Energy Dissipation in Particle-based Impact Damper Systems: Investigation based on Elasto-plastic impact model

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Outline

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Overview of particle-based dampers

- Particle-based dampers usually involve macroscopic particle(s) held within cavities as depicted in the figure.
- In systems involving particle-based dampers, the energy of the system is dissipated due to inter-particle, wall-particle collision and frictional contact between surfaces.

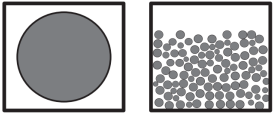


Figure: Image credit:-Prasad,et al. 2022

Energy dissipation

Studies are limited due to the non-linear nature of the interaction between the constituents of the system. The below assumptions are popularly employed to simplify the system,

- contacts with a **constant coefficient of restitution**,
- **instantaneous contacts**.

Outline

Description of System

EoM for primary system

$$m_{PS}\ddot{z} + C\dot{z} + Kz = F(t) + F_d(t)$$

EoM for i^{th} particle

$$m_i\ddot{\mathbf{u}}_\mathbf{i} = \Sigma_j(\mathbf{N_{ij}} + \mathbf{f_{ij}}) + \Sigma_k(\mathbf{N_{ik}} + \mathbf{f_{ik}})$$
$$I_i\ddot{\theta}_\mathrm{i} = R_i\Sigma_j(\mathbf{n_{ij}} \times \mathbf{f_{ij}}) + R_i\Sigma_k(\mathbf{n_{ik}} \times \mathbf{f_{ik}})$$

Non-linearity involved within the system

$$\mathbf{N_{ij}} = -(A_{ij}\delta_{n,ij}^{3/2} + \gamma_{ij}\dot{\delta}_{n,ij})\mathbf{n_{ij}}$$
$$\cancel{\mathbf{f_{ij}} = -\mu|\mathbf{N_{ij}}|\tanh(k_s\dot{\delta}_{t,ij})\mathbf{t_{ij}}}$$

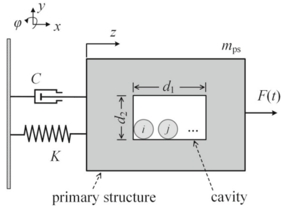


Figure: Schematic of system, Image credit-Li. et al. 2024

Impulse load

$$F(t) = \begin{cases} F_0 \sin(\pi\frac{t}{t_0}) & \text{if } t \leq t_0 \\ 0 & \text{if } t > t_0. \end{cases}$$

Elasto-plastic impact model

Jackson, Green, and Marghitu 2010

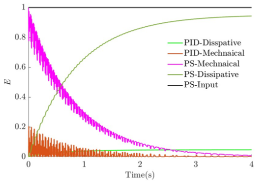
$$e = \begin{cases} 1 & \text{if } 1 > V_1^* > 0 \\ 1 - 0.1 ln(V_1^*) \left(\frac{V_1^* - 1}{59}\right)^{0.156} & \text{if } 60 > V_1^* \geq 1 \\ 1 - 0.1 ln(60) - 0.11 ln\left(\frac{V_1^*}{60}\right)(V_1^* - 60)^{2.36\epsilon_y} & \text{if } 1000 > V_1^* \geq 60. \end{cases}$$

$$V_1^* = \frac{V_1}{V_c}, \qquad V_c = \sqrt{\frac{4\omega_c P_c}{5m^*}}, \qquad \omega_c = \left(\frac{\pi \dot{C}_k S_{y,k}}{2E^*}\right)^2 R^*,$$

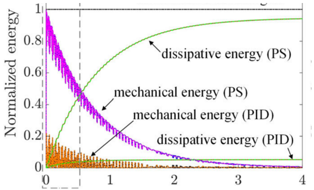
$$P_c = \frac{4}{3}\left(\frac{R^*}{E^*}\right)^2 \left(\frac{\pi}{2} C_k S_{y,k}\right)^3, \qquad C_k = 1.295 e^{0.736\nu_k},$$

Outline

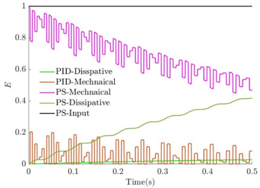
Benchmark Validation



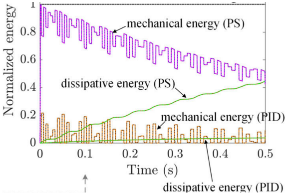
(a) Current work



(b) Li et al. (2024)



(c) Current work



(d) Li et al. (2024)

