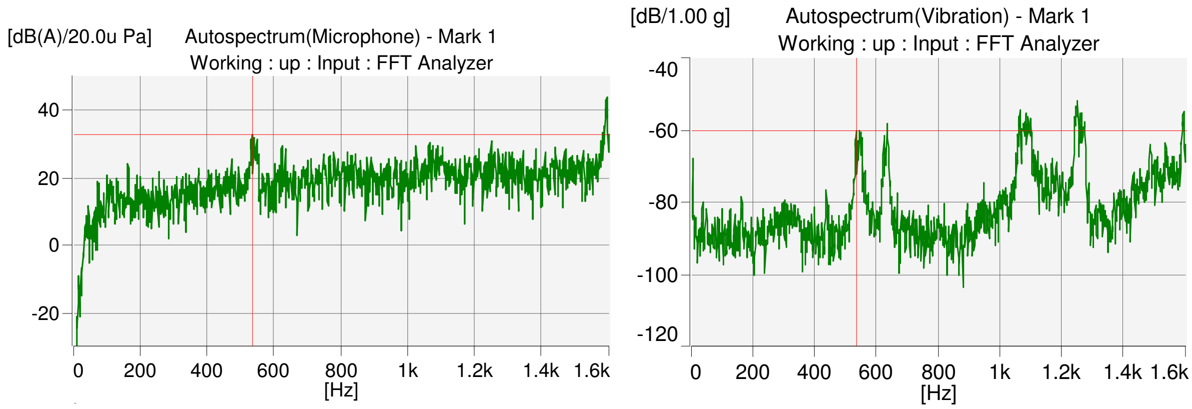

Figure 3 Noise and vibration spectrum at the operating mode of the both end up for Vehicle C.

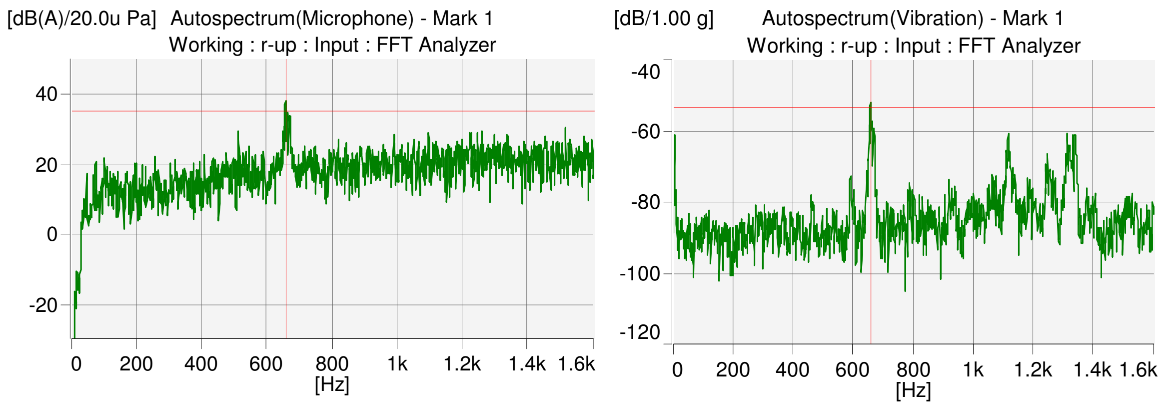

Figure 4 Noise and vibration spectrum at the operating mode of the rear end up for Vehicle C.

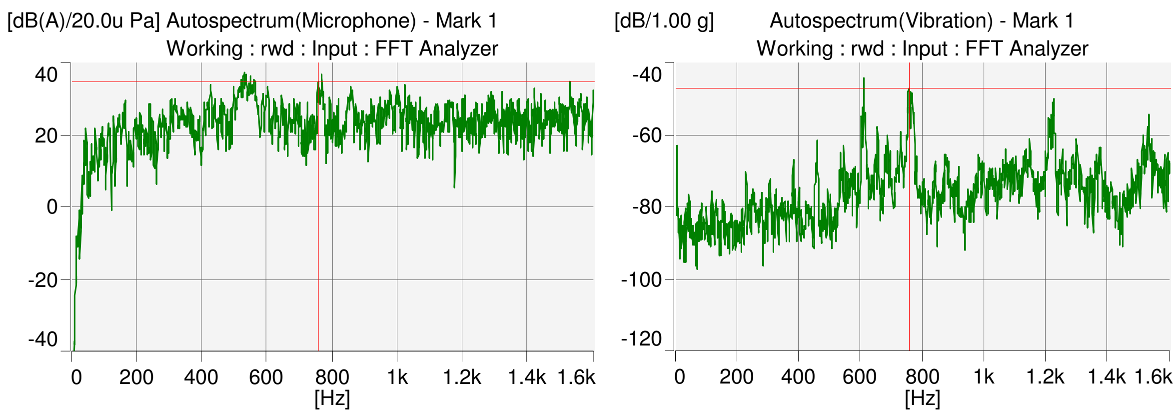

Figure 5 Noise and vibration spectrum at the operating mode of the backward for Vehicle C.

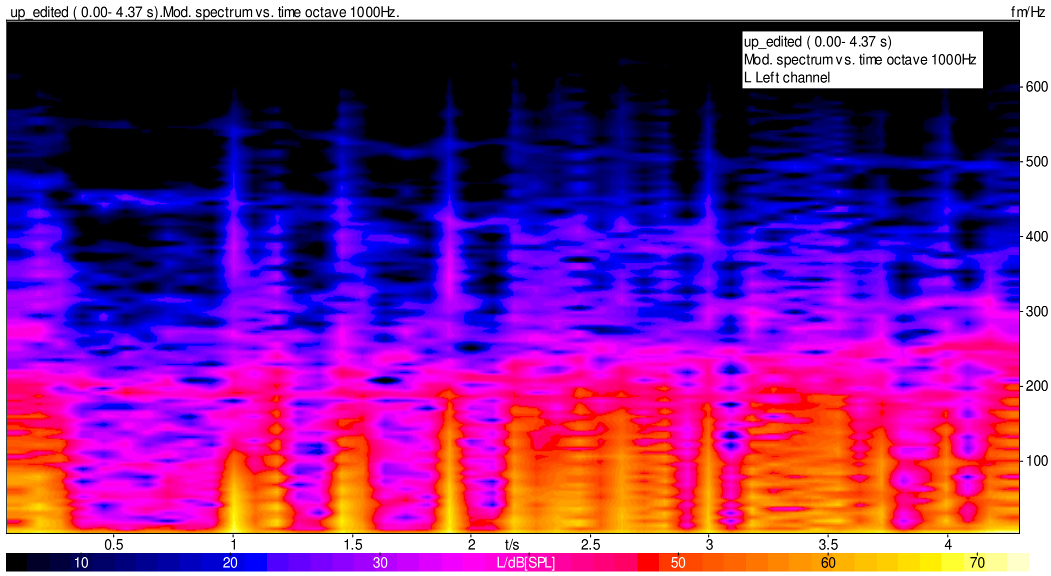

Figure 6 Frequency modulation spectrum contour map at the operating mode of the both end up for Vehicle C

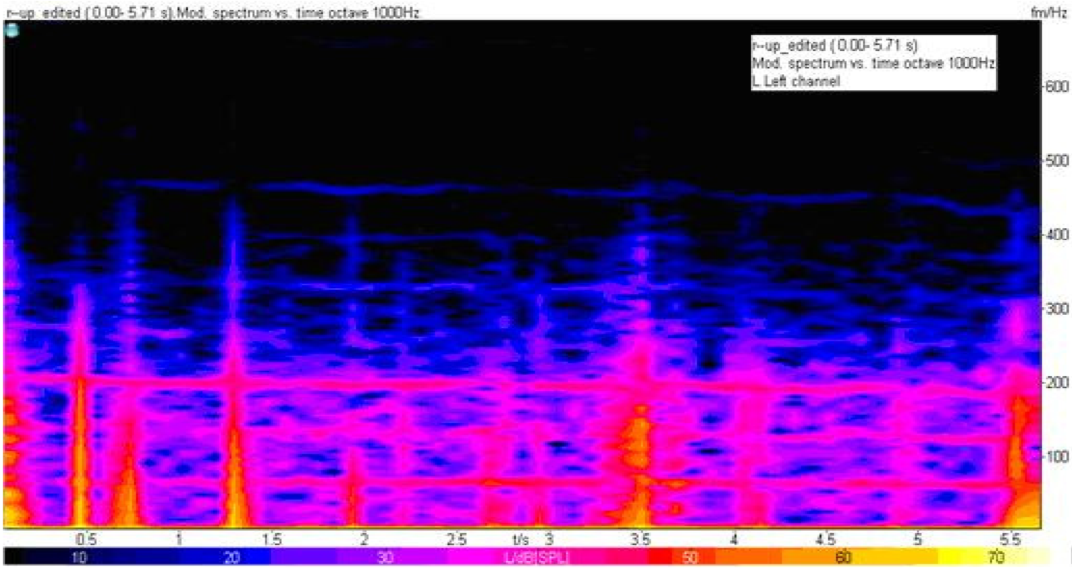

Figure 7 Frequency modulation spectrum contour map at the operating mode of the rear end up for Vehicle C.

The frequency modulation exhibited by the seat adjuster coincides with two psycho acoustic phenomena referred to as fluctuation strength and roughness. In other words, the frequency modulation and loudness determine the sound quality of the seat adjuster. This is verified by the operating mode of the both end up of Vehicle C in Table 1 where fluctuation strength, roughness and loudness had the largest or second largest values among the all operating modes, the sound quality was the worst in this operating mode. In Table 1, the loudness, fluctuation strength and roughness in the operating mode of the front end down for Vehicle A was least and had the best sound quality. These results match well with the subjective evaluation results in Table 1. The frequency modulation may be caused by variations in the load applied to the motor at each tooth in the reduction gear.

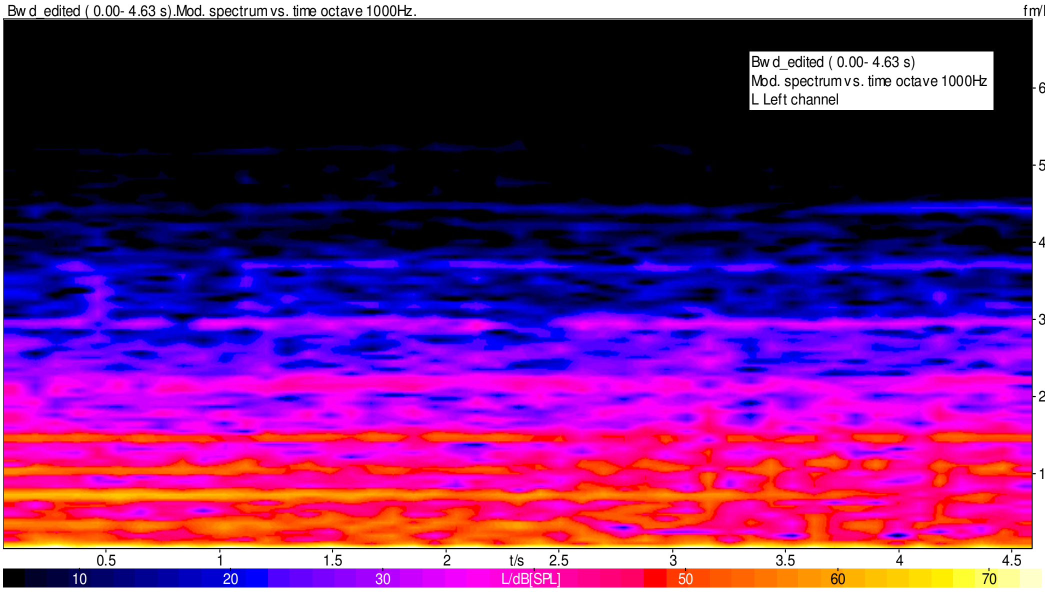

Figure 8 Frequency modulation spectrum contour map at the operating mode of the backward for Vehicle C.

4. CONCLUSIONS

- The seat adjuster operating noise is structure borne noise.
- In regard to sound pressure level and sound quality of the seat adjuster noise, Vehicle A is the best, Vehicle C is the worst.
- The sound quality of the seat adjuster noise is determined by the frequency modulation. The frequency modulation is assessed by psychoacoustic parameters Fluctuation Strength and Roughness, and Loudness. Sharpness and Tonality have very little influence on the frequency modulation, and therefore on the sound quality of the seat adjuster noise.
- The poor sound quality is induced by the frequency modulation around 600 Hz (and 1600 Hz). The high sound pressure levels of the noise at the operating mode of the backward may be caused by a loud motor.
- The maximum and minimum Loudness correspond to the maximum and minimum sound pressure levels.
- If design target for the seat adjuster sound pressure level is set as 50 dB(A), and if the design targets of the loudness, the fluctuation strength, the roughness, for the seat adjuster noise are set as 25.2 soneGF, 0.0697 vacil, 3.18 asper, Vehicles A meets the design targets Vehicle B nearly meets the targets and Vehicle C does not meet the targets.
- The objective sound quality data match well with the subjective evaluation data for Vehicle A, B and C.

5. REFERENCES

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