

Development of a Virtual Road Simulator for Motorcycles

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ABSTRACT

Virtual road simulator technology for motorcycles was established as a method to help predict motorcycle fatigue strength due to loading during running. This technology helped enable the prediction of dynamic behaviors and stresses during the road simulator durability test. The technology consists of the Finite Element Method, Multi Body Simulation, Road Simulator control, and fatigue analysis. The study helped enable the reproduction of the behavior of motorcycles using a simplified model of motorcycles and test rigs, including component Finite Element models. As a result, prediction of fatigue life, damage distribution, and stress waveforms of the high-stress regions in a Road Simulator durability test was achieved.

1. Introduction

Linear static analysis using the Finite Element Method is available as a method of predicting strength when establishing specifications at the drawing stage of motorcycle design. Applications of this method during design have been increasing, given its effectiveness when boundary conditions and load conditions are clear, and as relatively little manpower is required for analysis. However, prediction using linear static analysis is a challenge for parts on which multiple loads are applied at different times, and for parts having local vibration modes.

As a method to address this issue, we have developed a Virtual Road Simulator (VRS below) system that uses Multi Body Simulation to dynamically reproduce the behavior of the Road Simulator (RS below) durability test⁽¹⁾.

2. RS Durability Test

Fig. 1 shows the appearance of the RS. To shorten development time, this test can be used to confirm fatigue

strength against the load received from the road surface on the bench, rather than conducting a durability test using an actual motorcycle on a track. The RS reproduces the behavior of the motorcycle using three hydraulic actuators. The drive signals input to the actuators are calculated using in-house RS control software to reproduce the loads on a motorcycle during actual running, according to the following procedures:

- (1) Target signals are measured during actual running.
- (2) Transfer functions are measured in a bench test.
- (3) The first drive signals are calculated using the target signals and transfer functions.
- (4) The motorcycle on the bench is activated using the calculated drive signals, and response signals are measured.
- (5) New drive signals are calculated after correction of errors between the target signals and the response signals.
- (6) Steps 4 and 5 are repeated until errors are brought within a tolerable range.

This procedure of trial activation and corrective calculation is called iteration. The target signals are front axle vertical acceleration, rear axle vertical acceleration, and front fork bending stress.

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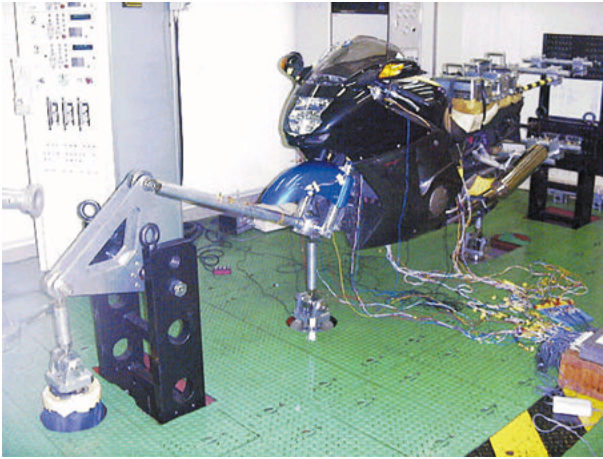


Fig. 1 Appearance of the Road Simulator (RS)

3. Outline of the VRS System

Fig. 2 shows the system flow of the VRS system. The system consists of the following four technologies:

- (1) Finite Element Method (FEM) technology: Conducts analysis of mass properties and modal parameters necessary to include the Finite Element model (FE model below) in the MBS model.
- (2) Multi Body Simulation (MBS) technology: Conducts motion simulation of the MBS model consisting of rigid body and flexible body components.
- (3) RS control technology: Measures transfer functions of the MBS model and calculates drive signals by conducting iteration.
- (4) Fatigue Analysis technology: Calculates the fatigue life and the stress waveform of the FE model using the results of the MBS.

The use of different analytic tools in the technologies described above makes data formats and their transfer complex. We therefore developed a Graphical User Interface (GUI below) to make the system easy to operate by automating the procedure and simplifying the operation.

3.1 Simulation Models

Fig. 3 shows the entire simulation model of the VRS. The VRS simulation model consists of a test rig model and a motorcycle model. Simplified models mainly using rigid body elements are used to reduce the number of man-hours involved in model preparation and computation time.

3.2 Test Rig Model

The test rig model consists of actuators, a transmission mechanism and a datum face. Although geometry is included for appearance, the models are made up of constraints without mass properties, enabling a lower computation time over models composed of flexible parts. Because this is a computational model, drives can be applied which are impossible to achieve in a RS test due to the limitations of the hydraulic actuators.

3.3 Motorcycle Model

A motorcycle model is first built up using rigid body elements for simplicity. Later, the required components are replaced with FE models to obtain the desired behavior in the part being focused on. In the model discussed here, the main frame body, engine crankcase and rear sub-frame were replaced with FE models to predict the fatigue strength of the main frame, and a flexible front fork was used.

The FE model is defined using mode characteristics calculated using the Craig-Bampton method.

The rigid body elements are defined using mass properties (mass, inertia, the moment of inertia), and three-dimensional CAD data are used for their appearance.

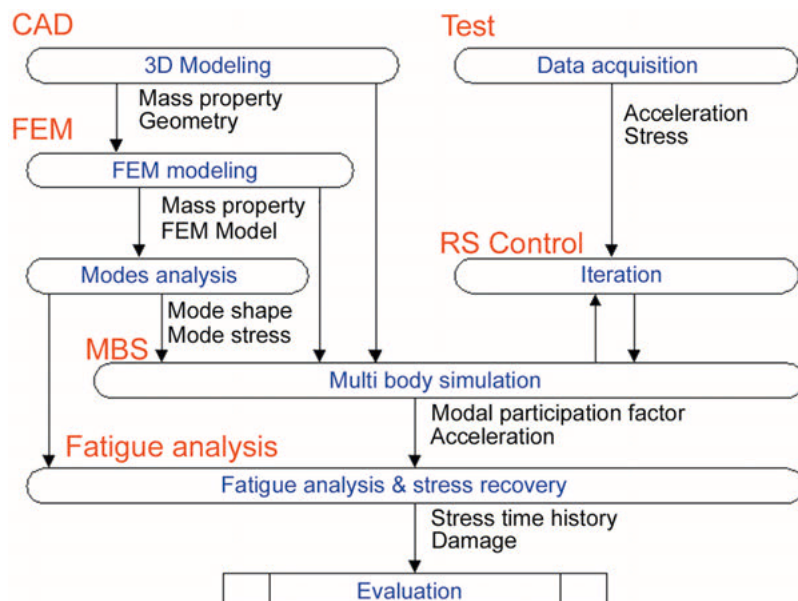


Fig. 2 System flow of virtual road simulator

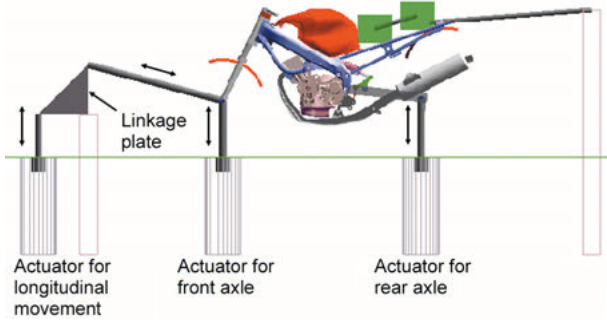


Fig. 3 Construction of virtual road simulator

3.4 Filtering

A data recorder with a built-in anti-alias filter is used for measurement of the target signals during actual running and measurement of response signals in the RS. The individual frequency characteristics of the anti-alias filter causes amplitude attenuation or phase shift in the waveform passing through it. Therefore, correct evaluation is impossible when comparing calculated results and measurement results if no filter or a filter with different characteristics has been used for calculated results. For this reason, an anti-alias filter with the same characteristics as the data recorder is used to process calculated results in the VRS.

3.5 Iteration

In this system, iteration is conducted on the VRS using target signals obtained from actual running, and drive signals are calculated. To prevent differences between the iteration on the VRS and RS caused by differences in software, the same in-house RS control software as used in RS durability tests was used.

