BASIC RESEARCH FOR A NEW AIRBAG SYSTEM FOR MOTORCYCLE

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ABSTRACT

Computer simulation of motorcycle crashworthiness was introduced in the development of a new airbag system. We chose MADYMO and PAM-SAFE as the basic software for the simulation. The new airbag system has several features suited to the special needs of motorcycles. Tests have shown that this air bag system is promising, but there are remaining technical issues that need to be resolved before it can be put to practical use.

INTRODUCTION

Yamaha Motor Company has long worked to improve maneuverability and braking performance from the perspective of active safety. Recently, through participation in the Advanced Safety Vehicle (ASV) project promoted by the Ministry of Land, Infrastructure and Transport, Yamaha has also been looking at practical application of advanced active safety systems using information technology (IT). In addition to active safety, it is obviously important to study passive safety in collisions. Passive safety systems in automobiles already play an important role in reducing the number of traffic fatalities, and there is an increasing need for development of passive safety systems for motorcycles.

As announced in ASV-2 (Phase 2 Activities, 1996-2000), Yamaha has continued research on the practical application of airbags as a device to reduce rider’s injuries in collisions (Figure 1). The airbag announced in ASV-2 exhibited a substantial effect on reducing the rider injury in frontal and similar collisions. However, a number of areas that needed improvement came to light. To overcome these problems and expand this effect, we are developing new motorcycle collision simulation technology and analyzing collision phenomena in computer simulations, while also collecting data from crash tests with actual motorcycles. Based on these results, we set a goal of improving the effect of the airbag system by restraining the rider's body to the motorcycle in the initial phase of collisions.

This article introduces motorcycle crash simulation technology that is essential in the development of our airbags. Compared with automobile collisions, motorcycle collisions have specific problems such as the diversity of collision configurations that need to be investigated and the larger motions of motorcycle riders than automobile occupants during collisions. In the following we describe, with the introduction of case examples, how Yamaha approaches these problems. Then, using these simulations, we introduce the new airbag system now being studied.

Figure 1. ASV-2 Airbag.

CRASH SIMULATION TECHNOLOGY

In developing vehicles and devices to reduce the rider injury in motorcycle collisions, experimental evaluation with actual motorcycles is essential. However, a huge number of factors need to be considered in collision phenomena, including vehicle speed and direction at the time of the collision, shape of the opposing vehicle, and location of impact. It is not practical to cover all these factors in experiments, and the method of reproducing collisions on a computer through numerical simulation is useful as a means to supplement experiments. We have adopted two simulation methods in our simulations: MADYMO, multi-body dynamics-based software, and PAM-SAFE, crash analysis software based on the finite element method. Simulations using the finite element method generally require much greater amounts of modeling data than does multi-body dynamics analysis, and much time is needed for calculations. Conversely, high computational accuracy can be expected because of the detail of the model. With multi-body dynamics analysis, on the other hand, calculation time is short but it has the characteristic of being difficult to assure computational accuracy. Motorcycle crash simulations have a greater variety of configurations than do automobile simulations, and are characterized by the very long event time that needs to be considered. In motorcycle collisions with automobiles, considering primary impact (in which the rider dummy hits the opposing vehicle), 0.5 sec from the moment the motorcycle crashes into the automobile is required in ISO13232, which stipulates research evaluation methods for motorcycle rider protective devices. Considering also the entire impact sequence (which includes up to dummy to ground contact), usually 1 sec or more (at most 3 sec) needs to be analyzed after the initial impact between the motorcycle and automobile. We aimed to develop a simple but highly precise simulation method for the present research by adopting MADYMO as the base simulation method, and partially incorporating results of high computational accuracy from PAM-SAFE into the MADYMO model.

