Particleworks™
Particle-based simulation software for CAE

users interview

Honda R&D Co., Ltd. Motorcycle R&D Center

Aeration analysis inside an engine

The motorcycle business of Honda Motor started in 1948, and has given shape to the wide-ranging joys and fun of riding on two wheels, through such products as the Super Cub, which went on to become the standard for commuter models, and the Dream CB750 Four, which triggered an unprecedented sports bike boom across Japan. The Honda motorcycle business has entered the global market fast and been holding the top world market share. Now it leads the motorcycle industry with its advanced technology having a high valuation from users. We have had the pleasure to interview Mr. Koji Matsui, in the Technology Development Division #2 of Honda R&D Co., Ltd. Motorcycle R&D Center to listen about the bubble behavior simulation in engine lubrication oil using Particleworks.

Please introduce the business of the Motorcycle R&D center.

Matsui: Motorcycles have attracted people in the world as a tool to make our life free and comfortable, and convenient mobility. We are promoting the research and development of reliable products using advanced technologies and leading-edge facilities, to produce attractive new motorcycles giving people joy, by respecting people's feelings and life and following our idea of "Forming joy of driving" since our company's establishment. We have a wide variety of products from family type motorcycles for daily use to large size sports motorcycles.

CRF1000L Africa Twin(DCT)

What is your role in the Technology Development Division?

Mr. Koji Matsui,
Department1, Technology Development Division #2
Honda R&D Co., Ltd.
Motorcycle R&D Center

Matsui: Motorcycle structure is generally divided into a body system and an engine system. I'm in the engine R&D department and I work on shaping unique engines satisfying both the joy of driving and global environment protection every day. The engine development is proceeded as 1) definition of concept → 2) consideration of engine specifications → 3) prototype car design and test → 4) production car design and test → 5) mass production. In this process, we take advantage of CAE to create better products in a shorter time. There are different fields and timings to use CAE in the development process. For example in engine systems, CAE is used for strength calculation, motion simulation of valve systems and crank systems, specification calculation of intake and exhaust systems which impacts output characteristics, and cooling and lubrication systems calculation, during the drawing consideration before prototyping and for trouble shooting after testing.

What kind of problems did you have in the engine design process?

Matsui: There are various problems to solve for securing durability in the engine development process. I'll introduce the aeration in engine oil, one of the major problems which should be avoided in such a process. The excess aeration in the oil raises the contact between metals of the sliding bearing, which produces abnormal abrasion and seizures of the engine. It is caused by the mixing of rotational bodies including gears, and the scattering/reflux oil drops on the oil surface. However, we didn't know in which area of the engine this aeration occurred until we made the actual engine. Besides, as the amount of aeration bubbles differs a lot depending on the operating conditions, we couldn't understand it quantitatively and clarify the bubble behavior. So it had been required to take measures by visualization tests in case the volume of the aeration was too much after making actual engines, and this would take a lot of time and money. In this context, we've been promoting CFD simulation as a method to predict bubble behavior in engine oil during the design process.

That means Particleworks is one of the key CFD technologies, doesn't it?

Matsui: CFD has been a necessary tool in the engine development process already, and the simulation using traditional grid method tools was standard so far. However, the grid method didn't suit the simulations of oil sloshing from rotational bodies and micro bubbles behaviors, and it also has a problem regarding the calculation cost. Then I luckily found Particleworks. Now, we use Particleworks for various oil behavior predictions inside engines (**Fig.1**). I think that MPS method software is the best solution to calculate complicated phenomena including large deformations of free surface produced by attached oil flow in the engine inside wall, oil mixing from the gear and oil sloshing caused from car bouncing and quick tuning.