3.6 Prediction of Fatigue Life and Calculation of Stress

In this system, the following data were analyzed to predict the fatigue life in the FE model:

- (1) Stress amplitude distribution on target part surfaces
- (2) Damage distribution on target part surfaces
- (3) Hot spot (high-damage area) distribution
- (4) Stress waveforms at hot spots.

Hot spots were specified by evaluating two-dimensional stress changes on the surface of target parts. Stress $\sigma_x(t)$ at time t on hot spot position x is calculated using the following equation:

$$\sigma_x(t) = \sum \sigma_{xi} \xi_i(t) \quad (1)$$

where σ_{xi} is the mode stress at position x of the ' i 'th mode (including constraint modes and normal modes) and $\xi_i(t)$ is the modal participation factor (displacement) of the ' i 'th mode at time t .

4. Verification of Simulation Accuracy

This section discusses an example of verification of simulation accuracy using an in-line 4-cylinder road sports model.

4.1 Verification Criteria

The measured results of the RS were adopted as the criteria for verification of the simulation accuracy of the VRS. In the case of measurements conducted during actual running, the number of channels that can be measured during one test is limited by the capacity of the measurement instruments, and if further measurements are conducted to increase the number of channels, consistency of data cannot be guaranteed. The reproducibility of the RS allows repeated measurements to be conducted under the same conditions. The correlation of the RS with actual running has already been verified⁽²⁾. Figs. 4a and 4b show comparisons between target signals obtained from measurements during actual running and results from VRS and RS simulations respectively.

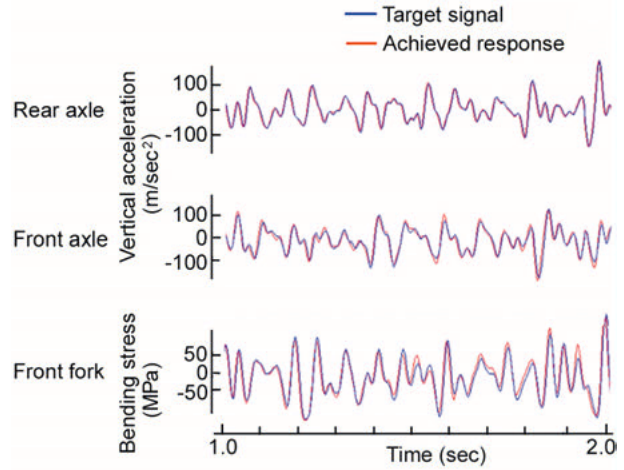


Fig. 4a Comparison between target signals (Actual running) and achieved responses on VRS

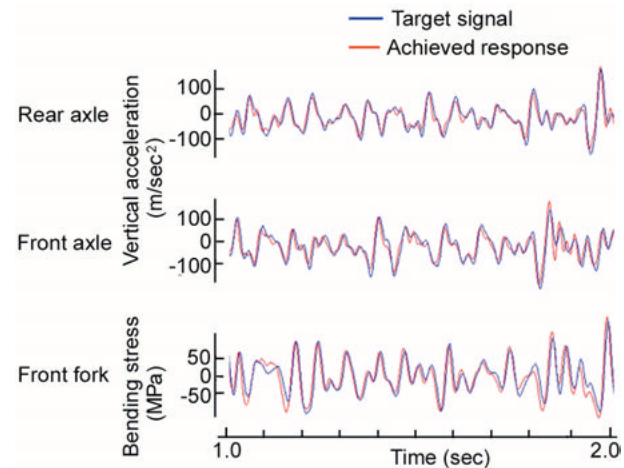


Fig. 4b Comparison between target signals (Actual running) and achieved responses on RS

4.2 Acceleration Waveforms

Fig. 5 shows acceleration measurement points and Fig. 6 shows the acceleration waveform comparison at each location. Calculation results show a strong correlation with measurement results for both vertical and longitudinal acceleration at the front and center of the body, and reproduction of movement was determined to be very high for the entire body. Using this system it will be possible to input predictions for parts with local vibration modes.

