A Study on Integration of Energy Harvesting System and Semi-Active Control for a Hydraulic Suspension System

整合液壓減振器能源擷取系統及半主動減振控制之研究

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Outline

- Introduction
- Test Rig Layout
- System Modelling and Simulation
- Controller Design
- Results and Discussions
- Conclusions

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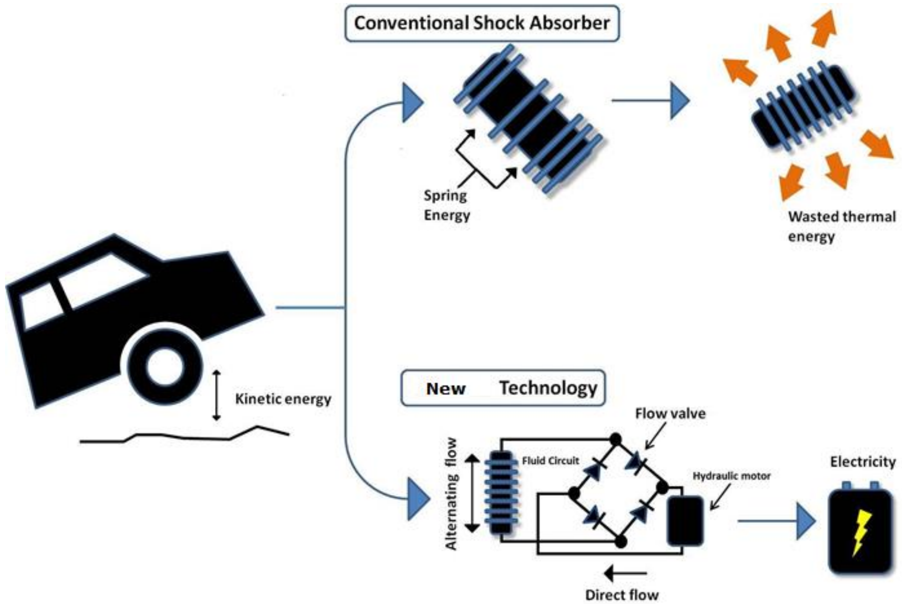
Motivation(1/4)

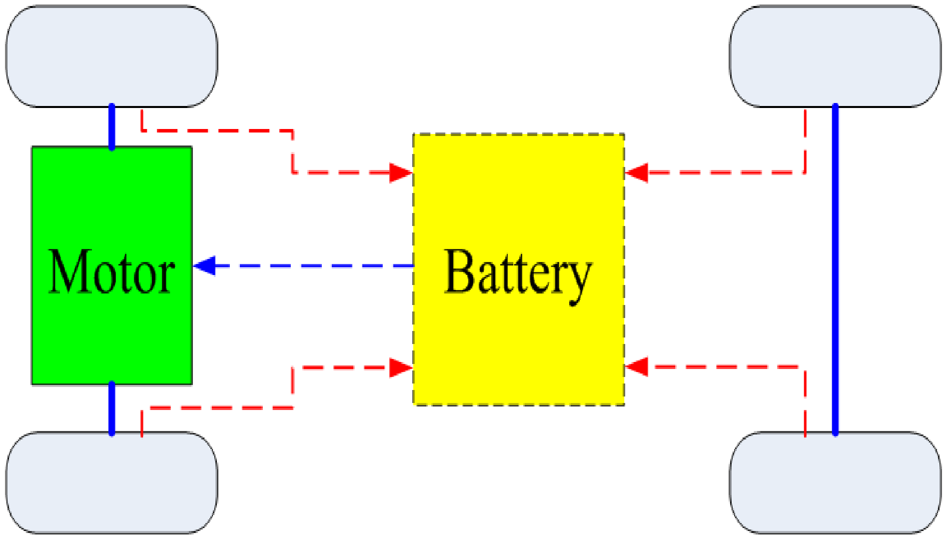
- Exhaustion of energy
- Green concept
- Renewable energy technologies

Fig. 3

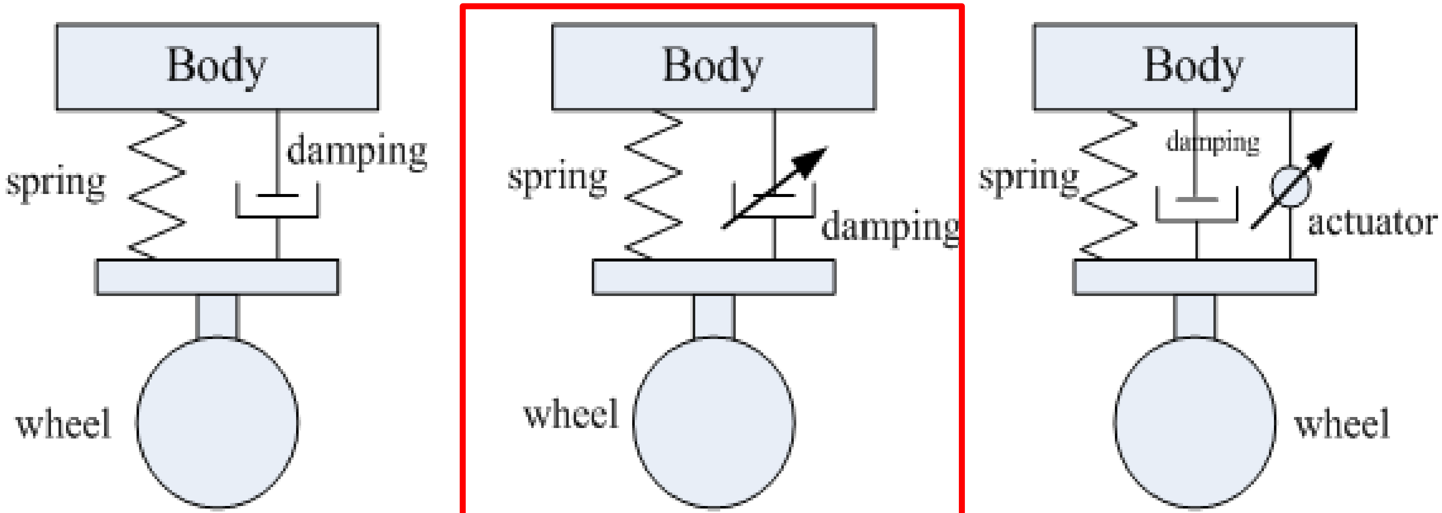
Motivation(2/4)

