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传动系统管理功能的发展

Function Development in Driveline Management

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[摘要]为了推进产品包括功能的创新,汽车在与过程相关的研究领域内取得了快速发展。这是因为最终用户是否购买取决于新车的价值。问题的实质是汽车必须工作可靠、功能齐全。

对于以软件为主的产品,如几乎所有的电子元件或组件,其质量不仅必须通过单独试验,而且还需用可再现的过程加以预确认和预保证。因此,在产品完善前,传动系统产品功能的开发必须包涵各个方面。新开发的基于控制模块的锁止离合器可作为一个实例。

[**Abstract**] In addition to pure product innovation which includes functions, automobile development increasingly involves process-related research topics. Why is this so? The end customers' buying decisions hinge on the value added to their new cars. And it is a matter of course to them that their cars work reliably and their functions are fully reproducible.

For software-dominated products, i.e. for almost all electronics components or sub-assemblies it is particularly true that their quality must not only be tested separately but also pre-determined and guaranteed by means of reproducible processes. Therefore, development of functions in production drivelines must include all aspects before product maturity can be reached. The new development of a model-based controlled lock-up-clutch is an example of this approach.

关键词: 传动系统 锁止离合器 过程管理 软件

Keywords: Driveline Lock-up-clutch Process management Software

中图分类号: U463.2 **文献标识码**: B

1 前言

不管在开发的初始阶段还是在对软件需求急剧增长的时期,软件的质量和消费者的满意程度都是相同的,即在不增加成本的基础上不断改善。在最近几年,ZF公司已经在集中解决这种矛盾。改善效率的关键在于现代化的开发方法,包括巨大的仿真能力和标准化的设计及适用于汽车的可再现的试验。

在各阶段所采用的各种的开发方法和工具都与软件的发展相关。试验中一个主要的成本源是再现试验环境、试验向量和试验评价方法。而有效的降低成本的措施是在各个开发阶段中重复使用模型和试验向量和自动进行程序运行和评价试验。

这里所选择的程序及由此获得的好处可通过变速器控制模块中锁止离合器控制软件的开发来体现(图1)。特别需强调的是"基于发展的模型",它是一种认可方法,被称为是对系统详细的理解,并在功能

1 Introduction

Despite shorter development lead times and increasingly stringent requirements on software, the quality of this software and levels of customer satisfaction need to be sustained, or ideally improved upon, without any increase in cost. Over the last few years, ZF has been heavily committed to resolution of this conflict. Key contributions to the efficiency improvement required here are delivered by modern development methods with extensive simulation capabilities and standardized design coupled with reproducible tests which are suitable for automation.

Various different development methods and tools are employed during the many stages involved in the development of modern software. One major source of cost in the testing process is incurred by

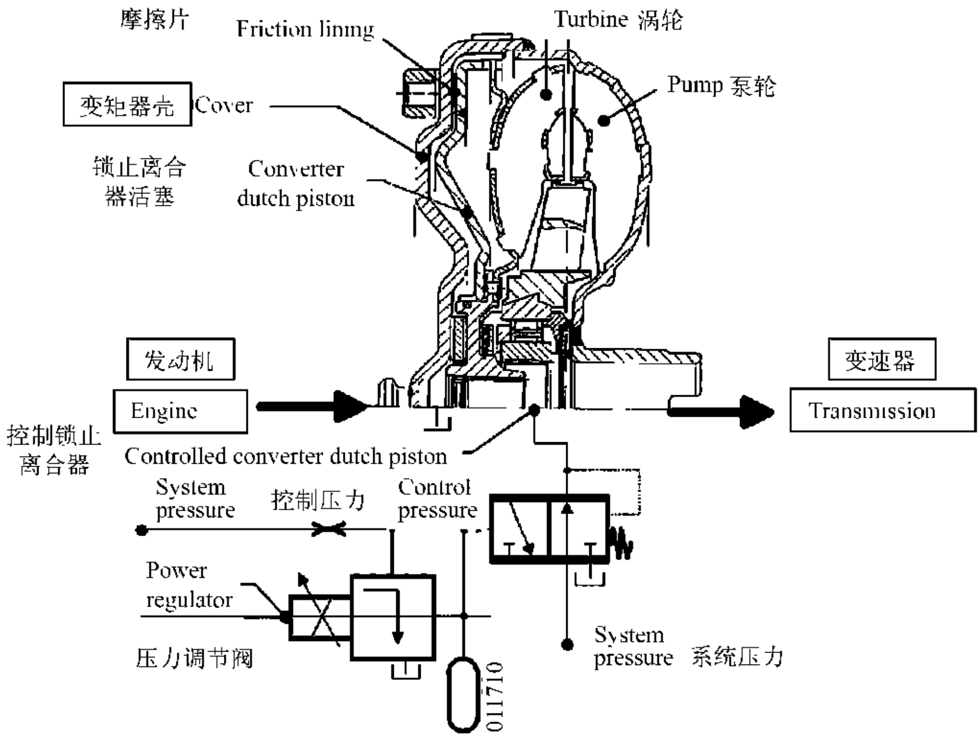

图 1 液力变矩器的机械和液压元件示意图

Fig. 1 Mechanical and hydraulic diagram of a torque converter

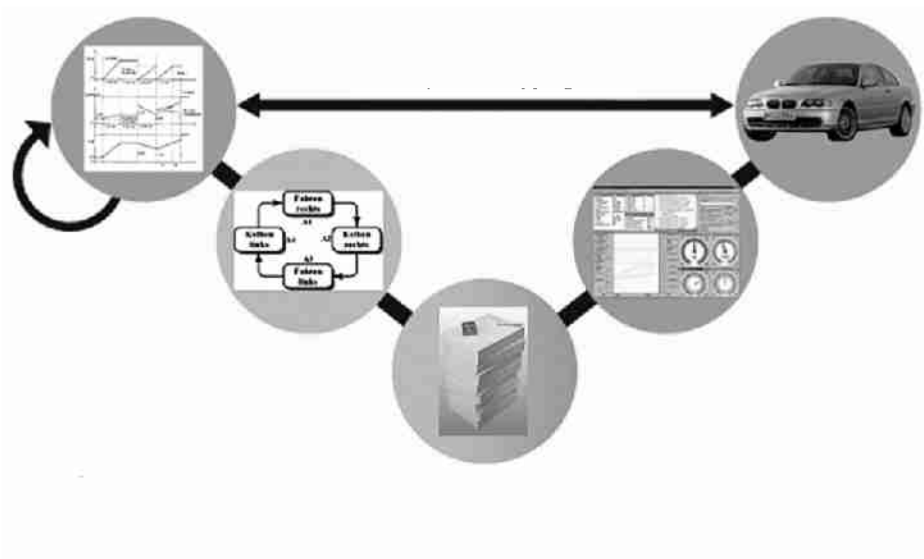

图 2 基于V 模式的软件开发过程

Fig. 2 Software development process based on the V model

上具有实质性的好处。

2 开发过程——概述

在ZF 公司植入式软件的发展中倾向于采用经典的V 模块(图2)。在项目启动阶段的系统规范时,变速器中的机械、液压、电气和电子元件及它们之间的关系都给出了定义。据此才能获得有关电控单元及其软件的需求。在功能规范阶段,勾划并详细定义由软件实现的功能。

implementation of test environments and test vectors, and also by the test evaluation process. A substantial reduction in expenditure is achieved by reusing models and test vectors created during the various development phases, and by automating the process of running and evaluating tests.