MADYMO simulation

As mentioned above, MADYO is multi-body dynamics analysis software in which the simulation model generally consists of rigid bodies, connecting joints, and the surfaces that show the shape of the object. At the same time that the surface shows the model shape, it is also attached to the rigid body to calculate the reaction force in contact.
Simulations of motorcycle-automobile collisions require a motorcycle model, rider dummy model, and automobile model. The process of creating these models was reported in ESV2003 (1) and ESV2005 (2). In those reports, the HYBRID-III standing model was used for the rider dummy model, but later the MATD model (dummy model specified in ISO13232) was introduced in the research. Figure 2 shows the MATD model as well as the helmet model that is also recommended in ISO13232. These models are multi-body models with facet surfaces (FE mesh-like surfaces), and are now available in the MADYMO dummy database. These facet surfaces were partly replaced by ellipsoidal surfaces to resolve some problems related to airbag contact, although they reproduce the dummy's outer skin faithfully.

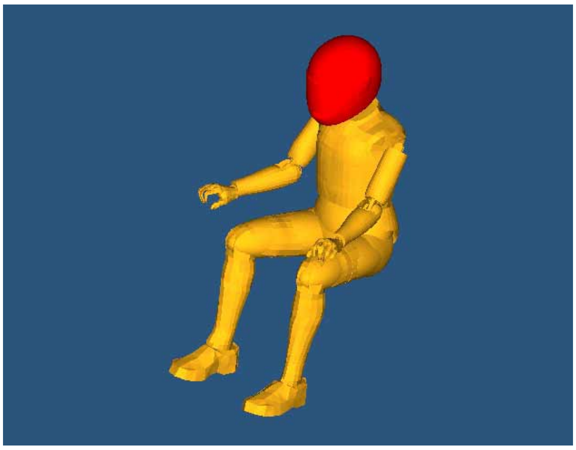

Figure 2. MATD model.

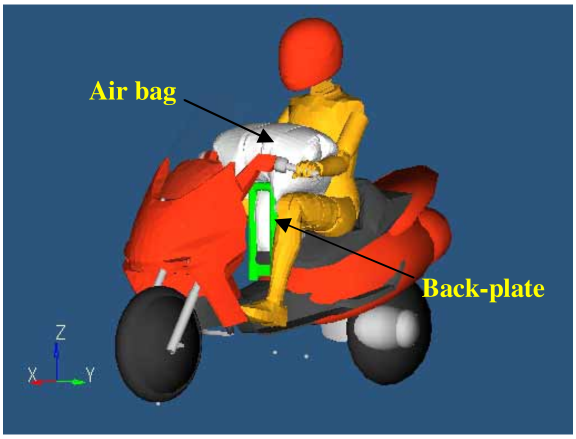

Figure 3. Airbag model (MADYMO).

In the present research an FE airbag model was created and added as a device to reduce the rider injury (Figure 3). However, the folding process is greatly simplified in this model, and the model does not consider gas flow. For this reason, the shape of the airbag in the initial phase of deployment may not be accurately reproduced. In order to improve the dummy motion, a few temporary and imaginary contacts were added to the model by analyzing the dummy motion in the initial phase of airbag deployment.

PAM-SAFE simulation

PAM-SAFE is collision analysis software used worldwide that is based on the finite element method. As stated above, at YAMAHA the role of crash analysis based on the finite element method is to supplement analysis based on MADYMO, because of the special circumstances of motorcycle crash analysis. Therefore, the PAM-SAFE model is used mainly with a focus on analyses thought to contribute to raising the accuracy of MADYMO models. A crash model of a motorcycle front tire can be given as a specific example (Figure 4).

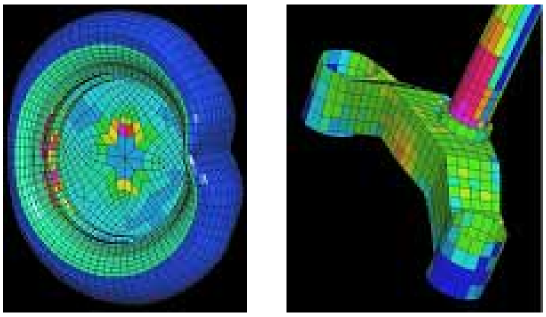

Figure 4. Front tire and fork model.

