Vibration Analysis of Tread Brake Block in the Brake Dynamometer for the High Speed Train

Min-Soo Kim

***Abstract*—** This paper deals with the frequency analysis of the abnormal vibration in the specific speed range when the tread brake test is applied in the brake dynamometer. Generally brake system of railway vehicles has a crucial role for the safety as well as riding quality of passengers. And dynamometer tests are widely used to evaluate the friction and wear performance of railroad friction composition brake shoes including the emergence brake, continuous brake, and so on. Experiments on the brake dynamometer for the high speed train are provided to illustrate the frequency analysis of the abnormal vibration in vehicle speed at 140 [km/h] and 70 [km/h] under the 920 [mm] wheel diameter using the 3-axis accelerometers.

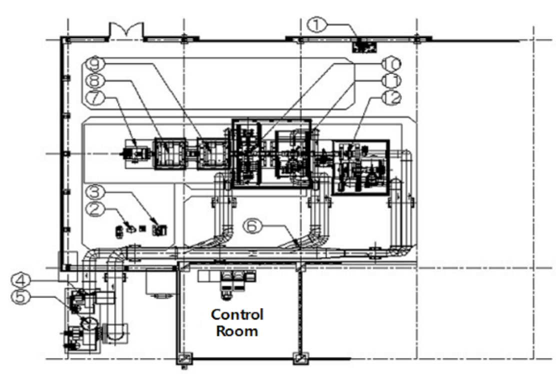
***Keywords*—** Tread Brake, Brake Dynamometer, Railway Vehicle, 3-Axis Accelerometers.

I. INTRODUCTION

GENERALLY brake system of railway vehicles has a crucial role for the safety as well as riding quality of passengers[1]-[3]. During the early 19th century various attempts were made to get away from the concept of vehicle brakes which had to be individually controlled and provide a train brake with one point of control. A scheme of 1840 had a chain which ran along the train to the guard's position at the rear where it was wound round a drum. To apply the brake the drum was lowered until it touched an axle, causing it to rotate and tighten the chain. Levers connected to the chain applied the brakes In addition, as railways developed during the mid 18th century, there were a number of accidents caused by trains becoming uncoupled (a breakaway) or just failing to stop. Sometimes, breakaways ran down a grade and collided with the following train or trains became parted and the second half ran into the front half after the crew had stopped it because they had noticed the uncoupling. The traditional form of wheel tread brake consisting of a block of friction material which could be cast iron, wood or a composition material hung from a lever and being pressed against the wheel tread by air pressure in the air brake or atmospheric pressure in the case of the vacuum brake.

Dynamometers are a device for measuring the torque, force, or power available from a rotating shaft. The shaft speed is measured with a tachometer, while the turning force or torque of the shaft is measured with a scale or by another method. The first dynamometer was designed to measure the brake horsepower of a motor. This invention was the work of an engineer, Gaspard. He invented the Prony Brake Dynamometer in 1821 in Paris. Variations of this dynamometer are still in use today.

In general, break dynamometers are widely used to simulate the break performance of the railway vehicle[4]-[7]. An example of such a dynamometer is shown in Figure 1. There are many variations to this basic format, because of the high speed rotation operation. There is an electric motor inserting and absorbing power, an inertia section, and a test section where the brake is mounted. Each size of vehicle will require different amounts of inertia. Since these disks are in discrete steps, there is often a compromise among the number of disks and wheels, the changeable inertia. Many test procedures specify how much inertia should be used based on vehicle weight and wheel load. The test procedures performed on the brake dynamometers cover a wide range of operational conditions. They may simulate actual vehicle operations. For instance, in aircraft dynamometers it is typical to simulate actual operating conditions including taxing, take-offs, and landings. In passenger vehicle testing, standard procedures are often used which do not simulate typical vehicle operations, but instead, represent critical operational scenarios that test the limits of brake performance or elicit a specific type of performance characteristic.



No.	Component	No.	Component
1	Lubrication equipment	7	DC Motor
2	Pneumatic equipment	8	Flywheel A
3	Oil pressure equipment	9	Flywheel B
4	Air supply fan	10	Tread break equipment
5	Air ventilation fan	11	Disk break equipment
6	Air duct		

Fig. 1 drawings of the brake performance dynamometer

This paper contains the frequency analysis of the abnormal vibration in vehicle speed at 140 [km/h] and 70 [km/h] considering the 920 [mm] wheel diameter based on the 3-axis accelerometers.

