EFFICIENT ENGINE DEVELOPMENT BY VIRTUAL TESTING

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Abstract

Reliability, safety and quality are key issues for placing products successfully on the market. To achieve these goals Reliability Engineering has to be employed from the concept phase and throughout the lifetime of a product. During the product development phase it is important for the engineer to better understand the factors that cause components and systems to fail. This precondition should considerably lower the risk of delaying the SOP due to failure of prototypes. It is necessary to intensively use computer simulation tools and application methodologies during the design phase and the prototype development in order to make up front investigations based on accurate digital models under real operation conditions.

Targets for such calculations are to
- *analyze proposed design and evaluate the reliability potential,*
- *ensure that all components, subsystems and systems in a design will behave as the designer anticipates and*
- *prepare procedures for the later test runs on components, subsystems and systems.*

The prerequisites to successfully develop and employ such efficient and reliable simulation methodologies are development platforms which consist of
- *various mathematical simulation tools including mathematical optimization capabilities,*
- *testing tools corresponding to the mathematical simulation tools,*
- *data and workflow management based on engineering knowledge.*

The paper describes the development platform for "NVH and Durability" and the employment to optimize crankshaft design and to evaluate the stresses in the cylinder head – cylinder block compound based on system simulation.

Comparisons of simulation and experimental results are shown and an evaluation of the method in terms of maturity and limitations to reduce the risk of failures is outlined.

Keywords: *reliability, MBD, simulation, development process, virtual testing*

1. Introduction

The automotive industry's marketing policy is increasingly imposing new challenges by the need for
- faster product development cycles to meet the requirement of increased frequentation of new car models,
- a growing range of product variants based on a reduced number of platforms,
- development of products with reduced life cycle costs,
- increasing system complexity (function, comfort and luxury) and
- increased safety.

It is well known of course that the only way to succeed is to make the right design decisions during the concept phase. This makes it necessary that reliability is designed and built into products at the earliest possible stages of product development as the costs of change are very low compared to changes during the development phase. Considering the discrepancy of product knowledge and locked in product life cycle costs it is important to find measures to increase the product knowledge in these early stages of the development process, Fig.1.

