

Research on Longitudinal Vibration of MT Vehicle at Clutch Engagement

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ABSTRACT

Formulas have been developed to describe the longitudinal vibration that occurs when the clutch engages in an MT vehicle, and the vibration waveforms have been used to formulate evaluation indices that possess a high degree of correlation with sensory evaluations.

The parts that contribute to longitudinal vibration of the vehicle when the clutch engages were determined, and a simulation of the first-order vibration of the torsion system of the body and drivetrain was constructed, enabling specifications to be evaluated at the initial stage of vehicle development, when no prototype vehicle has yet been constructed.

The use of the new method in the development of a production vehicle enabled early determination of specifications, such as driveshaft stiffness, and the application of control to rapidly reduce engine speed, enabling effective responses to be proposed.

1. Introduction

Smooth running when shifting is an important aspect of performance for an MT vehicle.

However, when the vehicle gives rise to transient input to the drivetrain, it excites resonance and subsequent longitudinal vibration of the vehicle occurs. In this case, a driver would feel uncomfortable and find it challenging to drive smoothly.

Pressing down on the accelerator pedal is one of the operations that introduce transient input to the drivetrain. Past research⁽¹⁾⁻⁽³⁾ has enabled quantitative evaluation of the longitudinal vibration of the vehicle when the accelerator pedal is pressed down. In addition, simulations enable specifications to be examined from the initial stages of vehicle development in relation to this form of vibration.

However, the study of specifications in relation to the longitudinal vibration of the vehicle when the clutch is engaged relies on sensory evaluation and experience in most cases. In addition, because simulation techniques in relation to this form of vibration are as yet insufficiently developed, vehicle designers are unable to decide on specifications in the initial stages of development.

This research project therefore set out to develop

formulas to enable numerical evaluation of the longitudinal vibration generated by clutch engagement, and to construct a simulation model of the phenomenon. This paper will report the details of this project.

2. Development Goals

Refining vehicle specifications as much as possible in the initial stages of the development process, thus reducing the degree of trial and error during vehicle tests, is an important factor in enabling more effective countermeasures to be adopted during vehicle development.

Changes to specifications following completion of the prototype have a large effect on other aspects of performance, and as a result in many cases insufficient changes are made. This makes it challenging to efficiently develop countermeasures relative to the person-hours spent on the project.

The research discussed in this paper therefore established the following main objectives:

- (1) To develop a method of numerical evaluation that is able to replace sensory evaluation
- (2) To formulate a simulation that is able to be employed from the initial stages of development

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3. Formularization of Evaluation Indexes

In order to formulate evaluation indexes, the longitudinal vibration of the vehicle at clutch engagement was first formularized using equations of motion.

To enhance ride comfort, it is necessary to establish evaluation values for longitudinal vibration based on sensory evaluations of the driver's feeling of comfort. ISO 2631⁽⁴⁾ has been established as an international standard for exposure to whole-body vibration, providing an international standard for automotive ride comfort. It is known that humans are sensitive to 4-8 Hz vertical vibration and 1-2 Hz horizontal vibration.

A variety of methods of evaluation in relation to vibration and ride comfort have been proposed⁽⁵⁾⁻⁽⁹⁾, but the majority use a restricted set of conditions, such as relying on laboratory test equipment, and do not achieve a sufficient correlation with objective evaluations of ride comfort in actual vehicles. These methods have therefore not been applied to vehicle development. The project discussed here isolated the physical factors that represented the main components of sensory evaluations in actual vehicle driving tests and elucidated the correlation between these physical factors and physical equations describing vehicle behavior, in order to develop a numerical evaluation method that is able to be applied in the vehicle development process.

Here, the physical equations describing vehicle behavior will be considered first. The equations will be considered using a model for the evaluation of the magnitude of impact, of the type shown in Fig. 1. A sphere impacts with the vehicle, and stops inside the vehicle. The momentum, which indicates the magnitude of the impact, is

$$p = m \cdot v \quad (1)$$

If the sum of the forces imparted to the vehicle at the instant of impact is termed P , and the impact is considered to occur instantaneously at time $t=0$, then the change in momentum after the impact can be expressed as