This paper is organized as follows. Section 2 overviews a brake dynamometer. Section 3 describes the experiment environment for the tread brake for analyzing the abnormal vibration when the tread brake is applied. Section 4 shows the experiment results. The main conclusions are then summarized in section 5.

II. Brake Dynamometer

A dynamometer consists of the following main elements.

◆ The drive-train consists of the following elements: motor, interchangeable flywheels and brake disk. The flywheels and brake disk is matched to the part number to be tested.

◆ The test bed consist of the following elements: caliper & adapter, power transfer axle, load bearing arm and load cell to calculate the breaking force.

Fig. 2 brake performance dynamometer for high speed train

Brake dynamometer is designed to simulate the brake characteristic of the high speed train, and has a function of record the data which can be reproduced and help to analyze and compare the experimental object, and also is used to develop and test the brake system.

The expected effect and practical scheme of the brake dynamometer are followings:

(1) Development of the brake, disk-pad, wheel and brake system of the high-speed & conventional train

(2) Test and performance evaluation of the brake system of the high-speed & conventional train with the international standard

(3) Performance and certification test of the brake system of the manufactured high speed train.

Briefly, the dynamometer has the following features that make it suitable for brake show testing:

(1) a 397 [kW] (540 [HP]) DC motor capable of speeds from 0 to 2,500[rpm] in either direction with dynamic control.

(2) flywheel disks that allow selection of inertias in 100 equal increments ranging from 400 to 1,600[kg·m²] with 820[mm] wheel except 1700[kg·m²].

(3) brake cylinders capable of either 60 or 120 [kN] forces with controlled force.

(4) precise measurement of speed, torque, temperature, and stop distance.

(5) computer control of test sequence, test parameters, and data acquisition.

Table 1 shows the main features of the brake dynamometer that make it suitable for brake shoe testing

Table 1 Main specification of the brake dynamometer

Max. drive power	397kW(540HP)
Max. drive torque	2,527Nm
Max. drive speed	2,500rpm(400km/h)
Max. brake torque	25,000Nm
Pressure Brake	6,000 N x 2
Flywheel Inertia	Max./Min. 1900kg·m²/400kg·m²
Diameter of the test wheel	Φ700~1120mm
Acceleration time (0~1500rpm)	2 min. 30 sec

III. Experimental Environment

The friction coefficients between dry and wet condition must not deviate from each other by more than 15% under the same conditions according to the requirements of the UIC CODE 541-4 [10].

The instantaneous friction coefficient μ_a , which is determined in any moment of braking by the ratio of total braking force F_t to total contact force F_b , is calculated as

$$\mu_a = \frac{F_t}{F_b} \tag{1}$$

And the mean friction coefficient μ_m determined from reaching 95% of the nominal contact force F_b of the friction coefficient μ_m for the braking distance S_2 as (2).

$$\mu_m = \frac{1}{S_2}\int_0^{S_2} \mu_a ds \tag{2}$$

It was found from the results of the tread brake test appeared from something abnormal vibration in the ranging of the vehicle speed at 140 [km/h] (i.e. about 808 [rpm]) and 70 [km/h] (i.e. about 404 [rpm]) considering the 920 [mm] wheel diameter. Therefore, we examined the frequency analysis on the axle and the brake block using the 3-axis accelerometers and displacement measure sensor.

Fig. 3 shows the surface of the wheel tread when it applied the braking process at initial speed of 270 [km/h]. We can observe the movement of the thermal band according to the speed variation.

Fig.3 Tread breaking test at 180 [km/h]

Fig. 4 shows the abnormal vibration phenomenon of the tread braking torque (or braking force F_t) in the range of the vehicle speed at 140 [km/h] .