The procedure selected here and the benefits derived from it can be illustrated by the example of software developed for a controlled lock-up clutch

系统规范阶段由一系列原始模型方法所支持。在虚拟样机阶段, 通过系统仿真检查模型所定义的功能。如果必须在实车环境下加以检验, 试验可在快速成形阶段完成。这些方法非常适合在设计早期阶段发现规范中的缺陷。当使用虚拟样机时, 仿真质量决定了能被应用于实车环境的范围。

这时进入到规划阶段, 在该阶段不进行大量细节检验, 因为还未涉及目标表述。

在软件批量生产时, 规划有两个试验阶段。第一阶段是验证功能规范, 包括在 PC 机上功能测试仿真。然后是系统认可检验, 包括整个系统的各项试验。某些元件的功能试验和系统认可检验工作可在实验室通过仿真完成。

3 可控锁止离合器——基于发展的模型

ZF 对“基于发展的模型”阶段的理解是该过程是开发基于系统物理相互作用特性模型的开环和闭环控制功能。(图 3)

3.1 分析阶段

在分析阶段, 系统模型已建立。在本例中, 离合器传递的转矩是摩擦系数和正压力的乘积。同时应对系统的物理意义、公差和环境特性作出估计。在分析阶段的最后, 已有一个详细的与目标相一致的详细描述系统各种工况的模型。

在草图设计和仿真阶段, 详细的系统模型被应用在仿真环境中。使用来源于闭环控制技术的方法, 所开发的反馈控制器能以适当的方式对系统产生影响。在本例中, 离合器动作所需的目标包括一

(Figure 1) in transmission control units. In particular, emphasis is placed on the key phrase of “model-based development” which refers to a methodological approach which calls for a detailed understanding of the system and which delivers substantial benefits in terms of functionality.

2 Development Process-Summary

The development process for embedded software in ZF products tends to favor the classic V-model (Figure 2). In the system specification at the start of a project, the mechanical, hydraulic, electrical, and electronic components in the transmission and their inter-relationships are all defined. From this, it is possible to derive the requirements relating to electronic control units and their software. During the process stage known as the function specification stage, the functions implemented in the software are drafted and defined in detail.

The system specification stage is supported by a range of modern prototyping methods. During the virtual prototype stage, a model of the specified function is inspected by means of a simulated model of the system. If the intention is to apply this inspection in a real vehicle environment, this test can then be implemented by means of a rapid prototyping stage. These methods are ideally suited to detecting specification errors at the earliest possible

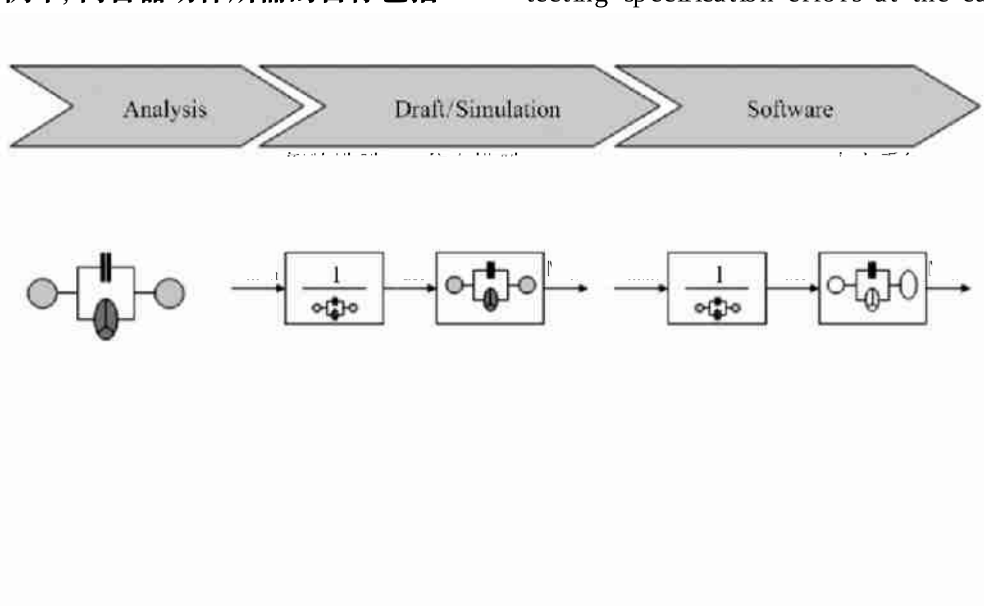

图 3　基于发展的模型　Fig. 3　Model-based development

个在名义转矩下操纵离合器的规范。

如将离合器名义转矩除以摩擦系数，便获得操纵力。如果在实际操纵和模型中都能获得理想的摩擦系数，仿真将给出一批理想的工作特性。通过改变模型的物理参数，便能对草图的鲁棒性进行研究。

当将草图转化为具有实时处理能力的软件时，便能对实际系统的功能作出检验和评价。在实际系统中出现的任何偏差和误差表明离合器名义转矩和实际转矩之间并未造成过大的误差。

3.2 系统模型

如上所述，系统模型在开发闭环或开环控制系统算法中扮演了一个主要角色。在这些模型中，物理意义是由设计数据和试验所确定的。根据设计数据对参数进行外推的实例见机械模型(图4)。这里，整个传动系被描述成一个3阶系统，其惯量包括发动机、变速器和车辆。根据额定转矩的不同，可给出包含上述3惯量参数的运动方程。为阐明低档位时的往复振动，在变速器和车辆惯量中插入了弹性阻尼系统模型。

这里给出了如何通过试验确定液压操纵系统的时间常量(图5)。在设计闭环控制系统时。无需在微观水平上使用有限元法(FEM)检验液压效能。这里的相关因素是可由试验台试验确定的操纵系统的动态特征。如图5所示，液压时间常数与温度和压力有关，并呈现出强烈的非线性。

time. When using a virtual prototype, the quality of the simulation determines the extent to which results can be applied to the real-vehicle surroundings.