- Energy harvesting system of electric vehicles
- Energy efficiency





Semi-active control

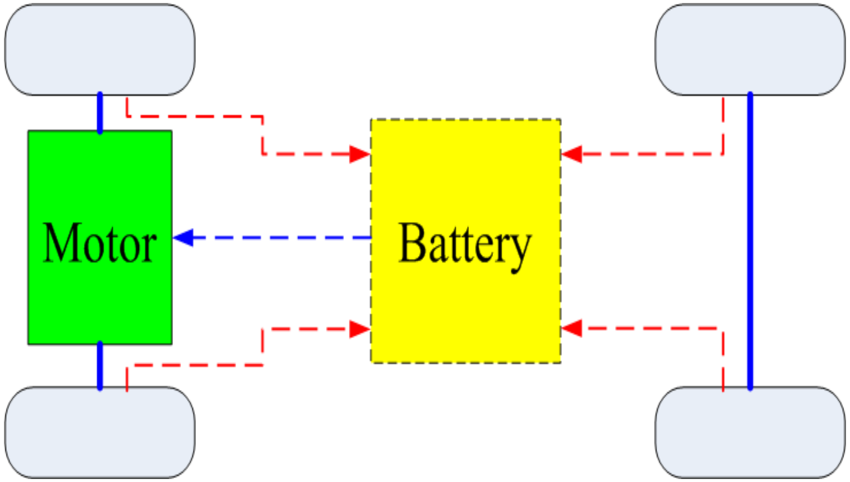


Passive — Semi-active — Active

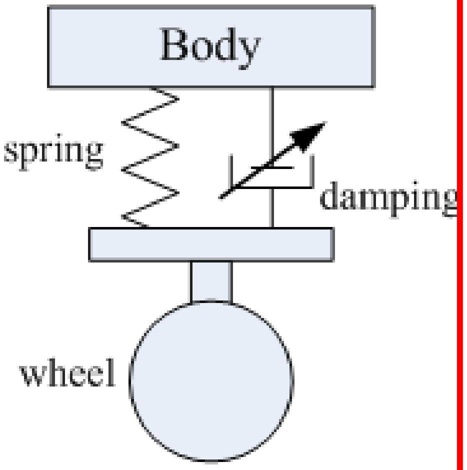
Passive	Semi-active	Active
1.Fixed damping coefficient 2.Simple	1.Adjustable damping coefficient 2.Combining advantages	1.Force apply 2.Need external energy 3.Expensive

Motivation(4/4)

Energy harvesting system



Semi-active suspension



Semi-active control

Literature Survey(1/3)

■ Semi-active suspension

In 1981, Segel and Lang [1] used the relationship of F_d-V to test the performance of damper.

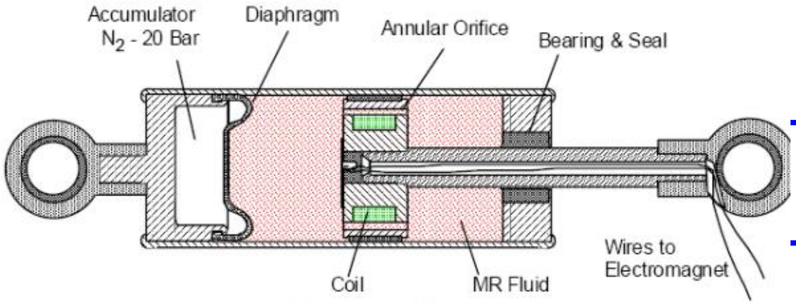


Figure.6 Schematic of MR Damper

In 2002, Yao et al.[5] proposed a semi-active control of vehicle suspension system with a MR damper.

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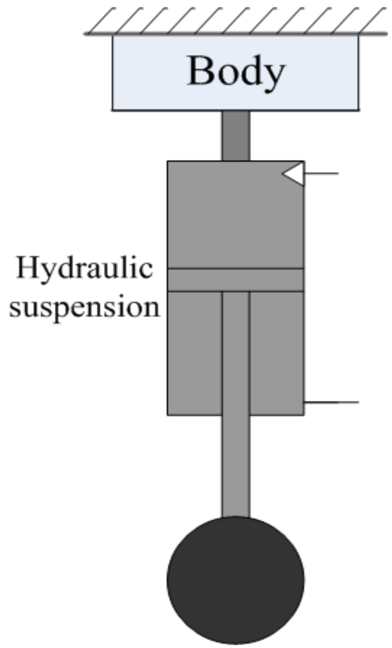
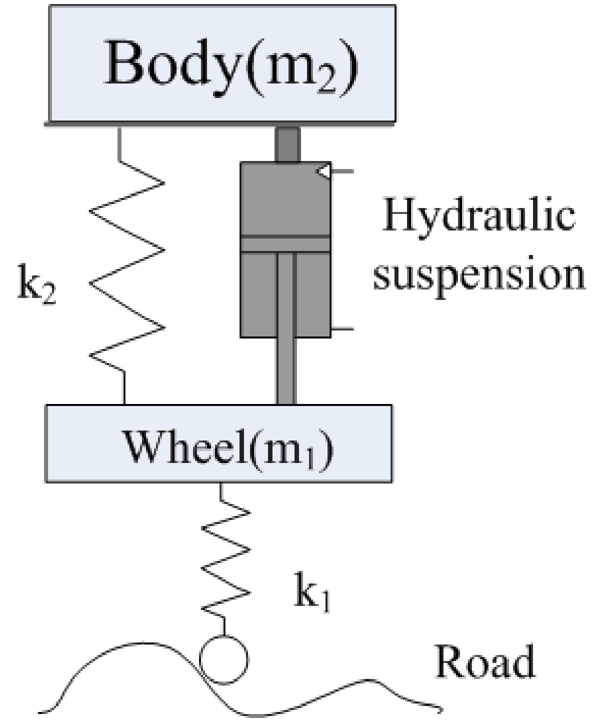
Test Rig Layout