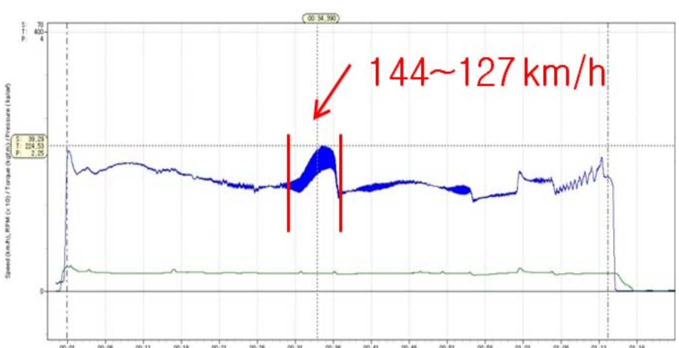


Fig. 4 torque and pressure brake of tread brake

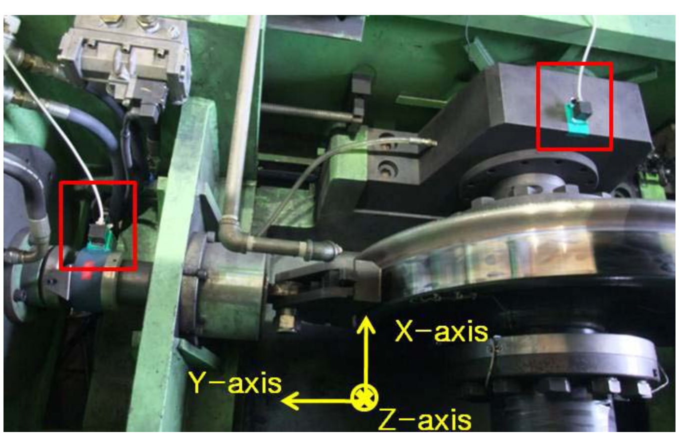


Fig. 5 position and coordinate system of the 3-axis accelerometers

The position and coordinate system of two accelerometers for measuring the vibration characteristic and a laser sensor for measuring the displacement appear in Fig. 5 and Fig. 6, respectively.

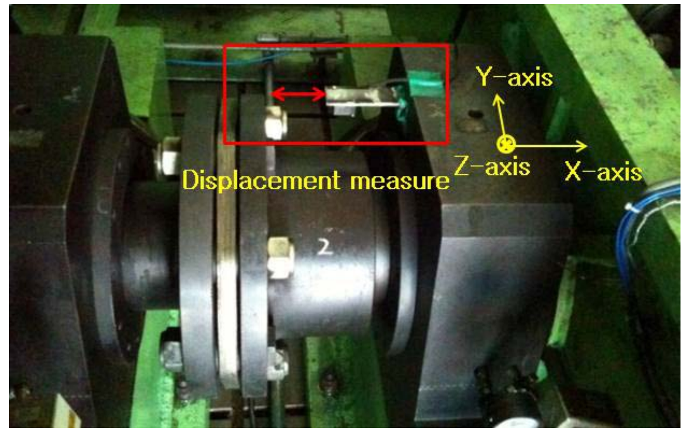


Fig. 6 position and coordinate system of the laser sensor for measuring the x-axis displacement

In the tread braking test of the brake dynamometer, the initial test speed is set out at 270 [km/h] with composite tread brake blocks for the high speed train.

Fig. 7 measurement system for the brake experiment (DAQ)

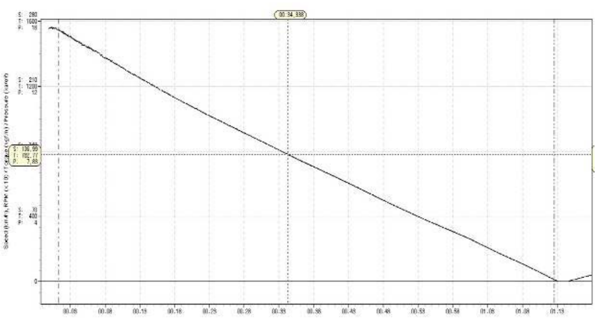
Table 2 summarizes the main features of the DAQ systems for measuring the signals and those of the various sensors for analyzing the vibration of the axle [11].

Table 2 Main specification of the DAQ and sensors

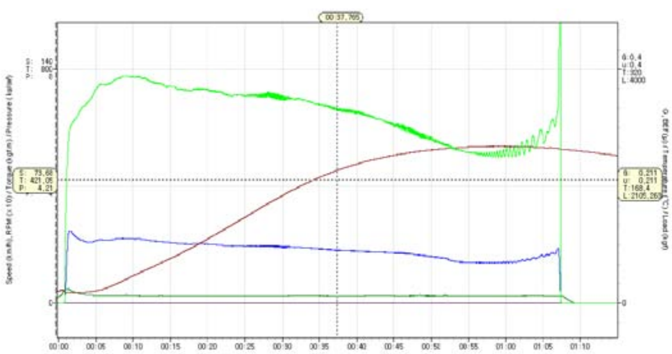
DAQ	◆ DEWE-43 ◆ 8 analog inputs (24 bits, 50ks/s) ◆ 8 analog inputs (24 bits, 50ks/s) ◆ 8 counter inputs ◆ 2 CAN-bus interface