Unlike automobile collisions, in most motorcycle collisions the front tire collides with the opposing vehicle. As a result, the nonlinear deformation of the front wheel and tire and its contact reaction force influence the later motion of the motorcycle itself. For this reason, the model was constructed with the relatively detailed finite element model to obtain an accurate reaction force.
The root of the front fork also sustains large plastic deformation in collisions, and the nonlinearity in material strength should be considered (Figure 4). Therefore, this part is modeled and analyzed with the finite element method.
Next, calculations of deployment of the airbag (which is divided into compartments) from a folded shape need to consider the detailed contact phenomena with the seat around the airbag. A PAM-SAFE model using detailed finite elements is suited to such analysis (Figure 5).

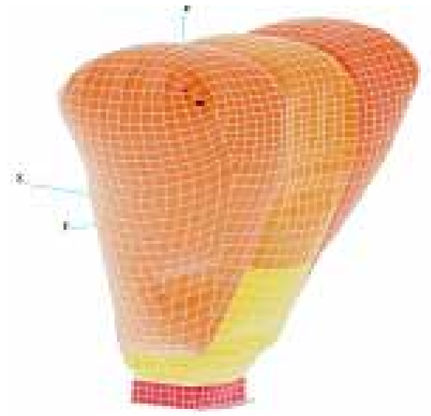

Figure 5. Airbag model (PAM-SAFE).

AIRBAG DEVELOPMENT

As stated above, the ASV-2 airbag was shown to have an effect to reduce the rider injury in certain collision configurations. Our aim is to give it this effect in a wider range of collision configurations. To achieve this, we are attempting not so much to prevent collisions of each part of the rider's body (mainly head and chest) with the opposing vehicle or motorcycle body, but to decelerate the rider's body itself. For this purpose, the airbag is positioned to remain as close as possible in contact with the rider. Also, to support the rider a member (called a back plate) to receive the force sustained by the airbag is used (Figure 3).
This prevents the rider from deviating greatly from the center of the airbag even in oblique collisions, and we can therefore expect an improved effect. In addition, the rider is decelerated by the airbag, so even in cases when the rider is thrown from the motorcycle, deceleration caused by the airbag is expected to reduce the injury suffered when the rider collides with the road or a roadside structure.

Airbag

The function demanded of the airbag under study is to decelerate the rider's body itself. For this reason the airbag is close to the rider's center of gravity, shaped to act on the chest and lumbar area, and smaller than the ASV-2 airbag. However, it has sufficient front-to-back thickness to prevent injury to the rider's chest and abdominal area. Another characteristic of the airbag is that it has two internal dividing walls, separating the airbag into three chambers (Figure 6).

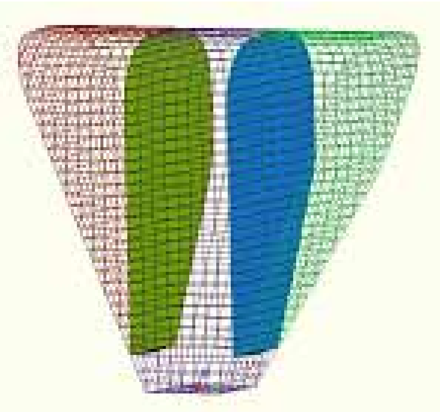

Figure 6. 3 chamber airbag.

The reason for dividing the airbag into chambers like this is so that it will rapidly pull up the back plate as described below. The center chamber is connected to the inflator. In deployment of the airbag, gas flows into the center chamber first, and the pressure rises quickly since the volume is small. The center chamber is therefore the first to rise quickly, and as it rises it pulls up the back plate. Gas flows into the left and right chambers through holes in the dividing walls, so that the side chambers deploy a little slower than the center chamber.

When deployment of the entire airbag is nearly complete, the pressure in each chamber becomes uniform at a value that is little different from the internal pressure in a single-chamber airbag. Therefore, when the rider collides with the airbag, the center chamber no longer has higher pressure than the other chambers and there is no adverse effect on the airbag's performance.

Back plate

The back plate is a special part that receives the force sustained by the airbag from the rider. With the use of a back plate we can expect that, regardless of motorcycle body layout, the airbag will be expected to function not only in frontal collisions but in oblique collisions as well. Before a collision, the back plate is stored with the airbag within the motorcycle body, but during collisions it deploys immediately with the airbag. At this time, as described above, the deployment force of the airbag is used to lift the back plate. There is also the advantage of a simpler total mechanism with the use of the airbag force.

