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Vibration analysis of baby carriage running on a road having grooves at regular intervals

Chihiro Kamio[1*], Tatsuhito Aihara[2]

[1] Graduate School of Mechanical Engineering, Hosei University, 3-7-2 Kajinocho, Koganei-shi, Tokyo, 184-8584, Japan
[2] Department of Mechanical Engineering, Hosei University, 3-7-2 Kajinocho, Koganei-shi, Tokyo, 184-8584, Japan

* Corresponding Author: chihiro.kamio.5y@stu.hosei.ac.jp

Abstract. Baby carriage is useful tool for parents walking with children. However, baby carriage vibration under running conditions negatively affect not only comfort but also operability. Therefore, it is necessary to reduce the baby carriage vibration. There are many roads paved with tiles or bricks in sidewalks. Continuous vibration is generated when a baby carriage run on sidewalks because these roads have grooves between tiles or between bricks. In this study, in order to clarify the baby carriage vibration running on a road having grooves at regular intervals, experiments were conducted using a real baby carriage equipped with accelerometers. In addition, a multibody dynamics simulation model was developed by referencing experimental apparatus in order to efficiently improve performances including the vibration reduction. The validity of the simulation model was investigated by comparing simulation results with experimental ones when changed the driving speed, and necessary elements of multibody dynamics simulation model to analyze the baby carriage vibration running on a road having grooves were clarified.

1. Introduction

Baby carriage is useful tool for parents walking with children. One of the factors related to the safety and the comfort is the baby carriage vibration under running conditions. This vibration not only gives babies stress but also negatively affect operability of the carriage driver [1, 2]. Therefore, researches of the physical strain and the hazards feeling given to the carriage driver by road surface characteristics are conducted [3, 4]. In the design of baby carriage, it is necessary to reduce vibration and absorb impact.

Previous researches developed the vibration test system for a baby carriage [5], and conducted the modal analysis of a baby carriage [6]. Neither of these researches considered the vibration of a baby carriage operating on a real road surfaces. The vibration evaluation of a baby carriage under running conditions is limited to the sensory evaluation of the carriage driver [7]. Therefore, the quantitative evaluation of the baby carriage vibration is not conducted.

This study focuses on roads paved with tiles or bricks in sidewalks. Continuous vibration is generated when a baby carriage run on sidewalks because these roads have grooves between tiles or between bricks. In this study, in order to clarify the baby carriage vibration running on roads having grooves at regular intervals, experiments were conducted using a real baby carriage. In addition, this study developed a multibody dynamics (MBD) simulation model referencing experimental apparatus in order to efficiently improve performances including the vibration reduction. The validity of the simulation model was investigated by comparing simulation results with experimental ones.

2. Experiments
In order to measure the vibration of the baby carriage under running conditions, experimental results were obtained by using a real baby carriage equipped with accelerometers. The baby carriage was driven by a person to assimilate the actual environment. Experimental apparatus and conditions are shown in the below.

2.1. Experimental apparatus
Figure 1 (a) shows the baby carriage used in experiments. This baby carriage, common model in Japan, is high-seat and light-weight. The height of the seat is 450 mm, and the weight of the baby carriage is 5.4 kg. The seat cushion and the cloth top were removed because these parts are not modeled in simulations. Accelerometers were attached the front right leg (I) and the rear right leg (II) to measure the vibration from road surface.

Figure 1 (b) shows the road surface used in experiments. Plates were placed on the ground at regular intervals to replicate roads paved with tiles or bricks. The grooves of between plates was 10 mm.

2.2. Experimental conditions
Baby carriage vibration was compared by changing the driving speed. The driving speed are about 500, 600, 700, and 800 mm/s. These speeds were controlled by setting the step size of the carriage driver and using a metronome. Moreover, the mass of 10 kg modeling the weight of a baby and a seat cushion was placed on the seat frame.

3. Simulations
In order to efficiently improve performances including the vibration reduction, this study developed a MBD simulation model to use mechanical design. Model development and numerical calculations were performed using the general-purpose MBD software RecurDyn [8].