Triaxial Accelerometer	◆ KISTLER K-Beam 8393B10 ◆ measures 3-axis simultaneously ◆ frequency response: 0~250Hz ◆ acceleration range:±10g
Laser sensor	◆ Omron ZX-LD100L ◆ 100mm±40mm with 16μm resolution

In the process of the brake stop application, the motor increases speed to the initial setting value and then put on the brakes. The initial speed for the test is set up 270 [km/h]. Fig. 8 shows the measurement data on the dynamometer control desk including the vehicle speed, instantaneous friction coefficient, brake force, wheel temperature, and contact force.



(a) transition of the vehicle speed from 270 [km/h] to 0 [km/h]

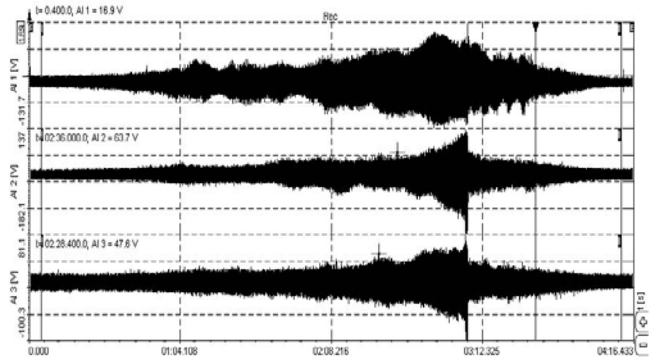


(b) instantaneous friction coefficient, brake force, wheel temperature, and contact force

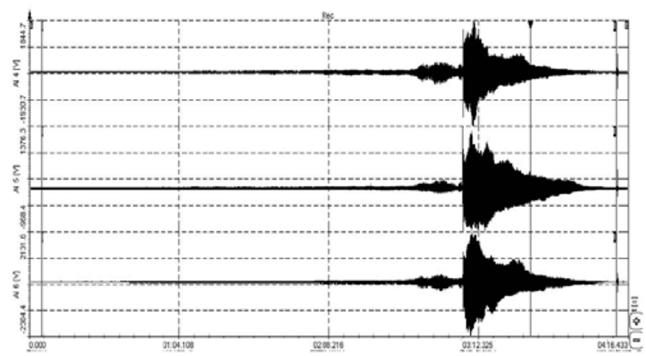
Fig. 8 measurement data on the dynamometer control desk

In the tread braking test, braking distance was measured 2,228 [m] and braking time was gauged 65.3 [sec] during the braking test with cylinder pressure 22.6[kg/cm2] (i.e. cylinder force 5.9 [kN]).

An inertia dynamometer system provides a fixed inertial mass flywheel and computes the power required to accelerate the flywheel (load) from the starting to the ending the braking application. The inertia value was chosen 800 [kg•m²] because the UIC test program prescribed 4 [ton] (mass per brake disc) in case of the high speed train[10]. The brake application force setting up 5.9 [kN] is supplied by the compressed air cylinders acting on the brake shoe. During braking, the force should not vary from the normal value.



(a) on the axle



(b) on the brake block

Fig. 9 output signals of the tri-axial accelerometer

Fig. 9 describes the output signals of the tri-axial accelerometer installed on the axle and brake block for analyzing the vibration.

IV. Experiments

A. *Vibration of the Axle and Brake Block*

The measuring signals for analyzing the vibration of the axle and brake block using the 3-axis accelerometers are transmitted to the DAQ via A/D converter, and the frequency analysis is performed.

Fig. 10 DAQ screen for the analyzing the vibration

Fig. 10 shows the experimental results about the full measurement data including the braking images installed with the 3-axis accelerometers on the axle and its frequency analysis at 140 [km/h].