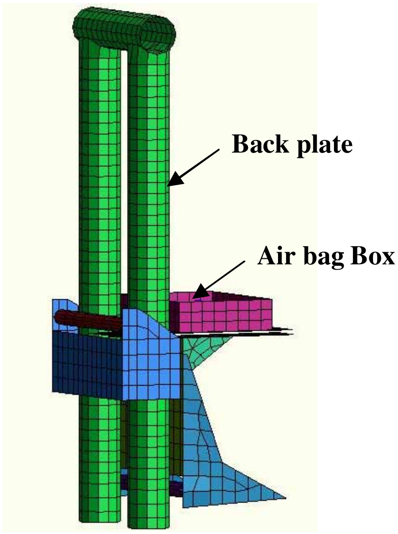

Figure 7. Back plate.

Considering the airbag function (that is to decelerate the rider), larger back plate height and width is desirable, but considering that the back plate is stored in the motorcycle and that it must be pulled up in a very short time, a smaller mass is advantageous. In determining the shape of the back plate, simulation of the rider dummy’s motion using MADYMO and simulation to obtain deployment time using PAM-SAFE are very helpful.

The airbag and back plate are connected with a short belt. This belt is used when pulling up the back plate, but it also has another role. That role is to keep the airbag between the rider and back plate so that the airbag function is maintained even in cases of oblique impact.

Experiments and simulations

Sled test Sled tests were conducted to confirm the characteristic functions of this airbag system; specifically, the function of lifting the back plate with the use of airbag deployment force, and the basic rider restraining function with the back plate. Two collision patterns were simulated, a frontal collision and an oblique collision. Figures 8 and 10 show the respective results of rider dummy motion in the sled tests and computer simulations for frontal and oblique collisions. The back plate was lifted by the airbag deployment force in each of these tests, confirming the fundamental possibility of lifting the back plate. In addition, in looking at dummy motion, even in tests when the sled was moved obliquely backward for an oblique collision, it was found that the dummy's lumbar area was restrained near to the seat.

Figure 9 shows the acceleration curve in the forward-backward direction of the dummy's chest corresponding to the case of a frontal collision.

The values estimated from this simulation show good agreement with the experimental values, confirming the validity of this modeling method. The influence of minor airbag specifications changes on dummy motion and other matters can be evaluated efficiently with the use of simulations.

