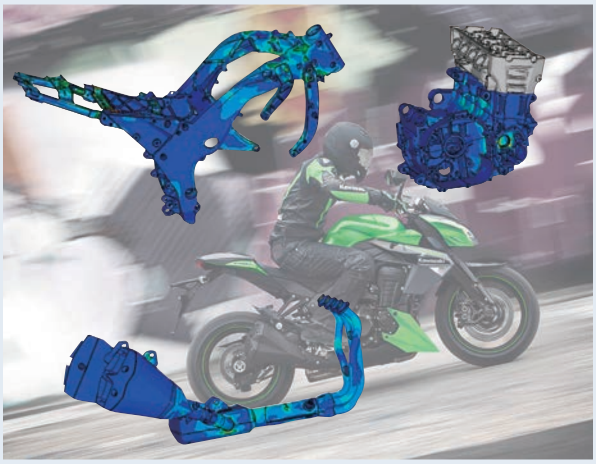
Advanced simulation technology that enables front-loading of development



In order to develop attractive motorcycles with greater efficiency, it is extremely important to achieve high quality and performance upstream in the development process when there is greater freedom for design study. To enable such frontloading of the development process, Kawasaki has been developing advanced numerical simulation technology and validation technology.

This paper will focus on aspects that concern durability, and examine how such technologies are actually applied in virtual simulation, body weight reduction and road simulator testing.

Preface

In order to develop attractive motorcycles, it is important to secure quality and to achieve high performance and marketability. This is accomplished most efficiently by, as shown in Fig. 1, polishing quality and performance upstream in the development process, when there is greater freedom for design, and then, in later development, focusing on such factors as feel which require a prototype vehicle to confirm. Through such front-loading of development, we hope to shorten development time and reduce cost.

In the upstream development process, when there is not yet an actual vehicle, accurate evaluation of various factors, as shown in Fig. 2, requires numerical simulation technology and evaluation technology to be more accurate than ever. Building these technologies requires advanced experiment and measurement technology to elucidate the theory behind phenomena.

This paper will focus on aspects that concern durability, in regard to the critical engine crankcase, muffler, and frame of a motorcycle, and road simulators for durability tests.