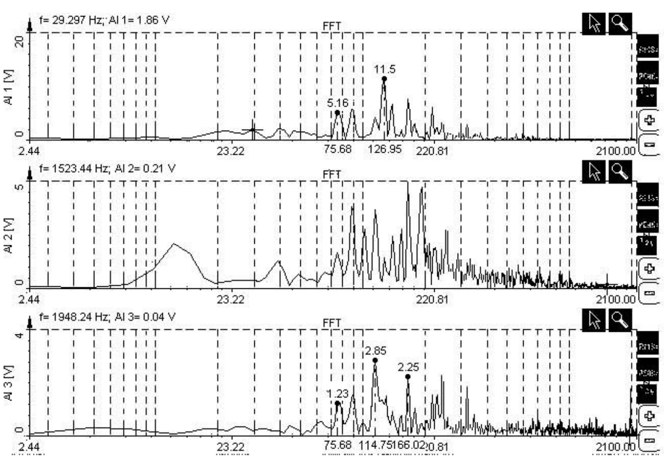
We can represent the results of the frequency analysis at 132[km/h] in the axle vibration and brake block vibration as follows:

◆Common main frequencies of the x-axis : 75.68 and 126.95[Hz]

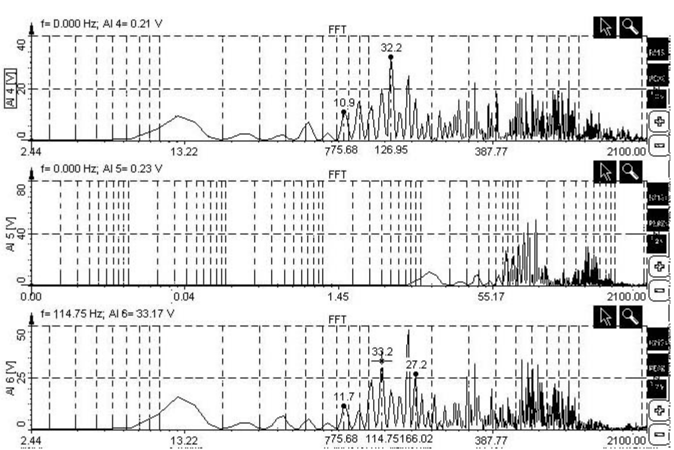
◆ Common main frequencies of the z-axis : 75.68, 114.75, and 166.02[Hz]

These five main frequencies (75.68[Hz], 126.95[Hz] and 75.68[Hz], 114.75[Hz], 166.02[Hz]) have similarities between the 3-axis accelerometer on axle and that on the brake block at a speed of 132 km/h.

Fig. 11 illustrates the measurement data with the 3-axis accelerometers on the brake block and its frequency analysis at 132 [km/h].



(a) on the axle



(b) on the brake block

Fig. 11 Frequency analysis at 132[km/h]

Main frequencies of the measurement data of the 3-axis accelerometer on the axle at 132[km/h] are shown in Table 3.

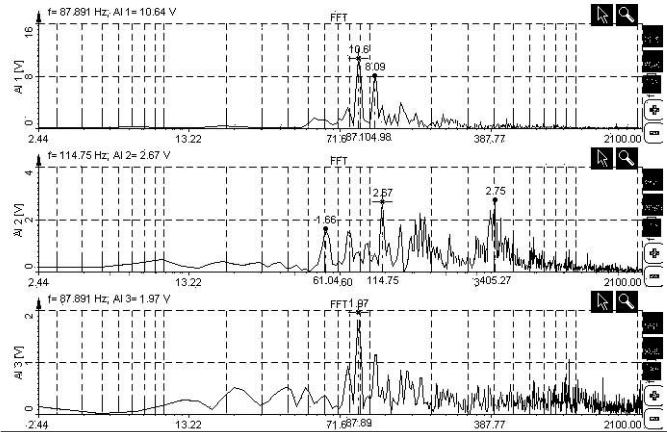
Table 3. Main frequencies of the measurement data of the 3-axis accelerometer on the axle

Axis	Frequency [Hz]	Voltage [V]	No.
x-axis	75.68	5.16	3
	90.332	5.82	4
	114.75	5.67	5
	126.95	11.5	1
	168.46	6.03	2
	219.73	5.62	6
	244.14	4.41	7
y-axis	90.332	4.87	2
	129.39	4.83	3
	168.46	6.22	1
z-axis	75.68	1.23	2
	114.75	2.85	1
	166.02	2.25	4
	244.14	2.02	3

