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Analysis of Friction Noise and Vibration from the Cushion Frame of a Driver's Seat in Passenger Cars

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Abstract

In this study, the vibration and noise for the cushion frame that directly contacts the driver of the car are investigated. The friction noise from the seat track generating the largest noise is measured and analyzed. Also, vibration measurement and analysis are performed in parallel to locate the position from where the noise is generated. In the next stage, the RPM of motor and the current changes during motor driving are measured. The vibration and noise generated during motor running are also measured and analyzed to examine the interaction between noise from the track and load on the motor. The vibration and noise analysis results are expressed using FFT analysis, octave analysis, spectrum contour map analysis, and sound visualization.

Keywords: *Squeak noise, Seat vibration, Automotive seat, BSR, Sound visualization*

1. Introduction

As interior parts of cars develop, a number of customers are placing premium on a vehicle's high sensitivity and amenity. Car seats are drawing more attention since they are in direct contact with the passengers. Several motors are attached to the power seat and the noise (BSR: Buzz/Squeak/Rattle) generated from seats when these are moved front/back and up/down by motors makes customers complain [1]. At present, researches about this noise generation are underway [2-3]. Choi *et al.*, [4] theoretically established that the noise was generated from the lead screw. Lee *et al.*, [5] analyzed the noise generated during car driving. Kang *et al.*, [6] determined the friction or contact generated from the car seats by a numerical analysis. However, the above researches are about noise analysis for general mechanical parts or assembled seats. The researches for the friction occurring between seat parts are still insufficient. Therefore, there is a need to investigate the characteristics of vibration noise between car seats for BSR problems [7]. The mechanism of the car seats is comprised of parts which move towards the front and back directions [8]. The structure of such mechanism is given in Table 1. The seat parts are operated in such a way that when a small DC motor is rotated, the worm reducer is rotated by the connected axis. Also, the screws and nuts connected with this worm reducer axis for the transfer convert the rotation movement into a reciprocating movement to move the seat towards the front and back. The major noise source is a friction noise between the track and slide, while the rest of the noises are assumed to be generated from rotational contact from the worm reducer and motor load. Though the drive part of the car seat is constructed with simple parts, the noise is produced while a driving force generated from the motor is transmitted to the seats through a flexible shaft, reducer, and lead screw [9-10]. The type of generated noise comes in a complex phenomenon unlike

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theoretical size. Vibration and noise, in particular, could be severely generated by various frictions of adjourning parts [11]. Therefore, in this study, the vibration and noise for the cushion frame that directly contacts the driver of the car are investigated. The friction noise from the seat track generating the largest noise is measured and analyzed. Also, vibration measurement and analysis are performed in parallel to locate the position from where the noise is generated. In the next stage, the RPM of motor and the current changes during motor driving are measured. The vibration and noise generated during motor running are also measured and analyzed to examine the interaction between noise from the track and load on the motor. The vibration and noise analysis results are expressed using FFT analysis, octave analysis, spectrum contour map analysis, and sound visualization.

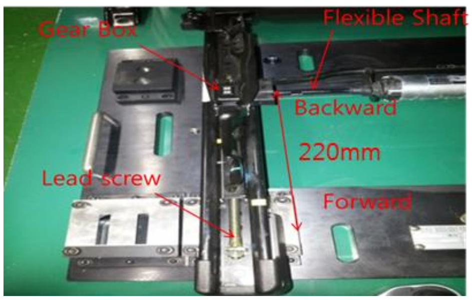


Figure 1. Photos of seat sliding parts' structure

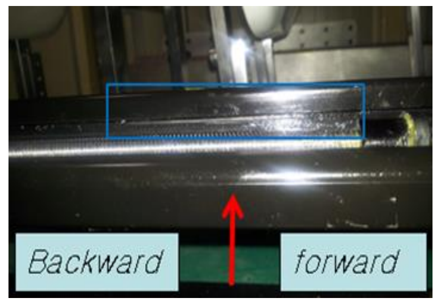


Figure 2. Abraded portion in the rail occurred during slide movement

2. Testing parts and testing methods

The power seat used in the present experiment is the one installed in the commercial vehicle from Company A. The motor installed in the power seat is DC motor having a capacity of 30W which is run at a voltage of 13.5-15V. The worm reduction rate is 3:1. Motor and reducer are connected by a urethane flexible shaft. The lead screw and lead nut used in the experiment are 8 mm in diameter, one line, 1.5mm in pitch, and with a screw angle of 29˚ with acme thread. Detailed specifications of the lead screw and the lead nut are given in Table 1. The photo of the test specimen is presented in Figure 3.

