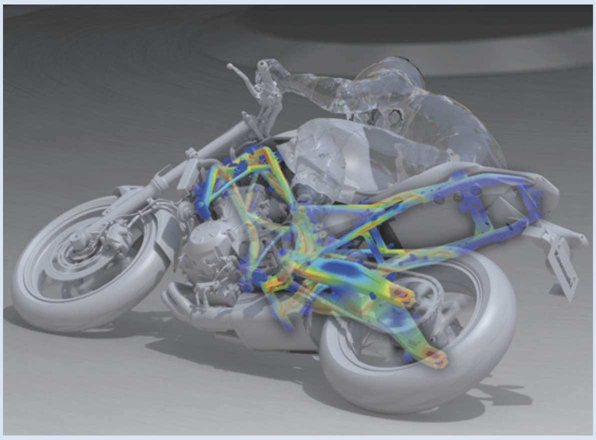
Achievement of an Extremely Lightweight Frame



Motorcycle weight reduction has a great impact on the factors that determine vehicular characteristics, such as ease of handling and maneuverability. During the development of the Z650 and Ninja 650, we worked on new techniques to develop lightweight frames, optimized the balance among stiffness, durability and maneuverability, and achieved significant weight reduction.

Introduction

In the development of motorcycle frames, vehicle mass is a key factor that greatly affects the ease of handling and maneuverability.

A smaller vehicle mass offers beginner riders a greater feeling of security in picking up and handling their vehicles. However, excessive weight reduction sacrifices vehicle stiffness and decreases stability during running, making it difficult to achieve vehicle performance that can satisfy intermediate and experienced riders. In addition, the durability of the frame itself, which affects reliability, decreases.

1 Background

The most important challenge in developing lightweight frames is achieving a good balance among stiffness, durability, and maneuverability, which determines a vehicle's characteristics.

In developing the main frame and swing arm, which contribute most to weight reduction among all the frame components, we repeat the cycle of design, static stiffness test, running test, evaluation, and design with an actual machine. Furthermore, in motorcycle development, we spend most of our time tackling this challenge, including replacing parts after modifications and test-riding the vehicle.

2 Policy for developing lightweight frames

We decided to develop a unique frame stiffness evaluation method and apply it to frame development with the aim of reducing the weight and at the same time achieving a good balance among stiffness, durability, and maneuverability for efficient mass-production vehicle development.

3 Conventional development process and challenges

In conventional frame development, the frame was developed by using design based on the static stiffness of the frame and riders' feedback after running tests. However, the static stiffness was calculated by conducting a static load test with the frame secured with a jig, so the load conditions and constraint conditions in the test differed from those during actual running. Because of this, we sometimes had difficulty understanding riders' physical sensations with static displacement only, and did not always achieve significant weight reduction.

4 New lightweight frame development method

(1) New frame stiffness evaluation method

We decided to numerically simulate frame deformation during running based on the motorcycle dynamics as shown in **Fig. 1**, and evaluate frame stiffness based on the displacement.

While a vehicle is running, the tire force and the inertial force of the vehicle are always in balance[1]. Therefore, we numerically and accurately simulated how the inertial force of the vehicle balances with a load applied to the tire contact point.