$$\int_{0^-}^{0^+} dp = \int_{0^-}^{0^+} P(t) dt \quad (2)$$

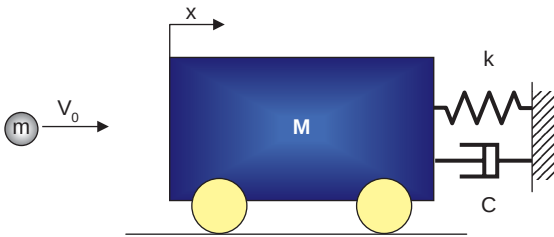


Fig. 1 Impact vibration model

If the initial momentum of the sphere is termed p_0 , the impact received by the vehicle is

$$-P = p_0 \quad (3)$$

The vehicle undergoes displacement x_0 as a result of the impact. The equation of motion for damped free vibration is

$$\frac{d^2x}{dt^2} + 2h\omega \cdot \frac{dx}{dt} + \omega^2 x = 0 \quad (4)$$

If the solution is assumed to be $x = \exp^{\lambda t}$ from the theory of differential equations, then the envelope curve for damped free vibration is

$$x(t) = \left(\frac{1}{\omega \sqrt{h^2 - 1}} \cdot \frac{dx_0}{dt} \right) \cdot \exp^{-h \cdot \omega \cdot t} \quad (5)$$

Nomenclature

p : Impact power [N]

m : Mass [kg]

v : Velocity [km/s]

P : Reaction force [N]

M : Mass [kg]

c : Damping property [Nms/rad]

k : Torsional stiffness [Nm/rad]

ω : Angular velocity [rad/s]

x : Displacement [m]

By this means, an evaluation method was able to be formularized based on a simple model.

4. Test Method

Next, a test method was developed and indexes were formulated based on the concepts that were formularized in the preceding section.

4.1. Test Method

The frequency of the longitudinal vibration generated by shifting differs depending on the gear ratio, and the frequency becomes higher the further the gear position moves towards the high-speed range. The magnitude of vibration is higher and the decline in ride comfort greater for shifting immediately following acceleration than for shifting during deceleration.

The 3 Hz longitudinal vibration generated when shifting up from 1st to 2nd gear is a particular issue. Figure 2 shows measurements of this vibration.

In order to determine the mechanism of production of longitudinal vibration during shift, torque and vibration were measured during shifting in test vehicles with sudden clutch engagement under conditions of a fixed predetermined engine speed and fully-closed accelerator. Measurements were conducted in more than ten types of test vehicles, changing in turn shift position, engine speed, and the degree of accelerator opening.

4.2. Formulation of Indexes

In order to formulate evaluation indexes, subjective evaluations were conducted in which a large number of drivers compared test drives in commercial vehicles. Indexes enabling numerical evaluation were formulated by means of comparative analysis of the results of these subjective evaluations and measurement results.

The drivers felt the sudden vibration peak when the clutch was engaged as a kick, and the subsequent counter-reaction as jerks. Figure 3 shows two evaluation indexes

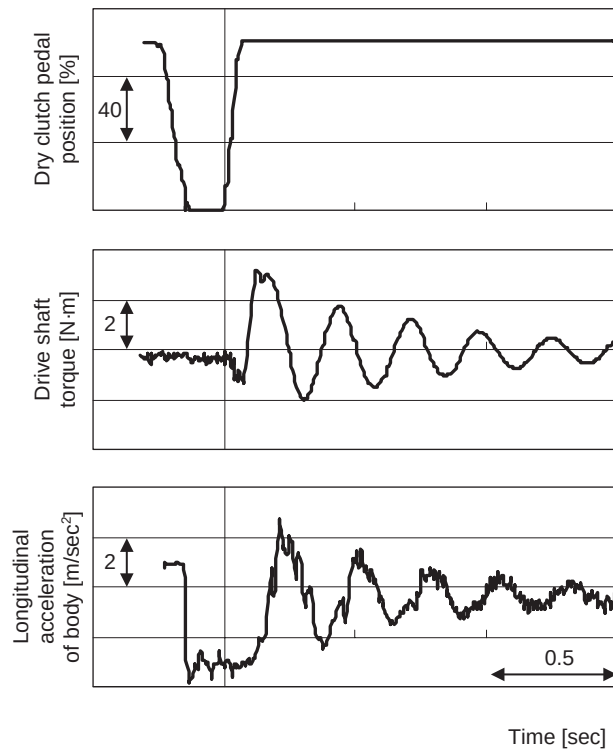


Fig. 2 Time history of body vibration by clutch engagement shock Closed accelerator, 1st-2nd gear, 3000 rpm

