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# Dynamic Response to Road Excitation and Noise Reduction

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## Summary

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The structural response to the impact generates structure borne noise as part of pollution to the environment. To reduce the wheel noise can be achieved by attenuating the intensity of structural vibration. Tyred wheel dynamic response to road excitation during rolling has been simulated using finite element modelling in a graphical programming environment. The relationship between the noise generation energy of wheel and damping is investigated. It is proposed to reduce the noise by increasing the damping in the tyre structure. The effectiveness has been demonstrated by the simulation result.

# Research Path

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- The actual contact to ground is an area and the contact edges are subject to continuous impacts during the rolling.

- Structural response to the impact generates structure borne noise as part of pollution to the environment.

- To reduce the wheel noise can be achieved by attenuating the intensity of structural vibration.

- Tyre vibration reduced by damping material is simulated.

- The effectiveness of noise reduction is demonstrated by the simulation result.

# Introduction

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- ❑ A major part of noise of fast travelling vehicle on road is generated from the tyre due to impact between the tyre contact area and road surface.

- ❑ One of the rubber tyre functions is to isolate the vibration excitation caused by the road roughness for the rider.

- ❑ Fast rolling wheel generates noise to all its surroundings through the air.

- ❑ Due to main target for tyre research and development have been the road gripping durability and safety, significant measures taken to reduce the noise has been limited so far.

## Introduction

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- A typical existing product example includes that an acoustic damping sheet is formulated for maximum damping efficiency over a broad frequency and temperature range with easy peel and stick features.

- Tests show that the absorption can be from 13 dB to 42 dB from frequency 100Hz to 5000Hz. The higher the frequency, the more effective. Therefore, to use damping material to reduce tyre rolling noise becomes a hope for road noise solution.

- This paper focuses on the simulation of vibrating wheel using finite element model in graphical dynamics environment, and how the vibrating energy is dissipated by increasing the damping in the tyre structure.

- For better understanding of tyre wheel behaviour, displaying the dynamic characteristics is realised in MATLAB SIMULINK environment, graphically presents the real-time dynamic behaviour. This novel methodology has combined the merit of real-time simulation and straightforward finite element visual effect.

# Dynamic Model and Impact Responses to Road Excitation

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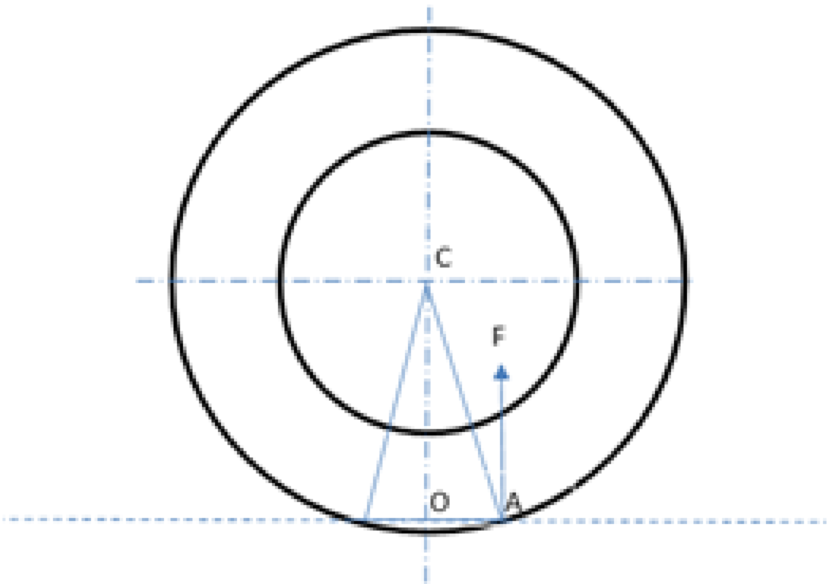