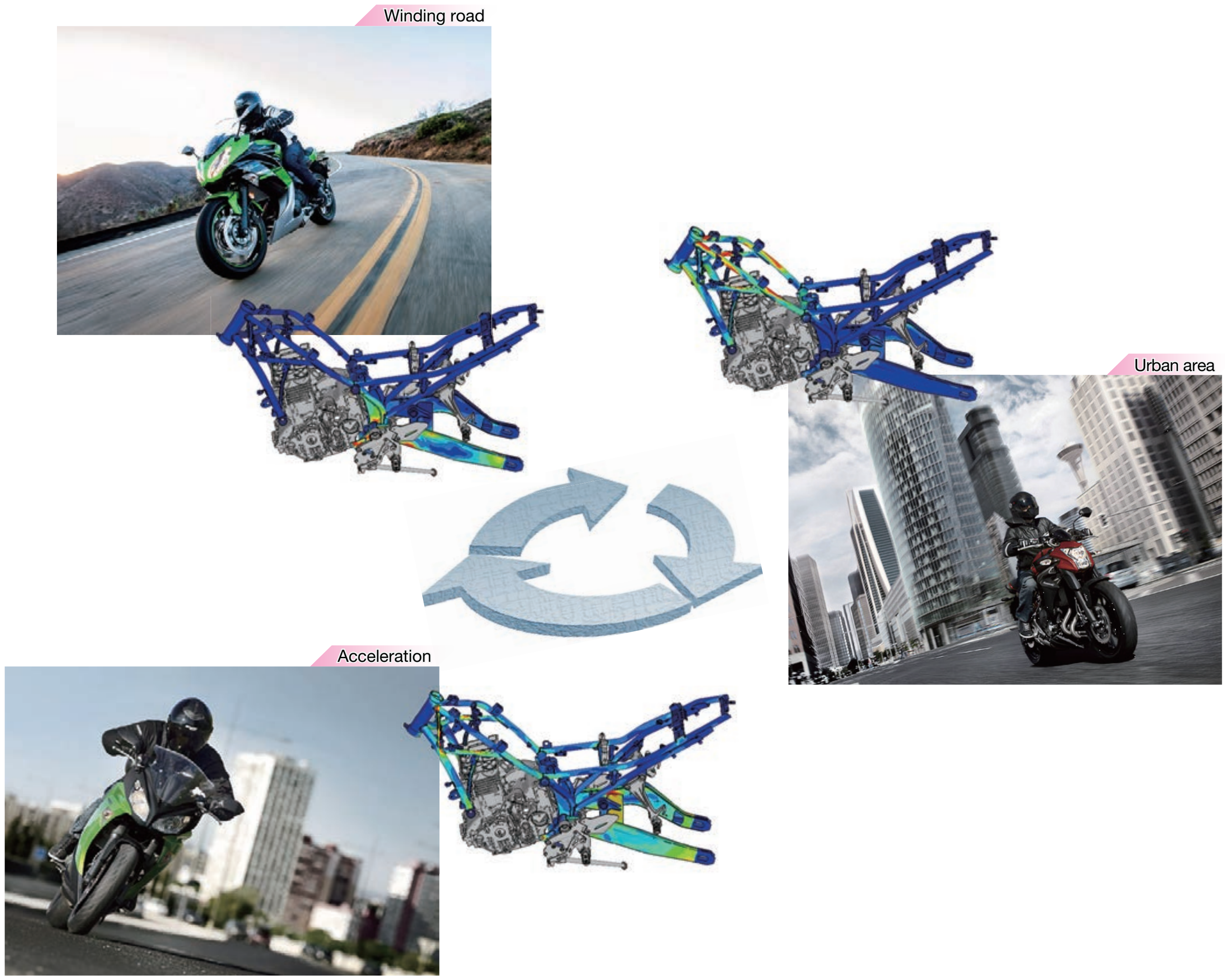


Fig. 1 Quantification of frame deformation during vehicle running

For efficient simulation even in the early stage of development where no detailed layout is available, we adopted a simplified model with the frame, swing arm, and engine only. The engine does not contribute to frame deformation but produces a large part of the inertial force acting on the frame, so modeling the engine was considered to be essential. We replaced the other components with rigid bodies and ignored their impact on frame deformation.

The frame stiffness was calculated based on the relative deformation of the engine, which has the highest stiffness among all the motorcycle components, and the tire.

(2) Running situations subject to stiffness evaluation

We performed stiffness evaluation under the following three running situations where the frame stiffness is greatly affected.

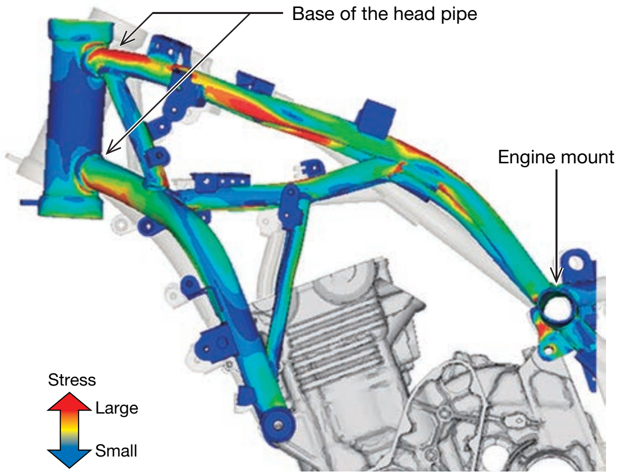
(i) Braking

As shown in **Fig. 2**, a vehicle runs with the braking force of the front tire and the inertial force of the vehicle in balance with each other, and the head pipe is bent by the moment caused by the braking force. A large stress is generated at the base of the head pipe and the front engine mount.