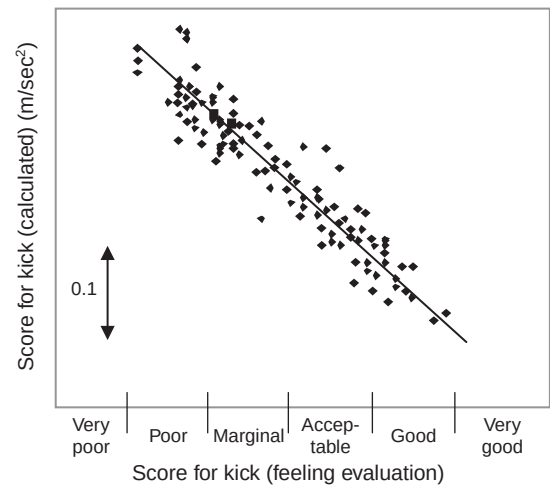


Fig. 4 Comparison of measured and calculated kick score

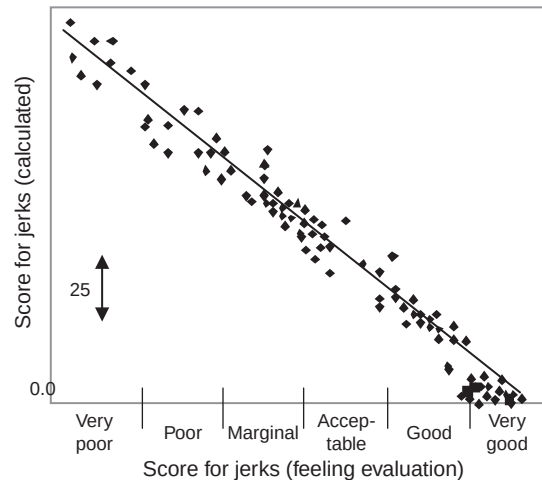


Fig. 5 Comparison of measured and calculated jerks score

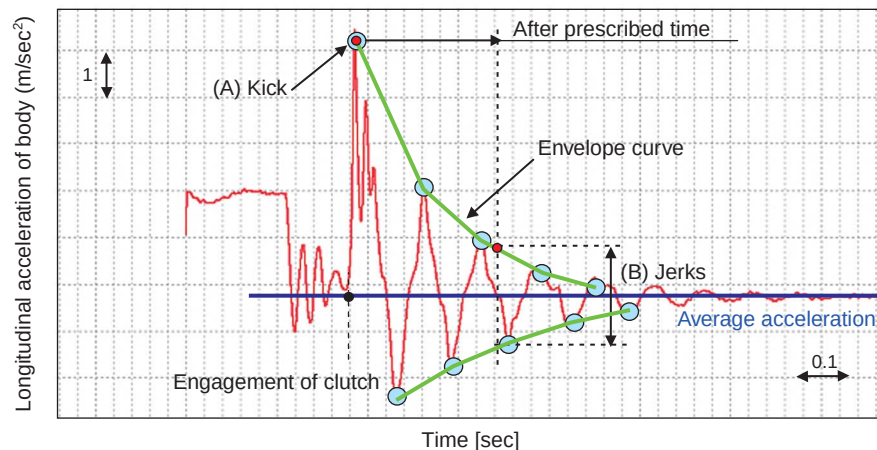


Fig. 3 Definition of index

formulated by quantifying these subjective drive feelings based on the results of a questionnaire survey. The equations used to calculate the respective numerical indexes were formulated from Eqs. (3) and (5) as follows:

(a) Kick: Correlated with sum of impact forces

The higher the mass, m , and the degree of change in speed, $dv(t)/dt$, the greater the impact forces. Because m is a value unique to the specific vehicle, the index has been formulated as the change in speed per unit weight to enable general application.

$$Kick = \frac{1}{m} \cdot \frac{dv(t)}{dt} \quad (6)$$

(b) Jerks: Correlated with the degree of change in the envelope curve of the damped free vibration

The higher the index, $h \cdot \omega$, the better the damping performance of the vehicle. To enable general application, an index formulated by making the initial amplitude of the envelope curve constant was selected for use as the index.

$$Jerks = h \cdot \omega \quad (7)$$

Figures 4 and 5 show the results of verification of the correlation between the two numerical evaluation indexes, formulated on the basis of sensory evaluations in test vehicles, and from measurement data based on the equations discussed above. The good correlation indicates the validity of the indexes.

5. Formulation of Simulation Model

The transient torque generated by the engine speed differential while shifting is an important factor in reproducing the longitudinal vibration of the vehicle resulting from clutch engagement. This torque produced by the engine speed differential during shifting was reproduced by adding a clutch operation element to a conventional body-drivetrain first-order torsional vibration mechanism analysis simulation model.

Figure 6 shows an outline of the entire model. Figure

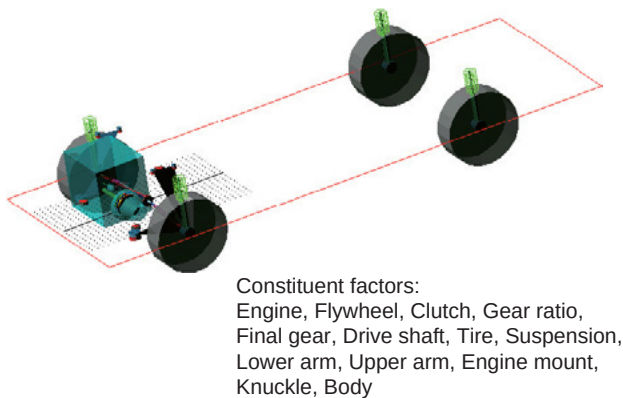


Fig. 6 Analysis Model

7 shows an outline of the clutch model. Clutch disks are positioned between the crankshaft and the clutch hub, and the torque capacity and clutch stroke are defined at the plates. The torque capacity is linked to the clutch stroke, and is transmitted to the transmission side as the amount of transmitted torque changes. In addition, the inclusion of the amount of play in the clutch pedal to the clutch stroke elements has enabled reproduction of the torque fluctuation resulting from the engine speed differential generated by operation of the clutch in a real vehicle. The formulation of a model in which clutch capacity can be varied in accordance with clutch operation has also

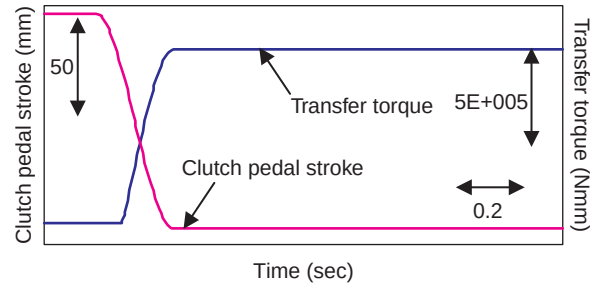


Fig. 7 Clutch model characteristic

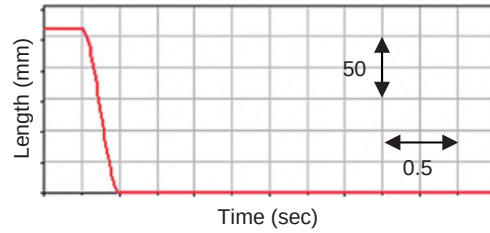


Fig. 8 Clutch operation

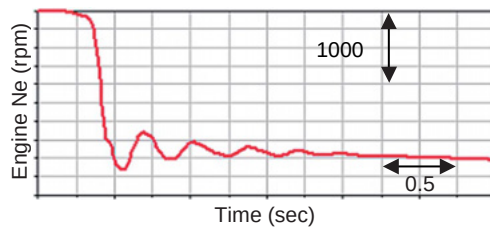


Fig. 9 Engine rotation

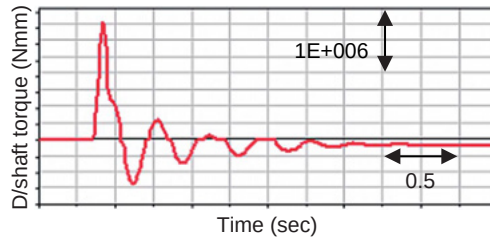


Fig. 10 Drive shaft torque

enabled reproduction of the effect on the kick feeling of differences in the time taken for operation of the clutch.

Figures 8 through 10 show simulation results for the drivetrain when shifting up from 1st to 2nd gear. As Fig. 8 shows, engine speed is absorbed by time series changes in the clutch stroke (clutch engagement), and as Fig. 9 shows, an engine speed differential is generated in response to the geometric ratio of 1st and 2nd gear. Torque is generated by the engine speed differential that is absorbed at this time, and is transmitted to the driveshaft, as Fig. 10 shows.

Design values were employed as the characteristics data for each of the simulation elements discussed above.

With regard to the vehicle body system model, consideration was given to nonlinear characteristics, and table functions were employed to provide static load-displacement characteristics for the engine mounts, suspension, longitudinal compliance, clutch, and driveshaft.

Figure 11 shows a comparison of simulation results for longitudinal vibration when shifting up from 1st to 2nd gear with measurement data from an actual vehicle.

The simulation has reproduced the first vibration peak and the following jerk vibrations.

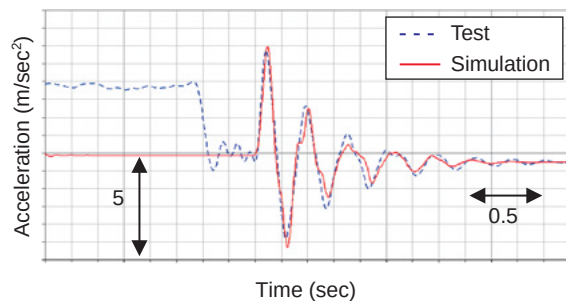


Fig. 11 Results of verification of simulation

6. Example of Application in Vehicle Development

6.1. Degree of Effect of Vehicle Body System

The developed simulation incorporating elements for clutch operation was employed in the initial stages of a vehicle development, and a parameter study of each component affecting the longitudinal vibration of the vehicle at clutch engagement was conducted. The results are shown in Figs. 12 and 13.

The effect of the geometric ratio between 1st and 2nd gear, the compliance bush characteristics, and the engine mount characteristics on the kick feeling was highest. The effect of the torsional stiffness of the driveshaft on the jerk feeling was highest.

Focusing on these areas that had a strong effect on kicks and jerks, a simulation was conducted in order to

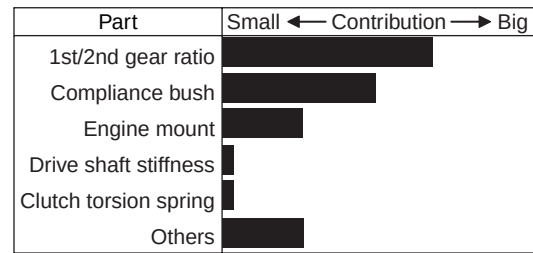


Fig. 12 Contribution to kick of body and drivetrain parts except tires by ADAMS simulation

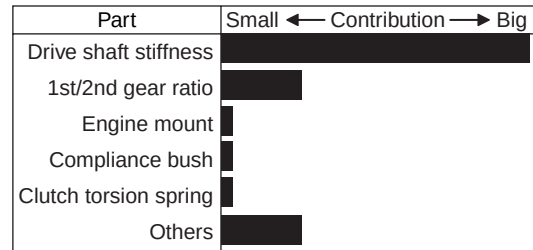


Fig. 13 Contribution to jerks of body and drivetrain parts except tires by ADAMS simulation

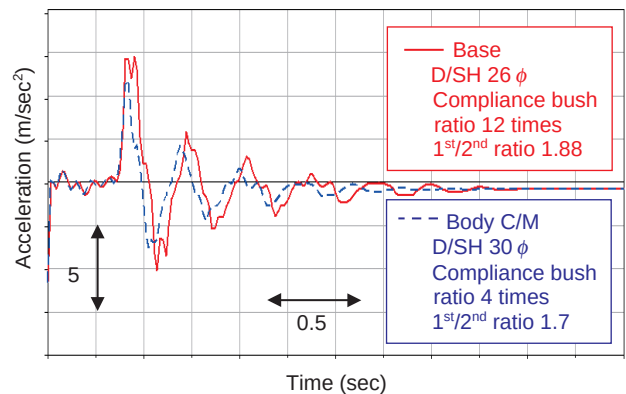


Fig. 14 Effect of body and drivetrain countermeasures by ADAMS simulation

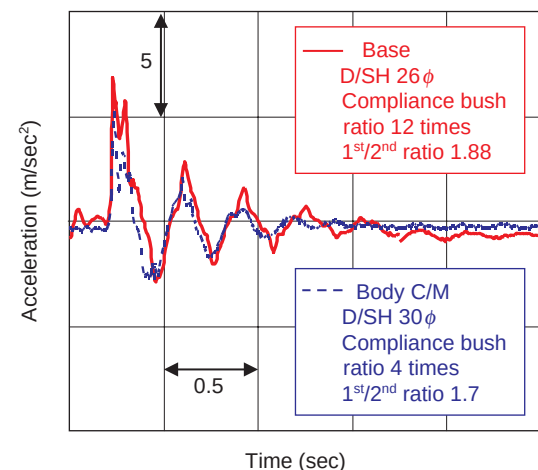


Fig. 15 Effect of body and drivetrain countermeasures in actual car

determine specifications that would reduce both kicks and jerks to an acceptable level. The results are shown in Fig. 14. The results of applying countermeasures in an actual vehicle are shown in Fig. 15. The kick feeling and the jerk feeling when shifting from 1st to 2nd gear have been reduced, as predicted by the simulation.

6.2. Engine Synchronizer Control

Figures 16 and 17 show the results of a simulation in which the engine speed differential was reduced by approximately 50% at clutch engagement as a measure to reduce the kick feeling when shifting from 1st to 2nd gear. The results show a reduction of approximately two-thirds in the first vibration peak occurring in the vehicle.

Figures 18 and 19 show the results of a simulation in which engine torque is imparted in the opposite direction to the direction of the torque at the driveshaft⁽¹⁰⁾,⁽¹¹⁾ as a measure to reduce the jerk feeling when shifting from 1st to 2nd gear. In these results, there is a reduction in the second and following vibration peaks produced in the vehicle body.