Elasto-plastic impact model

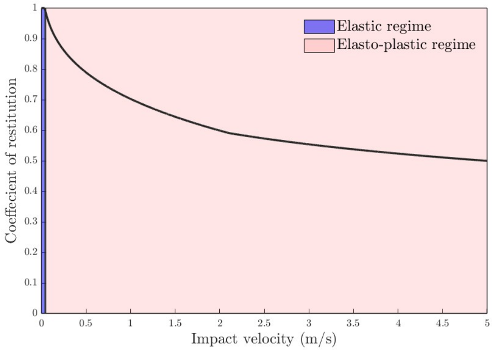


Figure: Variation of e with the impact velocity

S.no	Property	Value
1	Material	Steel
2	Modulus of elasticity	200 GPa
3	Poisson ratio	0.3
4	Yield stress	1030 MPa
5	Density	7850 kg/m^3
6	Diameter of particle	33.17 mm
7	Length of cavity	67.14 mm
8	M_{PS}	20 Kg
9	k	80000 N/m
10	Δt_1	5×10^{-6} s
11	Δt_2	3×10^{-8} s

Table: Parameters employed in this study

Outline

Phase portrait $F_0 = 0N$

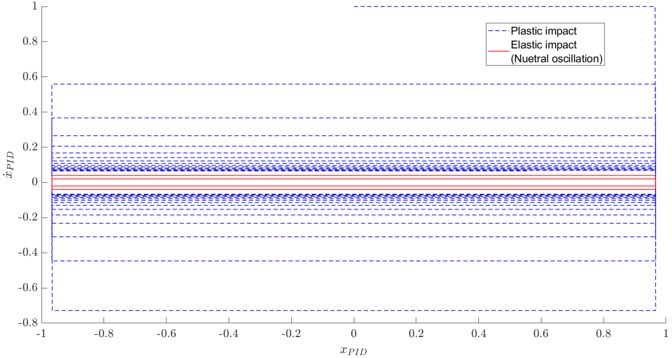
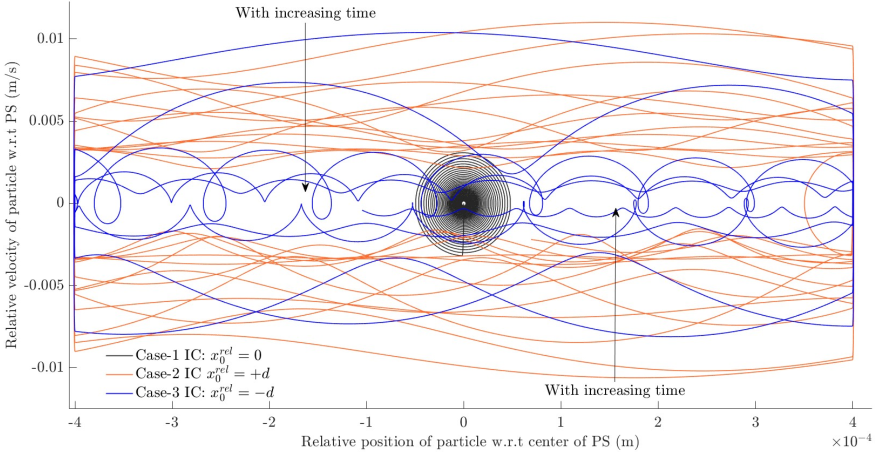
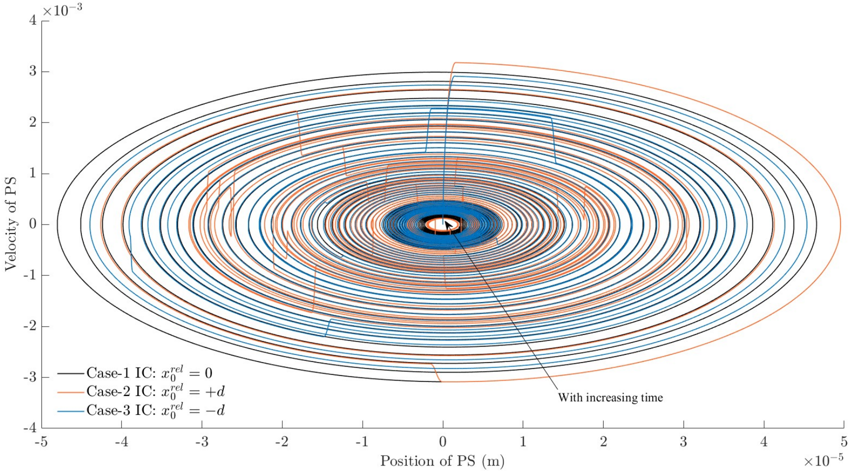


Figure: Phase portrait of the system; the PS is assumed to be fixed.