(ii) Steady turning

As shown in **Fig. 3**, a vehicle runs with the lateral forces of the front and rear tires and the centrifugal force of the vehicle in balance with each other, and the head pipe and swing arm are twisted by the lateral forces. A large stress is generated at the base of the head pipe and the joint between the right and left sides of the swing

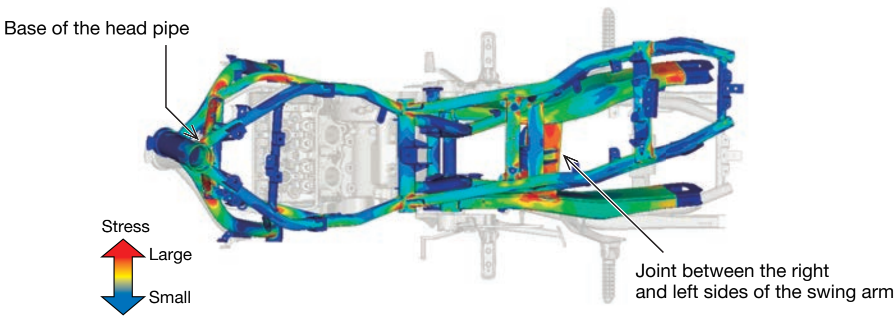
(a) Balance of forces



(b) Analytical result (side view)

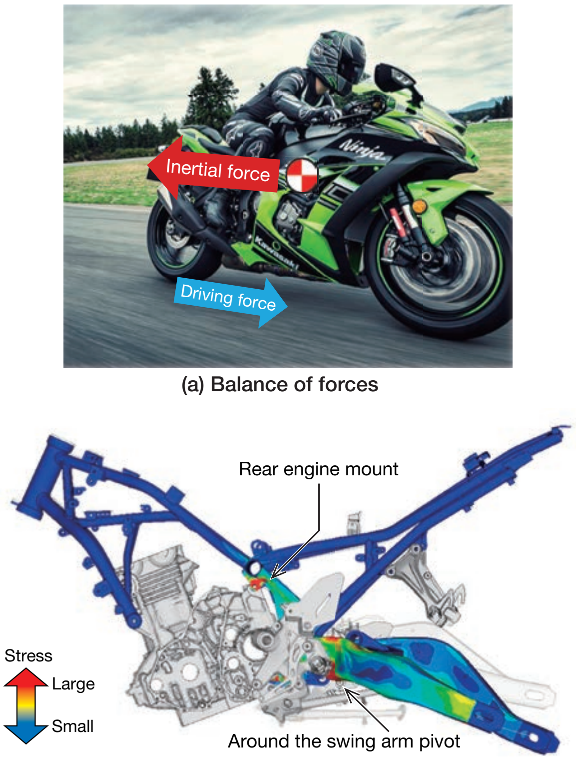
Fig. 2 Frame deformation with brake applied

(a) Balance of forces



(b) Analytical result (top view)

Fig. 3 Frame deformation during steady turning



(b) Analytical result (side view)

Fig. 4 Frame deformation during acceleration

arm.

(iii) Acceleration

As shown in **Fig. 4**, a vehicle runs with the driving force of the rear tire and the inertial force of the vehicle in balance with each other, and the swing arm is bent by the chain force. A large stress is generated around the swing arm pivot and at the rear engine mount.

5 Results of application of this new lightweight frame development method

Figure 5 shows the Z650 and Ninja 650, which are mid-sized models that are sold globally as strategic global models[2)] and offer beginner, intermediate, and experienced

(a) Z650 (b) Ninja 650

Fig. 5 Models developed with new frame weight reduction technique

† These models have 7% better fuel economy than the previous model (ER-6n/6f) in WMTC (Worldwide-harmonized Motorcycle Test Cycle) mode, and have lower CO, THC, and NOx emissions than the ER-6n/6f by 63%, 56%, and 50%, respectively.

riders "a fun to ride" and "ease of riding."

We adopted the new lightweight frame development method for the main frames and swing arms of these models, thereby significantly reducing the number of development manhours and achieving significant weight reduction while maintaining the well-balanced maneuverability of the previous models.

(i) Weight reduction

We derived the appropriate frame shape and optimal pipe diameter and thickness through numerical simulation. As a result, we successfully reduced the weight by over 10 kg in total with the main frame and swing arm shown in **Fig. 6**. **Table 1** shows a comparison of the mass between the Ninja 650 and ER-6n, which uses the frame before the model change.

(ii) Stiffness

Figure 7 shows the index values of frame stiffness. The Z650 and Ninja 650 have an extremely lightweight frame but have the same level of stiffness as the previous models, the ER-6n and Ninja 650.

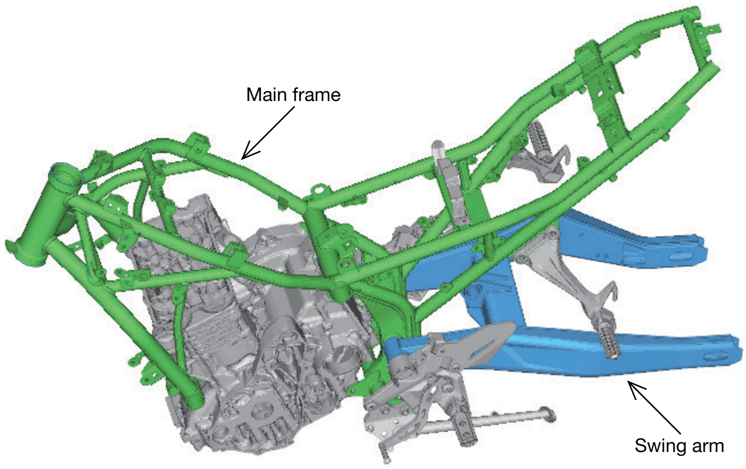


Fig. 6 Components subjected to weight reduction

Table 1 Weight comparison with existing model

Item	Ninja 650	ER-6n
Frame〔kg〕	17. 9	28. 1
Main frame〔kg〕	12. 9	20. 5
Swing arm〔kg〕	5. 0	7. 6

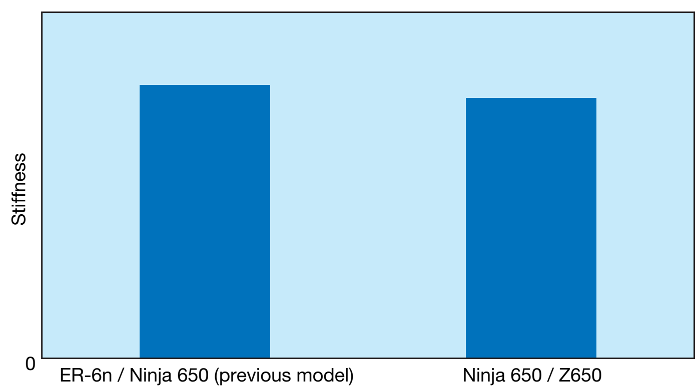


Fig. 7 Stiffness evaluation (during steady turning)

(iii) Evaluation by riders

In evaluations by riders, no comments were made suggesting a decrease in the maneuverability due to weight reduction, and we confirmed that adequate stiffness was achieved in every riding situation.

With this method, we have achieved a significant weight reduction and adequate levels of stiffness, durability, and maneuverability.

Conclusion

Owing to the new lightweight frame development method, the Z650 and Ninja 650 are lighter than the previous models by 19 kg. The method we developed has been applied to the new Ninja 250 and Ninja 400, and will be applied for all models.

Kenji Idaka
Design Department 2,
Research & Development Division,
Motorcycle & Engine Company

Kazuhiro Ichikawa
Strength Research Department,
Technical Institute,
Corporate Technology Division

Kazuya Nagasaka
Strength Research Department,
Technical Institute,
Corporate Technology Division

Reference

1) Y. Nakamura, K. Ichikawa, T. Kawasaki, Y. Okabe, H. Ishii, A. Yamazaki: “Development of Technology for Measuring Dynamic Deformation of Motorcycle Bodies,” 19th Small Engine Technology Conference (2013)

2) Tanaka: “Ninja 250/300 - A strategic global model beyond its class,” Kawasaki Technical Review, No.174, pp.21-26 (2014)