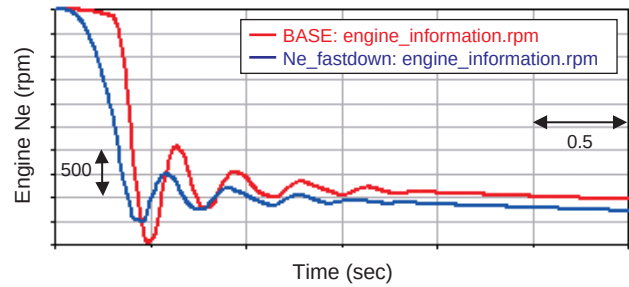


Fig. 16 Engine Ne control – Engine Ne

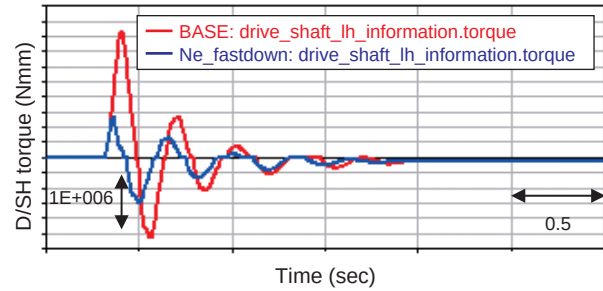


Fig. 17 Engine Ne control – D/SH torque

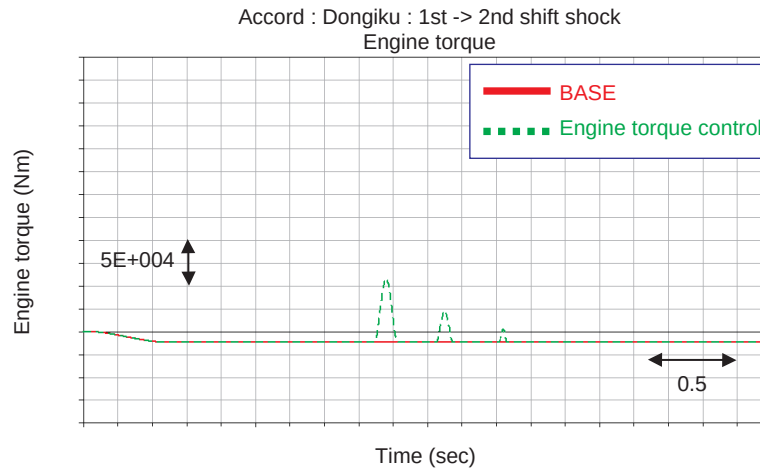


Fig. 18 Engine torque control – Engine torque

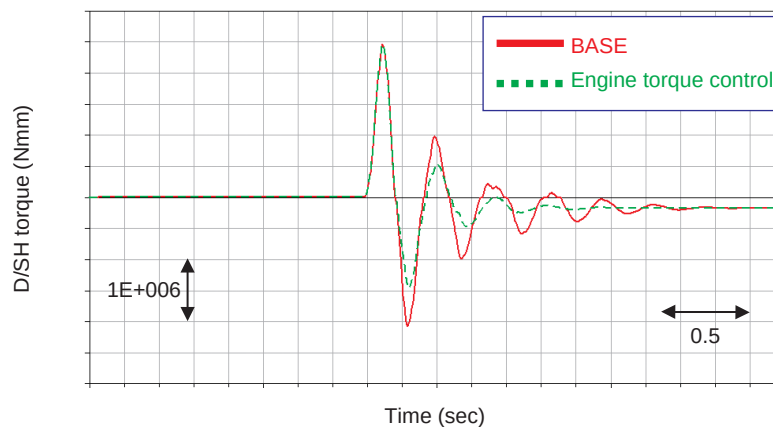


Fig. 19 Engine torque control – D/SH torque

Figure 20 shows the engine control method, termed synchronizer control, employed in the actual vehicle on the basis of the simulation predictions discussed above.

Deceleration kick is an issue when the accelerator pedal is suddenly released after it has been pressed down to accelerate the vehicle. In this case, it is necessary to reduce engine speed as slowly as possible.

However, it is necessary to reduce engine speed as quickly as possible in order to reduce the longitudinal vibration produced by engagement of the clutch. In order to reconcile these contradictory demands, as a measure

against kicks, a clutch sensor was included in the vehicle specifications, and control is applied to reduce engine speed rapidly only during shifting. Giving consideration to the robustness of vehicle characteristics, ignition timing control is applied for one cycle only as a measure against jerks.

Figure 21 shows the results of employing synchronizer control in a test vehicle. As predicted by the simulation, the control has reduced the kick feeling and jerk feeling when shifting from 1st to 2nd gear.