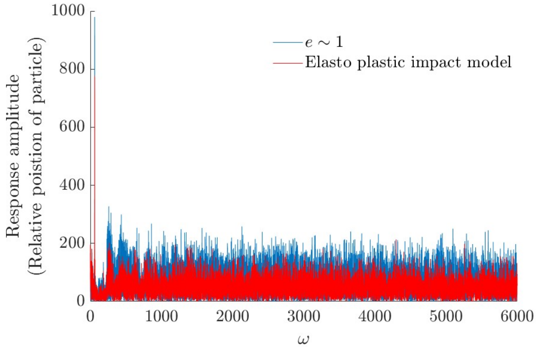
Phase portrait $F_0 = 100N$, $t_f = 0.001s$

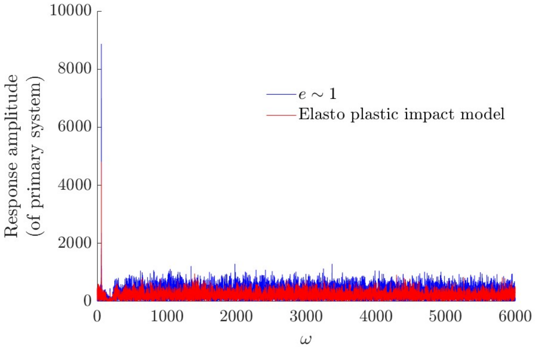


Phase portrait $F_0 = 100N$, $t_f = 0.001s$



Amplitude response in frequency domain





Outline

Energy dissipation characteristics

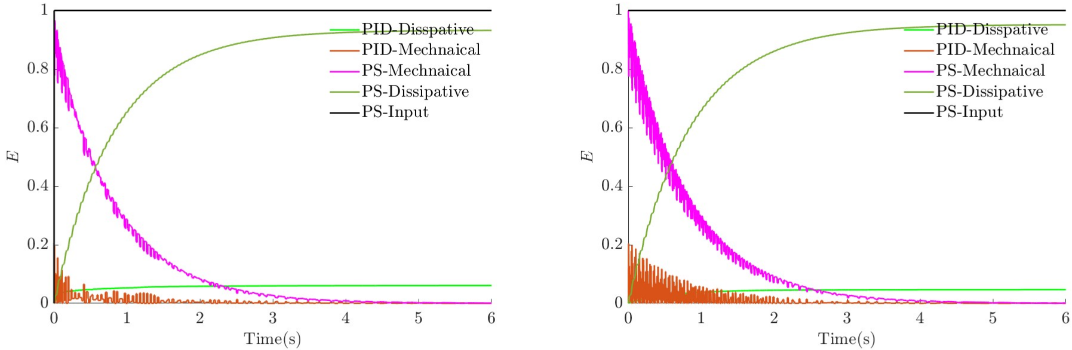


Figure: Energy dissipation characteristics (a) Elasto-plastic impact (b) $e \sim 1$

Energy dissipation characteristics (contd..)

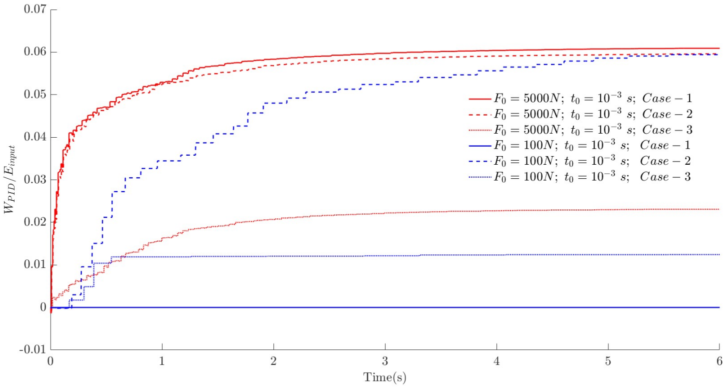
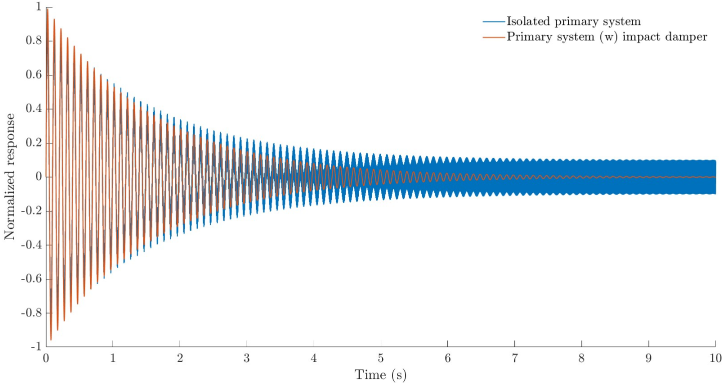


Figure: Sensitivity of energy dissipation characteristics on initial condition

Energy dissipation characteristics (contd..)



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Conclusion and perspectives

1. The energy dissipation in the work of Li et al. 2024[1] is observed to be an underestimation as they assumed a constant coefficient of restitution.
2. Similar to observations made in Li et al. 2024[1], the energy dissipation is observed to be sensitive to the initial topology of the system. The chaotic behaviour is confirmed from the phase portraits.

[1] Li, X., Mojahed, A., Wang, C. et al. Irreversible energy transfers in systems with particle impact dampers. Nonlinear Dynamics 112, 35–58 (2024)

Thank You!