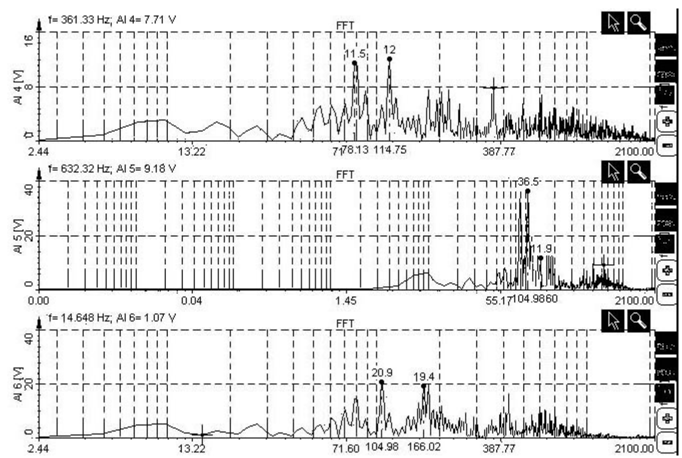
Table 4. Main frequencies of the measurement data of the 3-axis accelerometer on the brake block

Axis	Frequency [Hz]	Voltage [V]	No.
x-axis	75.68	10.9	10
	126.95	32.2	1
	153.82	25.74	2
	271.00	15.58	12
	322.27	21.28	6
	412.60	21.56	5
	539.55	15.84	11
	566.41	22.97	4
	605.47	20.55	8
	761.72	18.89	9
	773.94	20.81	7
	790.34	23.52	3
y-axis	129.39	49.34	2
	153.81	50.77	1
	529.79	26.10	3
z-axis	75.68	11.7	3
	114.75	33.2	1
	166.02	27.2	2

Next, another frequency analysis was performed continuously before and after the speed of 132 [km/h]. Fig. 12 and Fig 13 shows the frequency analysis at vehicle speed 92 [km/h] and 170 [km/h], respectively.

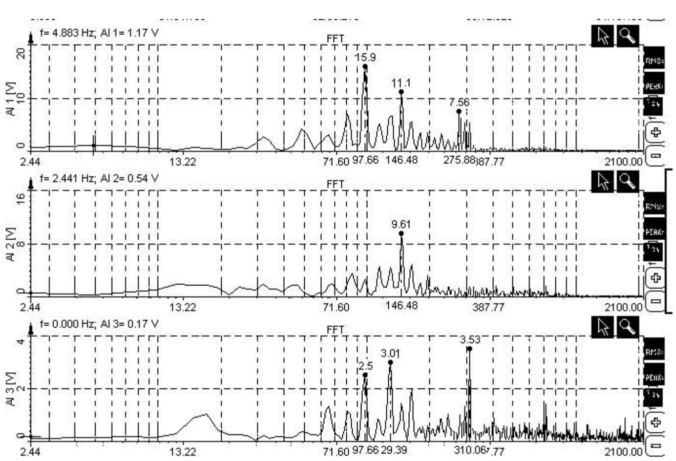


(a) on the axle

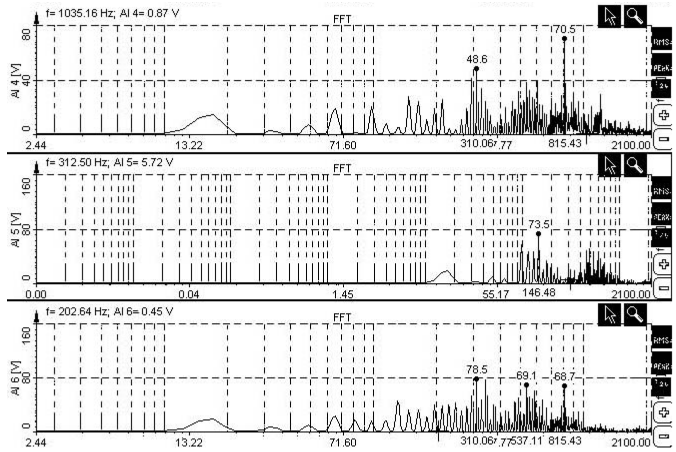


(b) on the brake block

Fig. 12 frequency analysis at 92[km/h]



(a) on the axle



(b) on the brake block

Fig. 13 Frequency analysis at 170[km/h]

Compared with the frequency analysis at the speed of 132[km/h], the main frequencies of the 3-axis accelerometer on the axle have no relevance at all to those on the brake block at a speed of 170[km/h] and 92[km/h].

B. Displacement of the Axle

Displacement data of axle were gathered from laser sensor installed for measuring the movement of the x-axis and applied the LPF to the sensor signals. Fig 14 shows the change of the axle displacement and its frequency analysis at 134 [km/h] are shown in Fig. 15.

