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Optimal Design of a Wheelchair Suspension Based on a Compliant Mechanism

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1. Abstract

In recent years, a compliant mechanism has been paid to attention as a new mechanism to replace a traditional rigid link mechanism and the use of compliant mechanisms in mechanical products, medical instruments and MEMS can be expected to increase. In our previous research, we focused on a vehicle suspension as a promising application target of a compliant mechanism and proposed an optimal design method for a vehicle suspension based on a compliant mechanism or a compliant suspension. In this research, we now apply a compliant suspension to a wheelchair and design a compliant suspension for a wheelchair using the method developed in the previous research. Most wheelchairs except some expensive ones don’t have a suspension and only rely on tires for absorbing vibration and shock from a road. Since a compliant suspension consists of fewer parts than a traditional suspension and can be potentially integrated into a frame of a wheelchair, a compliant suspension can be added to a wheelchair at low cost. We design and manufacture a compliant suspension, retrofit an existing wheelchair with it and test ride quality of a wheelchair with a compliant suspension.

2. Keywords: Wheelchair, Suspension, Compliant mechanism, Topology optimization, Shape optimization.

3. Introduction

In mechanical design, mechanisms consisting of rigid parts linked to moveable joints are often used, and in such mechanisms, the relative motion of the links is constrained by the joints. On the other hand, compliant mechanisms [1] utilize a structure's flexibility to achieve a specified motion, by deforming the structure elastically instead of relying on joint movements. Such compliant mechanisms often consist of fewer parts than rigid link mechanisms, or can even be monolithic, and, compared to rigid link mechanisms, they have several merits [1] [2], such as reduced wear and operation noise, zero backlash, freedom from lubrication requirements, weight savings, manufacturing advantages, and ease of miniaturization. Therefore, the use of compliant mechanisms in mechanical products such as mechanical products, medical instruments and MEMS (Micro-Electro Mechanical Systems) [1] [3] can be expected to increase. In our previous research [4] [5], we focused on a vehicle suspension as a promising application target of a compliant mechanism and developed an optimal design method for a vehicle suspension based on a compliant mechanism or a compliant vehicle suspension.

In this research, we now apply a compliant suspension to a wheelchair and design a compliant suspension for a wheelchair using the method developed in the previous research. Most wheelchairs except some expensive ones don’t have a suspension and only rely on tires for absorbing vibration and shock from a road. Figure 1 shows examples of wheelchairs without and with suspensions. Since a compliant suspension consists of fewer parts than a traditional suspension and can be potentially integrated into a frame of a wheelchair, a compliant suspension can be added to a wheelchair at low cost.

Figure 1: Wheelchairs without a suspension [6] (Left) and with a suspension [7] (Right)

4. Two stage design method of a compliant mechanism

Two stage design method [8] is the method for designing a compliant mechanism, consisting of topology and shape optimization. In this method, topology optimization first creates an initial outline of a compliant mechanism by considering only linear analysis. The optimal configuration of topology optimization is converted to an initial shape optimization model. At this point, design domains not considered during topology optimization can be added. Shape optimization then yields the detailed shape of a compliant mechanism by considering non-linear analysis, stress constraints and making accurate quantitative performance evaluations. Using this method, a designer can more easily and efficiently create a practical compliant mechanism. In a series of our previous researches, two stage design method was extended to apply a design of a vehicle suspension based on a compliant mechanism. From many design requirements for a practical vehicle suspension, 5 essential requirements i.e. stroke, camber angle, roll centre height, lateral rigidity and natural frequency of a suspension system were selected and used as an objective function and constraints conditions of topology and shape optimization. See the references [4] [5] for their details. In this research, this method is applied to a design of a wheelchair suspension based on a compliant mechanism.