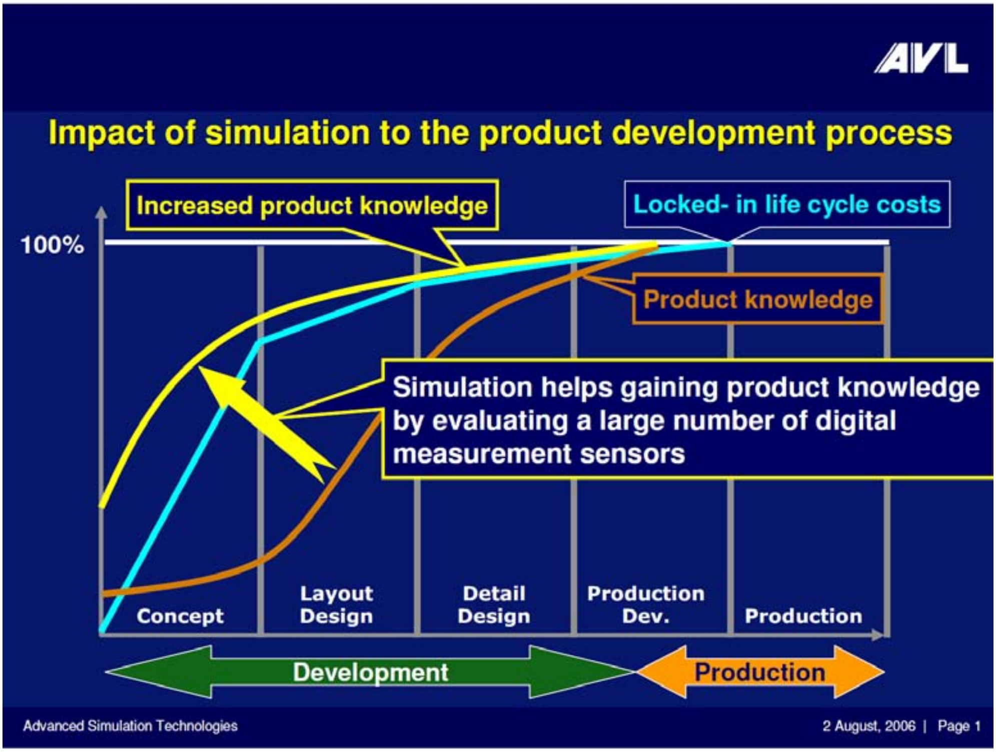

Fig. 1. Locked in life cycle costs and product knowledge

Therefore it is clearly visible that the up-front mathematical simulation has to be adopted to reduce reliability problems and increase product knowledge. Consequently this will reduce the product development cycle time and cost dramatically compared to experimental tests during the prototype stage as mathematical simulation helps to avoid the danger of encountering a problem close to the start of production.

To apply mathematical simulation as a tool for reliability engineering during the concept and design phase it is an absolute must to have all information available concerning

• the allowable material stresses in the structure depending on the geometry,
• the loads on the structure under real operating conditions and
• to have multidimensional mathematical models available which offer high accuracy of the results by short calculation lead-time.

T he results of such risk analysis have to make sure that the structure will not fail, if the loads on the structure do not exceed the allowable stresses. More precisely: the probability that a structure will fail is acceptably small, if the designer is lead by reliable calculations.

The challenges to apply mathematical simulation as a “virtual test bench” to perform risk analysis are

• integration of design, simulation and test systems,
• implementation of data management and
• implementation of process management.

All of the above mentioned items have to be treated as equivalent partners to reach the target. Process oriented activity ensures that the simulation fits into the process flow and is backed by appropriate tests. In parallel to that, the technology development guarantees accurate mathematical and physical models to simulate the operating conditions.

2. The engine development process (EDP)

Simulation and testing form an important part of the engine development process. In all phases of the engine development it is necessary that the following items progress in the order shown below to achieve an integrated development process:

- design,
- virtual test,
- real test (real life conditions).

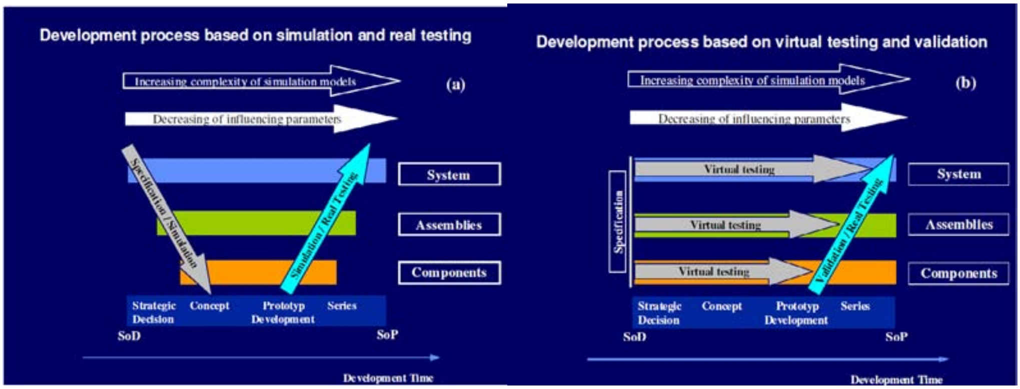

Fig. 2. Influence of virtual testing and real testing on the EDP

Fig. 2 shows the influence of the different depth of simulation, virtual testing and real testing:

The traditional development process, Fig. 2a, starts with system and assembly specification supported by simulations using simple simulation models calculating many variants within a short time to find an optimum solution. In a second step individual components are optimised using different physical models, e.g. FEM, CFD.

During the prototype phase the product development is carried out by prototype testing supported by sophisticated simulations to finally optimise the entire system. The future approach, Fig. 2b, allows virtual testing based on mathematical simulation of the entire system starting during the concept phase. Components are tested as a part of the system, not individually.

