

Application of Model-Based Development to Engine Restart Vibration After Idling Stop

Satoshi Watanabe and Yuji Miyata
Honda R&D Co., Ltd.

Yosuke Ogata
Siemens K.K.

Vincent Ivosic
Siemens Industry Software S.A.S.

ABSTRACT

Idling stop systems are being increasingly adopted in conventional engine vehicles as well as hybrid electric vehicles to increase fuel efficiency. When the engine starts, body vibration occurs that is caused by the rigid body eigenvalues of the power plant during initial combustion. Engine restart vibration after an idling stop is caused by the input force from the transmission, and the reaction force from the drive shaft as well as the input force from the engine. This phenomenon occurs frequently when the engine is restarted from the idling stop, the vibration is increasingly annoying to passengers.

Usually, the vehicle development process is carried out in accordance with the V process. The V process divides the vehicle development process into two stages. The first stage is called the vehicle design stage to determine the characteristic. The second stage is called the vehicle verification stage to verify the performance. However, we have no prediction techniques in the design stage for engine restart vibration. Therefore, engine restart vibration can only be verified in the verification stage. A technique that can predict the system and parts characteristics at the design stage is needed in recent development processes.

This study develops a prediction technique for restart vibration with in-cylinder pressure prediction that can determine the required system and parts characteristics by applying model-based development from the vehicle design stage. Furthermore, this study develops a method that can properly evaluate restart vibration in order to refine the directions and frequencies of the vibration to be measured.

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INTRODUCTION

Many recent vehicles with the conventional engine have adopted the idling stop system as well as hybrid electric vehicles. The most significant reason for this is the decrease in fuel consumption achieved by stopping the engine, for instance, while waiting for a signal. The idling stop is also advantageous for quietness in the cabin while the engine is stopped, because the engine is the vibration source and when stopped, the noise and vibration levels decrease drastically. However, this can also be a disadvantage when restarting the engine. Every time the engine restarts, the uncomfortable noise and vibrations are felt just as strongly as when the car is initially started. The reason this engine restart vibration is felt so strongly is that the input force from the engine and transmission increase, as do repetitions, in order to shorten the start-up time, and to maintain the launch performance.

Both engine normal start and engine restart after an idling stop result in vibrations that are caused by passing the rigid body eigenvalues of the power plant when the engine speed is rising. The following differences are noted between normal start and restart.

1. In order to quickly restart the engine, it is necessary to shorten the stroke time of the engine – intake, compression, combustion, exhaust. Furthermore, high in-cylinder pressure is needed.
2. In order to be ready for a quick restart, a conventional engine vehicle starts the transmission in direct connection with the crank shaft. In addition, input force and the reaction force to the power plant from the drive train occur.

Engine restart vibration increases the input force via the suspension from the drive shaft and the transmission, and the reaction force from the drive shaft, as well as the input force to the body via the engine mount from the engine. Thus engine restart vibration is a phenomenon with a wide range of input. [Figure 1](#) shows the transfer path for engine restart vibration. [Figures 2](#) and [3](#) show the difference of waveforms between engine start vibration and engine restart vibration. The data at the top in [Figures 2](#) and [3](#) is a time series data of seat vibration. The horizontal axis is time and the vertical axis is acceleration. The data at the bottom in [Figures 2](#) and [3](#) is a result of wavelet-transform analysis of seat vibration. The vertical axis is frequency.