3.1. *Multibody dynamics model*
Figure 2 shows the comprehensive view of the MBD simulation model developed in this study, where the *X*-axis represents the horizontal direction, the *Y*-axis represents the vertical direction, and the *Z*-axis represents the direction of carriage movement. The baby carriage and the road surface were modeled using experimental apparatus as a reference. The driver's arms were modeled using a translational spring. Massless objects were placed at tips of the springs, and these objects were applied the translational motion that is equivalent to pushing a baby carriage.

(a) Baby carriage (b) Road Surface

Figure 1. Experimental apparatus.

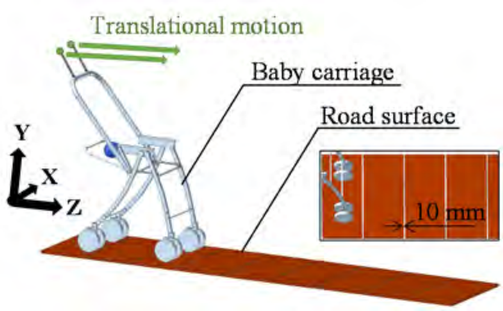


Figure 2. Comprehensive view of MBD simulation model.

Table 1. Numerical values of contact calculation between wheels and road surface in simulations.

Spring constant [N/mm]	50
Damping coefficient [N・s/m]	1
Friction coefficient [-]	0.8

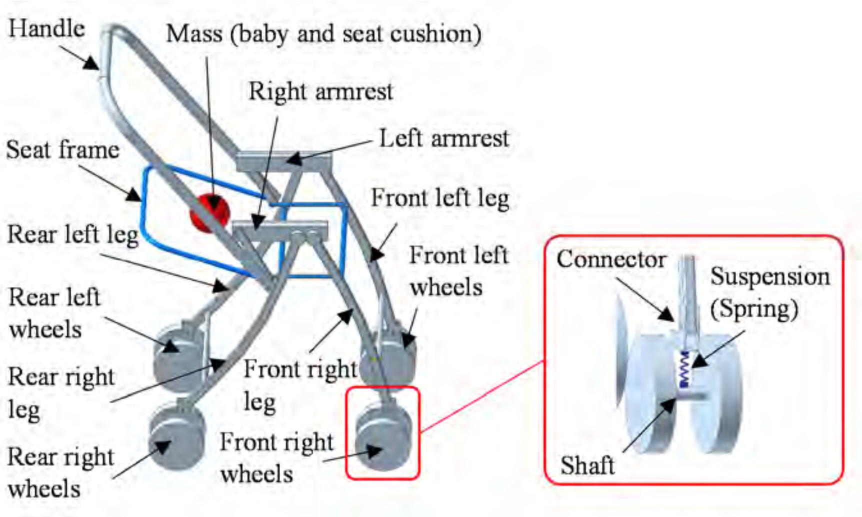


Figure 3. Structure of baby carriage model.

The contact stiffness between the wheels and the road surface was defined, and the contact forces (dependent on interference levels between two objects) were calculated. The contact forces are given as equation (1), where *k* is the spring contact, *c* is the damping coefficient, and *x* is the displacement as interference levels.

