Particleworks™ Particle-based simulation software for CAE **User Interview**

Hitachi Automotive Systems, Ltd.

Piston oil jet simulation using Particleworks

Hitachi Automotive Systems, Ltd. was established in 2009 by the split-off of Automotive Systems from Hitachi, Ltd., which has an 80-year history of producing automotive electrical components, including the first Japan-made alternators, and has been supplying parts to major automakers for about 80 years. Today, it's grown to be a global company with a total of 113 sites in 55 companies, not only in Japan but also in Europe, the United States, Asia, and China. It also has operations in the business domains of powertrain systems, chassis systems, advanced driver assistance systems (ADAS), and the development and provision of systems that support electrification and autonomous driving, which will become even more important in the future. We had an opportunity to interview Mr. Yuki Takahashi of Technology Development Div., who support automotive systems' product design and development by using CAE technologies, about the Particleworks application in piston development.

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Please tell us about the usage of simulation software in your division.

I was originally specialized in structural analysis and have been mainly in charge of structural and optimization until my second year after joining the company. Currently, I am mainly involved in thermal fluid analysis. Particleworks was introduced in 2017 and has been in use for two years since then. As it does not take much time for the pre-processing process because it eliminates the simplification of CAD models and meshing, I think that it is very effective in terms of its easy-to-use operation.

What are the challenges you are working on in CAE use?

Our department coordinates CAE technologies, and one of my tasks is to apply simulation to the design and development of engine parts. In recent years, environmental regulations surrounding automobiles have become increasingly strict, and components suppliers are required to achieve higher engine efficiency, that is, higher compression ratios and higher supercharging. Therefore, improving the cooling performance to prevent piston knocking is one of the key

Mr. Yuki Takahashi
Technology Development Div.

issues. At present, the cooling performance is often improved by using a piston with an oil jet and a cooling channel in the engine (Fig. 1). We conducted simulations to predict this cooling performance.

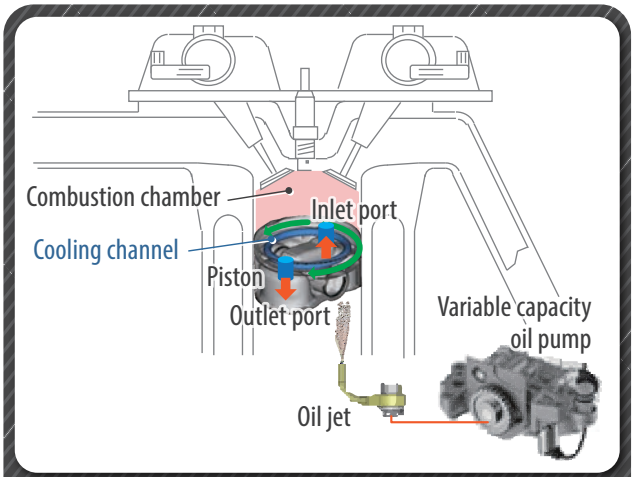

Fig.1 Piston oil jet system

How and why did you choose Particleworks?

Responding to the requirement to evaluate cooling performance, Particleworks had become one of the candidates for simulation. We had used FVM (Finite Volume Method) based grid method CFD software already, and we decided to choose the more effective one by comparing the time for pre-processing and calculation speed. Simulation of the piston oil jet shows that it is unsteady, the solid region moves, and the oil occupancy in the analysis region is small. Therefore, in FVM, oil was represented by VOF (Volume of Fluid) and solid movement was controlled by morphing and remeshing based on the movement profile written in text. On the other hand, in Particleworks, oil was represented by particles, and solid movement was controlled only by the movement profile.