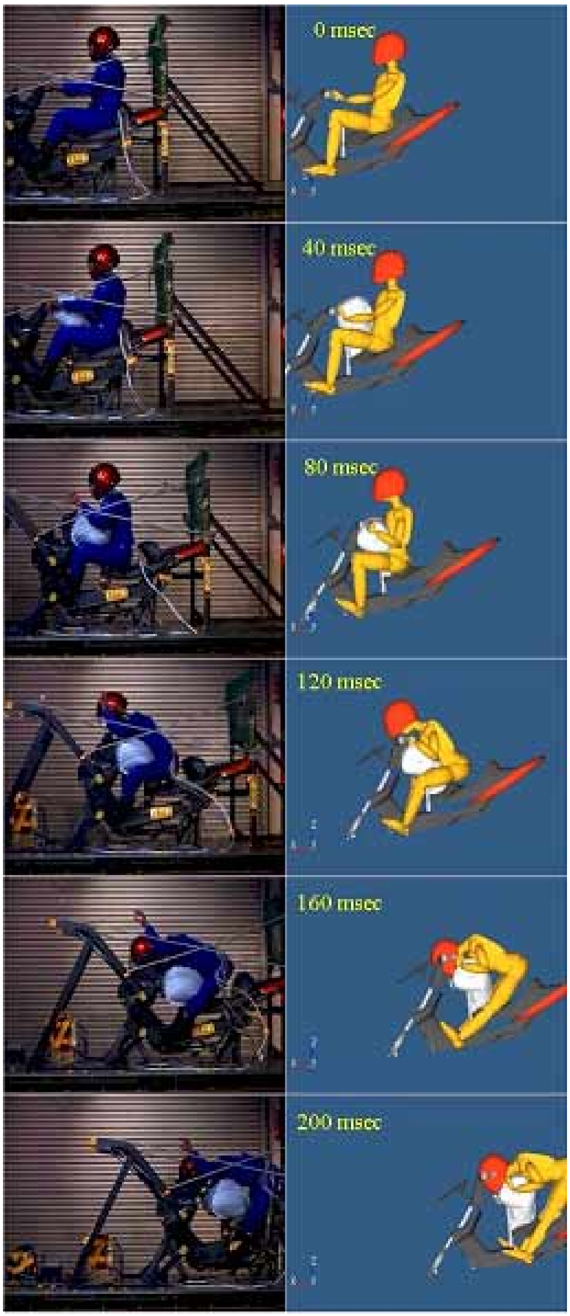

Figure 8. Sled test - 1.

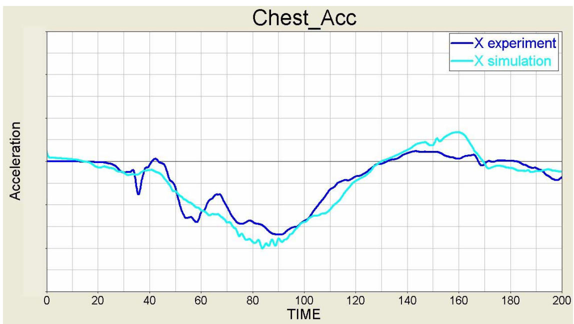

Figure 9. Chest acceleration.

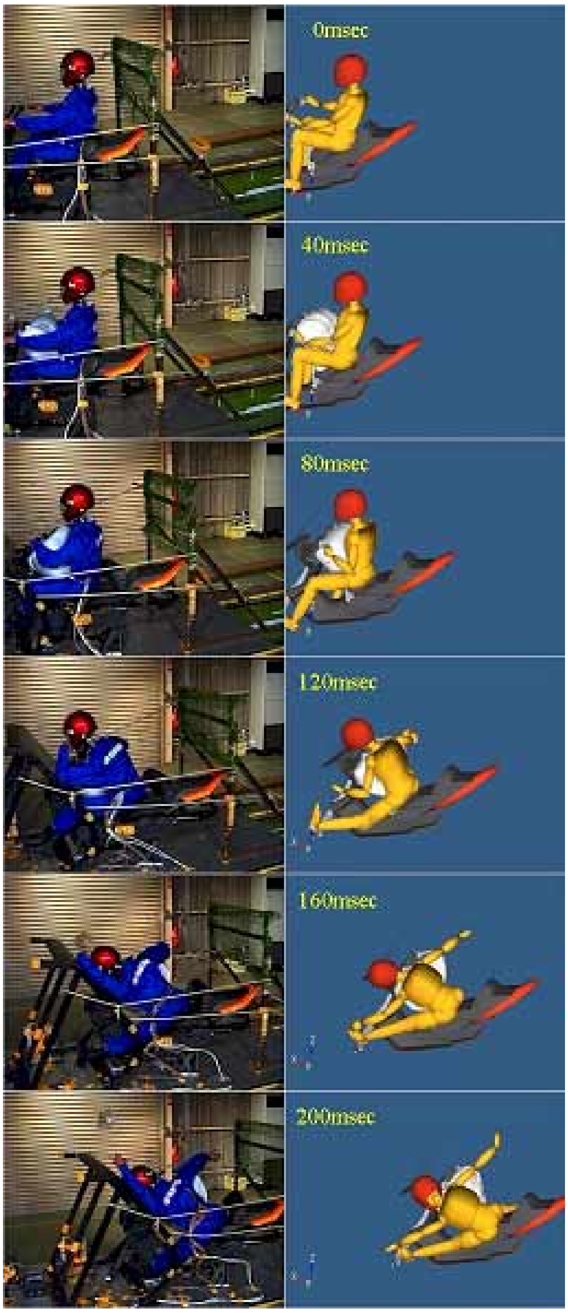

Figure 10. Sled test - 2.