Fig. 1. Road impact on rolling wheel

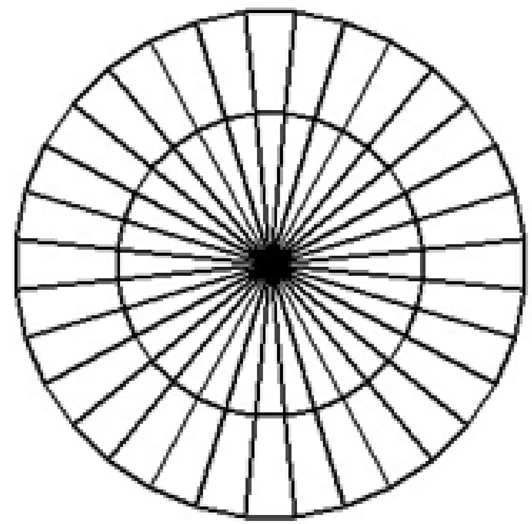


Fig. 2. Finite Element Wheel Model

During fast rolling, the velocity of contact A is significant, and the edge of contact receives an impact from the ground. This impact is continuously happening to the circumference of the tyre.

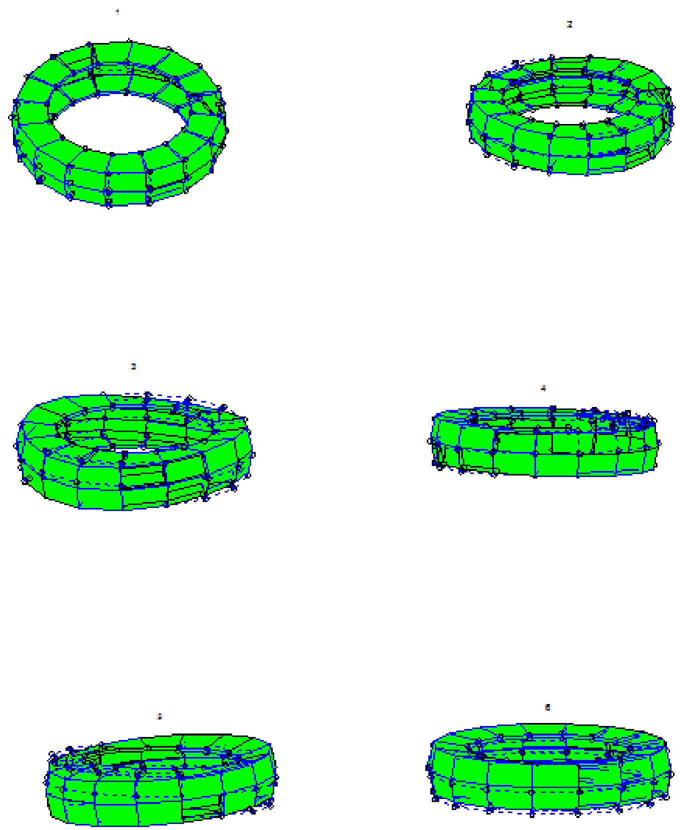
# Dynamic Model and Impact Responses to Road Excitation

With $N$ degrees of freedom, the dynamics of the model is governed by the equation of motion

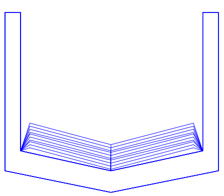
$$[m]\{\ddot{z}\}+[c]\{\dot{z}\}+[k]\{z\}=\{u(t)\} \tag{1}$$

where $[m]_{N\times N}$, $[c]_{N\times N}$, $[k]_{N\times N}$, $\{z\}_{N\times 1}$, $\{u(t)\}_{N\times 1}$ are the mass matrix, damping matrix, stiffness matrix, displacement vector and external force vector, respectively