The process step known as the programming stage will not be examined in greater detail here because this is not the subject of this presentation.

Two test stages are scheduled in during the creation of volume production software. The first of these is verification of the function specification, a process which involves a function test in a PC simulation. This is followed by a system approval inspection involving extensive testing of the complete system. Certain components of the function test and the system approval inspection can be performed by transferring them to the laboratory for simulation runs.

3 Model-based Development Based on the Example of a Controlled Lock-Up Clutch

ZF understands the key phrase "model-based development" to mean a process for developing open-loop and closed-loop control functions based on a model of the physical interaction characteristics of the system (Figure 3).

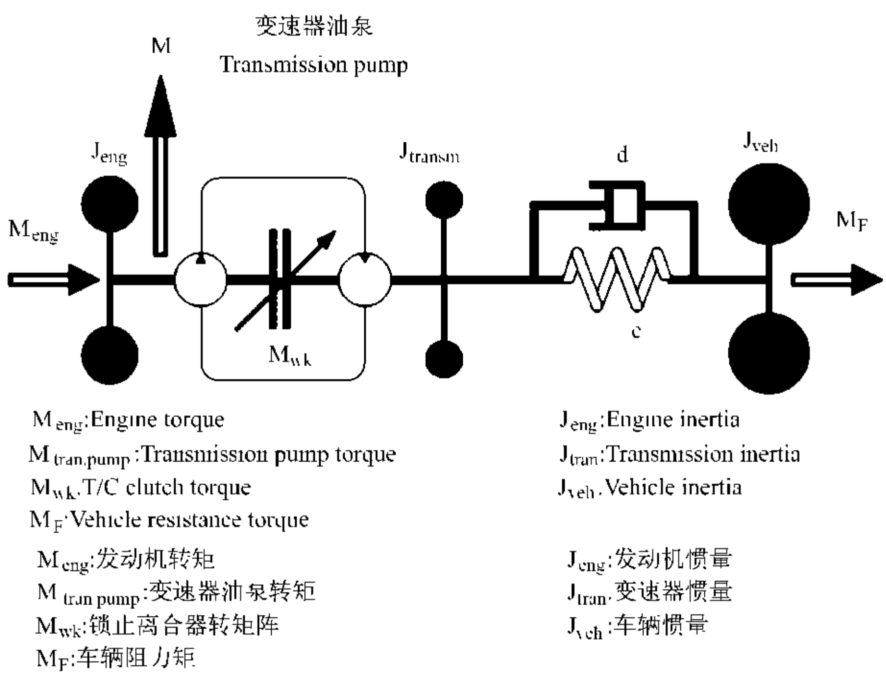

图4 机械模型

Fig. 4 Mechanical model

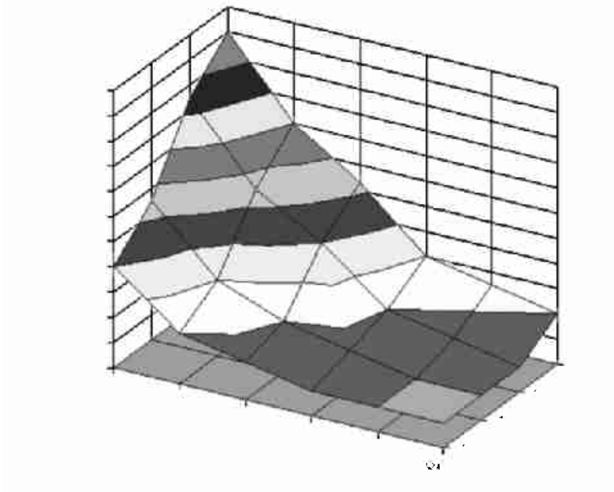

图 5 液压操纵系统的时间常数

Fig. 5 Time constant in a hydraulic actuation system

在这种模型开发中, 得到相当水平的细节是至关重要的。通过对数据和仿真的对比, 能确定模型是否足够准确地描述了系统。如果模型包含过高水平的细节, 将反过来影响仿真时间和仿真数据的稳定性。进一步而言, 如果这些细节在控制器草图设计阶段被集成在控制功能中, 将造成变速器控制单元极大的资源浪费。这不仅需要更精心的协同工作, 还使功能受到减弱。

ZF 通过用相对近似的术语描述发动机和变速器, 在模型水平上获得一个折中的结果。这些近似描述依然使我们在仿真阶段能够对整个传动系统的特性如负载倒拖作出定性描述。软件使得我们无需对发动机特性作出细节描述, 因为它们的影响在更大程度上是由于冲击负载的阻尼。由于变速器性能的描述需要更多的细节, 例如在锁止离合器的仿真中, 有可能在闭环过程的初始阶段进行调研 (图 6)。

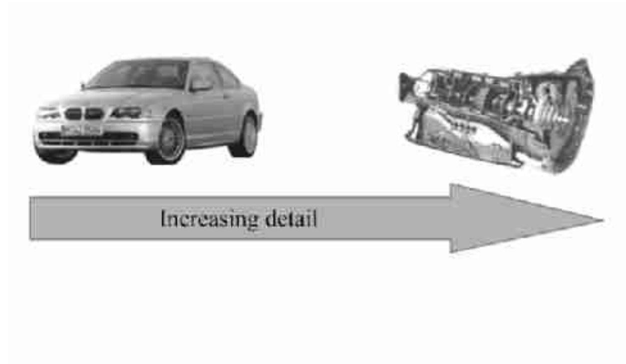

图 6 在模型阶段合适的细节水平

Fig. 6 Adapted level of detail provided in the modeling phase

3.3 控制器的草图设计

当系统模型被检验和评估后, 闭环控制方法可用来为闭环和开环控制功能设计合适的算法草图。

3.1 Analysis phase

In the analysis phase a model of the system is created. In this example, the torque transmitted by the clutch constitutes the product obtained by multiplying the friction coefficient against the activation pressure. All known physical effects and the influence of tolerances and environmental characteristics on the system need to be estimated. At the end of the analysis phase, you have a detailed model which describes the system in all the operating modes related to the task in hand.

In the draft design and simulation phase the detailed model of the system is implemented in a simulation environment. Using methods derived from closed-loop control techniques, a feedback controller is developed which influences the system in an appropriate manner. In this example, the desired goal for clutch activation involves clutch actuation at a specified level of nominal torque.