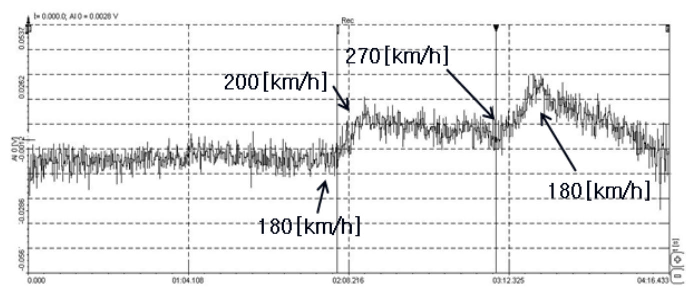


Fig. 14 measurement data with the axle displacement

The range of variation is measured by 0.036[v] under considering the initial bias and it can be converted into 0.32[mm] displacement with the maximum. More accurate measured values of the laser sensor in main points are followings.

- 0 ~ 180[km/h]: -0.0065 [v]
- 200[km/h]: 0.015 [v]
- 180[km/h]: 0.0294 [v]

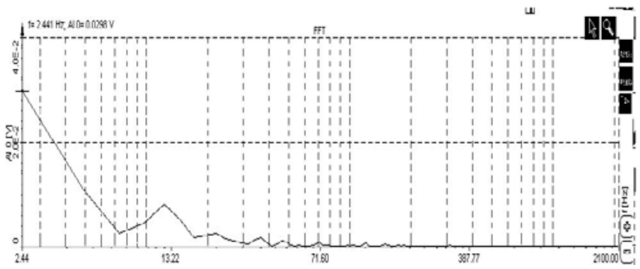


Fig. 15 frequency analysis of the axle displacement at 134 [km/h]

Main frequency of the displacement is marked by 2.441 [Hz] and 13.22[Hz]. As the range of the fluctuation of the axle displacement indicates, the abnormal vibration doesn't result from the clearance of the ball inside the bearing.

C. Sound from Microphone

Braking sound data were measured continuously before, during and after the brake application. And then, the frequency analysis was performed to make a comparison of the frequency characteristic between the braking sound and the axle vibration.

Fig. 16 shows the measurement data with the braking sound using the microphone. The sound level also grows according to increasing the vehicle speed in the braking application.

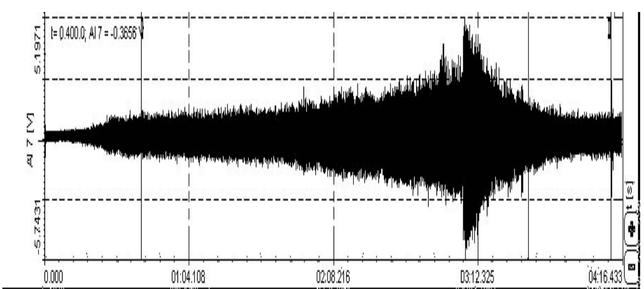


Fig. 16 measurement data with the braking sound

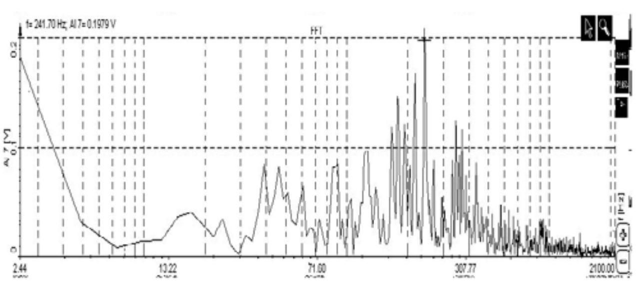


Fig. 17 frequency analysis of the braking sound at 134 [km/h]

Main frequency of the braking sound are 168.46 [Hz], 90.332 [Hz], 244.14 [Hz], and 219.73 [Hz]. These two frequencies (168.46 [Hz], 90.332 [Hz]) have coincidence between the braking noise and measurement data of the 3-axis accelerometers on axle at 134 km/h.

V. Conclusion

Brake dynamometer is designed to simulate the brake characteristic of the high speed train, and has a function of record the data which can be reproduced and help to analyze and compare the experimental object, and also is used to develop and test the brake system.

In this paper, we present a tread brake experiments on the dynamometer for high speed train in order to analyze the abnormal vibration in specific vehicle speed at 140 [km/h] and 70 [km/h]. For analysis we use the 3-axis accelerometers on the axle and on the brake block. As a result of the analysis we could verify the mutual action between axle vibrations and the brake block connection with the brake cylinder.