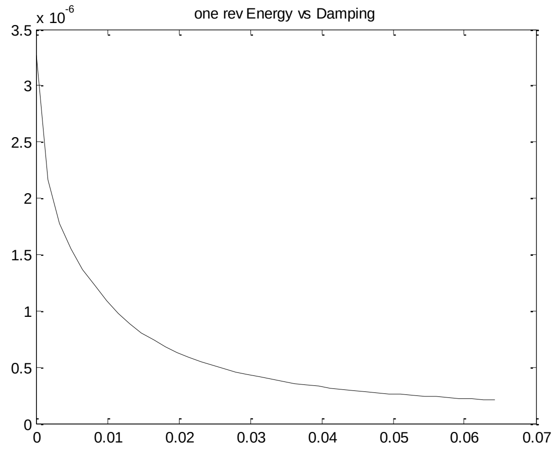
# FEA Modelling with Damping Layer



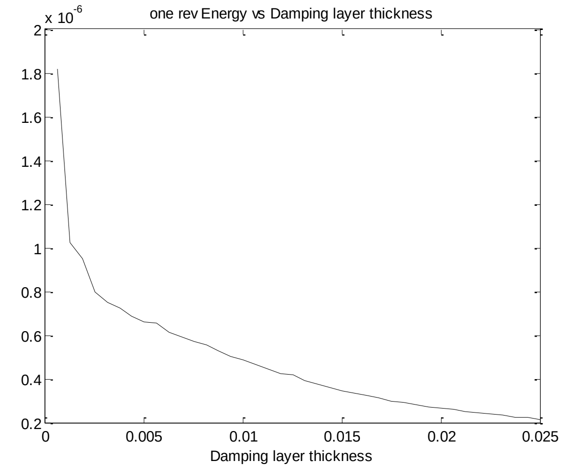
damping layer



# FEA Modelling with Damping Layer




Vibration energy vs damping ratio




Vibration energy vs damping layer thickness

# FEA Modelling with Damping Layer

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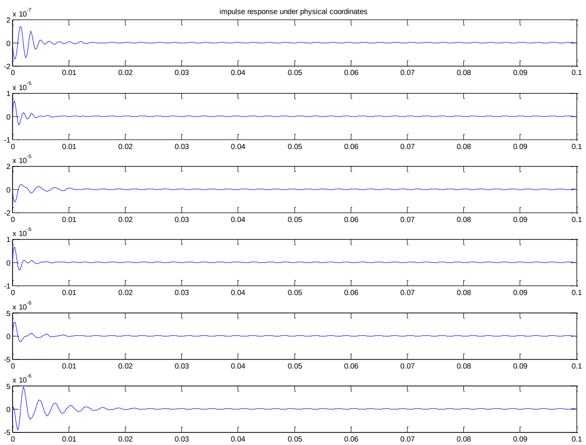


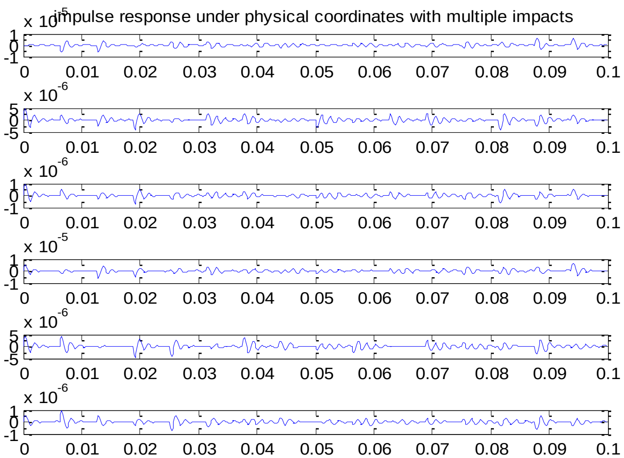


Impulse responses of 6 physical displacements with circumferential single impact (meters vs seconds)

Impulse response of 6 coordinates with circumferential multiple impacts over a full one revolution (meters vs seconds)

# Dynamic Model and Impact Responses to Road Excitation

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In the state space, the equation of motion

$$\begin{aligned}\{\dot{x}\} &= [A]\{x\} + [B]\{u\} \\ \{y\} &= [C]\{x\} + [D]\{u\}\end{aligned} \qquad (2)$$

$$\{x\} = \begin{Bmatrix} z \\ \dot{z} \end{Bmatrix}_{2N\times 1}$$

$$[A] = \begin{bmatrix} 0 & I \\ -m^{-1}k & -m^{-1}c \end{bmatrix}_{2N\times 2N} \qquad [B] = \begin{bmatrix} 0 \\ -m^{-1} \end{bmatrix}_{2N\times N} \qquad [C] = [I]_{2N\times 2N} \qquad [D] = [0]_{2N\times N}$$

# Dynamic Model and Impact Responses to Road Excitation

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Vibrating kinetic energy and potential energy in the tyre structure

$$E = \frac{1}{2}\{\dot{z}\}^T[m]\{\dot{z}\} + \frac{1}{2}\{z\}^T[k]\{z\}$$

The linear and viscous damping force

$$\{f_d\} = [c]\{\dot{z}\}$$

Damping work

$$W_d = \int \{f_d\}^T d\{z\} = \int \{f_d\}^T \{\dot{z}\}dt = \int \{\dot{z}\}^T [c]\{\dot{z}\}dt$$