If you divide the nominal clutch torque by the friction coefficient, you obtain the actuation pressure. If an identical friction coefficient is obtained in both real activation and in the model, the simulation will then yield a set of ideal operating characteristics. Through variation of the physical parameters in the model, the robustness of the draft version can be investigated by applying fluctuating parameters.

When the draft version is turned into real-time-capable software the functionality of the real system can be examined and validated. Any deviations and tolerances which appear in the real system then demonstrate the extent to which nominal torque and actual torque on the clutch fail to create a perfect match.

3.2 System Models

As described beforehand, system models have a central role to play in the development of algorithms for open-loop and closed-loop control systems. Physical effects are depicted in these models which can be defined from design data and trials. One example of how to extrapolate parameters from design data is shown in the mechanical model (Figure 4). In this instance, the entire driveline is modeled as a third order system with inertia values

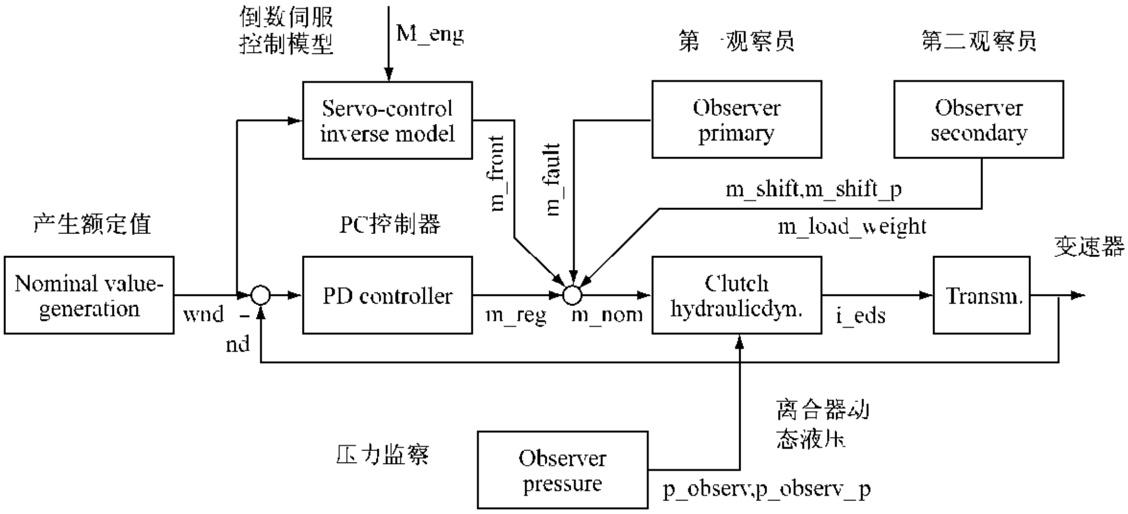

图 7　锁止离合器的闭环控制电路模型

Fig. 7　Model-based closed loop circuit for the lock-up clutch

图 7 是可控锁止离合器的电路框图单元。系统模型表现为"预先控制"单元。其机械模型的倒数模型被用来进行计算。

为补偿模型的偏差, 在离合器第一和第二轴处安排了观察员。因此, 至关重要的是确保在规划的前期阶段确定的整个系统主要误差。这是确保草图阶段的系统设计鲁棒性正确的唯一方法。

3.4　评价

当进入到批量生产阶段, 基于程序的模型交由从事相关工作的人员进行修改。在系统优化应用于车辆之前, 需获得所有的物理参数, 以及车辆制造商的数据(如轴的刚度和发动机惯量)。信息来自于试验装置的测量结果和设计参数。对车辆的一个基本要求是将模型与系统进行比较。由于计算误差, 协调员应确定哪些参数需作进一步的优化。这被称为对物理作用的了解和如何通过软件实现功能。当然该过程要求专业的协调和匹配技能。

基于近似的模型会影响开发过程, 基于产品的模型也不同于采用常规技术开发的模型。通过在初始阶段系统特性的使用, 可能会在多达 6 个方面提高动态特性。另一方面, 由于模型采纳了更多的系统性能, 控制单元会损失鲁棒性。

因此在鲁棒性和动态特性方面做出折中是必要的。如果设计了一个高水平的动态特性, 必须获得更佳的控制性能。由于额定速度特性只能被适用于舒适性或联接可靠两目标之一, 这将使得锁止离合器的工作必须是策略控制型的。

4　开发过程中的试验综合

在V 模型中, 动态试验之间的区别与采用的模

for engine, transmission, and vehicle. Based on the torque ratings applied, motion equations can be written for each of these three inertia values. To illustrate the reciprocal vibrations in the lower gears, the model features a spring damper system which is arranged between the transmission and vehicle inertia values.

The time constant for the hydraulic actuation system is shown here as an example of how to define parameters from tests (Figure 5). It is not necessary for the design of a closed-loop control system to examine the hydraulic effects at a microscopic level using the Finite Element Method (FEM). The relevant factor here is the overall dynamic profile of the actuating system which can be established on the test bench with measurements followed by identification of parameters. As you see in Figure 5, the hydraulic time constant is dependent on temperature and pressure in a strongly non-linear manner.

Achieving a commensurate level of detail is the decisive feature in the development of models of this kind. Through a comparison of measurement and simulation results, you can establish whether or not the model describes the system accurately enough. If the model contains too high a level of detail, this will adversely affect the simulation time and the digital stability of that simulation. Furthermore, if these details are incorporated in the control function during the controller's draft design

型、综合和功能试验的试验过程相一致。在模型试验中, 部分软件(模型)由试验向量给出激励。模型的输出参数和预期试验结果作比较。通常无需对车辆或变速器功能进行仿真, 这是因为试验的目标是检验技术结构程序和在模型中应用的编码。

在综合和功能试验期间, 将对软件的实际结构或者带各种诊断功能的整个软件包进行试验。为了使功能试验非常接近于实际车辆的工况, 需要对车辆和变速器进行动态仿真。以下将给出更多细节。

4 1 动态特性试验的自动控制过程

使试验更有效的第一步包括动态试验的自动进行和评价。所有这些过程都基于在仿真软件中使用闭环控制回路对动态模型的综合(图 8)。以下是一些理由:

- 在相同质量目标的前提下减少试验成本
- 与重复的手动操纵相比改善可靠性
- 确保试验的再现性
- 容易进行衰退试验
- 简化试验文件

ZF 公司从事的自动试验过程之一是“自动参考比较”(图 9)。这里试验的自动方法是为了获得两种软件状态的动态特性在功能上的一致性, 即通过改进设计来验证软件变化无任何不利因素, 或保证软件变化与应用平台相一致。

然而在检查绝对值时, 应用范围不应受限制。甚至可通过自动参考比较检查较方便地对功能改变进行试验。以前试验获得的试验向量无需更改,

stage, this will give rise to excessive levels of resource consumption in the transmission control unit. This not only requires more elaborate coordination work, it also makes the function less robust.

ZF has created a compromise at the modeling level by describing the engine and vehicle in relatively approximate terms. This approximate description still enables us to make qualitative statements at the simulation stage on the overall characteristics of the driveline, e.g. load reversals. The software also enables us to dispense with any detailed depiction of engine characteristics because this behavior is influenced to a large extent by the damping of load impacts. Owing to the fact that transmission properties are depicted in much greater detail, it can for example be possible to investigate the initial stages of the closed-loop process in the lock-up clutch quantitatively in this simulation (Figure 6).

3 3 Draft Design of the Controller

After a system model has been examined and validated, closed-loop control methods can be used to devise a suitable draft algorithm for open-loop and closed-loop control functions.

Figure 7 presents a block circuit diagram based on the example of the controlled lock-up clutch.

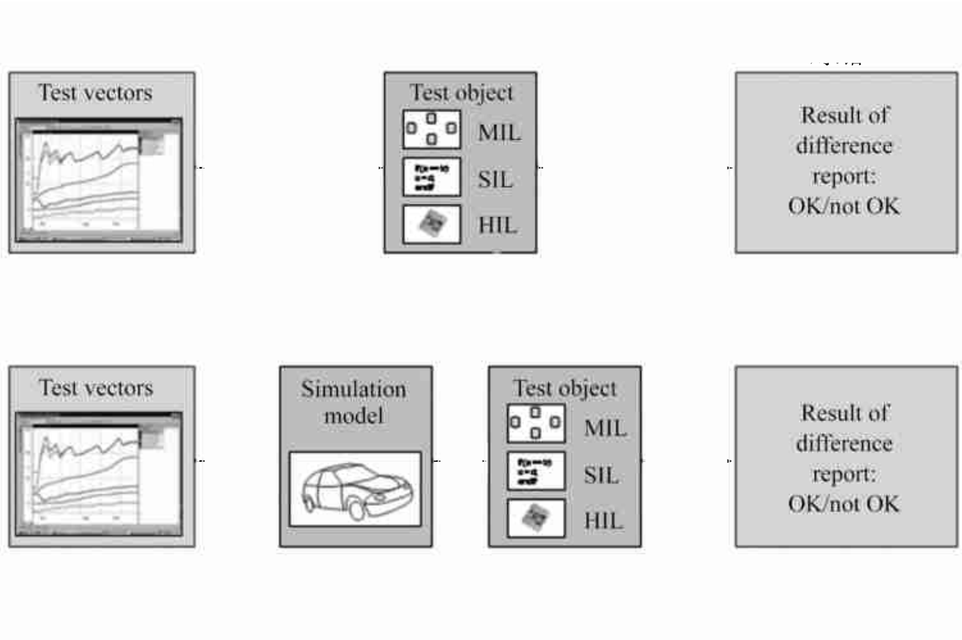

图 8 自动试验的闭环仿真

Fig 8 Closed-loop simulation for automated tests

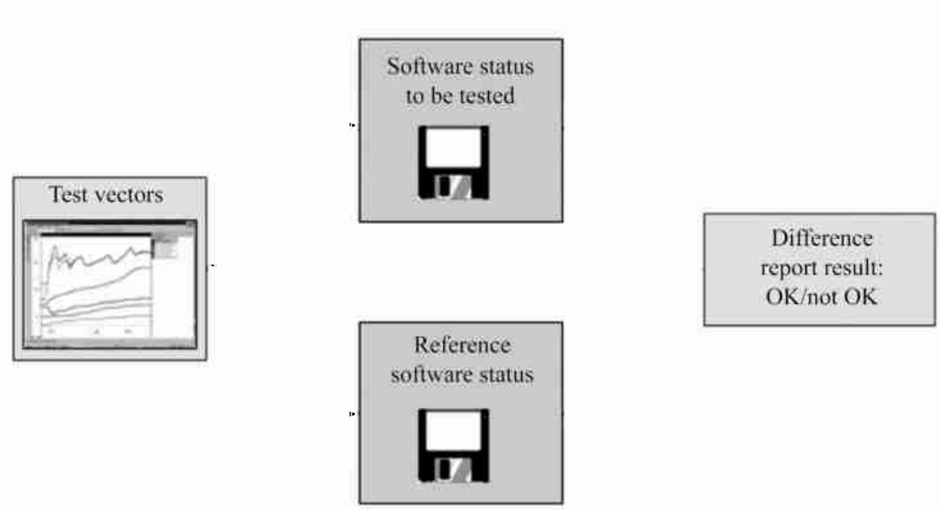

图 9　自动参考比较

Fig. 9　Automatic reference comparison

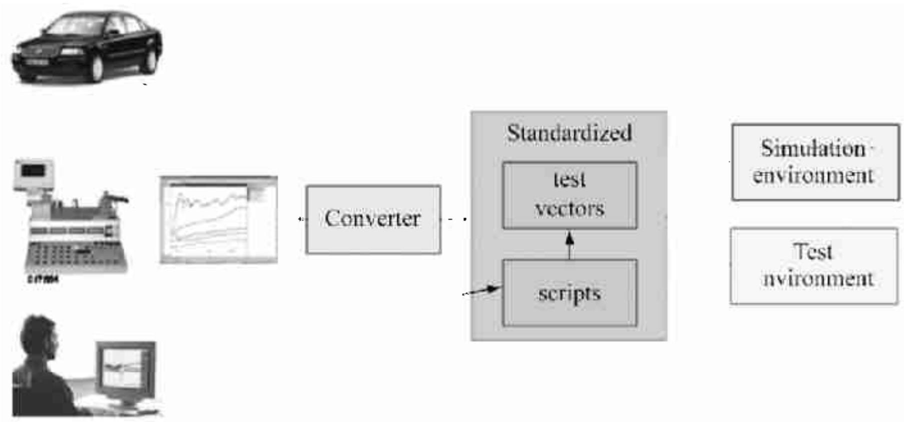

图 10　试验向量的执行

Fig. 10　Implementation of test vectors

也可以延伸发展。

这里预期的试验结果并不是等效值, 而被原始输入数据和经过功能改变后测量数据之间的确定差值所替代。

试验工程师能够将其注意力集中到检查预期的误差上。试验可在车间的 PC 机上实现。无需特殊硬件或系统。试验所需的操作系统(如循环任务调用)是模拟的。

参考和试验软件使用相同的试验向量时间特征。对被定义的测量值进行记录和比较。为了自动评价试验结果, 不仅在数值上而且在时间范围上都需对误差给出详细的定义。然后评价程序将生成以一份文本格式的方差报告, 并辅以图形显示方差。

4.2　试验向量在开发过程中的再使用

试验向量能在很大范围内使用(图 10)。最简单的过程包括记录车辆试验、实验室试验或 PC 机试验的测量数据。如需要可使用转换器, 将不同测量数据程序的试验向量格式转换成一种标准格式。该过程的其优点是较容易的使用各个独立试验事件。

The system model also appears in the "advance control" block. This is where the inverse model of the mechanical model is calculated.