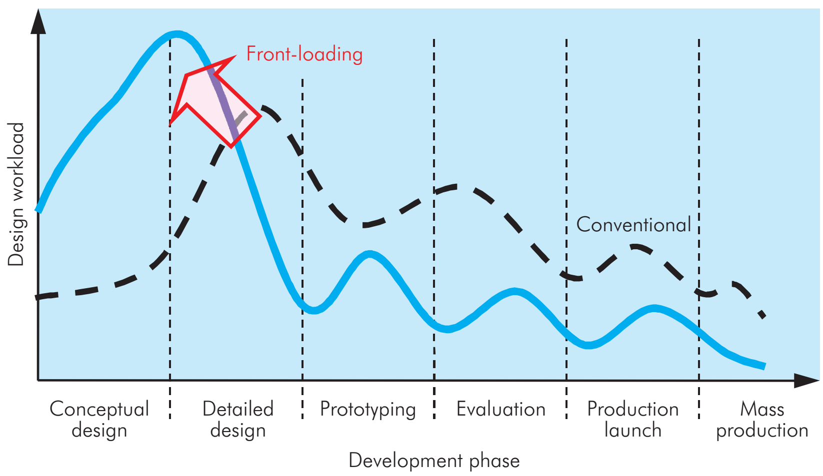


Fig. 1 Front-loading of development for design workload reduction

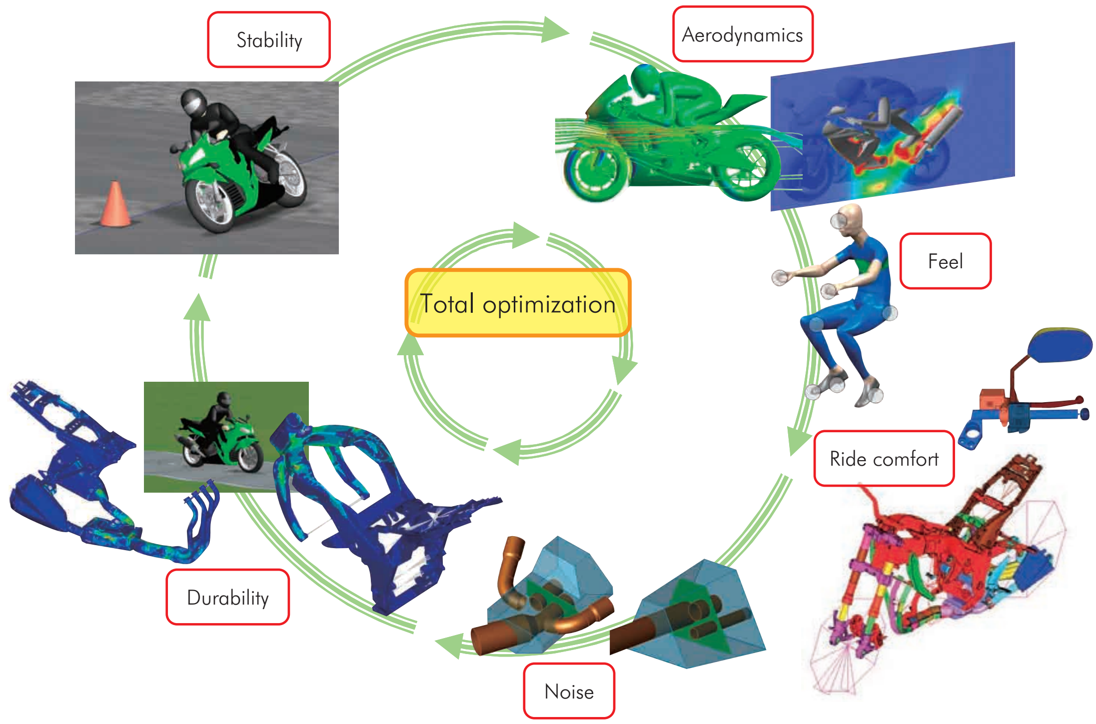


Fig. 2 Total optimization through mutual cooperation

1 Virtual durability simulation

(1) Engine (crankcase)

It is particularly important for a motorcycle engine to have a high engine speed and power and at the same time to be light. To achieve these at the same time, it is necessary to evaluate precisely the durability of the engine in the early stages of design. To do this, Kawasaki has developed highly accurate virtual durability simulation technology[1].

In the actual operation of an engine, as the piston-crank mechanism moves back and forth and rotationally, the force and inertia from the engine combustion act repeatedly on the crankcase. The magnitude and direction of the forces change with time, and therefore the stress conditions of the crankcase are complex and change every moment.

For such reasons, dynamic simulation would be best for numerical simulation of the crankcase. However, from a design efficiency standpoint, it is not practical to apply dynamic simulation, due to the calculation load and result volume. Instead, from the results of dynamic simulation using the model shown in Fig. 3, we decided to select multiple load conditions that would be hard on the engine