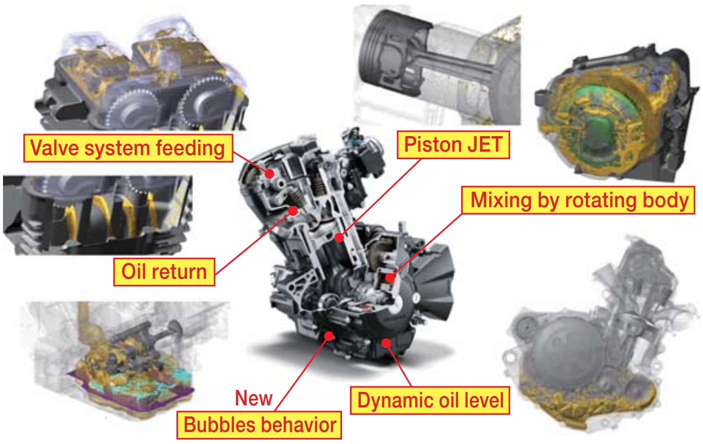

Fig1. Examples of oil behavior simulation using Particleworks

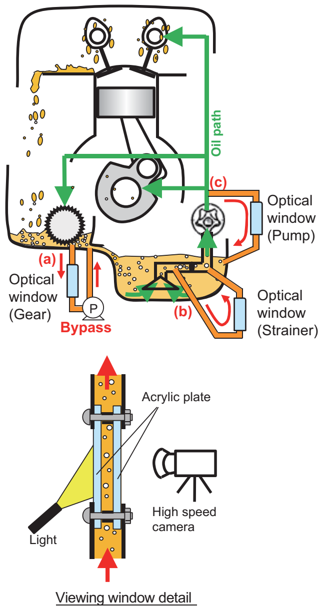

Fig2. The device for filming bubbles in the oil while the engine is operating

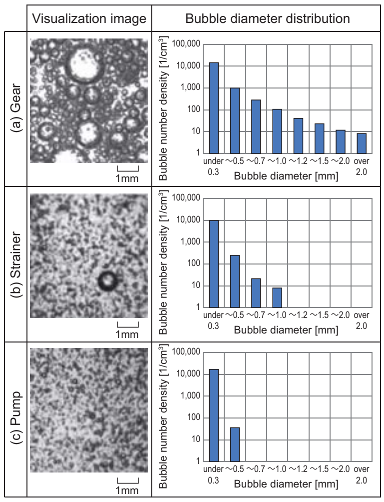

Fig3. Pictures showing aeration in the oil and the distribution of bubble diameter

In the recent development project cooperation with Prometech, we could realize the aeration analysis by adding our unique function to Particleworks, by which each bubbles behavior can be predicted correctly. This can't be simulated by other commercial CFD software products. We've continuously proceeded with the development with Prometech, and presented the first report at the 2016 JSAE Annual Congress in spring and the Prometech Simulation Conference. In this report, we simulated bubble transfer and evaporation which are the more important of the many bubble behaviors during the process from generation through transfer, separation, and conflation to evaporation. Before the simulation, we conducted a measurement using a real engine to understand the bubble behavior in the engine in detail and reflect it in a numerical model.

Will you please introduce how to measure using an actual machine?

Matsui: To see the aeration during the oil circulation in an engine, we used a converted commercial motorcycle for experimentation (**Fig.2**). In this engine, the accumulated oil in the oil pan is absorbed into the pump through the strainer. Then it is pumped to the crank shaft, the cylinder head, and the transmission, and dropped inside the crank case and returned to the oil pan. In this oil circulation, we made windows at (a) where bubbles are created by reflux oil dropping and gear mixing, (b) inside the strainer, (c) pump discharge opening, to view the bubbles going through each positions with a high speed camera. A transparent special oil is used in this experiment instead of using a commercial oil, to obtain clear pictures of the bubbles.

The pictures of aeration condition at each point and the bubble diameter and the number of bubbles visually counted from the pictures are shown in **Fig.3**. The horizontal axis shows the bubble diameter, and the vertical axis shows the number of bubbles in 1cm^3. From the results, we found that a lot of bubbles smaller than the diameter of 0.3mm existed at any measurement point. In contrast, there were many bubbles of diameter 0.5mm around the gear where we assumed that aeration was produced. Such bigger bubbles were decreased while going through from the strainer to the pump. So, we understood the bubbles behavior inside the engine, that the bigger bubbles produced around the gear moved and for the most part evaporated after rising to the oil surface. However, a part of them were absorbed by the strainer floating with the oil and the bubbles got smaller by going through the pump and remained in the oil. Therefore, we recognized that it was important to predict if the 0.3mm to 2.0 mm diameter bubbles rose to the oil surface and if they were absorbed by the strainer, to consider the reduction of the bubble amount in the oil supplied to the bearing. So we made a simulation model of the bubbles transfer and evaporation preferentially which was necessary to predict those phenomena.