To compensate for deviations in the model, observers are used for the primary and secondary clutch shaft. For this, it is important to ensure that the main tolerances of the total system are known right at the early stages of a project. This is the only way of ensuring that the system design is robust enough right from its draft stage.

3.4　Evaluation

When progressing to the volume production stage, this model-based procedure also entails a modification in the working method of the validation staff. Before a system can be optimized for use in a vehicle, all the physical parameters need to be obtained. As well as data from the vehicle manufacturer (e.g. axle rigidity levels and engine inertia), information needs to be obtained from test

试验向量应用的另一方面是正本语言的使用。运行时译员将正本指令进行转换, 生成试验向量激励试验样本。其好处是各试验事件易于修改和进一步发展。另一优点是提供了在初始页设定内部状况或试验样本测量参数通过反馈来影响试验过程的范围。

在 PC 机键盘上手动输入能够补充自动试验的顺序或叠加试验。这种对试验过程的更改能被记录下来, 其结果对今后的重复试验是有益的。

本文所描述的过程清晰地给出了所有的试验和仿真环境。如需作修改, 可由个别转换器完成。在过程中生成的所有试验向量可在今后整个开发周期内的任何时间中重复使用。这充分提高了效率和检查深度。

5　在批量产品开发中的改动管理和工作流程管理(过程控制)

这里我们所面临的巨大挑战之一是加速开发过程和软件编写。由于经营成本过高, 人工管理这些复杂工作是不可能的。通过使用贯穿整个过程的工具以支持变动管理和结构管理(图 11), 软件开发商在市场的重要因素、时间等方面有很大的改进空间。

使用这些强有力的工具, 开发商有了耗时少的助手和放心的目标管理, 并具有防出错的潜能。这些软件工具主要集中在过程开发和软件生产方面, 因此需加以选择和综合与最初定义的开发过程相一致。

5.1　变动管理

为了满足企业在可描述性、再现性和符合最后期限方面的需要, 需要这样一个管理结构, 它应能控

rig measurements and from the design data. One of the principal requirements in the vehicle is to compare the model against the system. Based on calculated model errors, the coordinator needs to decide which parameters are still in need of further optimization. This in turn calls for an understanding of the physical effects and of how to implement functionality in the software. This of course calls for specialist coordination and matching skills.

A model-based approach not only affects the development process: Model-based products also differ from ones based on conventional development techniques. Through the use of system properties in the initial activation process, it is possible to boost dynamic properties by as much as a factor of 6. On the other hand, the control unit loses robustness as it adopts more properties of the system.

It is therefore necessary to strike a compromise between robustness and dynamic properties. If you set a high level of dynamism, you can achieve better control characteristics. This then enables activation of the lock-up clutch to become strategy-based because the nominal speed characteristics can be used to target either a comfortable or a firm connection.