Thus a big effort has to be put into activities linking all the product shaping process steps, Fig. 3, in order to really benefit from them. Multidimensional modelling and simulation for powertrain and vehicle systems have become important areas of research for this reason. The data exchange between software tools of different domains, e.g. CAD, multi-body system simulation, control system simulation or FEM at any stage of the product development process has to be given the highest priority.

By using experimental, test bed and road test data the correlation between the virtual and physical prototype can be improved. This is an indispensable prerequisite for further development of the mathematical simulation methods.

The proportion to which each of the above items contributes to the course of the development process is changing.

Fig. 4 shows the intensity of computer and test bed simulations in the traditional (b) and the future (a) engine development process.

While in the traditional process the main development steps are done on the test bed by real testing, the future process relies on virtual testing during the design phase and uses testing only as a validation procedure.

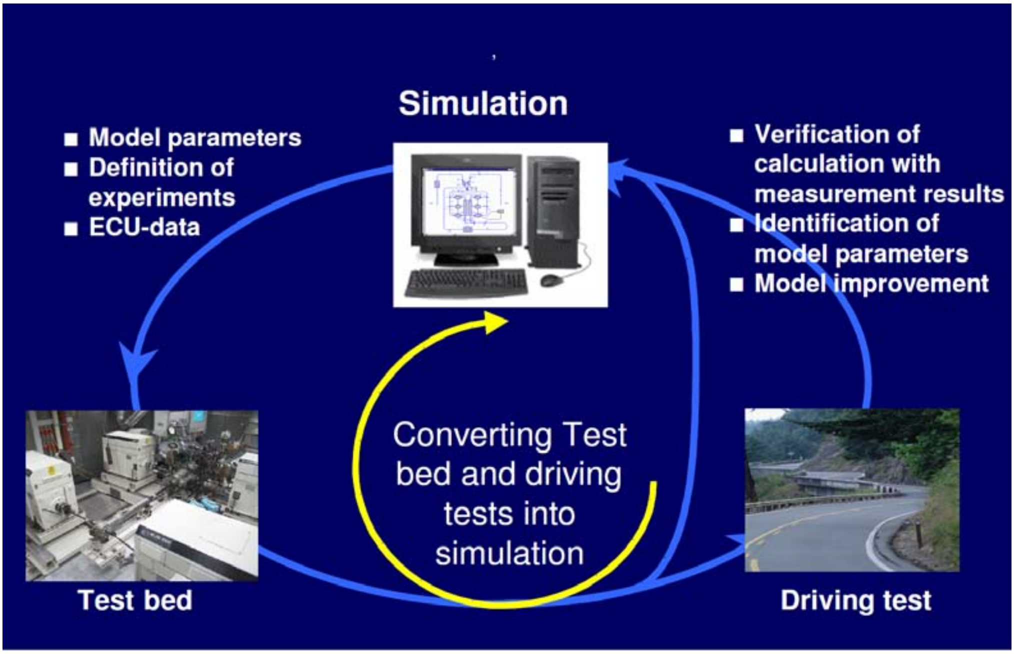

Fig. 3. Integrated Development Process

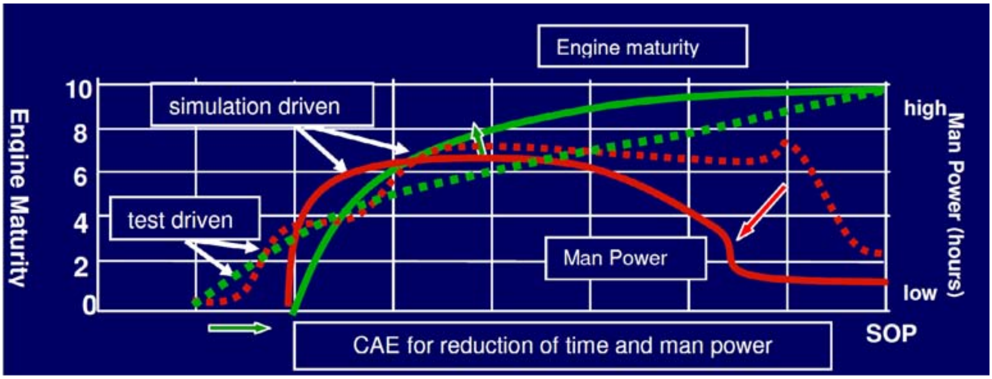

Fig. 4. Impact of development based on virtual testing and on real testing on the Engine Development Process