4.3 Stress Waveforms

Locations in the frame body for stress measurement and comparisons of time history stress waveforms for each location are shown in Figs. 7 and 8 respectively. At points A and B around the front of the frame, time history stress waveforms obtained by calculation show a very high correlation with measurement results. A high correlation can also be observed at point C at the rear of the frame, despite differences in absolute values. It is theoretically possible to reduce this difference by using FE model forms and increasing the accuracy of plate thickness at point C.

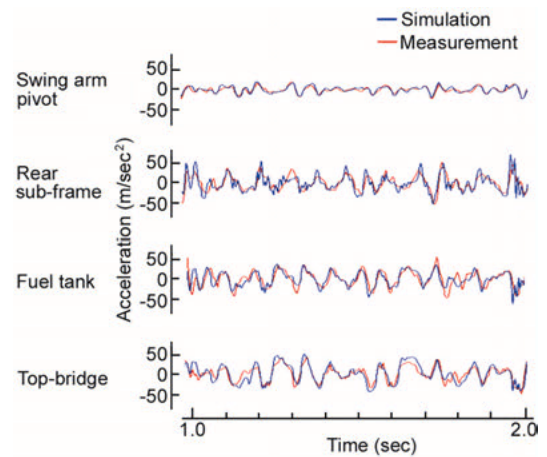


Fig. 6 Acceleration comparison between simulation and measurement

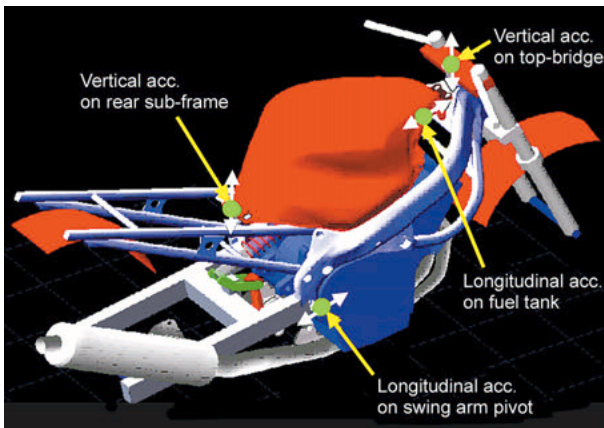


Fig. 5 Locations of acceleration measurement

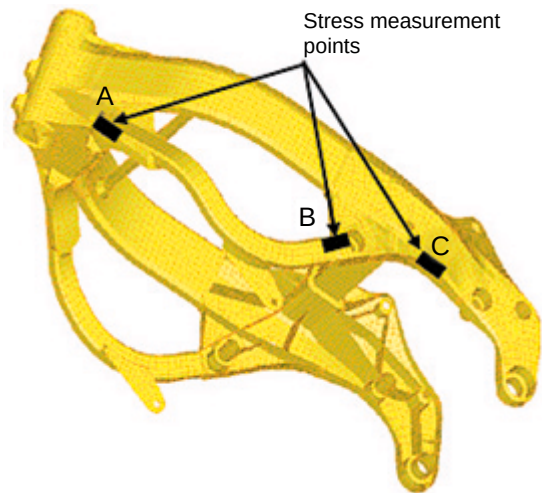


Fig. 7 Locations for stress measurement

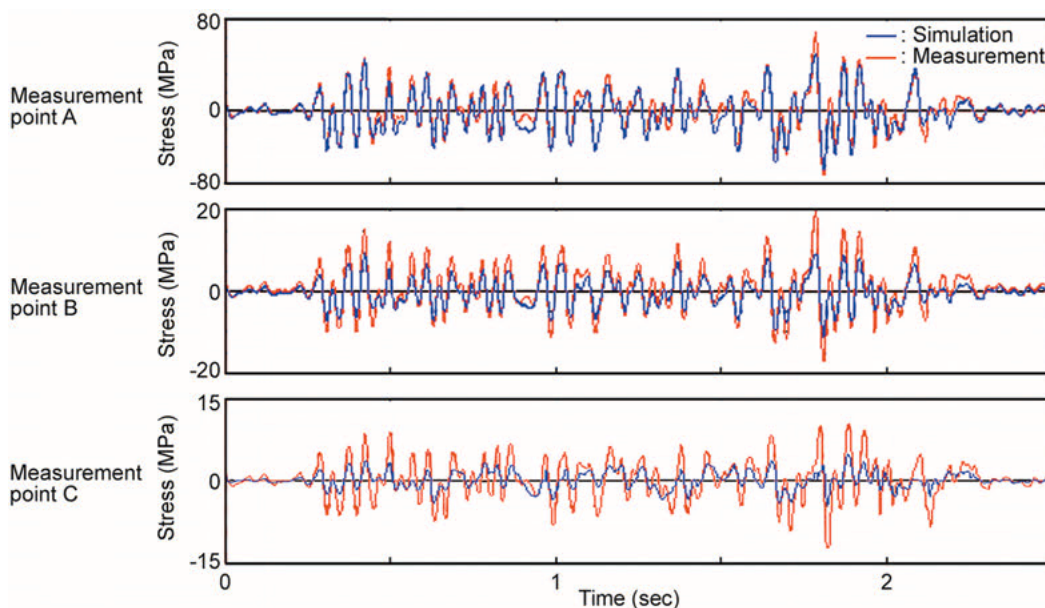


Fig. 8 Stress comparison between simulation and measurement

4.4 Damage Distribution

VRS technology makes it possible to observe damage distribution in specified parts. Fig. 9 shows an example of the result of a fatigue analysis. In the future, it will be possible to identify and respond to hot spots in the early stages of the design process, and to use the VRS to help predict the effectiveness of design changes.

5. Development of the GUI

A graphical user interface (GUI) has been developed to make VRS technology easy to use. Fig. 10 shows an example. The GUI has the following features:

- (1) Simplification of model preparation procedure