4　Integration of Tests in the Development Process

In the V model, a distinction between the dy-

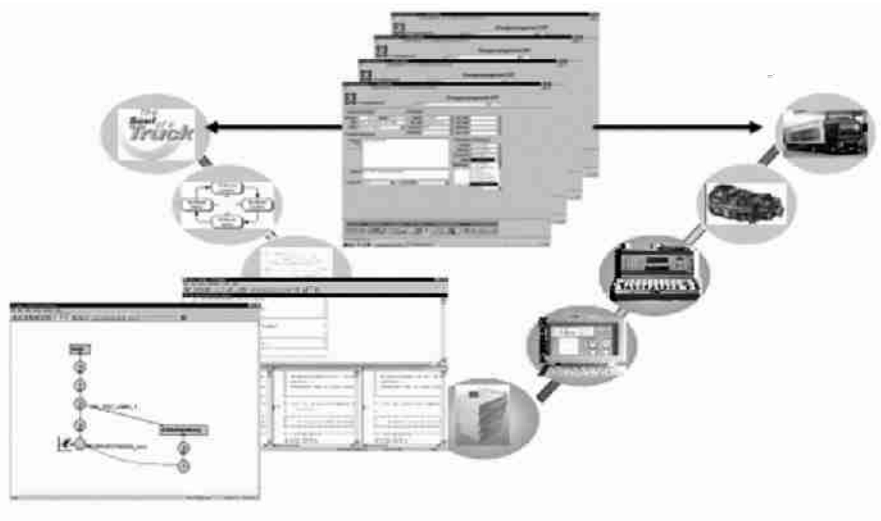

图 11　贯穿全过程的工具

Fig. 11　Tools employed throughout the process

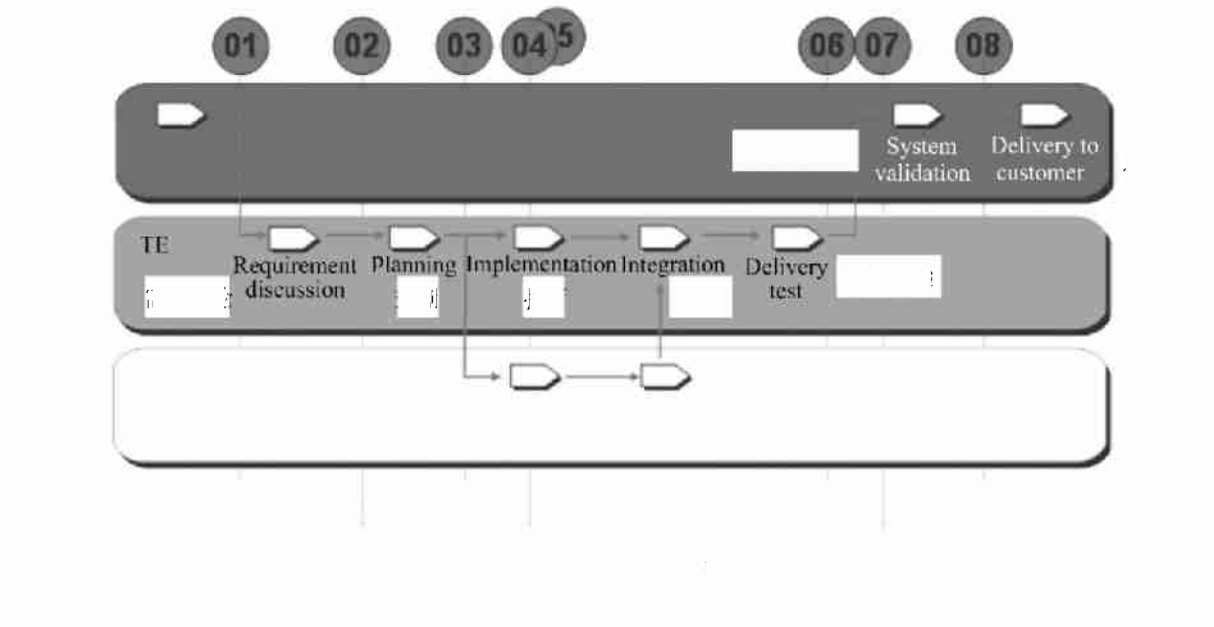

图 12　显示处理状况

Fig. 12　Displayed processing status

制在规划、设计和软件的编码阶段或软件开发环境方面的任何变化。当给出各种与需求相关的变化,每个需求应有一个可表示和可追述的处理状况,特别当开发工作的实施由大量系统伙伴通力合作时(图 12)。

在发展和质量阶段可利用这些辅助工具实现在线控制。所需的数据由项目数据库给出,并经评价。必须遵守过程各个阶段和已确认的各个过程(标准化质量)。这表明在开发过程中,开发商仅当前一目标达到后,才能进入下一阶段。开发商以这种方法被系统地导入整个过程,给他们自由,集中他们的核心活力。

在试验和确认过程各阶段中的次级过程基线是分配次级过程中一个基本成份,次级过程包括变动管理以释放高级别过程的软件。这表明不同的需求可由不同的开发团队(内部、外部、软件共享者、转包商)来执行,虽然软件集成商仍需对为实际释放过程负责。理想情况下,次级过程的需求同样依靠工作流程的管理(过程控制)通过定义界面或通过完全综合来释放。

在传动系统功能开发过程中,变动管理和工作流程管理事实上很难从外观上区分。ZF 公司在"工具清晰查询"过程中已成功应用了它们(图 13)。

这种过程控制手段使得需求和过程变更自动进行,并被证明有效地改善了效率。而且,文件存储的综合、最终期限、成本计划、特征数据的生成和功能报告等切实改善了项目的透明度。我们仍需强调的是在开发、试验和使用员工中各学科间的交叉已成

namic tests is made in accordance with the test processes applied to the module, integration and function tests. In the module test, part of the software (module) is stimulated with test vectors. The output parameters of the module are then compared against the anticipated test results. It is then usually not necessary to simulate vehicle or transmission functions because the aim of this test is to examine the technical program structure and the coding employed in the module.

During the integration and function tests, substantial components of the software, or even the complete software package together with any diagnosis functions are subjected to testing. In order to run a function test which most closely approximates real vehicle conditions, a simulation of the dynamic characteristics of vehicle and transmission is required. We will now look at this in greater detail.

4.1　Automation of the Process for Testing Dynamic Characteristics

The first step to make a test more efficient involves the automated testing and evaluation of dynamic tests. All these processes are based on integrating a dynamic model for the closed-loop control route (transmission, vehicle, road) in the simulation software (Figure 8). Here are the reasons why this is necessary:

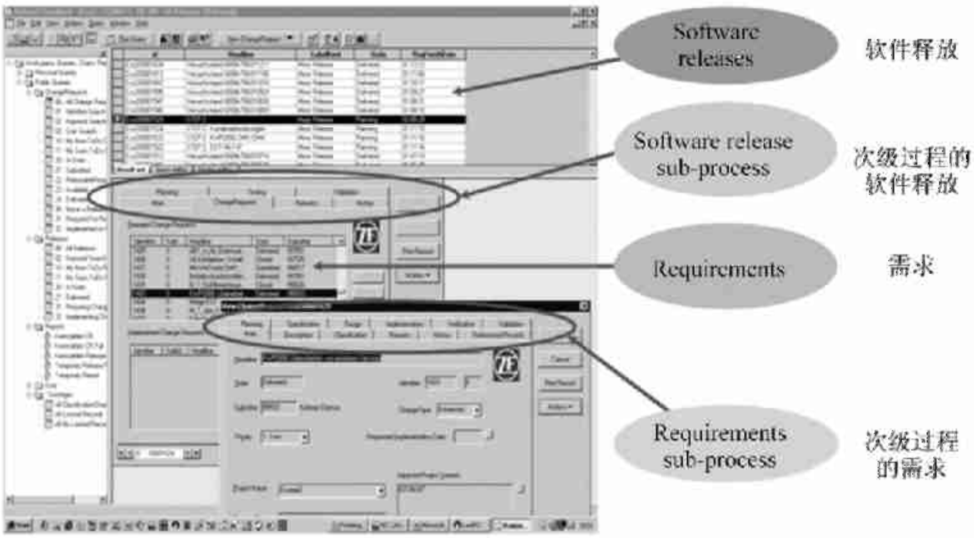

图 13　清晰查询的控制过程

Fig. 13　Process control with Clear Quest

为传动系功能开发工作的基石。

6　结论

在考察一个从概念到产品批量生产的完整的开发过程时, 你将发现采用基于开发的模型有了一些明显的变化。

在第一阶段, 即产品概念转化为功能定义时, 获得了对系统的了解。这是因为对物理作用的描述来源于相关的参数。由于分析阶段成为整个过程的一个固定部分, 系统设计中的问题在初期阶段已被认识到了。以变矩器锁止离合器为例, 操纵系统在滞后和动态特性方面的需求已作了考虑, 并对反馈控制品质提出了特殊需求。

在虚拟样机和快速成形阶段则提升了开发过程的效率。在虚拟样机阶段, 在变速器硬件存在之前即可对功能进行彻底地检验。如上所述, 某些情况下, 所获得的一组基础数据能成为车辆试验的起点。通过使用代码生成器, 使试验计算机的图形仿真平台具有实时生成代码的能力。这意味着可对车辆仿真结果进行更广泛的试验以及研究仿真模型未包涵的整个系统的实时行为。对锁止离合器而言, 与载荷倒拖有关。

必须清醒地认识到使用人员正在经受着更新, 一个来自旧学校并用纯实验方法武装的试验工程师正在成为一个至少具有基本闭环控制系统知识的系统工程师。

在批量生产环境中, 不再将主意力集中在给定的功能上。对最终程序可描述性和可再现性的要求意味着开发流程的每一步必须伴随着本文所描述的各种辅助工具。

- Reduction in cost of testing while retaining the same quality target
- Improved reliability compared with repetitive and identical manual inspections
- Ensuring the reproducibility of tests
- Regression tests are easy to conduct and
- Test documentation is simplified

One of the automated test processes employed at ZF is the “Automatic reference comparison” (Figure 9). The test automation method described here is employed in order to achieve functional equivalence between the dynamic characteristics of two software statuses, e. g. following a design modification to verify that software changes have no adverse effects, or to safeguard software changes in the context of a platform application.