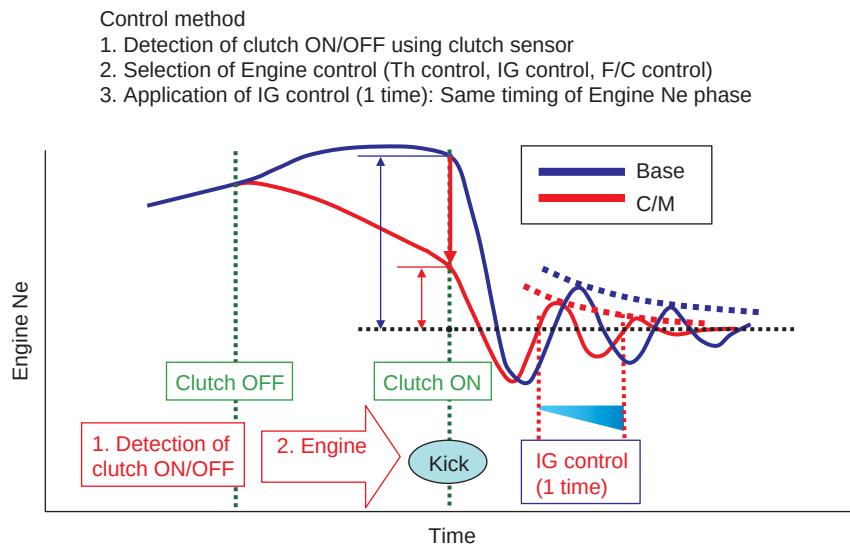


Fig. 20 Synchronizer control concept

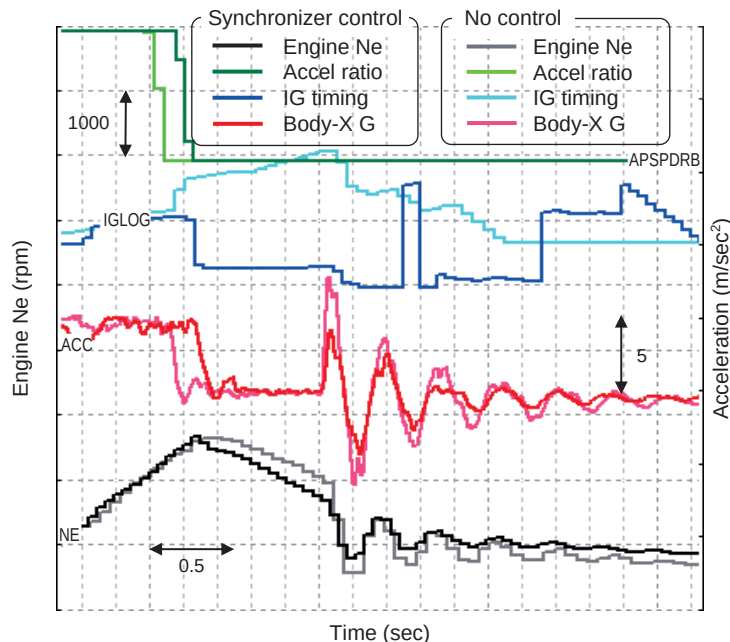


Fig. 21 Effect of synchronizer control

7. Conclusion

Research was conducted on the longitudinal vibration in an MT vehicle at clutch engagement. This research produced the following results:

- (1) A method enabling numerical evaluation of kick feeling and jerk feeling and able to replace sensory evaluation of vehicle body vibration at clutch engagement was developed.
- (2) A simulation model was formulated that displayed good correlation with results obtained from actual vehicles.
- (3) These developments have enabled study of specifications at the initial stages of vehicle development, when no prototype vehicle exists.

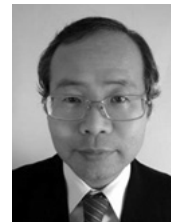
References

- (1) Kyuse, M., Watanabe, S., Sakai, T.: A Method for Evaluation of Low-frequency Noise and Vibration in Powertrain Mount Layouts using Degree of Coupling and Physical Matrices, Honda R&D Technical Review, Vol. 13, No. 2, p. 219-224
- (2) Thompson, M., Yoneyama, A.: Development of Engine Rock Dampers for the Manual Transmission 2003 Acura 3.2CL Type-S, Honda R&D Technical Review, Vol. 15, No. 1, p. 89-94
- (3) Katagiri, Y., Yatani, H., Igami, H., Saito, H., Shiraki, T., Oomori, I.: Research on Longitudinal Vibration of MT Vehicle during Acceleration, Honda R&D Technical Review, Vol. 15, No. 2, p. 139-144
- (4) ISO 2631: 1978, Guide for the Evaluation of Human Exposure to Whole-Body Vibration
- (5) Leatherwood, J. D., Dempsey, T. K., Clevenson, S. A.: A Design Tool for Estimating Passenger Ride Discomfort within Complex Ride Environments, Human Factors, Vol. 22, p. 291-312 (1980)
- (6) Dupuis, H., Zerlett, G.: Whole-body Vibration and Disorders of the Spine, International Archives of Occupational and Environmental Health, Vol. 59, No. 4, p. 323-336 (1987)
- (7) Doi, S., Ishiguro, M., Takei, K.: Sharyo no Katoshindou to Norigokochihyouka, Transactions of the Japan Society of Mechanical Engineers, Series C, Vol. 98, No. 920, p. 267 (1992) (in Japanese)
- (8) Takai, H.: Norigokoti Hyoukahouhouno Hensen, RTRI Report, Vol. 9, No. 8, p. 61-66 (1995) (in Japanese)
- (9) Griffin, M. J., Whitham, E. M., Parsons, K. C.: Vibration and Comfort I. Translational Seat Vibration, Ergonomics, Vol. 25, No. 7, p. 603-630 (1982)
- (10) Matsuyama, M., Nakamura, H., Matsuki, Y., Kouda, Y.: A Shaking Vibration Control System using Electronic Throttle Control (ETC) , 1999 JSAE Annual Congress Proceedings, No. 9-99, p. 5-8 (1999)
- (11) Sekozawa, T., Shioya, M., Atago, T.: An Adaptive Engine Control Algorithm for Acceleration Response, SAE Paper, 910256 (1991)

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