First, we compared the time for pre-processing. It took a considerable amount of time to simplify the CAD model in FVM. It meant reducing the number of meshes and simplifying fine edges, and fillets required a lot of time and effort. Such a simplification process is often necessary with the grid method in order to avoid mesh breakage when using morphing. After that, the process proceeds with meshing, macro creation of moving boundaries, setting of analysis conditions, and trial calculation. At this time, the CAD model was not sufficiently simplified, and the mesh was broken during the trial calculation, which caused additional man-hours to simplify the CAD model again. In contrast, Particleworks does not use meshes, so there is no need to simplify the CAD model, which saves a lot of time. In Particleworks, a shape that maps the particle values is required when evaluating the average heat transfer coefficient of the cooling channel. So, we took time to make the patch area of this shape uniform in advance. Nevertheless, when comparing the total time for pre-processing, Particleworks resulted in less than 1/3 of FVM's. (Fig. 2)

How about the comparison of the calculation speed and analysis results?

We compared the simulation time and results of FVM and Particleworks by changing the resolution according to the number of meshes and the number of particles. (Fig. 3) The horizontal axis of the graph is the operating cycle of the piston, and the vertical axis is the average heat transfer coefficient of the cooling channel wall. The FVM result is represented by a solid line, and the Particleworks result is represented by a dotted line.

When refining the mesh with FVM and changing the trim meshes to polyhedral meshes to increase the resolution, the FVM result approached the result of Particleworks. This means, the Particleworks results tended to be the same as the FVM high-resolution ones. Regarding the calculation time, FVM (high resolution) took 40.8

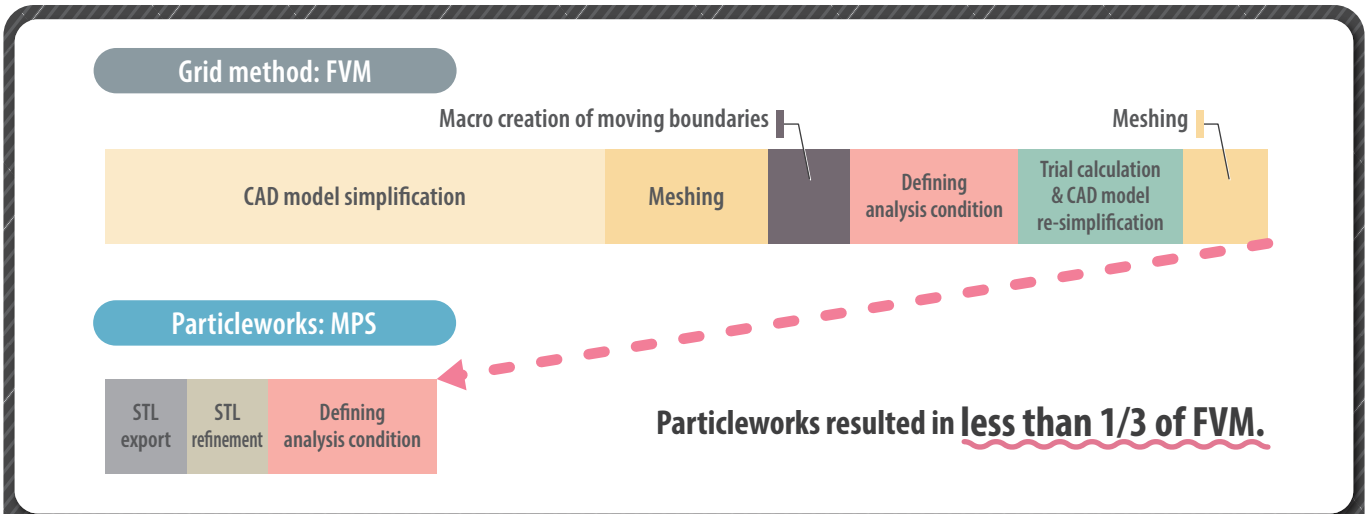

Fig. 2 Comparing the total time for pre-processing between FVM and Particleworks

hours, and Particleworks took 8.7 hours. Therefore, Particleworks has the same result as FVM and the calculation time is about 1/5. From these results, it was found that Particleworks was more advantageous in terms of calculation speed, so we chose Particleworks for evaluating oil jet cooling performance.