The motorcycle has been divided into major parts for modeling, and templates for each part have been prepared. Users can input parameters and combinations of templates to prepare models.
- (2) Automation of analytic procedure
Transfer of files between software applications, change of file format and calculation procedures have been automated.
- (3) Simplification of result output
Result output has been simplified so that calculation results can be easily recognized on the GUI.

6. Conclusion

The following results have been obtained by combining FEM, RS control, MBS and fatigue analysis technologies in the development of a VRS system:

- (1) The behavior of a motorcycle in a RS durability test has been accurately reproduced.
- (2) Damage distribution and stress waveforms at hot spots have been calculated from motorcycle behavior in a simulation.
- (3) Automation of model preparation and procedures has been achieved using a GUI.

These results have helped enable prediction of fatigue durability of the whole motorcycle, including multiple loads applied to parts at different times and local vibration modes that were not possible to predict using linear static analysis.

References

- (1) Harashima, S., et al., Development of Multi-use Road Simulator, SAE Paper 931912
- (2) Harashima, S., Evaluation Method of Motorcycle Fatigue Strength Using Road Simulator, SAE Paper 951817



Fig. 9 Fatigue analysis result

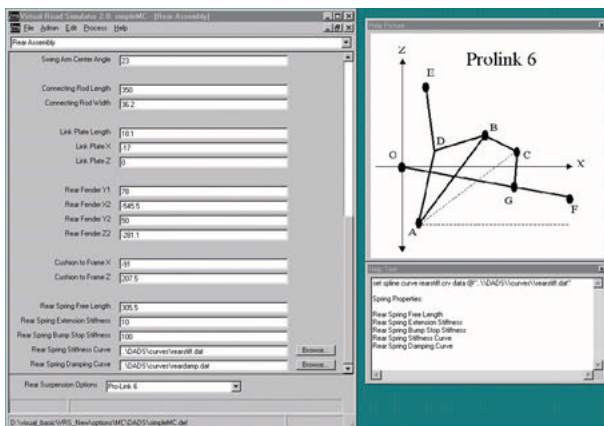
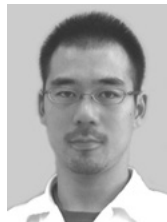


Fig. 10 GUI (Graphical User Interface)

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