$$F = kx + c\dot{x} \tag{1}$$

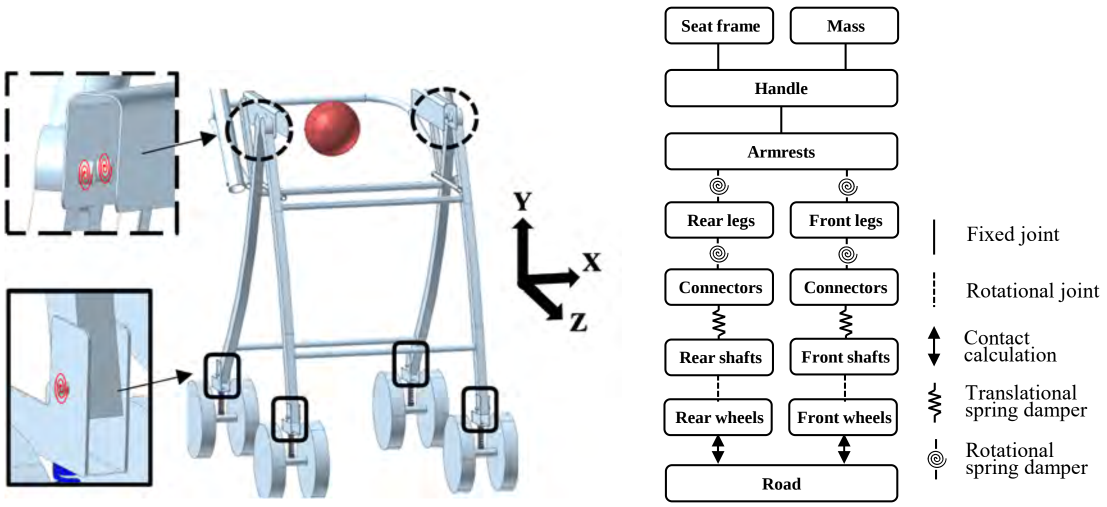
Table 1 shows the numerical values of contact calculation between the wheels and the road surface.

3.2. Baby carriage model

Figure 3 shows the structure of baby carriage model. The baby carriage model primarily comprised a handle, seat frame, armrests, legs, and wheels. A mass of 10kg, representing the weight of a baby and a seat cushion, was added to the center of the seat frame. Moreover, the connectors joined the suspensions to the legs. The suspensions were modeled by using linear springs.

The handle, seat frame, mass, armrests, legs, and connectors were treated as a single rigid body by using fixed joints. In this study, the baby carriage model not modeling elastic deformation other than the suspensions is referred to as the rigid-body model.

However, a real baby carriage allows for some movement between each of its parts. This study focus on the joints around legs. Figure 4 (a) shows modeling points in joints of the baby carriage. Legs and armrests are connected by rotational springs in order to model the motion of the legs in *X*-axis rotational direction. Legs and connectors are connected by rotational springs too. In this study, the baby carriage model using rotational springs to model movements between parts around legs is referred to as the elastic-connection model. Figure 4 (b) shows the system schematic of the elastic-connection model.



(a) Modeling points in joints of baby carriage (b) System schematic of elastic-connection model

Figure 4. Baby carriage model modelling joint around legs in simulations.

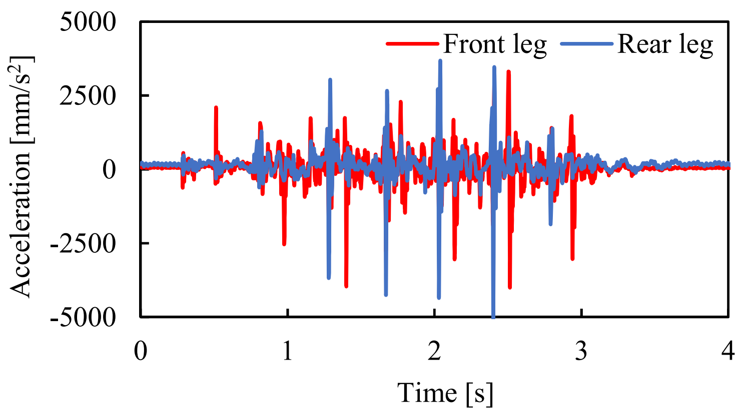


Figure 5. Experimental results when the driving speed is 800 mm/s.