The total vibration intensity of the structure

$$I = \int \{\dot{z}\}^T \{\dot{z}\}dt$$

# Simulation Model for Dynamic Responses

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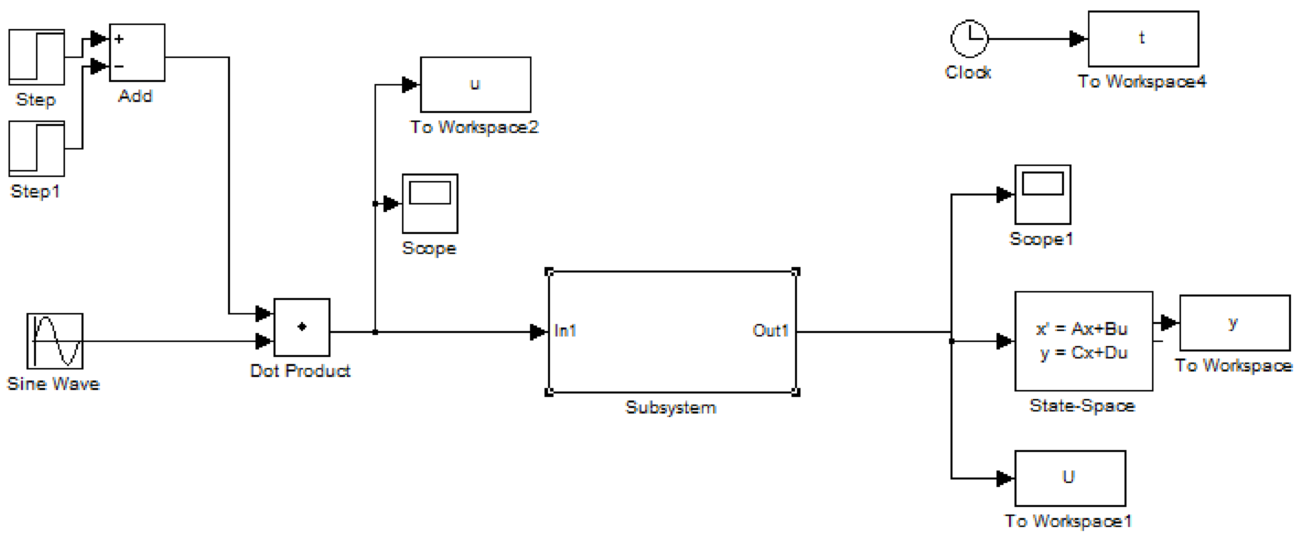