However, the scope for application is not just restricted to checking for absolute equivalence. Even function changes are easier to test by means of an automatic reference comparison check. Test vectors from a previous test can be adopted without any changes, or can also be developed more extensively.

The anticipated test result in this case is not identical equivalence but is instead the defined difference between the original input data and the measurement data obtained after a function change.

The test engineer is then able to direct his attention to the examination of anticipated differences. The test can be carried out on the workplace

PC. Special hardware or system components are not required for this. Operating system components required for the test (e.g. cyclical task calls) are emulated.

Reference and test software are then initiated using identical test vector timing characteristics. The defined measurement values are recorded and compared. For automatic evaluation of test results, tolerance definitions need to be defined. This not only applies to the values but also to the time range. The evaluation program then produces a variance report in text format together with a graphic display of the variances established.

4.2 Re-Using Test Vectors in a Development Process

Test vectors can be implemented in a tremendously wide variety of ways (Figure 10). The simplest process involves recording measurement data from a vehicle trial, a laboratory test or a PC-based test. A converter can then be used, if necessary, to convert the test vector formats of the different measuring data programs into one standard format. The advantage of this process is the relative ease with which individual test cases can be implemented.

Another process for implementing test vectors involves the use of a script language. An interpreter converts the script commands during runtime and, in the process, generates the test vectors required to stimulate the test specimen.

One advantage of this process is the ease with which test cases can be adapted or further developed. Another advantage is the scope this affords for influencing the test process on the previous page by applying feedback from internal status or measuring parameters to the test specimen.

Manual input on the PC keyboard can supplement the automatic test sequence or can be superimposed upon it. The changes this induces in the test process can be recorded and the results are then available for a subsequent repetition of the test.

The procedure described here is transparent for all the test and simulation environments applied here. If any adaptation is required, this can be performed by individual converters. Any test vectors created during this process can be re-used at any subsequent point in the entire development cycle (Re-Use). This substantially improves the efficiency and the depth of inspections.

5 Change Management and Workflow Management (Process Control) during Volume Production Development

Speeding up the process of developing and producing software is one of the greatest challenges we face in this field. Due to the high cost of administration, it is no longer possible to manage these complex operations manually. Through the use of tools employed throughout the process to support change management and configuration management (Figure 11), software developers can substantially improve on that all important factor, time to market.

Through the power and capability of these tools, developers are relieved of many time-consuming ancillary and administrative tasks, all of which harbor the potential for errors to creep in. These software tools are central to the process of developing and producing software so need to be selected and integrated in accordance with internally defined development processes.

5.1 Change Management

In order to comply with the industrial requirements for traceability, reproducibility and deadline compliance, an administration structure is required to govern each and every change in the specification, designs and code of any piece of software, or to the development environment of that software. Given the variety of change-related requirements, each individual requirement needs to have a displayable and traceable processing status, especially when development work is being conducted in collaboration with a large number of system partners (Figure 12).

Development and quality-related steps can be controlled on-line by accompanying the process with the assistance of these tools. All the data required are drawn from a project database and can be evaluated. Compliance with all process steps and approval stages is assured (standardized quality). This means that developers cannot progress to the next step in a process until the previous task has been completed. In this way, developers are guided systematically through the process, leaving them free to focus on their core activity.

Baselining of sub-processes during the processing steps of testing and validation is an essential component in the process of assigning sub-processes involved in change management to the superordinate process of software release. This means that different requirements can be implemented by various different development teams (internal, external, software sharing, subcontractor), although the software integrator does - and indeed must - remain responsible for the actual release process. Ideally, sub-processes of requirements 1.. n are coordinated by means of workflow management (process control) for the release, either through defined interfaces or through full integration.

Change management and workflow management are now virtually indistinguishable aspects of the development process for driveline functions and ZF has implemented them in the Tool Clear Quest process from Rational (Figure 13).

This process control instrument enables the requirements and change process to be automated and this has substantially improved efficiency. Moreover, the integration of document storage, deadline and cost planning, generation of characteristics data and reporting functions has led to tangible improvements in project transparency. We should also emphasize that the interdisciplinary involvement of Development, Testing, and Applications staff has become a cornerstone of development work into driveline functions.

6 Summary

If you consider the entire development process from the product concept to the volume production stage, you will find that the adoption of model-based development has given rise to some significant changes.

During the first phase, in which a product concept is turned into a function definition, an understanding of the system is obtained. This is because a description of physical effects is constructed from the relevant parameters. Due to the fact that this analysis phase forms a firm part of the process, problems in system design are recognized at an early stage. To take the converter lock-up clutch as an example, requirements on hysteresis and the dynamic properties of the actuator system were devised in order to deliver the specification requirements relating to feedback control quality.

The two process steps known as Virtual Prototype and Rapid Prototyping enhance the efficiency of the development process. In a virtual prototype, a function can be thoroughly examined before the transmission hardware exists. As described above, in some cases, a set of basic data can be obtained to form a starting point for vehicle trials. Through the use of code generators, it is possible to generate code with real-time capability from the graphic simulation platform for use in experimental computers.

This means that simulation results in a vehicle can be tested more extensively and that the real-time behavior of aspects of the entire system can also be investigated that are not covered by the simulation model. In the example of the lock-up clutch, this relates to the topic of load reversals.

It must however be made absolutely clear that applications staff are undergoing a paradigm shift. A test engineer from the old school, equipped with a purely empirical approach, is now called upon to turn into a systems engineer possessed of at least a basic grasp of closed-loop control systems.

In a volume production environment, it is no longer sufficient to concentrate solely on a given function. The demands for traceability and reproducibility of the final program mean that all steps in development workflow must be accompanied with the assistance of tools of the kind described in this paper.

参考文献　略