Please introduce the simulation.

Matsui: We performed the simulation to evaluate aeration in the oil by MPS-DEM coupling. The oil was modeled using the MPS method, and the bubbles were modeled using the DEM method. As the bubbles behavior differs much depending on the bubble diameter, it's better to create each bubble using DEM and the bubble diameter was set to be variable. As other conditions, one-way coupling was applied so that the oil flow influenced the bubble flow but the opposite was unable. In addition, it was defined that the bubble particles and the oil particles didn't interact with each other, and existed by polymerization in the same space.

Modeling procedure of bubble transfer

To define the bubble transfer model, we used a motion equation of bubble considering gravity, buoyancy, resistance, lift force, and virtual mass force which were proposed by Darmana et al. On top of this, we applied wall contact force considering influence against wall and contact force by impact between bubbles. To verify certainty of this MPS-DEM coupling simulation, we compared experiments and simulations with respect to the rising velocity of a single bubble in the oil tank. During the experiment, we made attention to bubbles not to be affected by convection in the oil tank, and used the special oil of 25 °C which we used for real engine measurement. **Fig.4** shows the comparison between the experimental result and the simulation result. The horizontal axis means bubble diameter and the vertical axis means the buoyancy velocity. The pictures on the left were bubbles levitating taken by the camera, and we could find that the bubbles were rising with forming flatly because of the resistance in the oil. The drag coefficient, which was used for calculating resistance force in this simulation, was based on the experimental formula when using water, where bubbles rise keeping true spherical shape. Because of the difference of the bubbles shape during rising, we needed to multiply resistance force adjustment factor β to obtain enough correlation with experimental measurements when using oil. Then we verified certainty of bubbles buoyancy behavior under the influence from the oil. The experimental device was an oil tank having an injection port on the side wall, which was for injecting oil to mix with bubbles. **Fig.5** is the comparison between the experiment on the left and the simulation on the right about bubble clusters rising in the oil. Thus, the bubble behavior tendency was similar in the point that the smaller bubbles were founded far from the injection port and bigger bubbles were rising near the injection port. We also summarized the bubbles transfer horizontal distance for each bubble diameter at the point of 30mm above from the injection port. As a result, the experiment and the simulation roughly corresponded and we could simulate that there was variability among the horizontal transfer distance even for the same bubble diameter, because of the fluctuation of oil flow field and the mutual interference between bubbles.