5. Design of a compliant wheelchair suspension

5.1 Design concept and conditions of a wheelchair suspension

Figure 2 shows the concept of a wheelchair suspension designed in this paper. A suspension is an independent part and attached to an existing wheelchair by an aluminium plate. Design domain of a suspension is 0.40m width and 0.25m height. Material of a suspension is ABS with Young's modulus of 2600MPa, Poisson's ratio of 0.32 and density of 1050kg/m^3. Allowable stress is 58MPa. Thickness of a suspension is 0.02m. As for load, a wheelchair has 2 front small wheels and 2 rear large wheels and they share the weight of people and a wheelchair itself. After consideration of total weight, position of the centre of gravity and shock load, it is assumed that maximum load of a suspension is 500N. As for design requirements specific to a suspension, only stroke is considered. Target length of stroke is 0.02m when maximum load is applied.

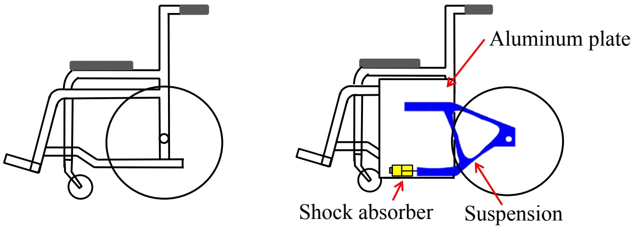

Figure 2: Existing wheelchair (Left) and concept of installation of a suspension (Right)

5.2 Topology optimization

By changing positions of input, output and constraints, the most promising initial outline of a suspension is explored. The volume constraint is set at 15%. Figure 3 and 4 show the design conditions and optimal configuration that are finally adopted respectively.

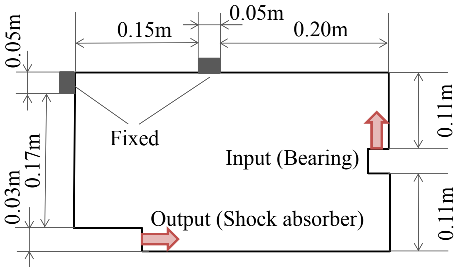

Figure 3: Design conditions

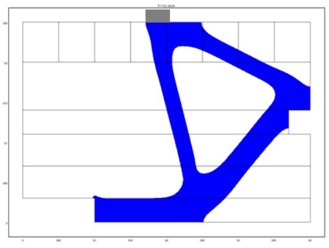

Figure 4: Optimal configuration

5.3 Shape optimization

The optimal configuration shown in Figure 4 is converted to an initial shape optimization model. In addition, connecting and bearing area is added to the model. Figure 5 shows the initial shape optimization model. Arrows shown in Figure 5 indicates control points whose coordinates are used as design variables of shape optimization. Table 1 summarizes initial, target and optimized values of stroke, maximum stress and weight. Figure 6 shows the optimal structure of a wheelchair suspension.

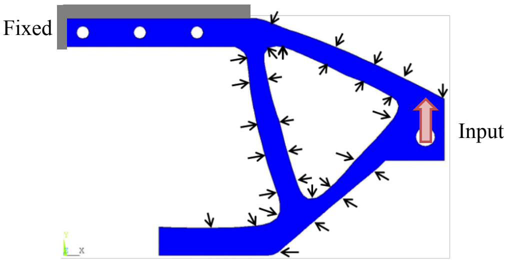

Figure 5: Initial shape optimization model

Table 1: Initial, target and optimized values of stroke, maximum stress and weight

	Initial	Target	Optimized
Stroke (m)	0.0056	0.02	0.02
Maximum stress (MPa)	22.9	<58.0	47.5
Weight (kg)	0.743	-	0.630

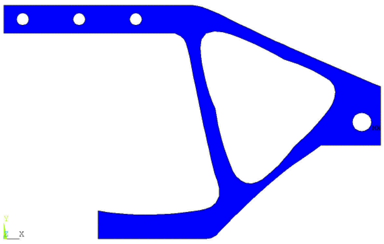

Figure 6: Optimal structure

6. Manufacturing and riding test of a wheelchair compliant suspension

The optimal structure of a suspension designed in the previous section is converted to a CAD model of SolidWorks. A suspension is made from an ABS plate by using a milling machine Roland D.G. MDX-540. Figure 7 shows the finished product. The suspension is attached to a wheelchair by an aluminium plate. Figure 8 shows a wheelchair with compliant suspensions. Since adequate shock absorbers cannot be bought due to time limitation, shock absorbers are not installed at this time. This is one of future subjects. The stroke length of a suspension when people ride on a wheelchair under stationary condition is 0.0085m.

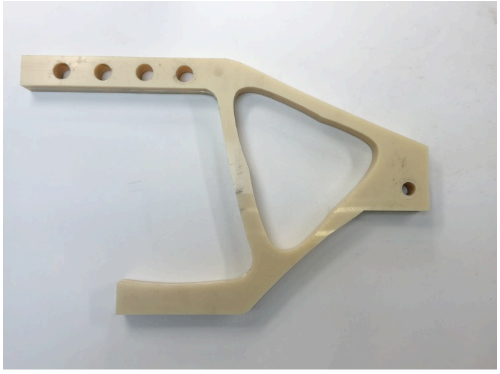

Figure 7: Suspension manufactured by a milling machine

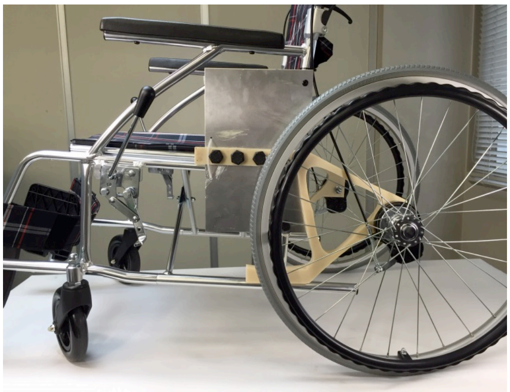

Figure 8: Wheelchair in which a suspension is installed

To test the effectiveness of a suspension, a riding test is conducted. 10 undergraduates participate the test as subjects. For comparison, they ride on wheelchairs with and without suspensions. A subject rides on a wheelchair and another person pushes a wheelchair to pass the obstacle shown in Figure 9. The obstacle is 0.45m width and 0.03m height. Ride quality of a wheelchair without suspensions when passing the obstacle is set at 3 and a subject relatively evaluates ride quality of a wheelchair with suspensions on a scale of 0.5 to 5. Figure 10 shows evaluation results and indicates that a suspension contributes the improvement of ride quality of a wheelchair.

Figure 9: Obstacle used for a riding test

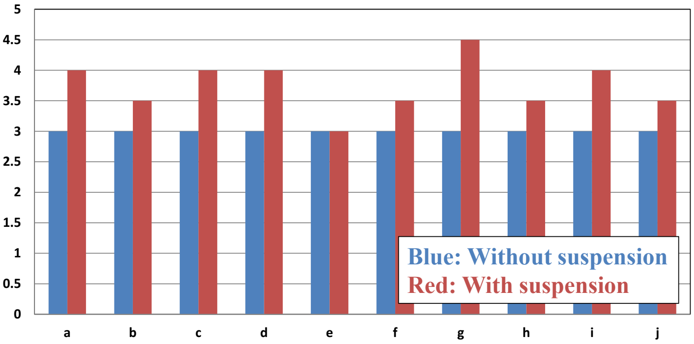

Figure 10: Evaluation of ride quality

7. Conclusion

In order to improve ride quality of a wheelchair with limited weight and cost, this paper proposes a wheelchair suspension based on a compliant mechanism. A suspension is designed by using two stage design method consisting of topology and shape optimization. To indicate the effectiveness of a suspension, it is designed, manufactured and attached to an existing wheelchair and a riding test is conducted.

As for future works, (1) installation of shock absorbers and measurement using accelerometer and (2) design of a suspension integrated into a frame of a wheelchair are planned.

8. Acknowledgements

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9. References

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