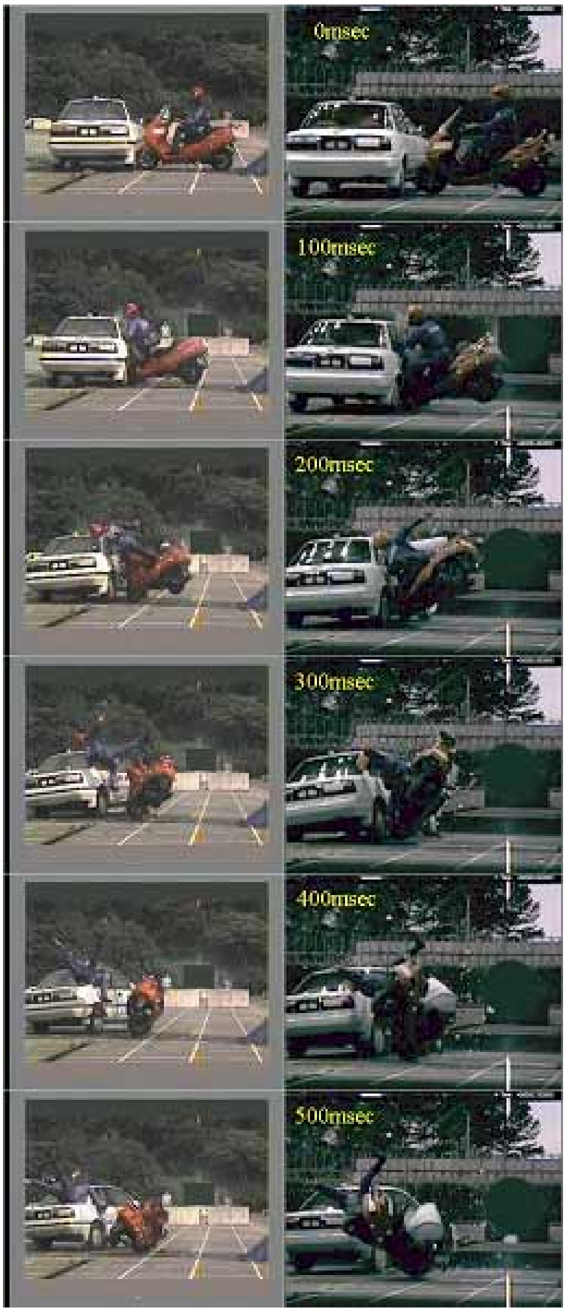

Figure 11. FST without/with airbag system.

__Full-scale test__ Since the fundamental rider restraining function was confirmed with sled tests, full-scale tests were performed next with an automobile as a collision object. Figure 11 shows a comparison of overall dummy motion with and without an airbag from 0 ms (at which time the first motorcycle/automobile contact occurs) to 500 ms at time intervals of 100 ms. In this case, a motorcycle traveling at 48 km/h collides at 90 degrees into the side of an automobile traveling at 24 km/h (configuration code '413-15/30' in ISO13232).

Without an airbag, the dummy's head collided with the automobile roof edge with almost no deceleration, and large head acceleration (HIC 690) was shown. When the motorcycle was equipped with the present airbag, the dummy's lumbar region was relatively well restrained near the seat, its head only collided slightly with the rear part of the automobile, and the head acceleration (HIC 153) was also inhibited. In a comparison of the height to which dummies were thrown off the motorcycle, the height was found to be somewhat lower with the airbag, so that reduced injury in impacts with the ground can be expected because of the reduced potential energy. The lifting function of the airbag was confirmed even in the full-scale test. We are currently evaluating the effect of this airbag system on reducing the rider injury based on the simulation evaluation method with 200 configurations called for in ISO13232.

These full-scale tests are carried out not only to give a preliminary assessment for effectiveness of the airbag system, but also to validate the simulation model that should be used for 200 configurations of simulation according to ISO13232. Figures 12 and 14 show kinematic comparisons between FST and simulation from 0 ms to 500 ms at time intervals of 100 ms. The pictures of FST in Figure 12 are the same as the ones without the airbag in Figure 11 (ISO configuration code "413-15/30".) In Figure 14, on the other hand, a motorcycle with the airbag system traveling at 48km/h crashes into the side of a stationary automobile at a right angle (ISO configuration code "413-0/30".)