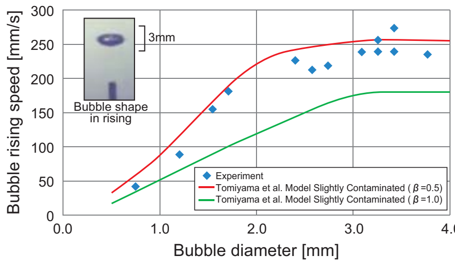

Fig4. Rising velocity of the bubbles in static oil

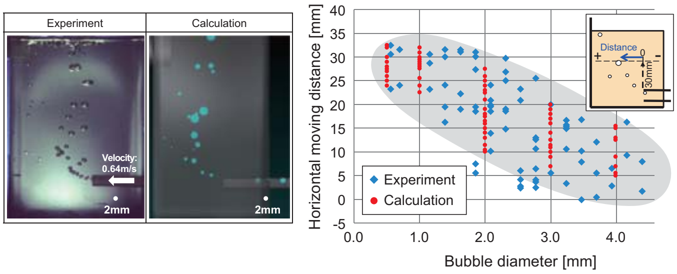

Fig5. Bubble behavior under the influence of oil flow

As for the bubble evaporation model, we applied the idea of Nguyen et al. that bubbles levitate on the liquid surface, then the liquid film of the bubbles gets thinner over time, and the bubbles would explode higher than the specific threshold. The liquid film thinning process is by capillary force and gravity, and we used the shorter one of those thinning factors in the simulation. Here we compared the experiment and the simulation of the duration from the bubbles generation by compulsion in a static oil tank through rising to the oil surface to evaporation. In the result shown by **Fig.6**, the horizontal axis is bubble diameter and the vertical axis is the bubbles evaporation time. From this result, we understood that the bubbles with 1mm diameter last the longest. Regarding this tendency, we obtained enough correlation between the experiment and the simulation and could simulate most of the variability of evaporation time for the same bubble diameter by introducing random numbers and variability.

Comparison of experiment and simulation results for all combined behavior

We verified simulation certainty by combining all above to perform a simple test. **Fig.7** is the experimental device which recreates the process that the circulation oil in the engine drops and generates bubbles, and part of them go onto the oil surface and evaporate, and then other bubbles flow to the oil pan by forced circulation. The upper oil tank generating bubbles and the lower oil tank were connected by a gutter. We took photos of the area surrounded by dash line in the **Fig.7** using a high speed camera, and verified them by measuring the number of bubbles and the distribution of bubble diameter. **Fig.8** shows the experimental results on the left and the

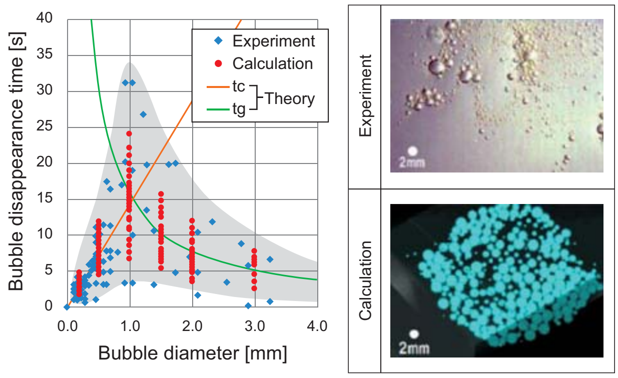

Fig6. Bubbles evaporation time

simulation results on the right. As it is still difficult to simulate the phenomena which bubbles generate automatically, we added the amount of bubble generation and the distribution of the bubble diameter as user's definition. From the results, we found that the bigger bubbles flowed off around the partition plate continuously and the relatively smaller bubbles flowed under the plate toward the gutter inlet. In this context, the simulation result corresponded roughly. However, the phenomenon, that the bigger bubbles once rose to the oil surface returned to the oil and was absorbed by the gutter, was more evident in the simulation than in the experiment. As the next step, we evaluated the remaining rate for each bubble diameter at each point. **Fig.9** shows the rate of bubbles which existed in the upper oil tank (a) reaching the gutter inlet (b). The bigger bubbles have a less of rate of reaching the gutter and evaporate. Such tendency could be seen in both the experiment and in the simulation and there is a good correlation between them. It seems that the reason why the simulation estimated the remaining rate a little higher than the experimental result was because of the influence that the bubbles after rising were absorbed again as mentioned before. **Fig.10** shows the bubble remaining rate at point (C) of the lower tank among all the bubbles existed at the gutter inlet (b). Here as most bubbles rose to the oil surface, the evaporation is the dominating phenomenon. So the remaining rate of 1mm bubbles is the highest and the smaller or the bigger bubbles were difficult to remain and there is a good correlation between the experiment and the simulation for this.

From those actual machine experiments to view the bubbles, we could understand the bubbles behavior inside the engine, and clarified the bubbles behavior and the range of bubbles diameter to be targeted for the simulation. Then we created the simulation models for bubbles transfer and evaporation using simple bubble