- Skyhook damper system
  1. Throttle valve control
  2. Resistance control



- Quarter-car system in resistance control



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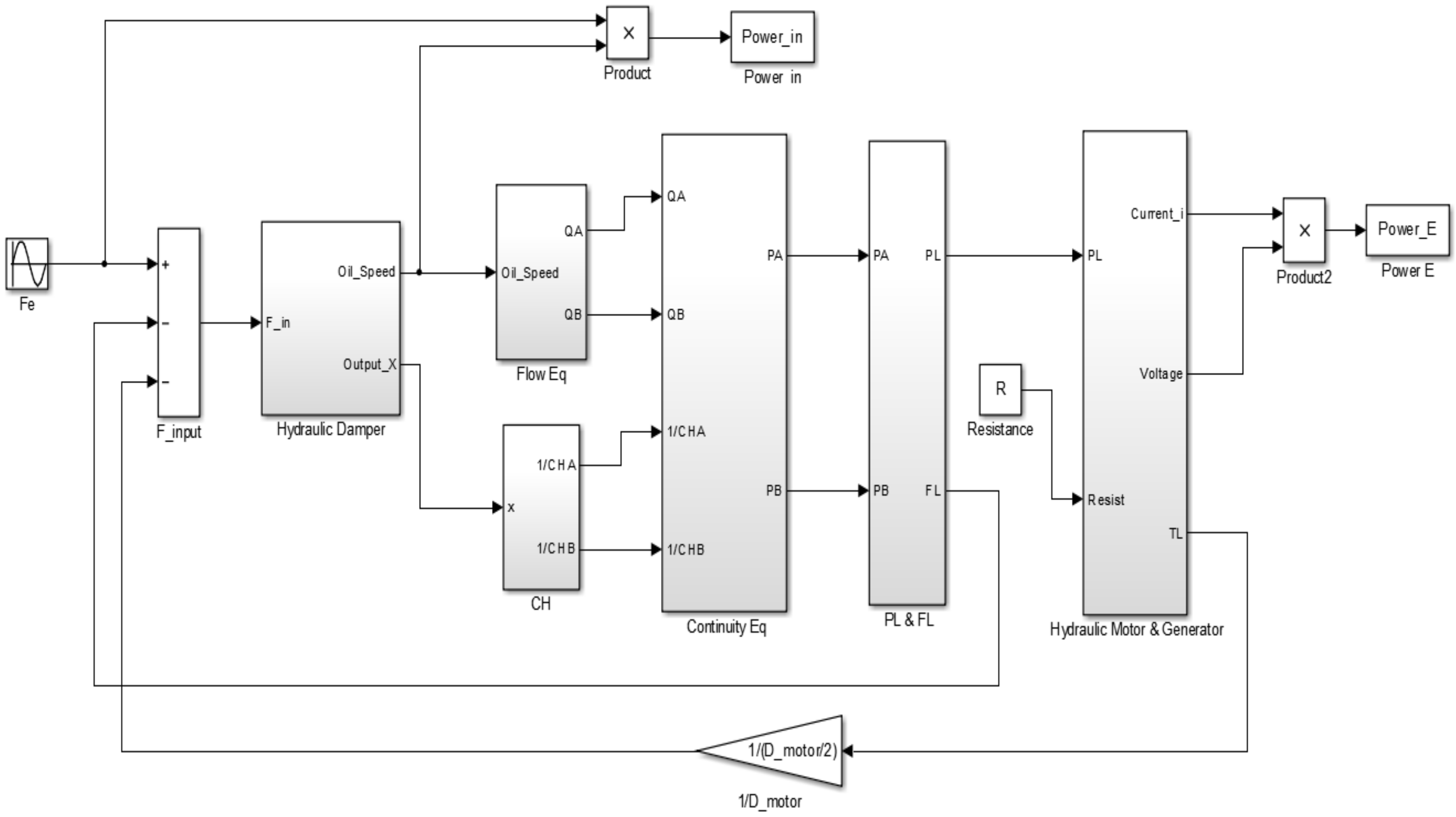
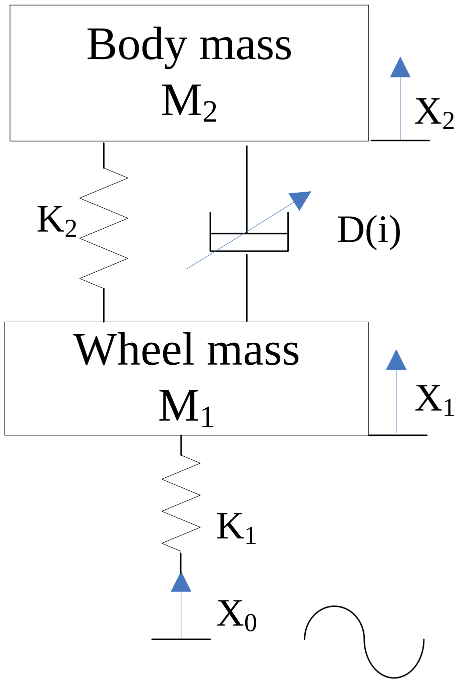
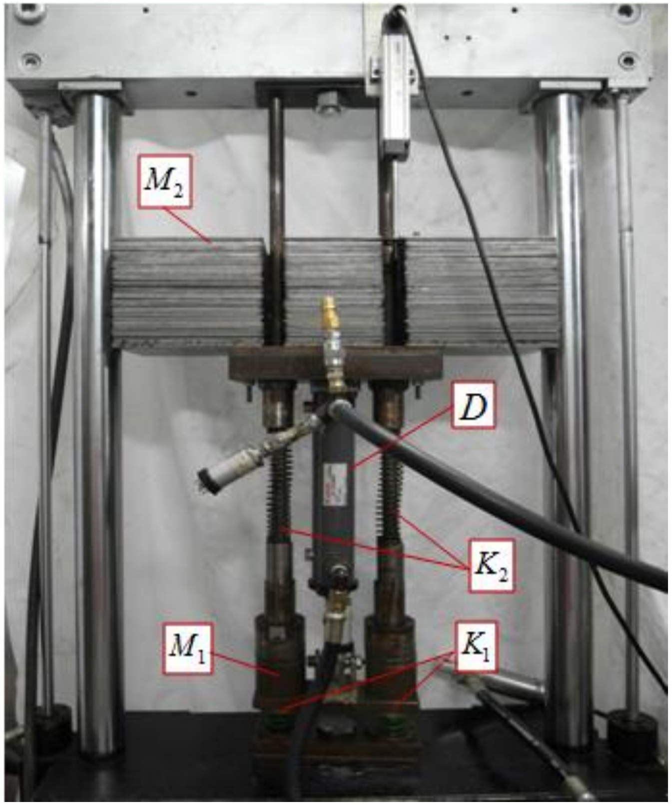
Skyhook damper system(4/4)