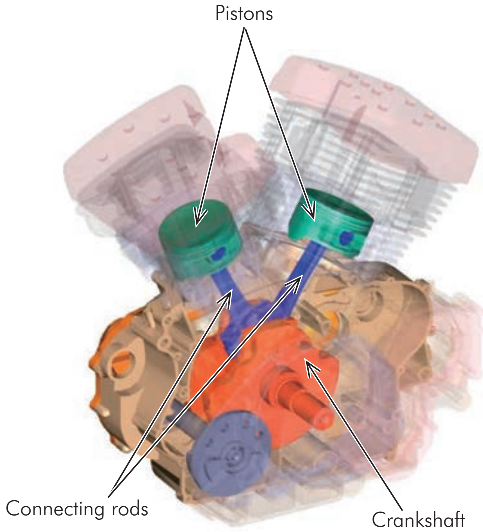


Fig. 3 Dynamic simulation model for engine

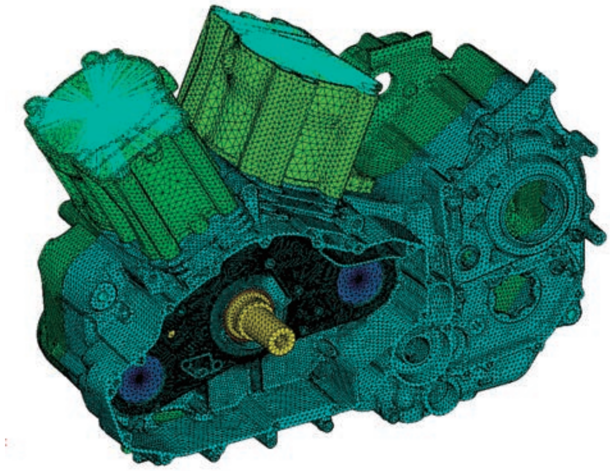


Fig. 4 Static analysis model for engine

in terms of strength, to evaluate durability based on their results. We applied these load conditions to the model shown in Fig. 4 and used the individual simulation results to calculate fatigue damage (durability evaluation). Example evaluation results are shown in Fig. 5.

Using this technology, it is now possible to conduct a virtual engine durability test and to consider many factors useful for polishing design.

(2) Muffler

In order to evaluate the stress applied to the muffler, the engine vibration needs to be analyzed accurately, and the muffler needs to be modeled appropriately. In addition, an evaluation method for the fatigue damage of welded joints is needed to predict the fatigue life of the muffler.

① We calculate engine vibration using mechanism analysis. Since the engine vibrations in a motorcycle range widely, they are evaluated by frequency domain.

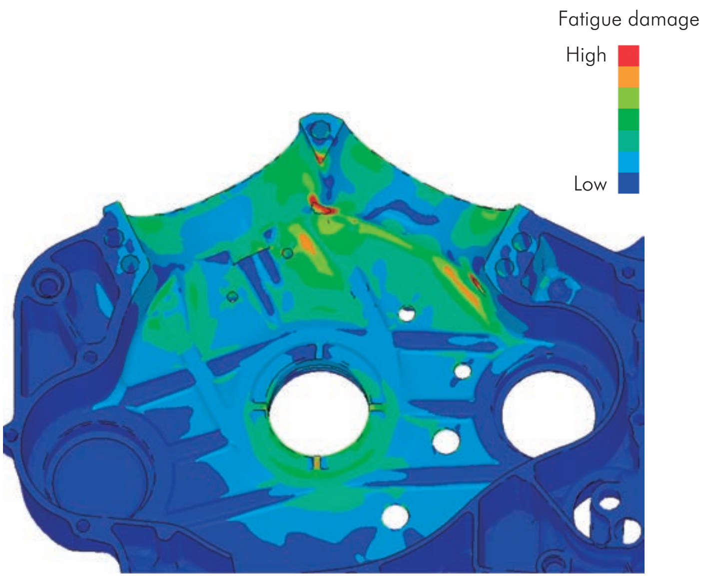


Fig. 5 Distribution of fatigue damage inside the right crankcase

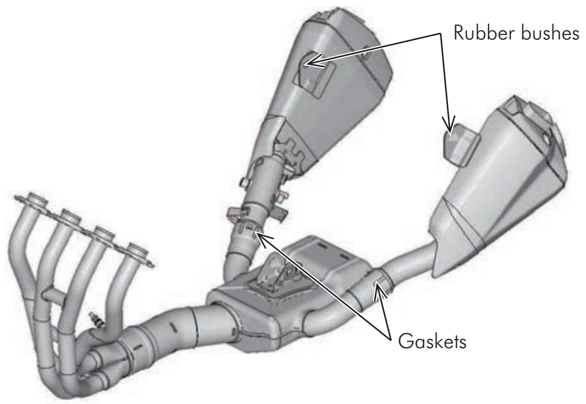


Fig. 6 Vibration analysis model for exhaust system

Fig. 7 Vibration test for exhaust system

② To evaluate muffler vibration characteristics, we improve the accuracy of the simulation by using a vibration analysis model as shown in Fig. 6 which includes gaskets for the joints with the engine and rubber bushes for the joints with the frame. We also validate the accuracy of the vibration simulation using a vibration test for the exhaust system as shown in Fig. 7.