References

[1] Simon Iwnicki, *Handbook of Railway Vehicle Dynamic*, CRC Press, 2006.

[2] Robert L. J., *Railway Brakes*, Autralia: Westinghouse Brake and Singnal Co., 1982.Simon Iwnicki, *Handbook of Railway Vehicle Dynamic*, CRC Press, 2006.

[3] Garg V. K. and Rukkipati R. V., *Dynamics of Railway Vehicle Systems*, Academic press, 1994.

[4] T.E.Johnson, *Results of Dynamometer Tests of Brake Shoes Under Full Load Conditions*, Illinois : Association of American Railroads, 1993

[5] Hecht Basch, R., Fash, J., Hasson, R., Dalka, T., McCune, R. and Kafold, R. "Initial Dynamometer and Laboratory Evaluations of Thermally Sprayed Aluminium Brake Discs," In Brakes 2000, *International Conference on Automotive Braking Technologies for the 21st Century*, pp. 163-173, 2000.

[6] QUESTION B-169: *Selection of parameters for testing thermal limits of wheels and brake blocks*, Utrecht : ERRI, 1989.

[7] M. C. Fec, H. Sehitoglu, *Thermal limits for wheels and brake blocks : monitooring of solid wheels in servi*ce *(Report No. R-600)*, Utrecht : ERRI, 1995

[8] UIC CODE 541-1 *Brakes – Regulations concerning the design of brake components*, 6th Eds.November 2003.

[9] UIC CODE 541-3 *Brakes – Disk brakes and their application – General conditions for the approval of brake pads*, 6th Eds.November 2006.

[10] UIC CODE 541-4 *Brakes – Brakes with composite brake blocks – General conditions for certification of composite brake blocks*, 3rd Eds. May 2007.

[11] *Dewe-43 Technical Reference Manual*, Ver. 1.0.0, DEWESOFT, 2009.

[12] Harper, Graham A., *Brakes and friction materials : the history and development of the technologies*, London : MEP (Mechanical Engineering Publication, 1998

[13] Min-Soo Kim, Joon-Hyuk Park, Byeong-Choon Goo, "Development of Brake System of Railway Vehicles for Real-Time HILS," *The 2007 International Conference on Mechatronics and Information Technologys(ICMIT 2007)*, Gifu, Japan, 5-6 December, 2007.

[14] Min-Soo Kim, Hyun-Moo Hur, "Braking/Traction Control Systems of a Scaled Railway Vehicle for the Active Steering Testbed," *The 9th WSEAS International Conference on ROBOTICS, CONTROL and MANUFACTURING TECHNOLOGY (ROCOM '09)*, Hangzhou, China, May 20-22, 2009.

[15] Min-Soo Kim, Hyun-Moo Hur, "Application of Braking/Traction Control Systems to the Scaled Active Steering Testbed in the Railway Vehicle," *WSEAS Transctions on System and Control* , 2009.

[16] Min-Soo Kim Jeong-Guk Kim, Byeong-Choon Goo, Nam-Po Kim, "Frequency Analysis of the Vibration of Tread Brake Dynamometer for the High Speed Train," *The 10th WSEAS International Conference on SIGNAL PROCESSING, COMPUTATIONAL GEOMETRY and ARTIFICIAL VISION (ISCGAV '10)*, Taipei, Taiwan, August 20-22, 2010.

[17] Aviles, R., Hennequet, G., Hernandez, A. and Llorente, L. I. "Low Frequency Vibrations in Disc Brakes at High Car Speed. Part I:

Experimental Approach," *Int. Journal of Vehicle.Dynamics*, 1995, 16(6), 542-555.

[18] Lang, A. M. and Smales, H. "An Approach to the Solution of Disc Brake Vibration Problems," *In Proceedings, Braking of Road Vehicles*, London, 1983.

Min-Soo Kim received the B.S., M.S., and Ph.D. degrees in electrical engineering from Soongsil University, Seoul, Korea in 1995, 1997, and 2003, respectively. From December 2005 he is a senior researcher at the Vehicle Dynamics & Propulsion Research Department at Korea Railroad Research Institute, 360-1 Woram-dong, Uiwang-si, Kyonggi-do, 437-757 Korea (corresponding author to provide phone: +82-31-460-5205; fax: +82-31-460-5299; e-mail: ms_kim@krri.re.kr). His research interests include control systems design of railway vehicle and dynamometer test for the railway brake components.