Optimized Design using High Quality Assurance CAE
- Example of the Automotive Transaxle Oil Seal Leakage -

TAKAHIRO ITO¹, MANABU YAMAJI², KAKURO AMASAKA³
Graduate School of Science and Engineering¹
The Advanced Research Center for Human Sciences²
Department of Industrial and Systems Engineering³
Aoyama Gakuin University¹, ³
Waseda University²
5-10-1 Fuchinobe, Chuo-ku, Sagamihara-shi, Kanagawa, 252-5258¹, ³
2-579-15 Mikajima, Tokorozawa-shi, Saitama-ken, 359-1192²
JAPAN
c5609012@aoyama.jp¹, manabu.yamaji@gmail.com², kakuro_amasaka@ise.aoyama.ac.jp³

Abstract: Technical problems where the structure of the problem is unknown are a cause for concern in the automotive manufacturing industry. One such problem is an automotive transaxle oil seal leakage problem, which the authors solved using a “problem identification – visualization experiments – logical reasoning – CAE analysis – design” process. The authors proposed optimized design using High Quality Assurance CAE as a series of processes to identify design factors and facilitate improvements in design quality, and have yielded significant results by applying the method to the oil leakage problem.

Key-Words: optimized design using High Quality Assurance CAE, automotive development and design, design quality, digital engineering, transaxle, oil seal leakage

1 Introduction

Recent Japanese enterprises have been promoting global production to realize uniform quality worldwide and production at optimal locations for severe competition. The mission of the automotive manufacturers in this rapidly changing management technology environment, is to be prepared for the “worldwide quality competition”, so as not to be pushed out of the market and to establish a new management technology model which enables them to offer highly reliable products of the latest design that are capable of enhancing the value to the customer.

In the area of management technology for the development and production processes that is being considered here, excessive repetition of “prototyping, testing, and evaluation” has been carried out for the purpose of preventing the “scale-up effect” in the bridging stage between testing and mass production. This has resulted in an increase in the development period and cost. Therefore, it is now necessary to reform the conventional development and production method. More specifically, it is increasingly vital to realize the “simultaneous achievement of QCD” (Quality, Cost and Delivery) that satisfies the requirements of developing and producing high quality products, while also reducing the cost and development period through incorporation of the latest simulation technology “CAE” (Computer Aided Engineering) and statistical science called SQC (Statistical Quality Control).

In the vehicle development process employed in the past, after completing the designing process, problem detection and improvement were repeated mainly through the process of prototyping, testing, and evaluation. In some current automotive development, a prototype of a vehicle body is not manufactured in the early stage of development due to the utilization of CAE and SE (simultaneous engineering) activities, and therefore the development period has been substantially shortened (first from four years to two years, and then to one year at present).

Given this background, therefore, the conventional development process of repeated evaluation using prototypes is no longer capable of handling this task. Collaboration between CAE and SE activities, which are now faster and more precise, will be indispensable for fully utilizing the accumulated knowledge database. As discussed so far, expectations are high for the realization of super short-term development,
which would be done through utilization of CAE. In other words, there will be a conversion from the so-called “development through real object confirmation and improvement” to “prediction evaluation oriented development”. [5]

2 The Necessity of Clarifying Technological Mechanisms
The hardware-software environment surrounding CAE has evolved. Though technological problems have been understood and general solutions have been derived and reflected in CAE analysis software, research findings that boost the credibility of CAE have still not been incorporated fully enough into the development design process. Therefore, because predicted CAE results are not reproduced experimentally and CAE experiments must be redone, reducing time to market and development cost currently remains more the ideal than the reality.

To revolutionize the design of forecast evaluation systems that effectively use CAE using the design of actual confirmation improvement systems, products must be evaluated and analytical CAE results must be guaranteed. It is important to outline a failure mechanism that captures the true reason for problems.

For this research, the authors have attempted to clarify a problem involving an unknown mechanism causing drive train oil seal leakage. [1]

3 Optimized Design using High Quality Assurance CAE - Oil Seal Leakage Example
In order to solve problems with unclear failure mechanisms, it is important to take an empirical scientific approach and use visualization technology to clarify the dynamic behavior at the time of occurrence. The structure of the problem must then be clarified, and an accurate model of the cause-effect relationships must be produced. The authors solved the transaxle oil seal leakage problem using the following process: Problem identification – visualization experiments – logical reasoning – CAE analysis – design.

3.1 Problem Identification
The study on the oil leakage mechanism involved looking at different technological issues affecting the leakage through several investigative experiments, as indicated in Figure 1. Causal relationships for the oil leakage were investigated using a relationship drawing to arrange related factors and knowledge previously obtained. Because the oil leakage mechanism was uncertain, the route through which the problem occurred could not be clarified. Points requiring visualization of the dynamic behavior were specified, and experiments were conducted on visualization devices. [2, 4]

3.2 Visualization Experiments
In order to visualize the dynamic behavior of the oil seal lip, a device was developed to visualize the oil seal (shown in Figure 2). The oil seal was reproduced as shown in the figure, and when soaked in lubricant in a similar way to the transaxle, changed into a glass axis that rotated the drive shaft eccentrically via the spindle motor. Operation in an actual vehicle was then reproduced with the transaxle.