Table 1. The specification of sliding screw

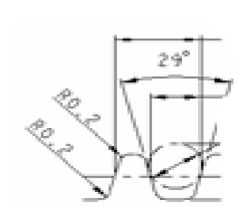
Item			TOOTH PROFILE DETAIL (S=10:1)
LEAD SCREW	OD	Ø 8.0	Normal angle 
	Depth of thread	1 line	
	Pitch	1.5	
	Pressure angle	22	
LEAD NUT	ID	Ø 8.0	
	Depth of thread	1 line	

Figure 3. Screw & nut

The seat is installed at the front part and raised with an incline five degrees in a similar fashion as it is installed in the car. For the seat movement test, a dedicated drive equipment power set adjuster as shown in Figure 4 is used. The weight of the passenger on the seat is adjusted by loading a 105kgf dummy on the upper part of the seat frame track based on the standard of the automotive makers (Figure 5). The input voltage 13.5V is uniformly maintained throughout the experiment. Noise and vibration are measured simultaneously by an LMS equipment from the USA based on the microphone (mic) installed at one place and from two places of vibration points as shown in Figure 6 and Table 2. The mic is installed at 600mm from the cushion which is the closest point as the head position of the passenger according to the vehicle testing standard. Vibration is measured with an accelerometer which can measure three axes at the same time. The load on the drive motor is estimated as rotation per minute while loaded current is also measured in real time. The motor load measurement results are used in the spectrum contour map and the FFT analysis by using the LMS commercial code. In addition, the generated noise is recorded during measurement time and the causes of noise are analyzed and compared to each other. Noise test and vibration test are performed in the hemi-anechoic room with a background noise level of 23.8dB(A).

Figure 4. Test equipment of seat

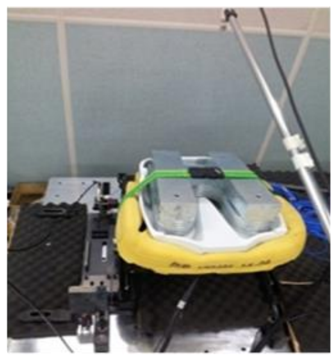


Figure 5. Position of dummy

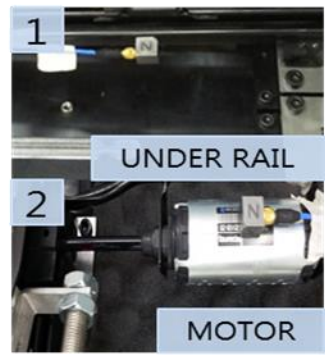


Figure 6. Position of sensor

Table 2. Position of sensor

Name	Installation location
MIC	600 mm from the cushion (at the position of the passenger's ear)
Sensor 1	Under rail
Sensor 2	Motor

3. Test results and discussion

3.1. Acoustic field visualization test

The transfer route of the noise and vibration generated from the slide drive mechanism of car seats is illustrated in Figure 7. The analysis is performed for the transfer route of the noise and vibration. Generally, seat noise (BSR) is created when the tolerances of two adjourning parts are out of the standard range or there is a gap between parts during assembly. Also, friction noise can be generated due to the absence of clamping fore in the parts. To investigate the abrasion at the center of the rail, the position and size of the noise during seat movement are measured using the visualization equipment. The visualization result is shown in Figure 8. The test range for the visualization of noise source is a frequency of 0-5,000Hz. It is confirmed that the largest noise source is present in the track where the lead screw and nut are fixed when seat track passes through the center of a stroke. This point is similar to that of abraded rail. The noise generation is initiated when screw brings about rotation vibration. This vibration is transmitted to the mount, and this transmitted vibration and the natural vibration of rail interacts with each other to amplify the noise.

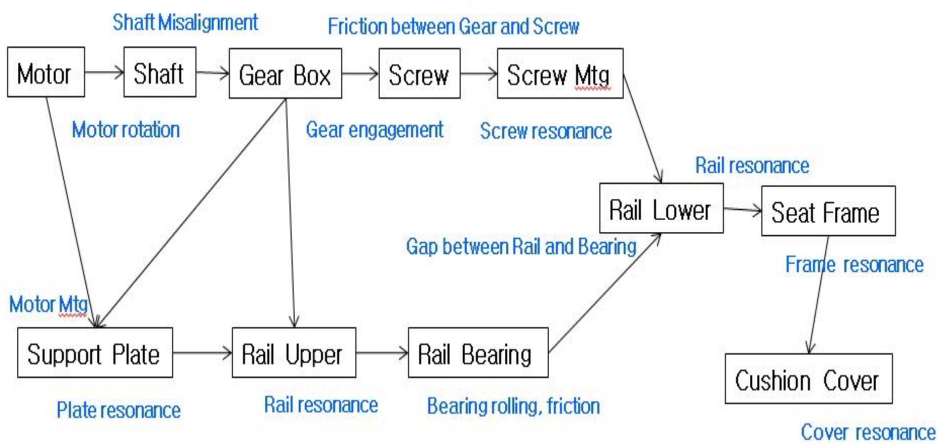


Figure 7. Transmission route of noise and vibration

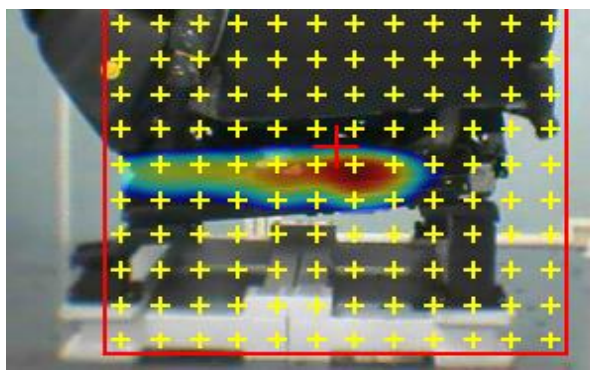
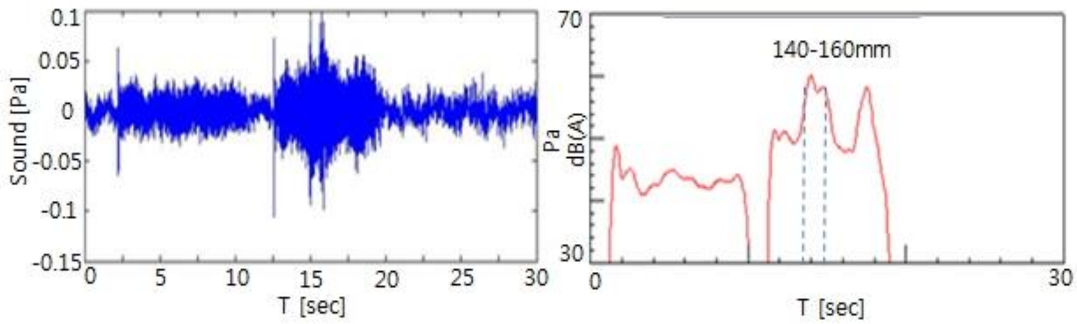


Figure 8. Visualized noise during slide movement to rear position

3.2. Noise test

The noise test is performed to investigate the accurate cause of noise generation based on the above visualization test. The analysis result of noise generated from the seat as time domain data and overall level is shown in Figure 9. In Figure 9(a), the high noise generations at 2.5 sec and 12.5 sec are caused by an impact type energy component which is generated when the slide starts moving. Also, it is noted that relatively large noise is generated between Sections [14 – 17] as Figure 9(b) shows an overall noise level in an entire stroke of the rail. The largest noise was generated from 140 ~ 160mm zone among total track length. This zone was matching with the abraded portion of the rain in Figure 2. Also, the noise generation timings were different between forward movement (hereinafter, referred as CW) and backward movement (hereinafter referred as CCW)of seat because of the speed difference of the seat which was installed as slope.



(a) Time domain data (b) Overall Level

Figure 9. Time domain data & overall level of the noise from the slide rail

Further analysis is carried out by comparing the noise difference during forward movement as well as backward movement at 1/3 octave band. The result is illustrated in Figure 10. The black area in the 1/3 octave band represents the common background noise level of CW and CCW. Meanwhile, the green area shows a high background noise level in CW. The red area refers to a high background noise level during CCW movement. The SPL in CW zone is 44dB(A) and 53.5dB(A) in CCW zone. The difference of the SPL between two zones is 9.5dB(A). Also, when a seat moves to CCW, a relatively high dB(A) is recorded in the high frequency zone as compared with that during seat moving towards the CCW. Here, a notable point is that a relatively large difference in the background noise level between CW and CCW zones at 400-500Hz is observed. Therefore, noise data towards seat moving directions are analyzed with FFT and spectrum contour map and the result is presented in Figure 11.

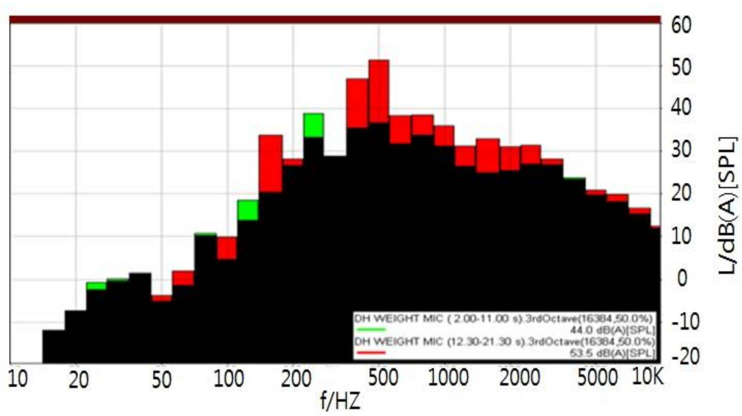
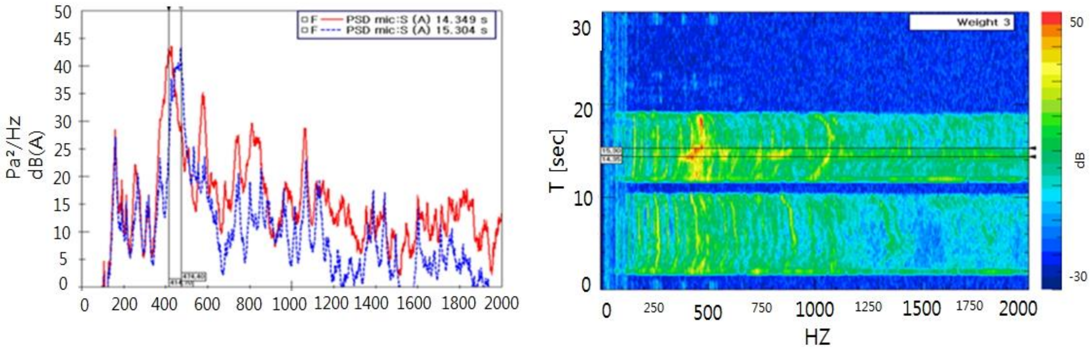


Figure 10. 1/3 Comparison of noise level in CW and CCW in octave band

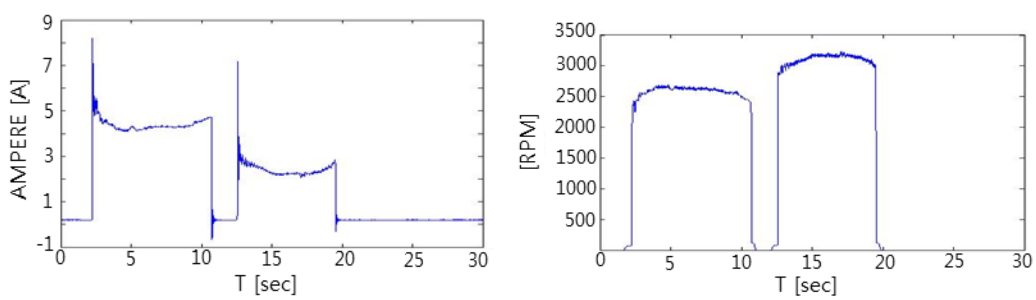
FFT analysis is performed to investigate the noise source at 14.3 sec where the largest dB(A) is measured and at 15.3 from where the second highest noise is generated. The FFT analysis result is illustrated in Figure 12(a). The resonance frequency of mechanism during slide movement is 400-470Hz. The spectrum contour map analysis is also performed for a detailed analysis of the whole seat stroke zone as in Figure 11(b). As expected, the large noise is generated from 400-500Hz zone and a band (line) is formed as a large frequency zone throughout a broad frequency range at 14.3-15.3 sec. This large frequency range might be due to the friction or resonance between the parts. That means friction noise is generated while listening at the site during testing. Noise might be amplified by the resonance in the 400-500Hz zone at the middle of the seat movement.



(a) FFT analysis (b) Spectrum Contour Map

Figure 11. FFT and Spectrum Contour Map of the seat

Meanwhile, current and RPM of motor are simultaneously measured in real time during vibration noise measurement to examine the changes of loaded drive motor when friction noise is generated. The result is illustrated in Figure 12. Figure 12(a) shows that while seat moves to CW and CCW, the load which is imposed on the motor is changed and results in increases in the resistor current. Figure 12 (b) presents RPM changes in the motor by time elapse. It is therefore indicated that with increases in the resistor current, motor speed (RPM) is affected. The speed during a seat moving forward is 24.61mm/sec and the backward movement speed is 27.31mm/sec. The reason of speed increases during a seat moving towards the rear side might be due to a five-degree inclination of the seat, a torque deviation of the motor during CW and CCW movement, and reducer and friction changes.

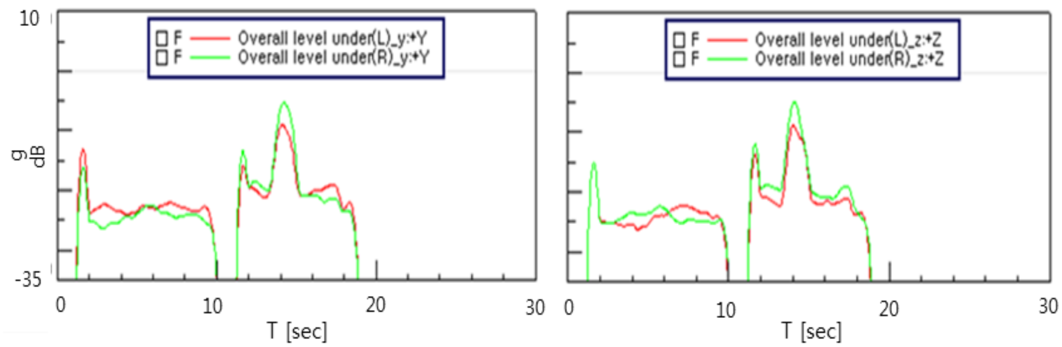


(a) Current of the motor (b) RPM of the motor

Figure 12. RPM and current of motor

3.3. Vibration test

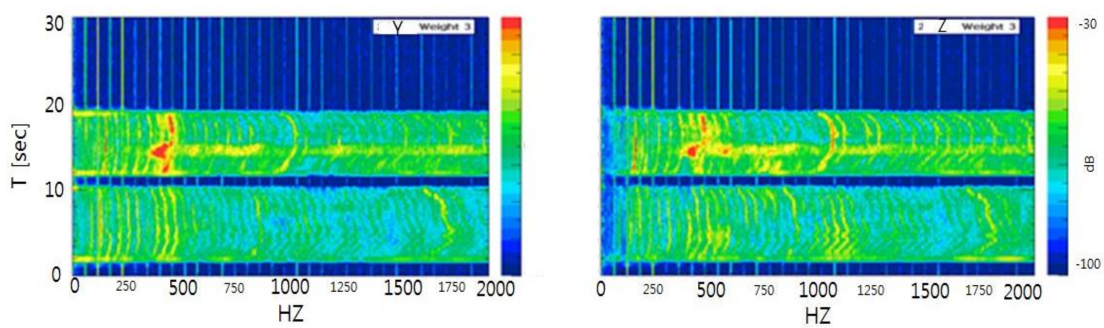
As a subsequent analysis, the noise level of the slide rail, which is regarded as a noise source, is measured based on the measurement by noise source visualization and noise data. The vibration result of the slide rail is illustrated in Figure 13. In Figure 13, the red line refers to the rail at the left side while the green line indicates the rail at the right side. The overall noise level at both the left and right side of the Y axis which is at the left and right direction of the rail is presented in Figure 13. Similar noise levels are observed from the left as well as the right side of the rail while the seat moves to CW. In the CCW zone, which is of our interest, the RMS value is 1.76mm/s while the seat moves to CCW at left rail. The RMS value obtained from the right side rail during CCW movement of the seat is 2.40mm/s. Figure 13(b) shows the overall noise level for both the left and right sides of the rails about the Z axis which move up and down the direction of the rail. As an observed noise level from the CCW movement, the noise levels show similar trends from the left as well as from the right side of the rail. During the CCW movement of the concerned seat, an RMS level of 1.69mm/s from the left rail and 2.35mm/s from the right side of the rail are recorded. Practically the right side rail shows relatively larger abrasion as compared with that of the left side rail.



(a) Y axis of slide rail (b) Z axis of slide rail

Figure 13. Overall vibration level of the slide towards Y axis & X axis

The spectrum contour map is prepared to analyze the frequency of the rail. The measurement result is presented in Figure 14. In the spectrum contour map of the slide rail, frequencies towards the Y axis are presented in Figure 14(a) and the frequencies towards the Z axis are presented in Figure 14(b). The maximum vibration occurs from the 400-500Hz zone at both the Y and Z axes. The vibration level increases again at 1,000Hz, concluding there is a second mode of vibration.



(a) Y axis of slide rail (b) Z axis of slide rail

Figure 14. Spectrum contour maps for Y axis and Z axis of slide rail

Based on the noise and vibration analyses, the frequency zone of the seat noise is investigated. It is confirmed that an unbalanced rotation of motor can generate a resonance from the rail. The experiment is conducted to search the natural frequency of the slide rail to check if the resonance frequency is the cause of the rail abrasion by a hammering test. The hammering test result is presented in Figure 15. The first mode of the natural frequency occurs at 332Hz, the second at 512Hz, and the third at 642Hz. The analysis results give an idea that the cause of the rail abrasion and noise might be the effect of the second mode at

500Hz. As a conclusion, while the seat moves to CW and the rail stops at the bearing stopper while the gear is tightly locked. After the seat moves towards CCW when the gear is released, a gap is created in the gear to make the gear rotate. The vibration is generated during gear rotation which causes noise level change.

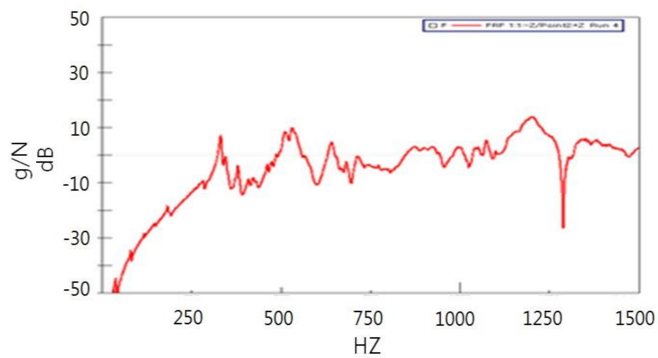


Figure 15. Modal analysis of under rail

4. Conclusion

This study is carried out to investigate an abraded point of the POWER SEAT in the passenger cars during the forward and backward movements of the seat. Among the various abnormal sounds, the major abnormal sound from the slide rail which can be generated during slide movement is investigated and the vibration characteristic of the rail is examined. Based on the measurement and analysis results, we have drawn the conclusions below.

1) The vibration characteristics analysis for the slide rail shows that the resonance frequency of the rail occurs at 400-500Hz. Further, the cause of the abrasion and noise generation at the rail might be the effect of the second vibration mode at 512Hz.

2) The resistor current increases due to changes in the load on the motor while the seat is moving. These changes in the motor affect the movement speed (RPM) of the seat.

3) It is confirmed that the sound quality changes from the drive part of the seat is generated mainly due to the friction load noise, not the normal drive sound of the motor.

4) The location of the noise source from the rail during slide movement is investigated using the visualization equipment for the noise source.

5) Further research should be carried out to investigate the noise cause thoroughly through vibration and noise analysis from different seat parts and through structural analysis. In addition, these analysis methods can be implemented not only in the slide but also in the recliner and height, among others, in the drive mechanism of the power seat.

Acknowledgements

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