③ In weld durability evaluation, we apply an evaluation method based on hot spot stress, allowing consistent evaluation that does not depend on the joint form of the weld. Hot spot stress is defined as a structural concentration of stress, not including local concentration of stress from weld beads. This method was originally developed mainly for application to thick plate components such as those used in ships and rolling stock, but we developed a technology by which the method can also be applied to thin plate components such as mufflers. We also take into consideration effects from heat from the engine.

The results of applying durability evaluation technology using these methods to actual mufflers (fatigue damage to the weld) are shown in Fig. 8.

Thus, we are now able to implement actual durability tests virtually, to consider design efficiently.

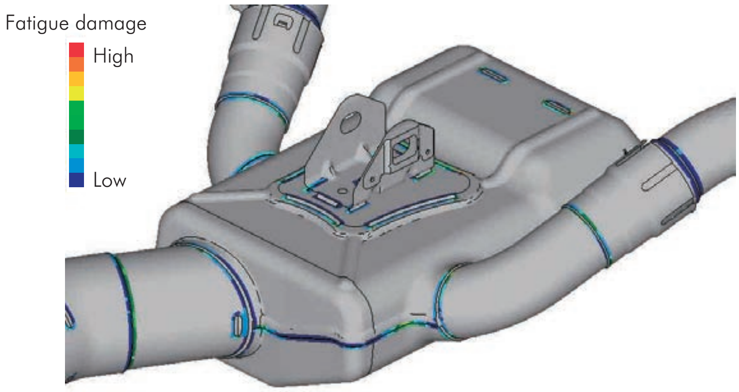


Fig. 8 Distribution of fatigue damage in exhaust system welds

2 Body weight reduction

Lighter frames are demanded, but they must maintain appropriate rigidity and strength. Therefore, we developed optimization technology for considering efficient form and component placement that fulfill the requirements for frame rigidity and strength.

Our frame optimization analysis model is shown in Fig. 9. We used the range in which the components of the main frame can be placed as the design space, while also modeling the engine, rear frame, swingarm, etc. The form obtained from our optimization analysis and the subsequent frame optimization process are shown in Fig. 10. We used the form obtained from our optimization analysis as a reference in determining the placement of ribs on the frame, etc. This makes possible efficient design that fulfills the conditions of rigidity, strength, and light weight demanded of a frame.

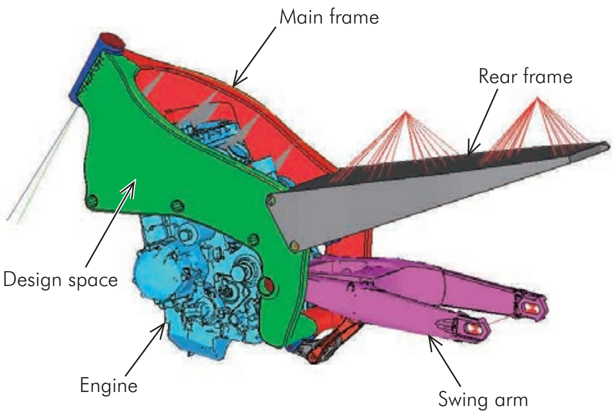


Fig. 9 Optimization analysis model for frame

3 Development of a road simulator for durability testing

In the use of virtual durability simulations, numerical simulation technology is becoming dominant. However, it is still essential to conduct validation tests under actual use conditions using a prototype vehicle.

Therefore, to verify rationally and efficiently that a product fulfills its target durability, we are advancing the use of a bench vibration system (road simulator) that can reproduce the conditions of riding on a course for an actual durability test (body load).

We are conducting durability validation tests with prototype vehicles in each development stage for motorcycles. However, these tests not only take a long time, but also are affected by the weather, cannot necessarily be continued day and night, and place a heavy