Fig.3. The SIMULINK model for wheel dynamics

# Simulation Model for Dynamic Responses

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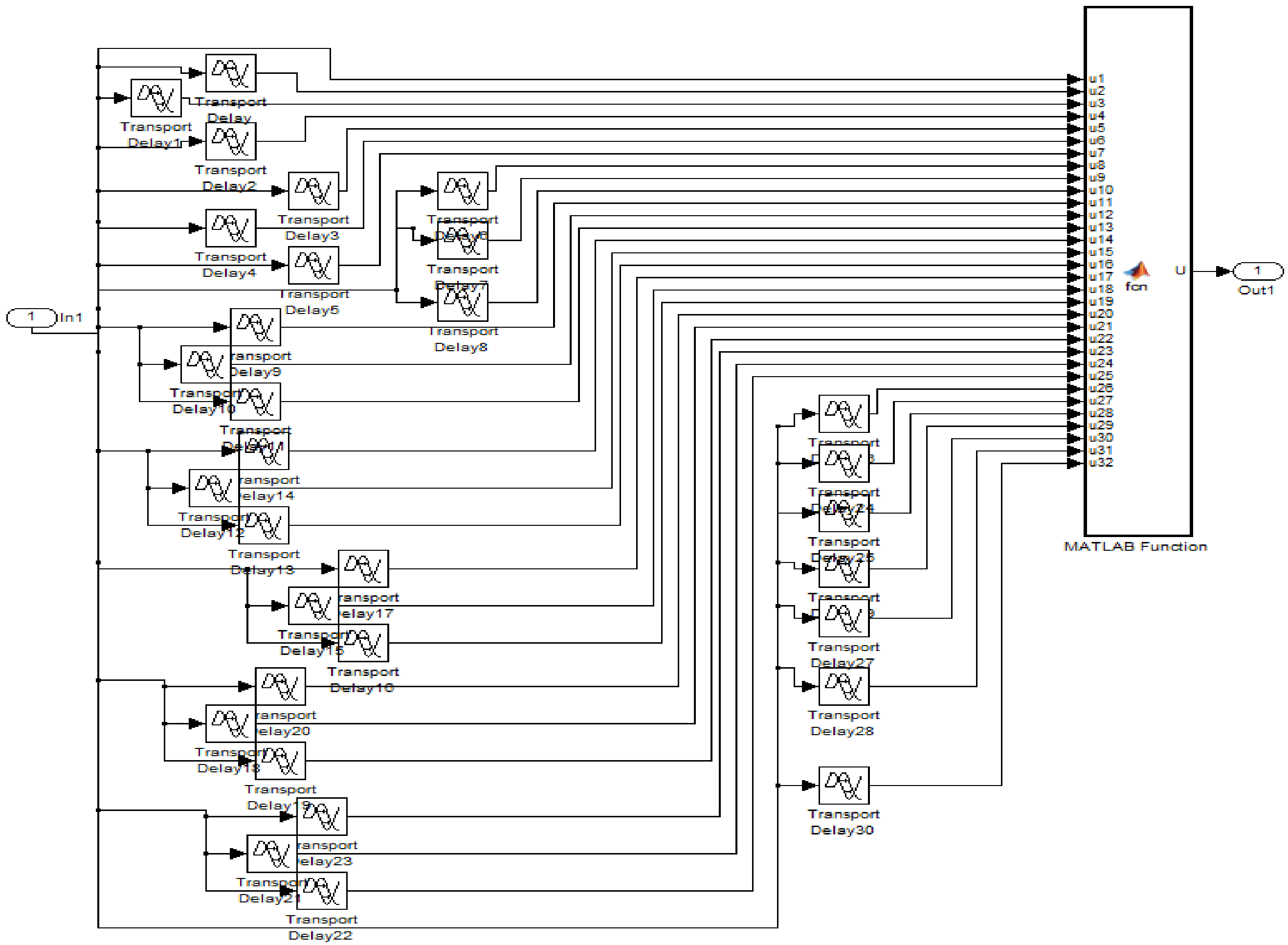


Fig.4. The subsystem for applying impacts on wheel

# Simulation Model for Dynamic Responses

```
function U =
fcn(u1,u2,u3,u4,u5,u6,u7,u8,u9,u10,u11,u12,u13,u14,u15,u16,u17,u18,u19,u20,u21,u
22,u23,u24,u25, u26,u27,u28,u29,u30,u31,u32)

N=length(u1);  U=zeros(195,N);B=2*pi/64-pi/2; U(4)=u1*cos(B);U(5)=u1*sin(B);

B=B+2*pi/32; U(7)=u2*cos(B);U(8)=u2*sin(B);
… …;

B=B+2*pi/32;  U(1)=u32*cos(B);U(2)=u32*sin(B); U=-U;
```