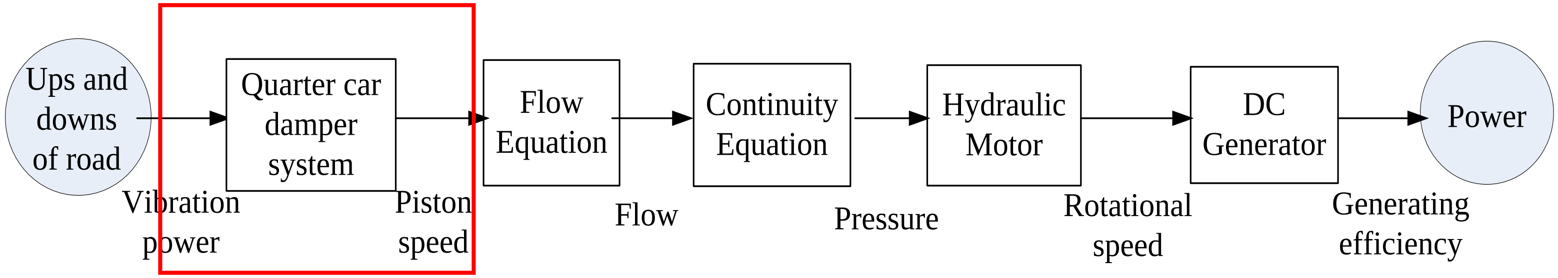
■ Quarter-car system(1/3)



Two-DOF system



Quarter-car system(2/3)



Dynamic equation of hydraulic damper

$$M_2\ddot{x}_2 + D(\dot{x}_2 - \dot{x}_1) + K_2(x_2 - x_1) - F_d = 0$$

$$M_1\ddot{x}_1 - D(\dot{x}_2 - \dot{x}_1) - K_2(x_2 - x_1) + K_1(x_1 - x_0) + F_d = 0$$

X_1	:	Wheel displacement
X_2	:	Body displacement
M_1	:	Mass of wheel
M_2	:	Mass of vehicle body
D	:	Damping coefficient
K_1	:	Wheel stiffness
K_2	:	Suspension stiffness
F_d	:	Damping force

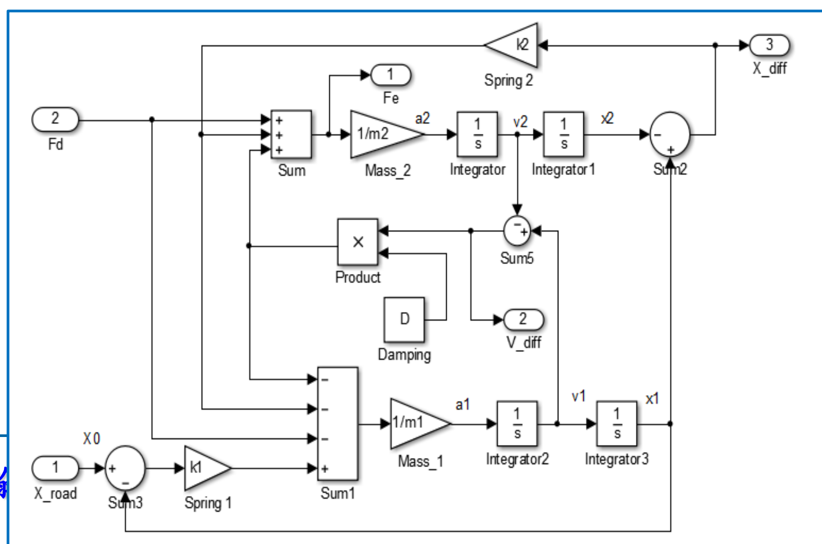
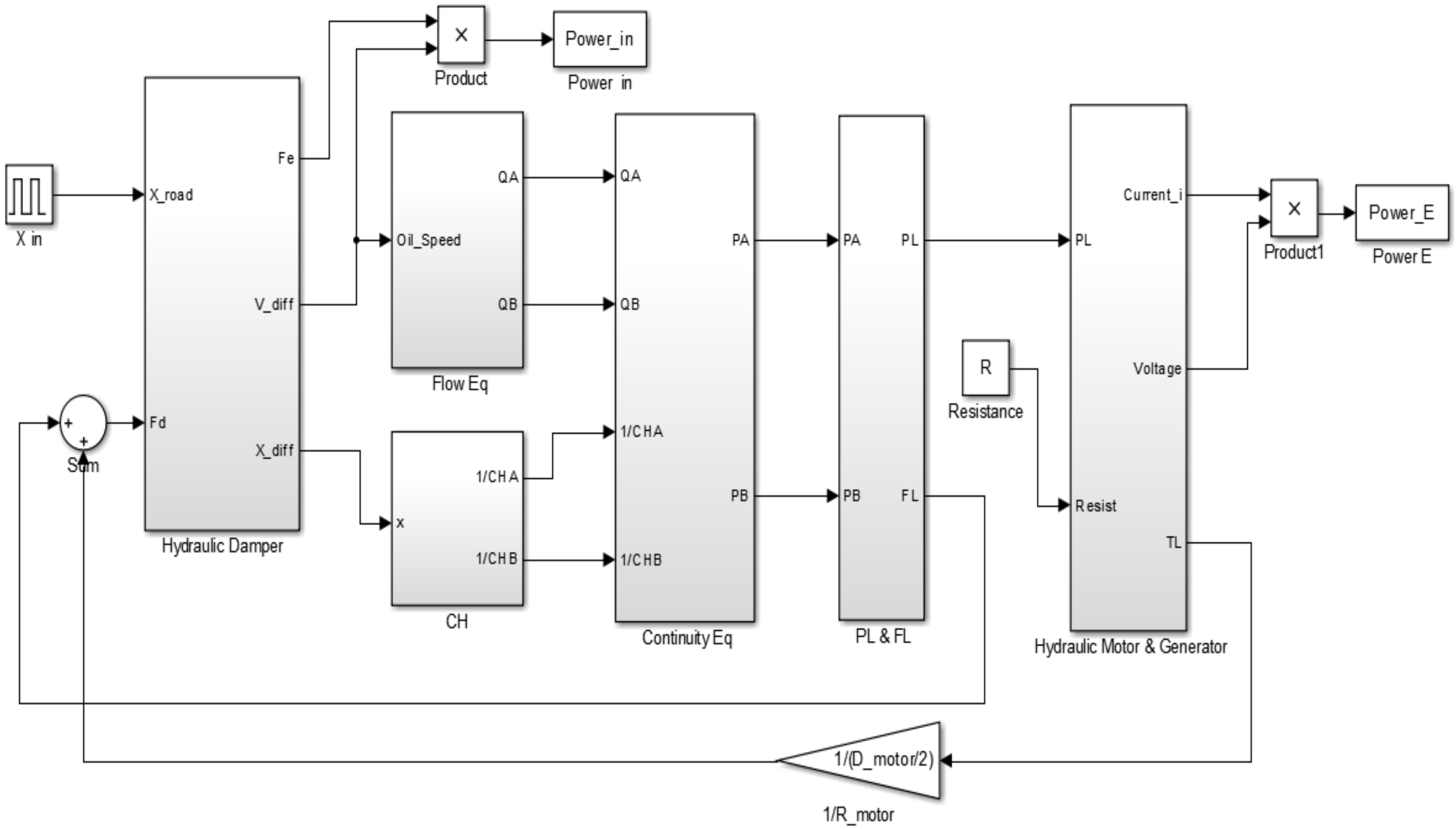