Figures 13 and 15 compare the head resultant linear acceleration between FST and simulation. The blue lines indicate test data and the light blue lines simulation results. These figures show good agreement both in the dummy general kinematics and head acceleration.

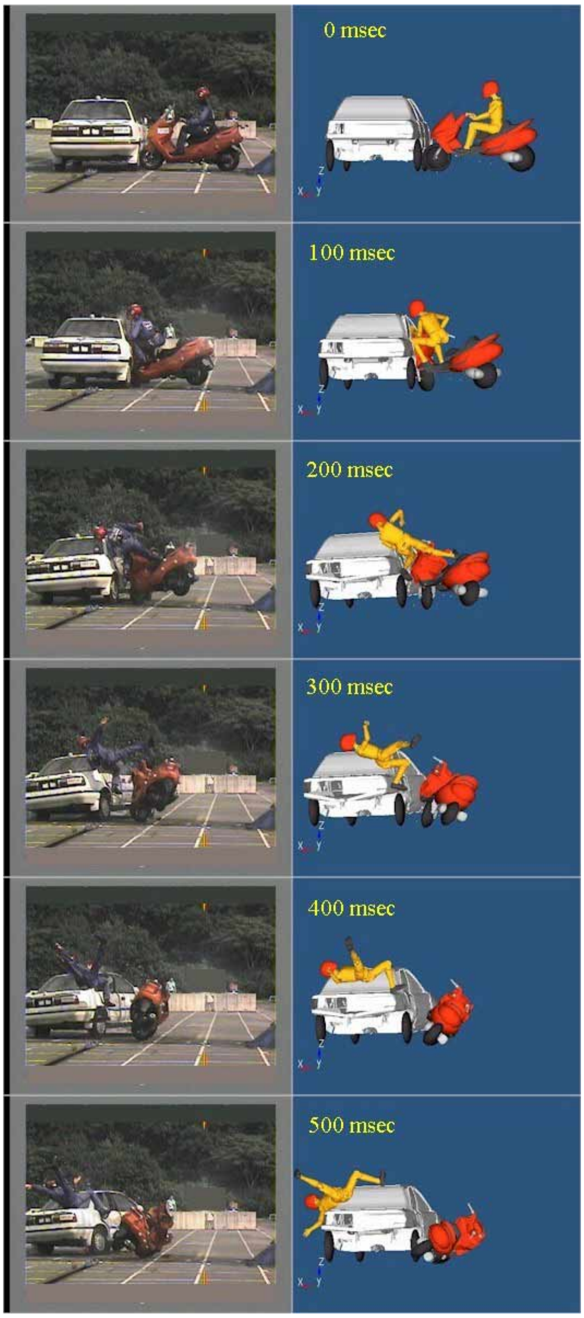

Figure 12. Kinematic comparison (413-15/30) without airbag system.

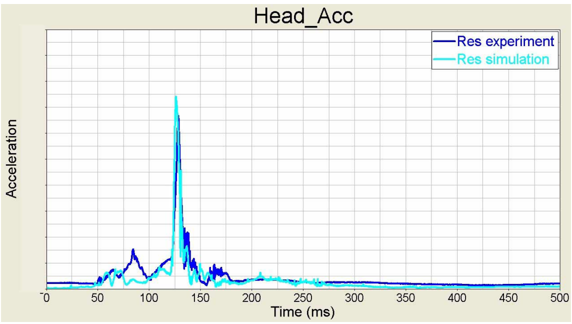

Figure 13. Head resultant acceleration (413-15/30) without airbag system.

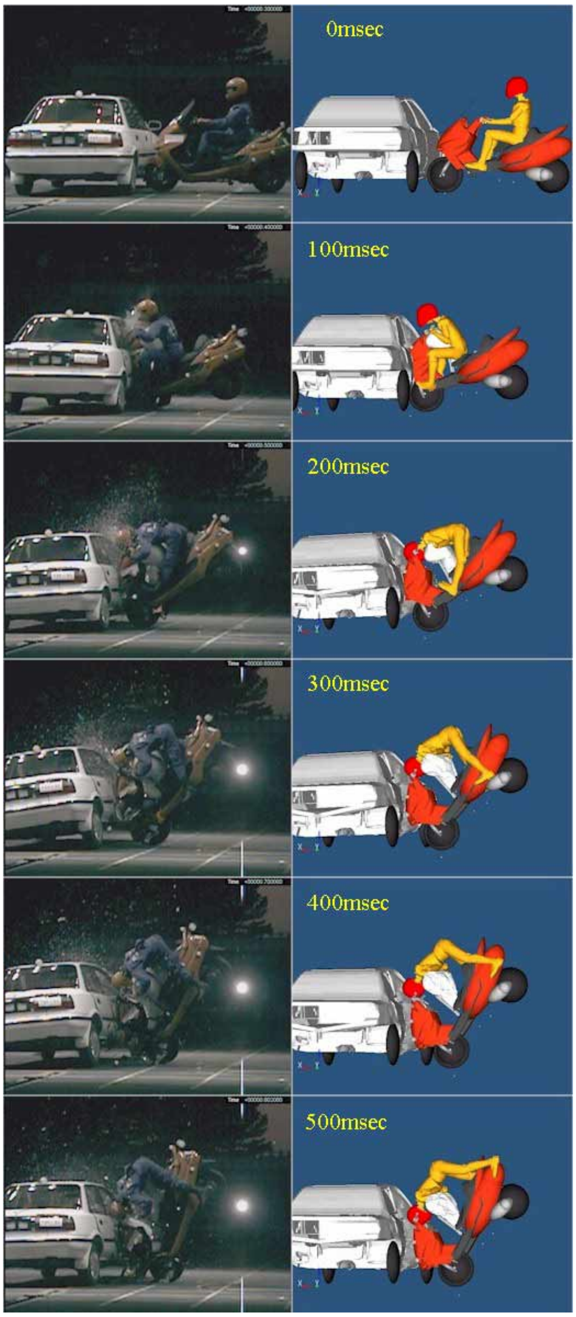

Figure 14. Kinematic comparison (413-0/30) with airbag system.

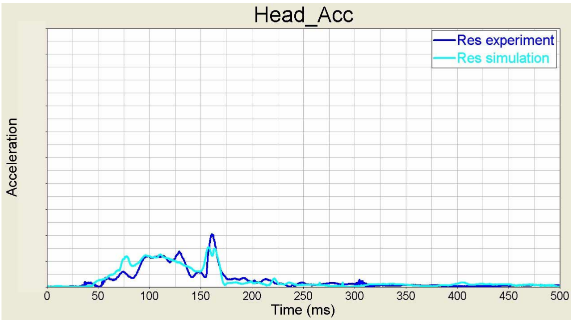

Figure 15. Head resultant acceleration (413-0/30) with airbag system.

Future issues

Issues we need to deal with next are, first, to optimize airbag shape, back plate shape, and their respective attachment positions. In addition, to confirm that this system is effective in reducing injury in various collision configurations, we will also need to conduct evaluations of effectiveness of the device based on ISO13232. The other tasks we need to do include development of a sensor and a control system to judge fire in airbags; investigation of the problem of out-of-position; investigation of the effect from differences in rider size and collision object; investigation of tandem riding; investigations of system reliability.

CONCLUSIONS

In the preceding we introduced collision simulation technology that was essential in the development of our airbag system. Yamaha uses mainly calculations by MADYMO supplemented with those by PAM-SAFE. We also have proceeded with research on the possibility of a new type of airbag that restrains the rider in the lumbar area. It was shown in both the sled tests and full scale tests that it is fundamentally possible to lift the back plate using the deployment force of the airbag. This system was also shown, although in limited collision configurations, to be effective in reducing the rider injury. In the future we plan to improve and optimize this system, focus on and resolve the above-mentioned issues including evaluation of effectiveness of the system based on ISO13232, and investigate the possibilities for practical application.

ACKNOWLEDGEMENTS

Finally, we would like to express our appreciation to the people at Toyoda Gosei Co., Ltd. for their tremendous cooperation in the development of this airbag system.

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