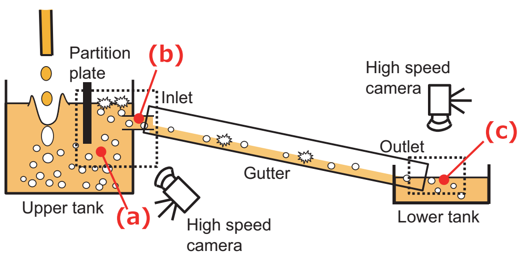

Fig7. Bubbles behavior experimental device shaping simplified engine

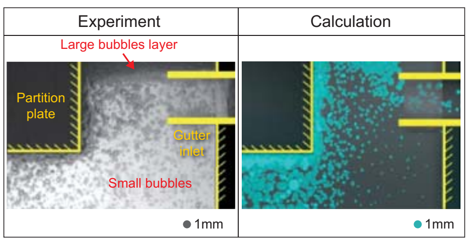

Fig8. Bubbles behavior in the upper tank

Bubble remain rate = Number of bubbles at (b) / Number of bubbles at (a)

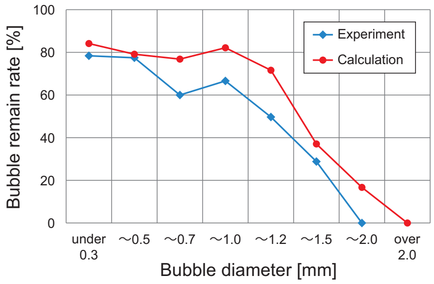

Fig9. Remaining rate of bubbles which existed in the upper oil tank (a) reaching the gutter inlet (b)

Bubble remain rate = Number of bubbles at (c) / Number of bubbles at (b)

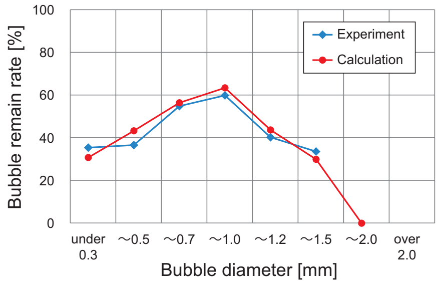

Fig10. Bubble remaining rate at point (C) of the lower tank among the all bubbles existed in the gutter inlet (b)

experiments in the oil tank based on the information we'd obtained. We confirmed that there was a good correlation between the experiment and the simulation roughly by comparing with simplified actual engine device. Those are the 1st reports of our research and we'd like to go forward with it continuously.

Could you please tell your impression of Particleworks, request, and future expectations of Prometech?

Matsui: Formerly we had to create an engine for testing remodeled to view the inside of it and to clarify the cause by taking photos of the real operating conditions using a high speed camera and others, when some trouble arose regarding the oil behavior in the engine. However, as we began to be able to predict the phenomenon by Particleworks, the clarification of the cause can be realized without actual machine testing. In addition, we can evaluate the optimal shape using Particleworks during the 2D drawing process before making a prototype, which contributes to the reduction of troubles during the testing process. As specific examples, now we can check and evaluate if the oil is fed to the valve system, if the cross-sectional area of the oil passage is enough on the way of oil circulation, if the rotating bodies including gears and oil interfere, and if the oil ununiformity occurs by the car body dynamic movement. In addition, we are able to check and evaluate if the oil pump absorbs the bubbles excessively by using the aeration module which we've developed in cooperation with Prometech. As for bubble tracking, using such an aeration capability has been inapplicable by other CFD software tools, we appreciate Prometech's motivation to take on new challenges and their support ability to develop such a great software program and it is one of the major reasons to use Particleworks. We'd like Prometech to continue such challenges to develop capabilities to simulate phenomena which other existing CFD tools can't deal with. We also expect improvement of the solver not only relying on the enhancement of the hardware performance for faster calculation time.

Thank you very much for your valuable feedback and information, and for cooperating with the interview despite your tight schedule. Prometech will continue to provide further support for your better product development.

Reference
Prometech Simulation Conference 2016 proceeding

Interview: September 9, 2016

HONDA The Power of Dreams

Honda R&D Co., Ltd. Motorcycle R&D Center

Office: Asaka-City, Saitama-Pref, JAPAN
Founded: In 1960
Activities: As the R&D center of Honda motorcycle business, researching and developing reliable products using its advanced technologies and the leading-edge facilities. The developed products are a wide variety of models including large-sized sport models to small models for daily use.
URL: http://world.honda.com/RandD/

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