Fig. 13

■ Quarter-car system(3/3)



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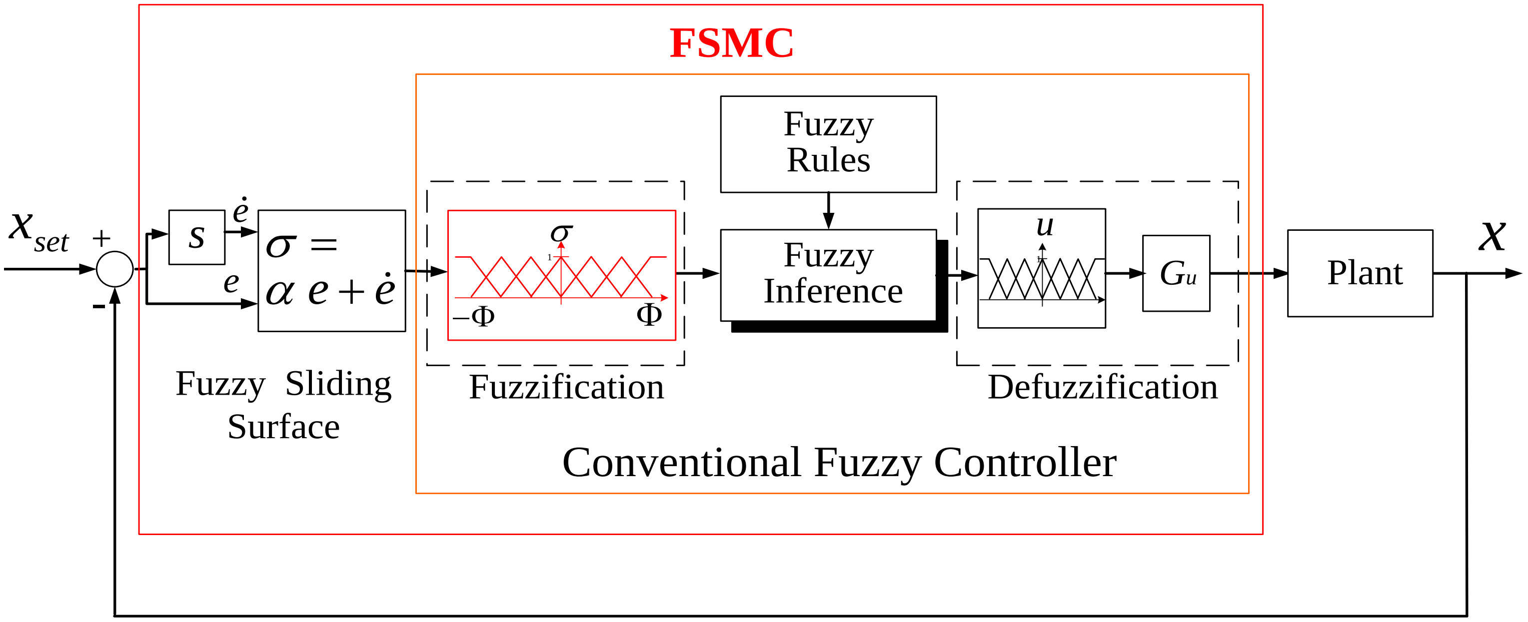
Fuzzy Sliding Mode Control

- **Fuzzy sliding mode control**



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List of Experiment

<table>
<tr><td rowspan="2">5-1</td><td colspan="6">Results of skyhook damper system in throttle control</td></tr>
<tr><td colspan="3">Open-loop simulation</td><td colspan="3">Open-loop experiment</td></tr>
<tr><td rowspan="2">5-2</td><td colspan="6">Results of skyhook damper system in resistance control</td></tr>
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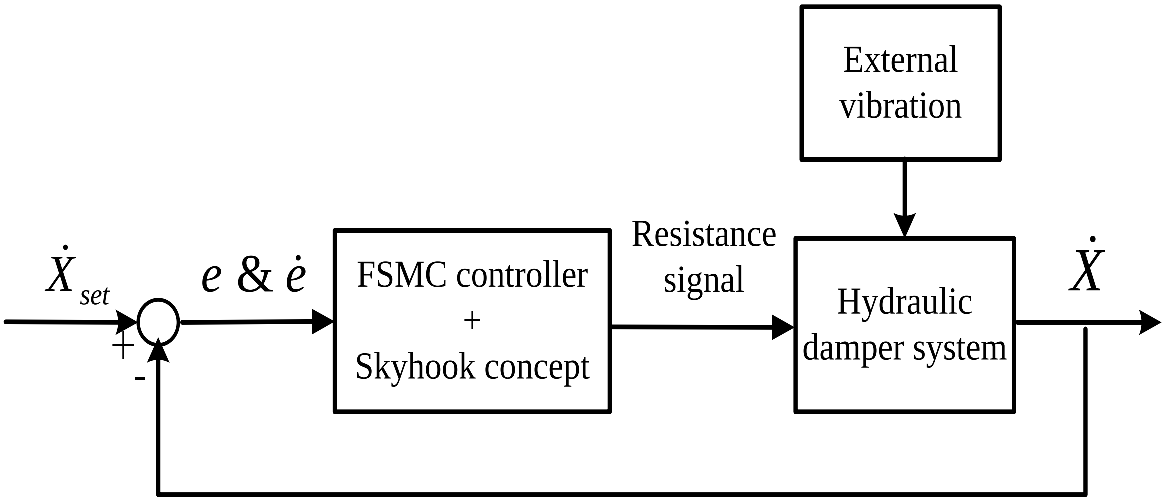
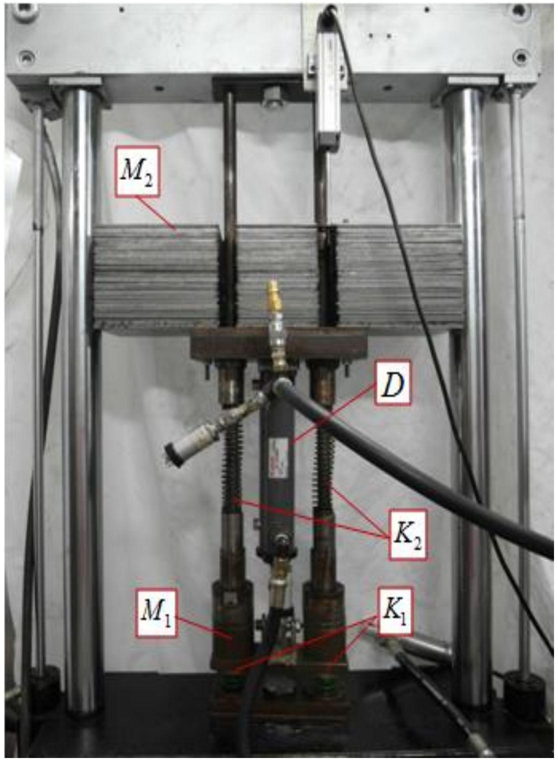
<tr><td colspan="3">Simulation</td><td colspan="3">Experiment</td></tr>
</table>