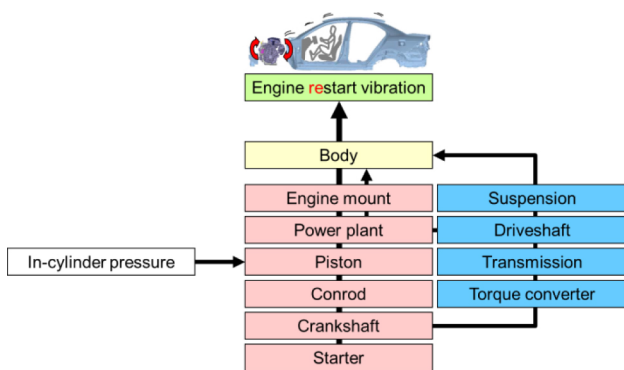


Figure 1. Transfer path for engine restart vibration

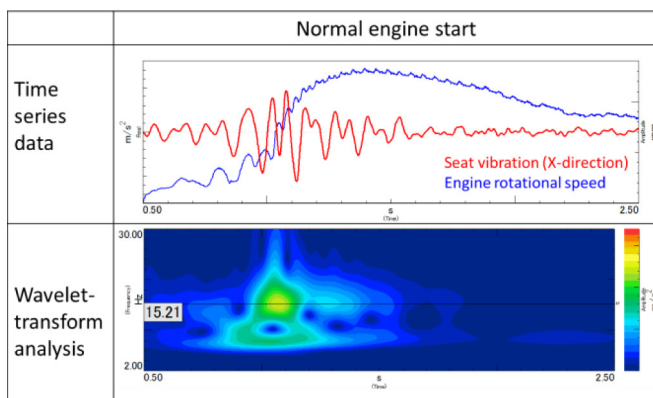


Figure 2. Waveform of seat vibration at engine start

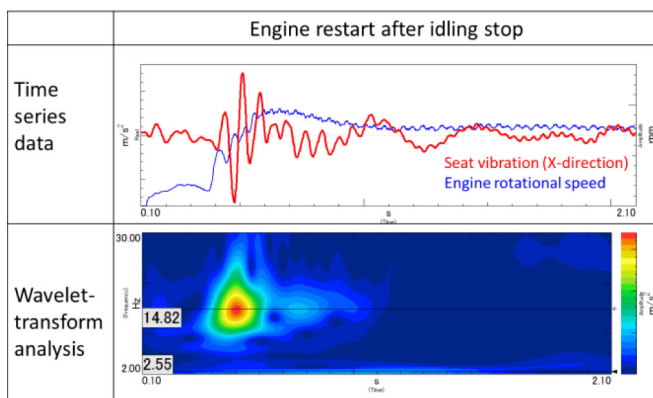


Figure 3. Waveform of seat vibration at engine restart

We have two issues concerning engine restart vibration development.

The first is a prediction method for engine restart vibration. Conventionally, prediction of the noise and vibration phenomena from the power train uses a method that inputs the measured in-cylinder pressure values as a source of engine vibration. However, we cannot consider the input force from the transmission and the reaction force from the driveshaft in the current prediction model for engine restart vibration analysis. Furthermore, we cannot consider the parameters for engine cranking and firing, which contribute greatly to engine restart vibration, as long as we use the measured in-cylinder pressure value. Since engine restart vibration cannot be predicted in the vehicle design stage, most of the work must be done in the

vehicle verification stage. If the target for engine restart vibration cannot be achieved at the verification stage, only later changes in software can be made to modify engine restart vibration, such as engine control modification. Therefore a technique that can propose specifications for the hardware, such as parts characteristics at the design stage, is required.

The second is an evaluation method for engine restart vibration. A transient vibration phenomenon such as engine restart vibration is usually evaluated by focusing on the waveform peak of the vibration. However, engine restart vibration is generated with different frequencies at different timings in about one second, as shown in Figure 3. Discrimination between the vibration caused by the rigid body eigenvalue of the power plant and the vibration caused by the input force from the driveshaft is needed in order to create countermeasures. In addition, the number of rigid body eigenvalues of the car body contribute greatly to restart vibration as well as the rigid body eigenvalues of the power plant. Therefore, restart vibrations are not necessarily all in a single direction of vehicle vibration. It is important to discriminate between the directions and the frequencies in order to analyze restart vibration, and to predict restart vibration in order to derive effective countermeasures.

In order to solve the two above-mentioned issues, this study focuses on a prediction technique and a new evaluation method for engine restart vibration.

SOLUTIONS

In vehicle development, we use the V process, consisting of vehicles, systems, and parts as shown in Figure 4. The V process divides the vehicle development process into two stages. The first stage is called the vehicle design stage to determine the system and parts characteristic through tests and CAE. The second stage is called the vehicle verification stage to verify the vehicle and system performance through tests. Noise and vibration phenomena are theoretically calculated, such as by transfer path analysis, multiplying the vehicle response by the input force generated from the powertrain. This study promotes the V process in the design of vehicle performance, and applies model-based development connected with each system and part physically. Model-based development is generally used for control system design. This study recognizes model-based development as a broad concept that can be used for many design phases in the vehicle design stage, including initial system design, structure design, performance design, and control parameter design. In order to apply model-based development to engine restart vibration development, we have defined the layer concept from L0 to L4 as shown in Figure 5. The definition of each layer is as follows.

1. L0: Vehicle target (engine restart vibration)
2. L1: System path (e.g. vibration via engine, etc.)
3. L2: System characteristics (e.g. input force from engine, etc.)
4. L3: Sub-system characteristics (e.g. power plant rigid eigenvalues, etc.)
5. L4: Parts characteristics (e.g. engine mount, crankshaft, etc.)