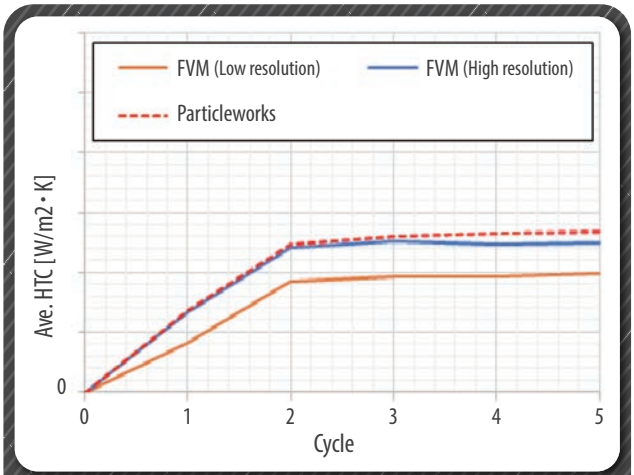

Fig. 3 Simulation result comparison between FVM and Particleworks (HTC: Heat transfer coefficient)

How specifically did you evaluate the cooling performance?

To begin with, by using Particleworks 6.1.2, we changed the engine rotation speed and oil flow rate, and compared the trends of the heat transfer coefficient. As a result, the faster the rotation speed got and the larger the flow rate got, the heat transfer coefficient became higher. In addition, it was found that the slope of the increase in the heat transfer coefficient became slower as the rotation speed increased. Next, the relativity between the oil filling rate in the cooling channel and the heat transfer coefficient was compared. (Fig. 4) As the rotation speed increased, the saturation filling rate decreased, but the heat transfer coefficient tended to increase.

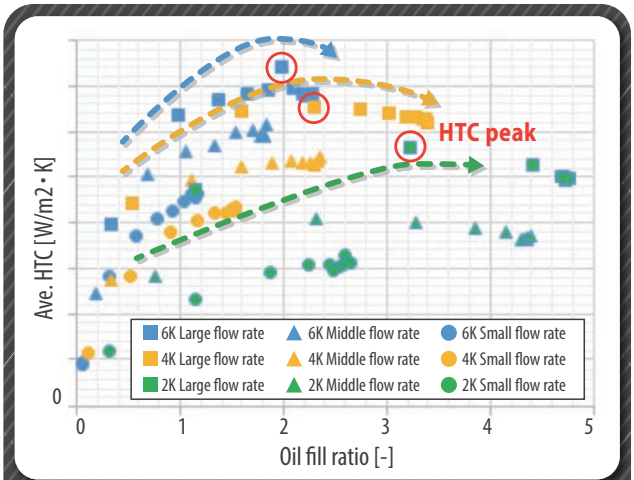

Fig. 4 Relativity of oil filling rate and HTC in the cooling channel (Plot color differs according to the number of rotation and plot shape differs according to the flow rate)

From this result, it was found that the stirring effect due to the faster engine speed contributed more to the heat transfer coefficient than the filling rate. Paying attention to the peak of the heat transfer coefficient of each rotation (red circle), it is within the filling rate from 20% to 35%, and the peak filling rate differs depending on the number of rotations and the flow rate. It was also found that if the filling rate was too high, the stirring effect was reduced, and there was an optimum value for the filling rate in the cooling channel.

Then, the optimization of the cooling channel shape was performed by coupling Particleworks with an optimization tool. In the optimization calculation, the shape of the cooling channel and the shape of the mapping were created by CAD, based on the input variables derived by the optimization tool. Then, the simulation was performed by Particleworks based on the created shape data, and the optimum shape was obtained by automatically repeating the flow of output the results to optimization software.

The purpose was to optimize the weight of the piston and maximize the heat dissipation capacity (heat transfer coefficient x heat transfer area). The input variables were the five dimensions that form the cooling channel hole (Fig. 5), and the number of combinations was 45,375. The optimization algorithms used this simulation were simulated annealing and genetic algorithms, and the total number of calculations was 325 and the calculation time was 74.5 hours.