# Dynamic Responses

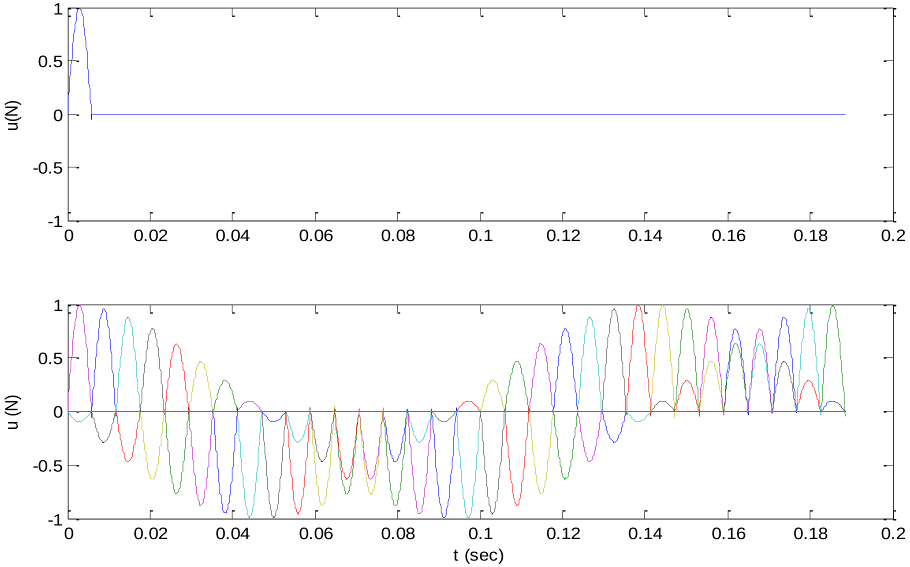


Fig.5. Upper: first impulse. Lower: impulses along wheel circumference for one revolution

# Dynamic Responses

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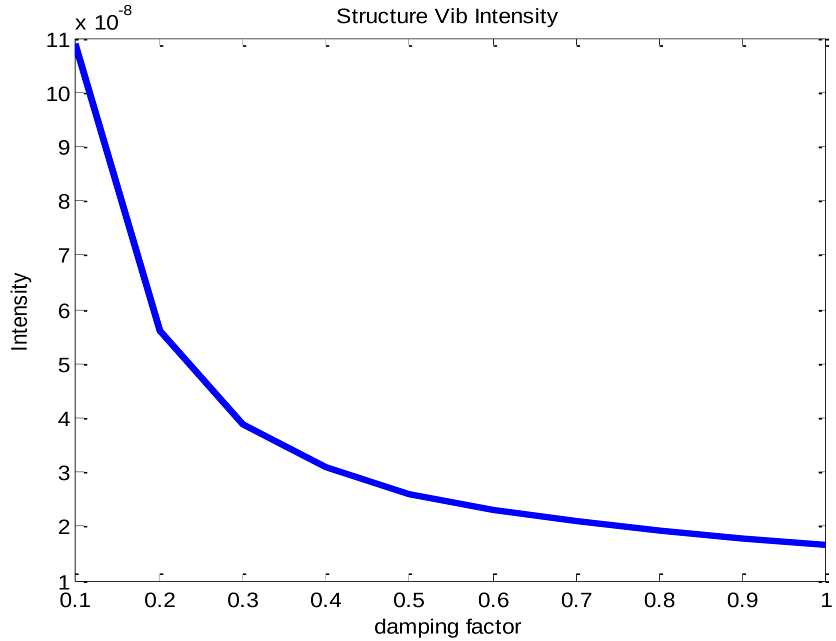


Fig.6. Total structural vibration intensity

# Dynamic Responses

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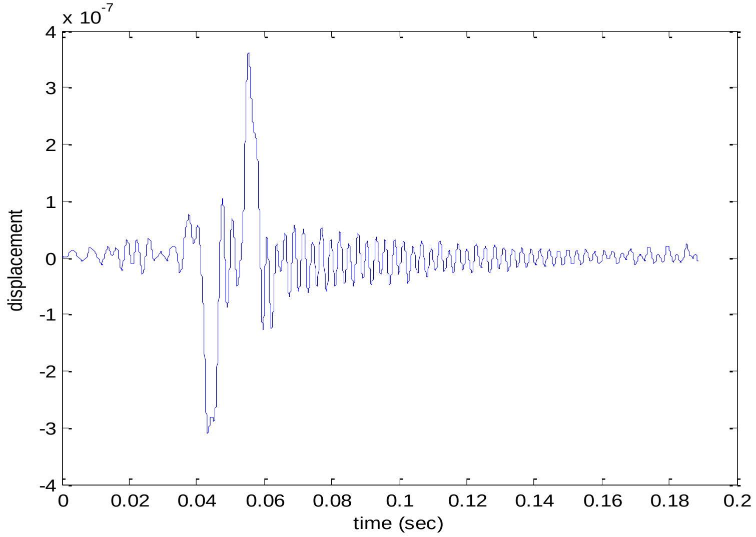


Fig.7. The wheel response at contact node by single impact

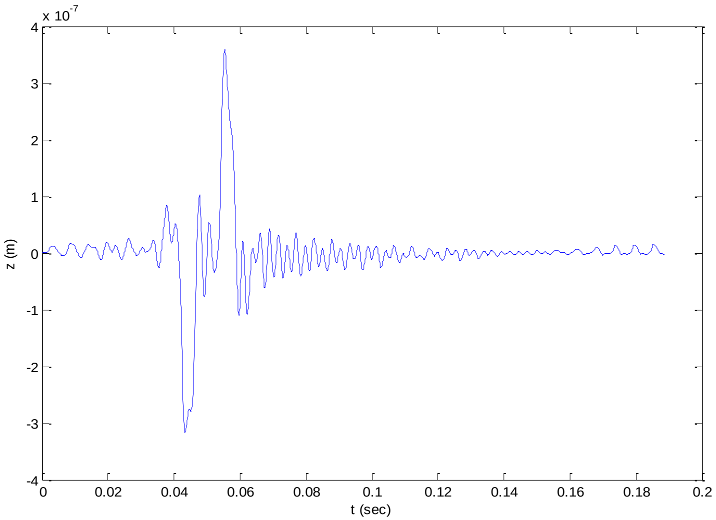


Fig. 8. The wheel response at contact node by single impact with higher damping

# Dynamic Responses

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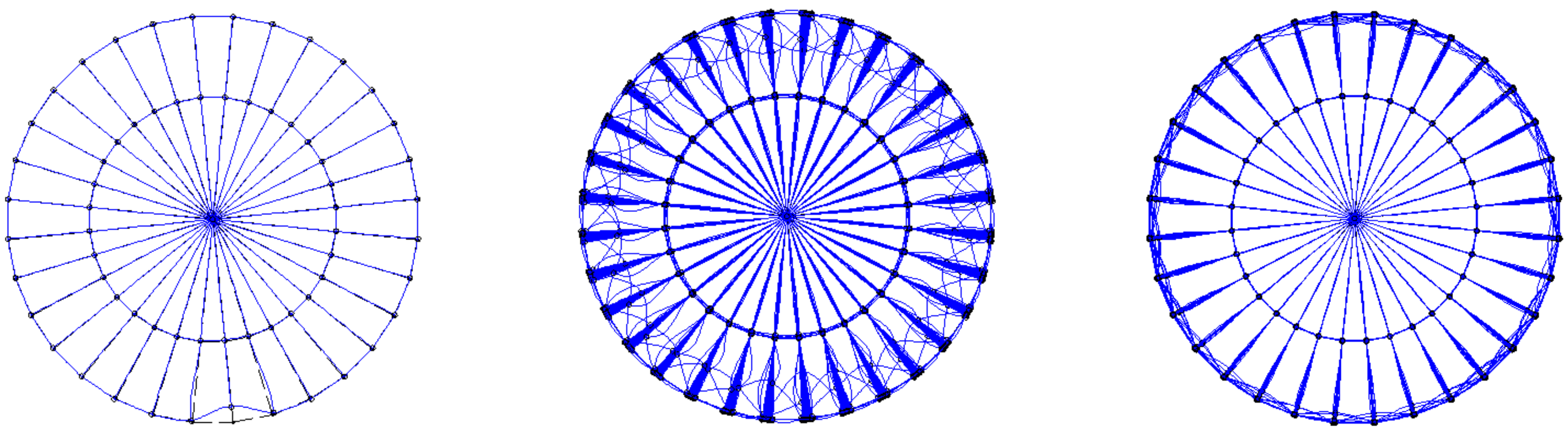

Fig. 9. Displacement instants on wheel from left to right: single impact response, one revolution responses and one revolution responses with higher damping

# Conclusion

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- ❑ A finite element model is combined into the graphical dynamic simulation for visualizing vehicle wheel's response to road excitation.

- ❑ Real time dynamic behaviour of the wheel to continuous impacts from the road during rolling is displayed.

- ❑The calculation result has indicated that the vibration which generates noise can be attenuated by increasing the damping in the wheel structure.

- ❑ This proposed modelling and simulation have improved the understanding of wheel dynamics and can be used for environment friendly wheel design and development.

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# Thank you

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