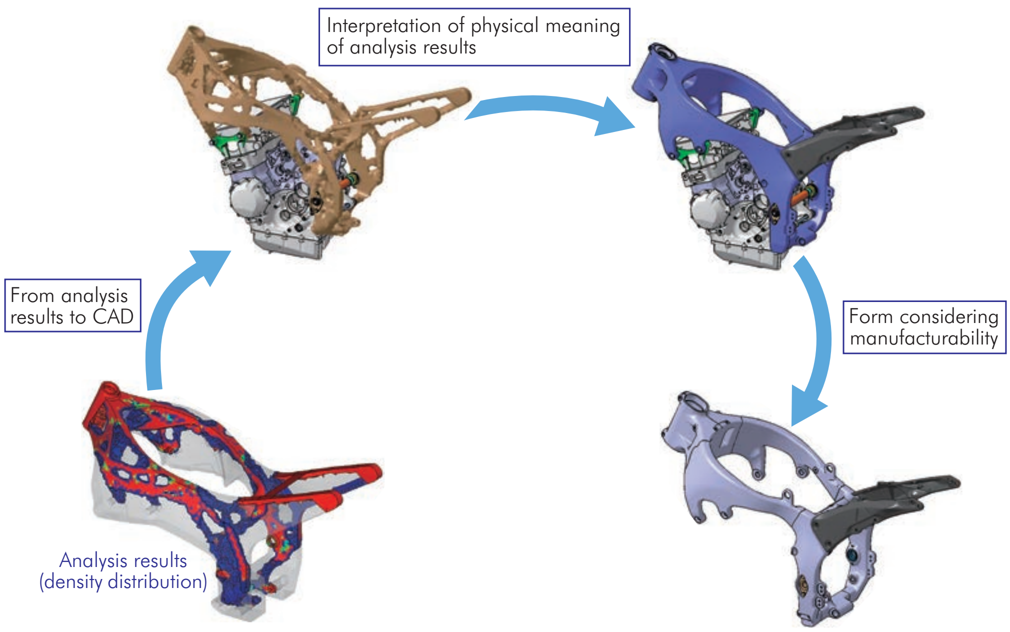


Fig. 10 Frame optimization process

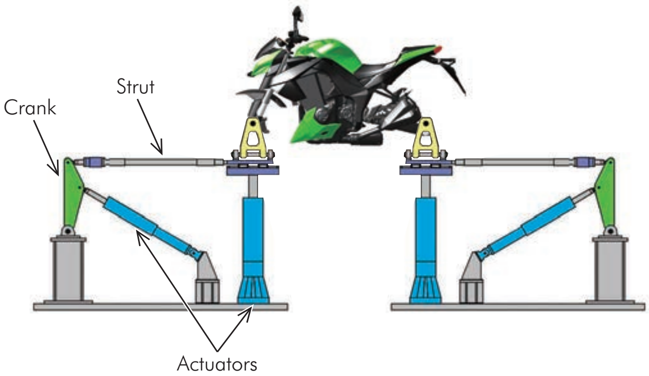


Fig. 11 Equipment composition of road simulator

Fig. 12 Durability test using road simulator

Takumi Kawasaki
Strength Research Department,
Technical Institute,
Corporate Technology Division

Kenji Nishio
Mechanical Evaluation Department,
Engineering Solution Division,
Kawasaki Technology Co., Ltd.

Masashi Michiue
Strength Research Department,
Technical Institute,
Corporate Technology Division

Eiji Ihara
Research & Development Administration Department,
Research & Development Division,
Motorcycle & Engine Company

Akiyuki Yamasaki
Research & Development Administration Department,
Research & Development Division,
Motorcycle & Engine Company

load on the riders. Moreover, since they form the final process in development, if there is some problem with them, it makes it difficult to stick to the target development period.

Therefore, it is crucial to establish a simpler and quicker test method to supplement actual riding durability tests, in order to make durability validation more efficient. Thus, we developed a road simulator for motorcycles, as shown in Fig. 11 and Fig. 12, as a bench testing method that can reproduce the conditions of an actual riding durability test with high accuracy.

The road simulator controls multiple actuators to faithfully reproduce the damage inflicted on the body when riding on an actual durability test course.

Concluding remarks

We have demonstrated our front-loading technology for motorcycle development and how it can be applied to durability evaluation.

We intend to continue to make our front-loading technology more precise, in order to make our development more efficient, and to develop technology that will help to polish product value.

Reference

1) K. Nishio, T. Kawasaki, F. Inamura, G. Matsubara, D. Kano, A. Yamasaki: "Prediction of Fatigue Failure in Multiaxial Stress States for Motorcycle Engines," Small Engine Technology Conference, SAE, 2010-32-0031 (2010)