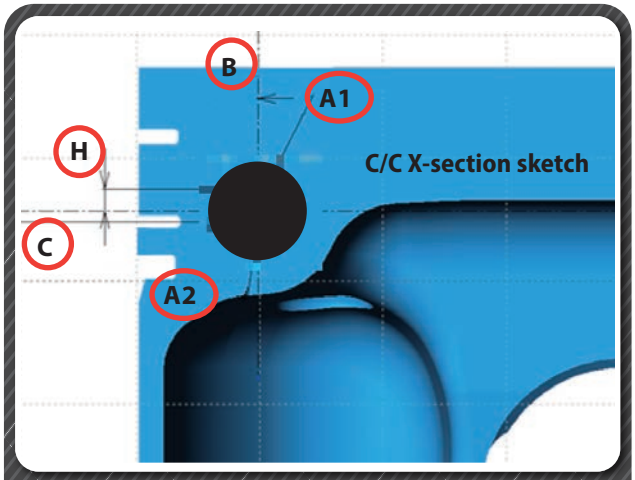

Fig.5 Input variables for optimization

As shown in Fig. 6, the optimization result indicated that the average heat transfer coefficient was better to the right for maximization, and the weight of the piston was better for minimization to the bottom. The initial design was located at the center of the graph, and there were some designs with higher heat transfer coefficients if making a little compromise in weight. In the actual shape, the heat transfer coefficient tended to be high with designs of horizontally long shape.

We also evaluated what was better than the initial design when

defining the design with the highest heat transfer coefficient was the optimal solution.

The difference in heat transfer coefficient was prominent when the oil reversed at the timing of top dead center and bottom dead center while the piston moved up and down, and the optimal solution was a design with a large stirring effect.

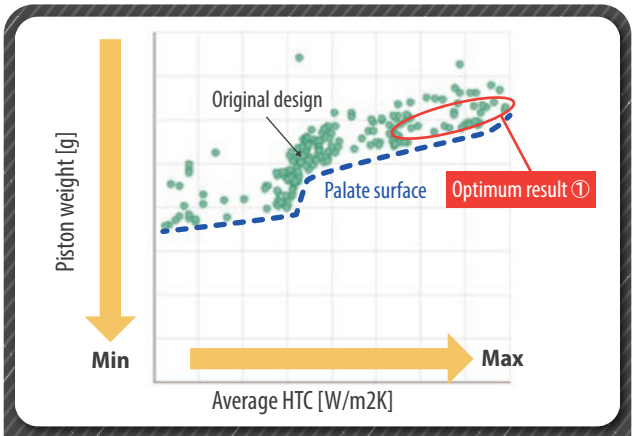

Fig.6 Optimization result

What is your impression of using Particleworks?

By using Particleworks, we were able to evaluate the cooling performance of the piston effectively, which we hadn't been able to simulate well, and we could determine guidelines for optimal design. Above all, the time and effort required for simulation could be greatly reduced, and it was important to obtain satisfactory results. We would also like to thank Prometech Software for their support during this research process. I'm very happy with the technical support now, as they always respond quickly and kindly. With respect to the simulation capabilities, it is sometimes necessary to choose the right tool in the right situation between Particleworks and other grid method software tools depending on the simulation fields. Particleworks can be said to be practical enough with the current function alone. I would be grateful if you could make further improvements so that the range of application can be expanded in the future.

Thank you so much for sharing your valuable opinions. Prometech would like to continuously offer our support so that we can keep contributing to your development of even better products.

[Reference]
Prometech Simulation Conference 2019 Presentation materials

The information on this article is of December 2019 at the time of coverage. Please note that product features and configurations may have changed since the time of the interview. Please contact Prometech Software (kaidai@prometech.co.jp) for the latest information.

Customer Information

Hitachi Automotive Systems, Ltd.

HITACHI Inspire the Next

Establishment : July 1, 2009 (Established by the split-off of Automotive Systems from Hitachi, Ltd.)
Businesses : Development, manufacture, sales and services of automotive components, transportation related components, industrial machines and systems, etc
Website : http://www.hitachi-automotive.co.jp/en/

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