The effect of sealing the oil seal lip was visualized using optical fiber. The sliding surface observation experiment used three types of seals made of different materials and shapes, and identified the status of sliding surfaces and their relationship to stopping the leakage. The experiment helped in gaining clear knowledge about the unknown mechanism. [2, 3]

3.3 Logical Reasoning
The condition of the sliding surfaces, which was clarified through the visualization experiments, is used as a basic component to generate the basic sliding surfaces structural model shown in Figure 3. This model shows the minute roughness that existed on the sliding surfaces by statistically approximating a central projection.

Sealing of the entire sliding surface is achieved when the intake and outtake quantity of oil is \( Q_{AA} > Q_{BB} \), due to minute projection AA’ having a greater wedge action than minute projection BB’. In addition, this oil flow works to prevent wear by forming a circulation pattern on the sliding surfaces and separating the two sliding surfaces. [7, 9]
3.4 CAE Analysis

3.4.1 Technological Elements of the Oil Seal Simulator

The technological elements used for numerical analysis must be selected using findings obtained from the visualization experiments. In general, because CAE first establishes the problem to be solved and models the problem using formulas, a computer is used as an initial method to analyze the model. The algorithm (calculation routine) is then used as an analytical method. Validity, coverage, and the performance of this algorithm stem from the theory, and computer technology is what actually carries out the calculation function (calculation technique). It is important to appropriately select technological elements such as establishing the problem, modeling, the algorithm, theory, and computer technology to obtain high reliability when conducting CAE analysis. Organically relating these technological elements results in successful CAE analysis. [8]

Figure 4 shows the technological elements that the oil seal simulator should have. In handling the oil leakage phenomenon, the problem is grasping the pump volume and lip side pressure distribution that directs the behavior and the circulation pattern of the oil on the minute projection area of sliding surfaces. The fluid resistance model, the contact model, and the material component rule model are used to solve these problems. The finite element method and numeric fluid is analyzed as a convenient algorithm. The Reynolds equation, Soft Elasto-Hydrodynamic Lubrication, and Navier-Stokes equation are appropriate theoretical formulas. Accuracy is ensured, and the time integration method, space difference method, and procession method are used as computer technologies to calculate in a realistic timeframe. Each of the above elements is used to construct the oil seal simulator. [6]

3.4.2 Two-dimensional Analysis

Utilizing the above-mentioned technological elements, numerical analysis was conducted through two-dimensional analysis to determine the behavior of oil around the minute projections. The space where oil is trapped between the seal and the shaft around minute projection AA’ and minute projection BB’ was represented and analyzed. The results are shown in Figure 5. This two-dimensional analysis showed that shear stress was generated in the fluid oil due to shaft rotation, and backflow was occurring on the seal side via the oil path between the minute projections.
3.4.3 Three-dimensional Analysis

Based on the findings from the two-dimensional analysis, three-dimensional analysis was conducted for the whole sliding surface model, taking into account oil flow in the third dimension (depth). Numerical simulation was conducted for the film of oil on the sliding surface with regard to the three types of seal used in the visualization experiments. Analysis models (fig. 6) were created using the basic sliding surfaces structural model shown in Figure 3. Conditions such as shaft rotation speed were applied to the models, and the amount of oil flowing on the oil side and on the air side was calculated. By comparing the flow of oil to the seal side and to the air side, it was possible to represent similar results to those obtained from the visualization experiments.
4 Application Example

Figure 8 shows optimized design using High Quality Assurance CAE applied to an automotive transaxle oil seal leakage problem, and summarizes the main points of the “problem identification – visualization experiments – logical reasoning – CAE analysis – design” process.

It was possible to estimate the mechanism involved in the oil leakage problem by enabling the visualization of dynamic behavior to show the buildup of foreign matter around the rotating and sliding parts of the oil seal lip caused by the mechanical binding of particles from gear rotation wear.

Based on the findings obtained, the following design measures were formulated: (1) Strengthen the surface of the gear teeth (material quality, heat treatment) so that foreign matter is not generated even after several hundred thousand kilometers of driving, and (2) Scientifically ensure appropriate lubrication of the surface (unevenness of the sliding surface) of the oil seal lip that rotates in contact with the drive shaft. This has enabled optimal design improvements (shape and material design), reducing oil seal leakage problems (market claims) to less than 1/8, as shown in Figure 7. [2, 3, 4]

5 Conclusion

Optimized design using High Quality Assurance CAE was proposed as a series of processes to identify design factors and facilitate improvements in design quality. The method yielded significant results when applied to an automotive transaxle oil seal leakage problem where the structure of the technical problem was unknown.
References:


