Core model process for improving drivability development efficiency

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Summary

In recent years, it has been necessary to shorten the development period for powertrain units. Toward that end, JATCO has been advancing reform of the development process by applying model-based systems engineering. In development activities to achieve drivability targets, we have started to shorten the development period by reducing the amount of rework. However, in order to maximize the benefits of model-based systems engineering, designs must be executed using highly accurate models at the initial design stage of the system and sub-systems. A new model development process was implemented in this project that has led to improvement of drivability development efficiency. This article describes the new process and presents examples of its benefits.

1. Introduction

Designers' familiarity with model-based systems engineering (MBSE) has improved in recent years, increasing the use of models. As a result, repetitive cycles of design, build and test have been reduced.

The range of model use extends from the design phase of the system and sub-system levels on the left side of the V-shaped development process to the validation phase on the right side involving parallel use of actual hardware, including a hardware in the loop system (HILS). Models have been utilized over a wide range of the V-shaped development process (Fig. 1).

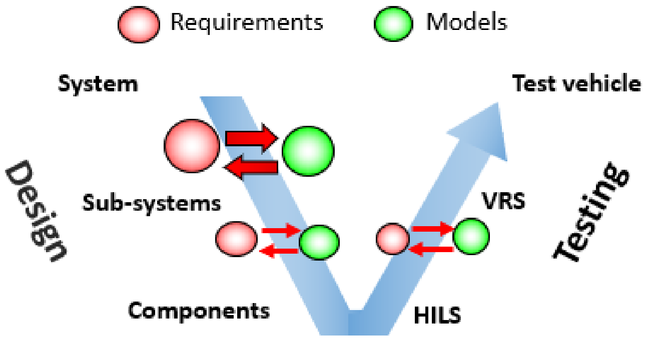

Fig. 1 Model application to V-shaped development process

In order to maximize the benefits of shortening the development period, models must by constructed that ensure an accurate response to the requirements and match the development plan.

This article describes activities undertaken to create a new model development process for improving model construction efficiency and model accuracy.

2. Model issues in drivability development

Drivability is an index for achieving performance that does not cause drivers any feeling of discomfort when a vehicle accelerates or decelerates or changes between forward and reverse motion. It is a critical design criterion that determines the product value of a transmission.

There are many driving conditions for evaluating drivability involving combinations of factors such as a vehicle's driving environment, vehicle speed condition and the driver's operations. Accordingly, the models used in design activities must enable highly accurate, wide-ranging studies in order to design drivability using models (Fig. 2).

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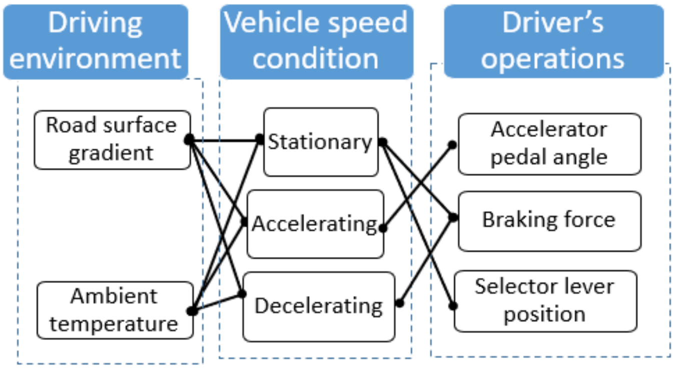


Fig. 2 Combinations of driving conditions

However, the models constructed and used in design activities heretofore have not necessarily provided sufficient design accuracy, giving rise to design specification changes in the later stages of the development process. Issues involved in model construction are described below.

2.1 Increase in model construction man-hours

In constructing models to date, the aim has been to achieve the same level of accuracy as the test results measured under each driving condition. Because each condition has been modeled separately, only a narrow range of studies can be conducted with a single model. The number of models used has also continued to increase as the driving conditions for which performance predictions are desired have been expanded (Table 1).

Table 1 Modelling according to driving conditions

		Vehicle speed condition		
		Stationary	Accelerating	Decelerating
Accelerator pedal angle	Large	・	Model A	・
	Small	・	Model B	・
Braking force	Strong	Model C	・	Model D
	Weak	・	・	Model E
Selector lever position	D	Model F	・	・
	R	Model G	・	・

In cases where part specifications are changed or new functions are added in the process of conducting design studies using models, the model composition and parameters must be modified. Because modifications are made for each model, the man-hours required for updating the models have expanded enormously as the number of models has increased.

Additionally, information exchanged between the model developers and designers for updating the models has remained only at the level of recognition between the individuals involved and has not been shared throughout the company.

Consequently, every time the scope of model construction or the designers change, parameter revision histories and details must be researched by asking around among the people involved. It has taken a lot of time to obtain the information because the sources of the information must be confirmed, mutual recognition of the assumptions underlying the parameters is needed, and there is waiting time before getting the answers.

As a result, there have not been enough man-hours for model construction, making it impossible to sufficiently secure the models needed in design studies.

2.2 Decline in design accuracy owing to the use of separate models

In order to guarantee model accuracy, the information of the model parameters must be properly defined. As development work progresses, parameters change owing to the dimensional tolerances of parts, their state of deterioration, and differences that occur between the required design values and the test data.

In this regard as well, there are times when confirmation is overlooked because the sharing of information depends on individuals, and models may be created that contain parameters unsuitable for design studies, leading to a decline in design accuracy.

Moreover, models have so far been created by individual model developers and designers, and the latter have selected and used models based on their own personal judgment. They have not always recognized whether models suitable for design studies are available or not. This has led to design studies being conducted using models that lack sufficient accuracy.

To resolve the foregoing issues, it was decided to implement a process for efficiently constructing high-accuracy models.

3. Concept of core model process

Let us consider the form desired of a model. If the parameters and characteristics of a model reflect the range of diving conditions for reproducing the behavior of the actual objects, predictive studies can be conducted without dividing the model. However, so far many models have been constructed separately for each driving condition, so the desired model form has not been obtained.

Our aim is to cut the man-hours needed for updating models through a reduction of their number as much as possible by periodically integrating them to create a model of the entire system, while expanding the scope of the studies that can be conducted.

Expanding the scope of a model increases the number of part elements, leading to an expansion of driving conditions that could not be examined previously. Assuming that this would improve design accuracy for overall development of drivability, we adopted this approach as the direction that should be taken for model construction (Fig. 3).

The model is positioned as a core model and is used in the overall development of drivability.

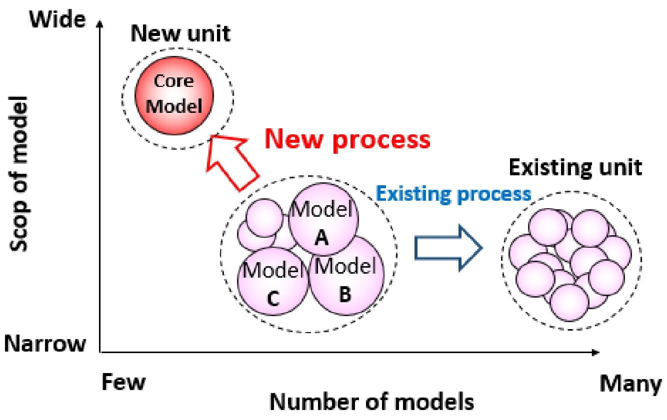


Fig. 3 Direction for model construction

As the development work progresses, the level of design detail increases, giving rise to a revision of the study conditions and parameter changes. Accordingly, after the design study, the model developers must reflect the specification changes and newly required conditions in the model immediately so as to increase its accuracy. It is essential for the designers to reduce any redoing of development work by conducting design studies using the updated model.

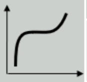
A core model process was constructed as a new method for efficiently carrying out the cycle of using and updating the core model. The specific activities for accomplishing this new process will be described in the following section.

4. Measures for accomplishing the core model process

4.1 Improving accuracy by standardizing the model

The concept of the core model is that it should achieve both high accuracy and broad flexibility. Ideally, the core model should reproduce response changes to inputs/outputs in line with the design study that are equal to those of the actual objects. The element levels needed to accomplish that were defined as shown in Table 2. Based on these definitions, the individual models to be integrated were selected, and new characteristic values were obtained for any places that were deficient.

Table 2 Definitions of model elements

Model scope	LV.1 Linear elements (Map)	LV.2 Nonlinear elements (fundam. eqs.)	LV.3 Nonlinear elements (fundam. eqs. + characteristics)
Hydraulic pressure elements		Pressure Transfer function $P(s)=G(s)\cdot Q(s)$	·Pressure loss in passages ·Oil leakage amount ·Lack of balance in oil supply volumes
Launch elements		Hydraulic coupling Torque transmission eq. $T=\tau\cdot Ne^2$	·Damping coef. ·Volume transient change ·Pressure response/balance
Forward/reverse changeover elements		Clutches Torque transmission eq. $T=\mu\cdot R\cdot F$	·Vehicle sensitivity ·Pressure response/balance

A quick pressure response matching the driver's intention can improve a vehicle's shift performance and drivability when changing between forward and reverse motion.

As such, the hydraulic pressure elements contribute significantly to the overall drivability of a transmission, so priority was put on improving their model. The details are explained below.

The hydraulic pressure system consists of multiple valves and complexly shaped oil passages. Nonlinear elements that must be considered in the model include pressure losses caused by oil passage bends and constrictions, oil leakage from the passages, and the lack of balance among the oil volumes supplied to the various parts of the system.

Previously, no definite criteria were determined for optimally modeling these nonlinear elements.

Using hydraulic pressure designs executed heretofore and empirical rules based on experimentation, pressure losses were modeled in this project only as a structure exceeding the criterion. This made it possible to construct a model without imposing any unnecessary computational load while still maintaining high accuracy (Fig. 4).

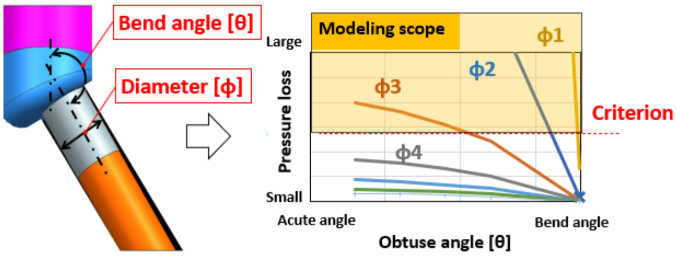


Fig. 4 Standardization of hydraulic pressure model

For oil leaks between parts and for passages with complex branching, 3D computational fluid dynamics simulations were conducted to accurately derive characteristic values in order to make accurate predictions (Fig. 5).

The characteristic values obtained for the nonlinear elements were reflected in a 1D model of the entire system, which led to improved accuracy.

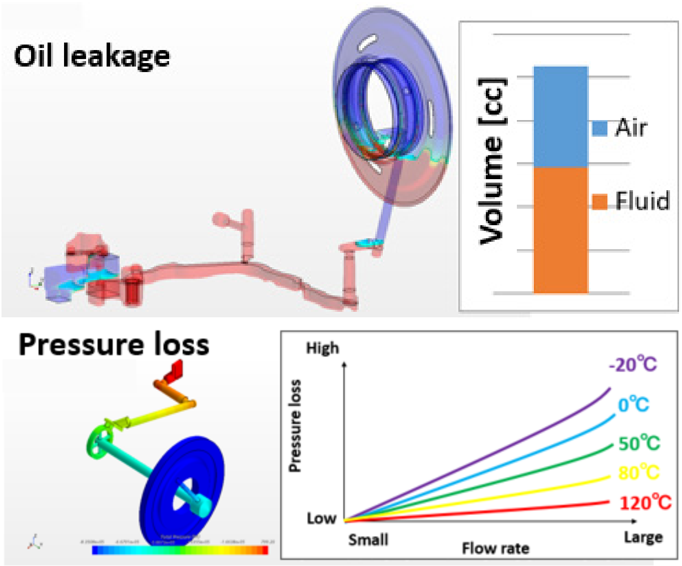


Fig. 5 Characteristics obtained by 3D CFD simulation

4.2 Reduction of model construction man-hours using the core model process

In order to reduce the time spent gathering the information described in section 2.1, model parameter information must be easy to find. Therefore, a single standard format was created that lists all the parameters defined in the core model.

The model developers describe in detail the constituent elements of the model and parameter information in this format. This makes it easy for the designers to recognize the information needed for the model.

When parameter changes are made, the designers take the initiative to share that information, thereby reducing the number of mutual inquiries and responses and enabling information to be shared efficiently.

To make sure that these measures are carried out without any omissions, the roles of the development engineers involved with the model and the details of the documents to be exchanged have been clearly defined (Fig. 6).

A process for continually improving design accuracy while continuing to evolve the core model has been adopted for development projects.

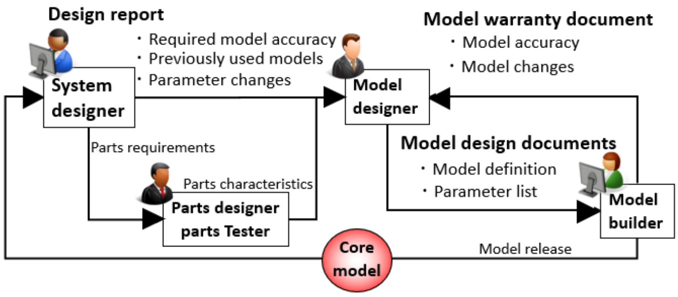


Fig. 6 Core model process

5. Benefits of applying the core model development process

Transmission functions for ensuring drivability include forward/reverse changeover by the clutches, pulley speed changes necessary for acceleration/deceleration, and torque converter lockup, among others. The core model was applied to execute a model design for each function.

Previously, design changes occurred in the latter stages of development especially regarding transmission performance for changing between forward and reverse motion. It was decided to use the model intensively for designing this performance, examples of which are described below.

Transmission performance for forward/reverse changeover is evaluated using two indices. One is the lag time from the driver's operation of the selector lever to the generation of driving force at the tires; the other is torque fluctuation that occurs at the time of clutch engagement. It is necessary to reduce both indices simultaneously, though they have a trade-off relationship.

In order to execute a feasible design for accomplishing that reduction, it is necessary to predict piston travel, which functions to engage and release the clutches, and also torque fluctuation at the time of clutch engagement.

Elements that contribute greatly to lag include the oil passage orifice that functions to suppress the inflow volume of oil for moving the piston (Fig. 7).

A part element that contributes greatly to torque fluctuation at the time of clutch engagement is the stiffness of the dish-shaped clutch spring (i.e., dish) that has a counteracting force proportional to the pressing force of the piston.

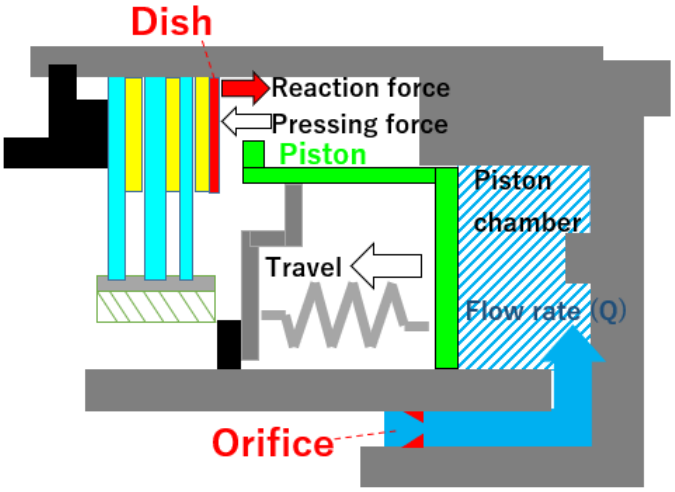


Fig. 7 Configuration of forward/reverse changeover system

Previously, it was not possible to accurately predict the effects on performance of the oil volume flowing into the piston chamber and specification differences of clutch engagement parts. Consequently, there was a repeated trial and error process of design and testing.

Use of the core model in this project enabled accurate prediction of lag and torque fluctuation due to changes in the orifice diameter and dish stiffness. As a result, the core model made it possible to determine optimal specifications for satisfying transmission performance for changing between forward and reverse motion (Fig. 8).

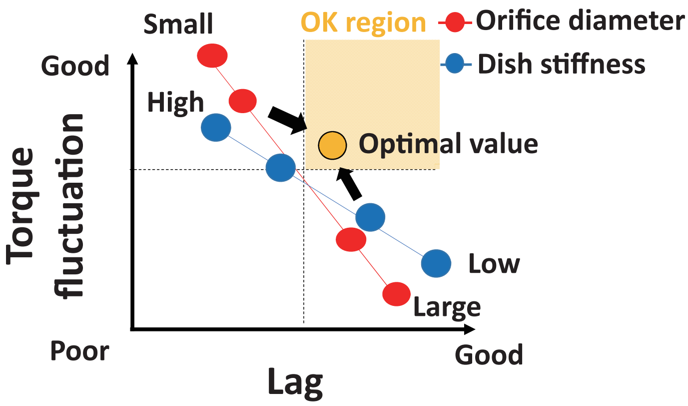


Fig. 8 Optimal design for selector lever performance

The results of verification tests conducted subsequently were equal to those obtained with the core model, thus confirming that the required performance was satisfied. This demonstrated the effectiveness of the core model process on improving design accuracy.

In addition, the core model process reduced the man-hours for collecting model information and the number of models created. As a result, it had the effect of reducing model construction man-hours by 75% compared with the existing process.

As described here, the implementation of the core model process has contributed greatly to improving development efficiency by reducing the repetition of design and testing in the drivability development process.

6. Conclusion

Design studies are conducted every day in the development process. Previously, there was an issue that models were not being developed simultaneously in a short period of time and were not available on a timely basis.

The core model process implemented in this project is an effective method enabling the many employees involved in development work to efficiently construct and use models.

It has reduced development man-hours especially for the hydraulic pressure system that was previously a major factor causing insufficient design study accuracy. That was achieved by enabling definition of the model criteria and model construction, thereby improving the accuracy of drivability studies and suppressing the occurrence of rework.

The aim going forward is to expand the application of this process to all areas of performance so as to increase overall development work efficiency.

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