Quarter-car System in Resistance Control

- Experiment(1/5)

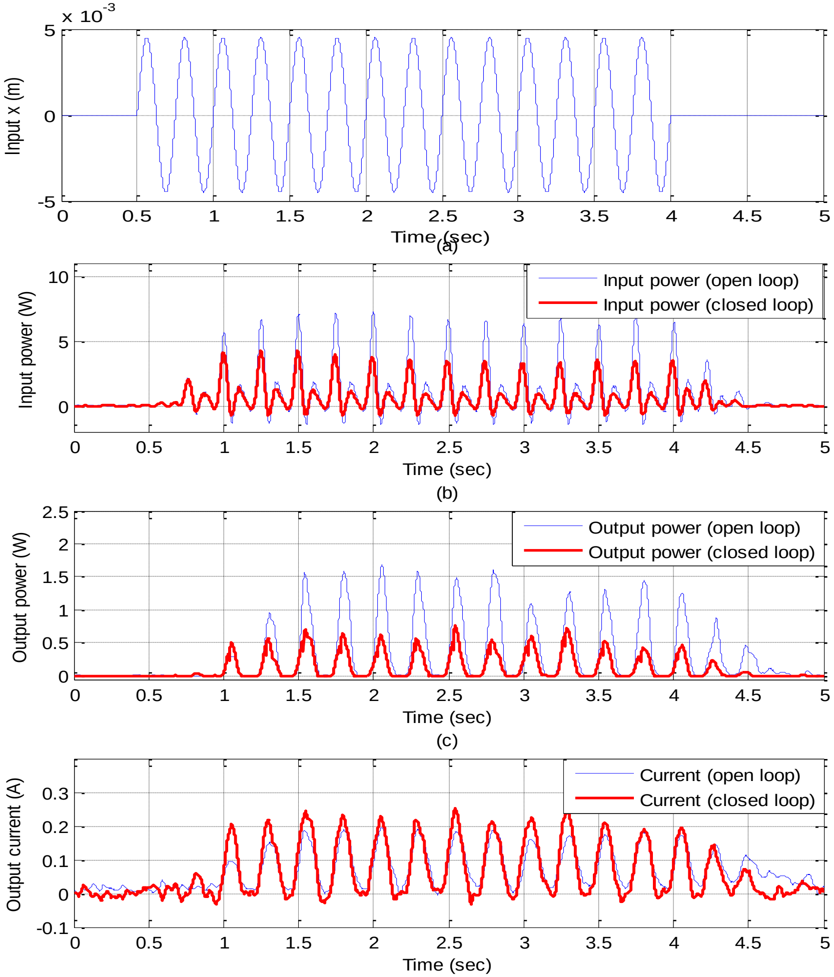


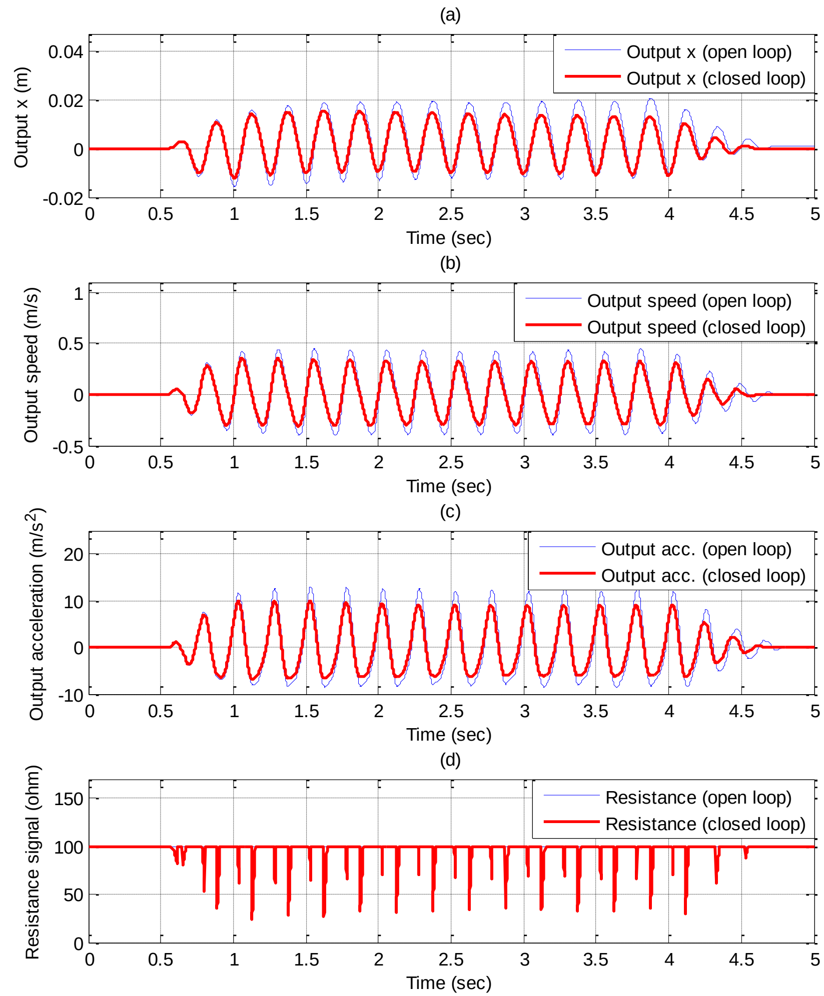


Target : Speed of $M_2 = 0$

■Experiment(2/5)

$$X(t) = 0.0045(8\pi t)m$$





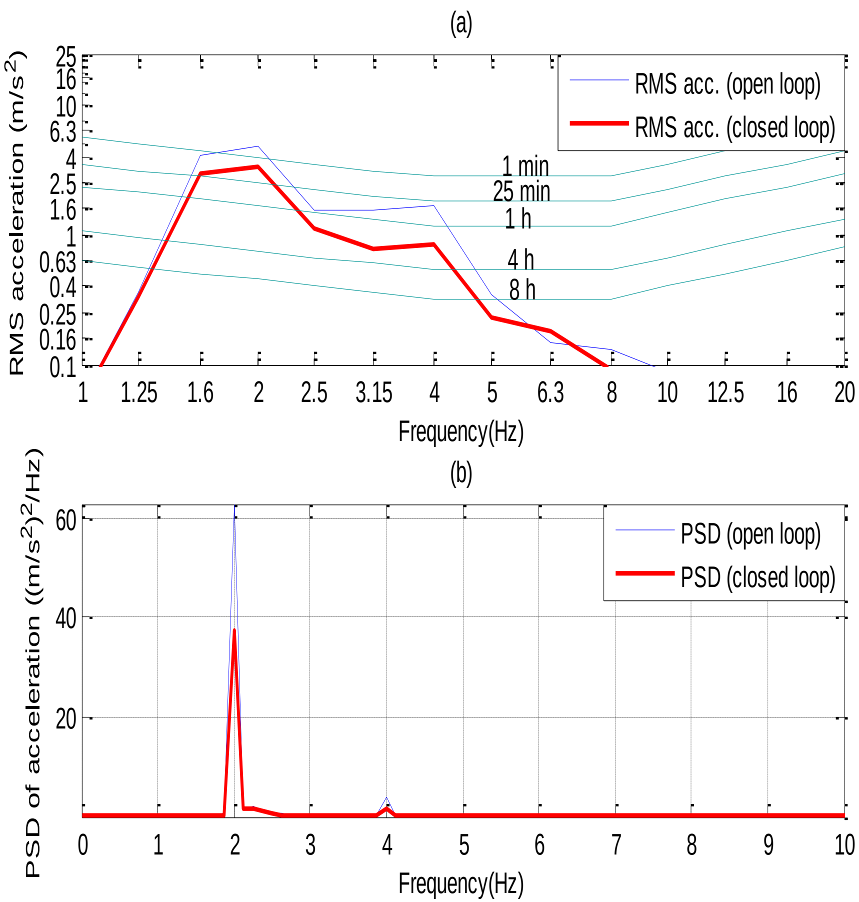
江茂雄、劉翰祥

Fig. 20

Quarter-car System in Resistance Control

■Experiment(3/5)

$$X(t) = 0.0045(8\pi t)m$$

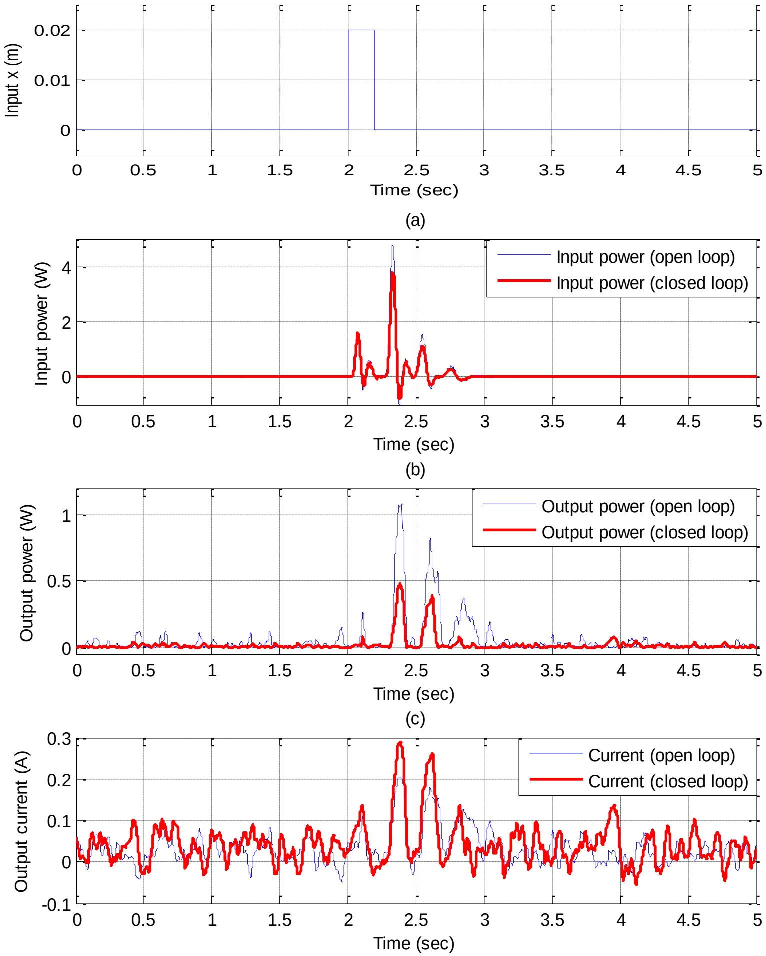


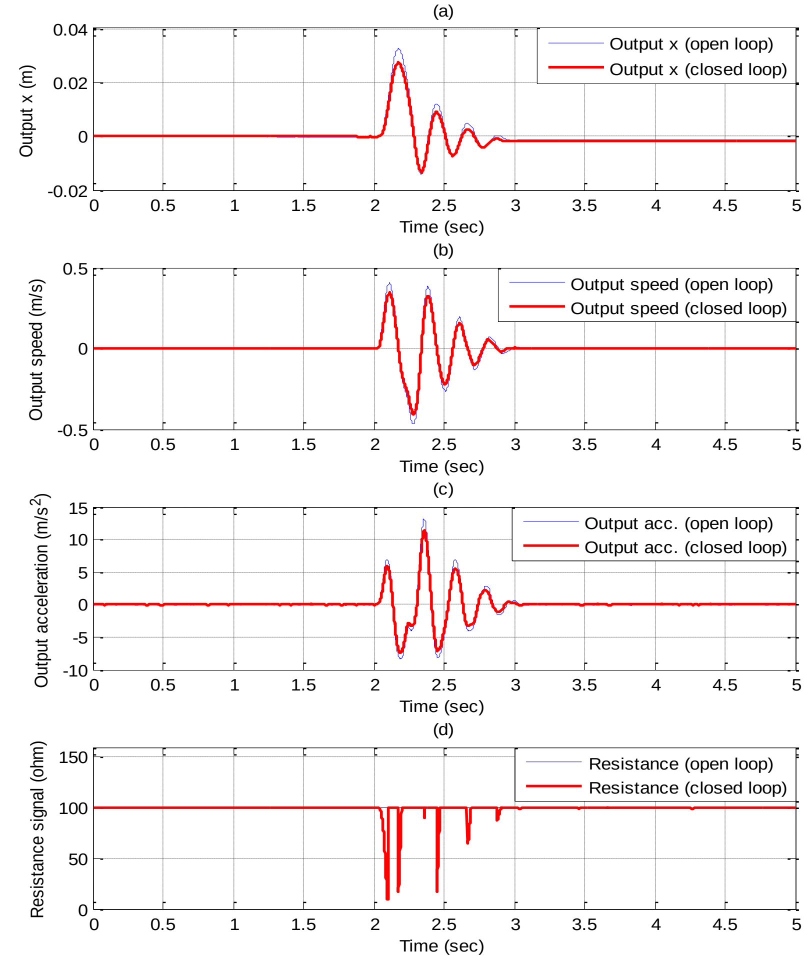
	Passive	Semi-active
Efficiency (%)	23.5%	17.3%
Car body speed (m/s)	0.42 m/s	0.37 m/s (-12%)
Acceleration (m/s^2)	12.6 m/s^2	10.1 m/s^2 (-19.8%)
Current (A)	0.18 A	0.24 A
$PSD_{acc,peak}$ ($(m/s^2)^2/Hz$)	63.2	37.8 (-40.2%)
Time of comfortable riding	Less than 1min	1min ~ 25min

Quarter-car System in Resistance Control

■Experiment(4/5)

$X(t) = 0.02m$ pulse



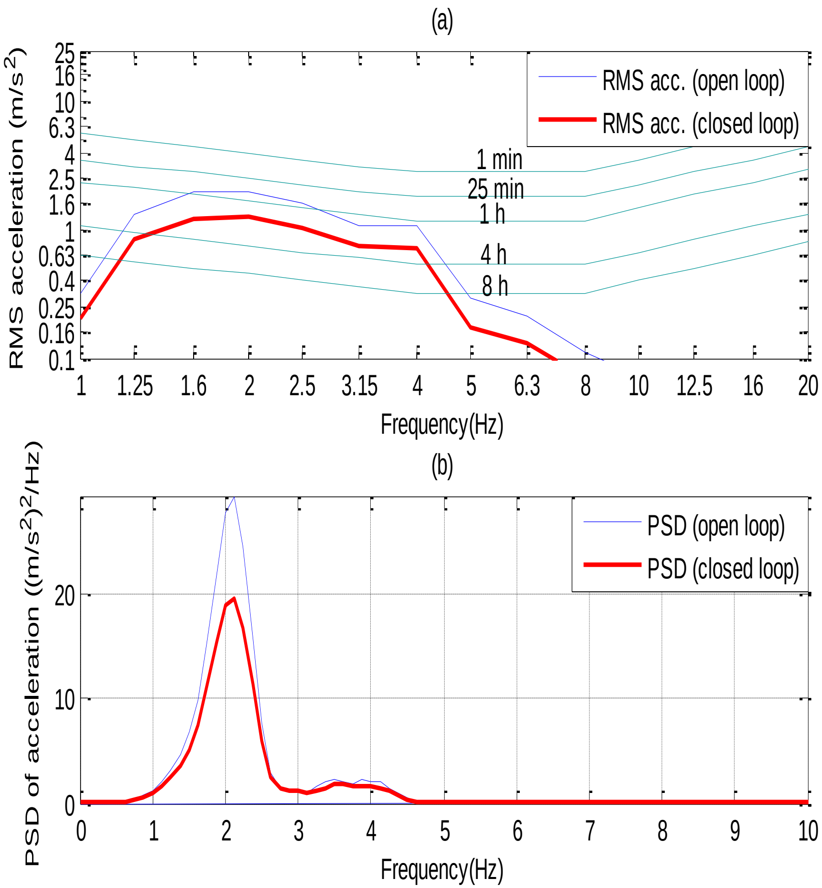


江茂雄、劉翰祥
Fig. 22

Quarter-car System in Resistance Control

■Experiment(5/5)

$X(t) = 0.02m \ \ \text{pulse}$



	Passive	Semi-active
Efficiency (%)	24.8%	12.1%
Car body speed (m/s)	0.45 m/s	0.395 m/s (-13.3%)
Acceleration (m/s^2)	13.1 m/s^2	11.9 m/s^2 (-9.2%)
Current (A)	0.2 A	0.293 A
$PSD_{acc,peak}$ $((m/s^2)^2/Hz)$	29.1	19.3 (-33.7%)
Time of comfortable riding	25min ~ 1h	1h ~ 4h

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Conclusions

- Skyhook damper system
  - The throttle valve control and the resistance control are effective to adjust damping coefficient.
  - Integration strategies of energy harvesting efficiency and damping effect.
  - The efficiency of the resistance control, 40.6%, is greater than that of the throttle control, 35.7%, due to huge oil friction in the throttle.

Conclusions

- Skyhook damper system
  - In semi-active control, fuzzy sliding mode control is applied. The controller can perform effectively for achieving the desired speed.
  - The ability of energy harvesting is examined. However, when controlling the vibrational speed, the efficiency of energy harvesting will be sacrificed.

Conclusions

- Quarter-car system
  - The results have demonstrated that the speed and the PSD of acceleration are significantly reduced.
  - The time of comfortable riding has been extended in Meister chart.
  - The harvesting energy is little due to light weight of the load and limit of the test rig.

Thanks for your attention!