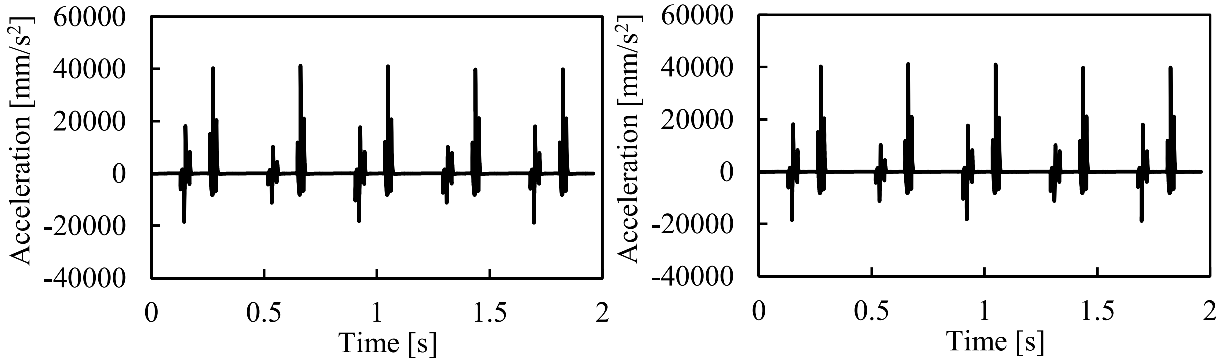
4. Results

4.1. Experimental results

This study defines the acceleration of *Y*-axis (perpendicularly upward direction) as the baby carriage vibration. Figure 5 shows experimental results when the driving speed is 800 mm/s. The horizontal axis is the time, while the vertical axis is the acceleration of *Y*-axis. In experiments, the high frequency vibrations were seen because the wheel surface is uneven. The large peaks were seen when the wheels of baby carriage get over the grooves. It can be seen that the vibration peaks are occurred alternately the front leg and the rear leg.

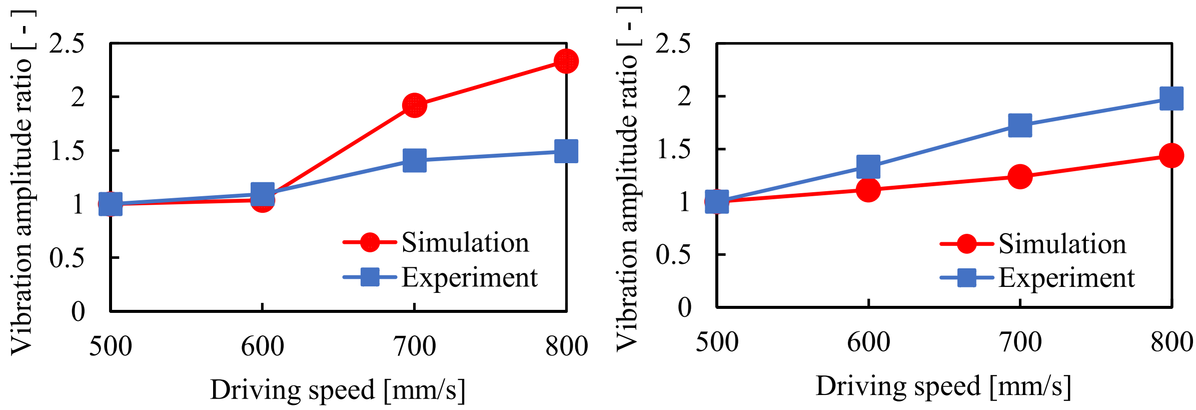
4.2. Simulation results

Figure 6 shows simulation results of the acceleration of front leg when the driving speed is 800 mm/s. Figure 6 (a) shows the result using the rigid-body model, and Figure 6 (b) shows the result using the elastic-connection model. As in the experiments, the vibration peaks are seen when the wheels of front leg get over the grooves.



(a) Rigit-body model (b) Elastic-connection model

Figure 6. Simulation results of front leg when the driving speed is 800 mm/s.



(a) Front leg (b) Rear leg

Figure 7. The comparison of experimental result with simulation result in influence of driving speed.

The vibration peaks of the elastic-connection model are higher freq uency than the rigid-body model. It is because the elastic-connection model allows for movement between parts around the legs. However, the vibration waveforms are very similar between these models. From this result, it is clarified that the rigid-body model can analysis the baby carriage vibration running on the road having grooves at regular intervals sufficiently because the vibration propagated to baby carriage is small. Moreover, the rigid-body model can be reduced by approximately 5 % from the elastic-connection model. In this study, the rigid-body model is used in simulations to analyze a baby carriage vibration running on the road having grooves at regular intervals.

4.3. Comparison of simulations and experiments

The validity of the simulation model was investigated by comparing the simulation results with the experimental ones when changed the driving speed. However, the absolute value of vibration peaks are very large in simulations. This cause is numerical values of contact calculation between wheels and road surface in simulations. Therefore, this study compared the rise rate of the amplitude of vibration peaks. Figure 7 shows the rise rate of the amplitude of vibration peaks in simulations and experiments. Figure 7 (a) shows the result of the front leg, and Figure 7 (b) shows the result of the rear leg. These results are based on when the driving speed is 500 mm/s. The trends of simulation results are in fairly good agreement with the experimental ones. Therefore, this simulation model is valid in analysis of the baby carriage vibration running the road having grooves at regular intervals.

5. Conclusion

The purpose of this study is to analyze the baby carriage vibration running the road having grooves at regular intervals. The MBD simulation model was developed by using experimental apparatus as a reference. The key points of this study may be summarized as follows.

(1) In order to measure the baby carriage vibration under running conditions, experiments were conducted by using a real baby carriage equipped with acceleration sensors

(2) As baby carriage model in simulation, the rigid-body model and the elastic-connection model (using rotational springs to model movements between parts around carriage legs) were developed.

(3) It is clarified that the rigid-body model can analysis sufficiently the baby carriage vibration running the road having grooves at regular intervals.

(4) To verify the validity of the simulation model, the comparison between simulation results and experimental ones in when changed the driving speed was conducted.

References

[1] Combi Corporation, Combi Press Information, Japan (2012), *Report of exam results for baby carriage vibration and baby's stress*, URL: http://www.combi.co.jp/topics/files/120626.pdf, accessed on 31/08/2017 (in Japanese)
[2] Yamada, Y., Gamoh, Y. and Morita, T. (2010). Analysis of Physical Strain of Baby Stroller Users in Driving Environment, *Transactions of the Japan Society of Mechanical Engineering series C*, vol.76, No.767, July 2010, pp. 1804 – 1811. (in Japanese)
[3] Muraki, S., Saito, S. and Ookura, M. (2013). Physical Strain and Risk during Stroller Locomotion on Cross and Combined Slopes, *Advanced Engineering Forum*, vol.10, December 2009, pp. 43 – 50.
[4] Ogami, H., Saito, S., Okura, M. and Muraki, S. (2014). Investigation of Physical Strain and Danger in Sidewalk in Stroller Users -Focusing on Cross and Compound Slope and Level Difference-, *Journal of Life Support Engineering*, vol.17, December 2005, pp. 108. (in Japanese)
[5] Kawashima, T. (2009). Investigation of a Sliding Mode Control System for a Shaking Table for Baby Carriages, *Journal of System Design and Dynamics*, vol.5, No.5, February 2009, pp. 881 – 892.
[6] Miyauchi, K., Nagao, H., Yamasaki, Y. and Shino, M. (2015). Analysis of vibration property and suggestion of vibration reduction methods of baby carriage, *the Dynamics and Design Conference 2015*, Aomori, Japan. (in Japanese)
[7] Taniguchi, A., Yanagita, Y., Ohmori, N., Manabe, R. and Terauchi, Y. (2009). Prospect on actual condition of using stroller and slings in Japan, *Proceedings of Infrastructure Planning*, Ishikawa, Japan. (in Japanese)
[8] FunctionBay K.K., RecurDyn Technical Support, Japan (2017). *RecurDyn Manual*, URL: http://support.functionbay.co.jp/support/manual/, accessed on 31/08/2017 (in Japanese)