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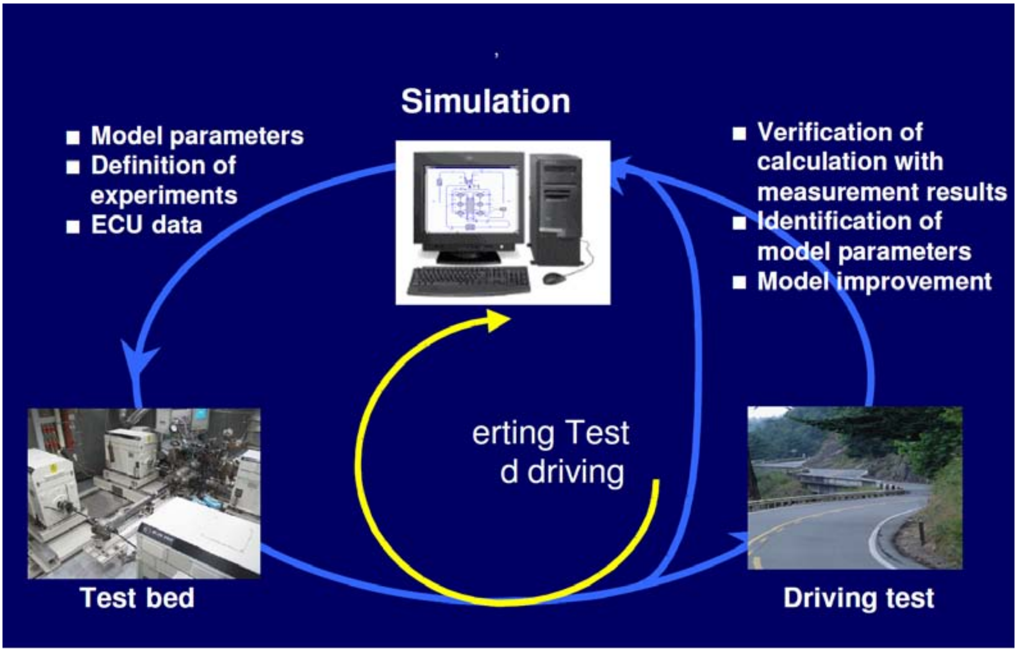

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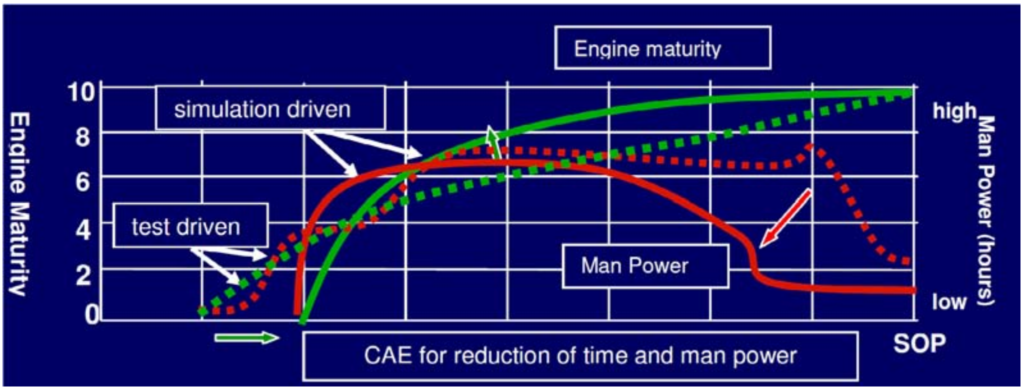

Fig. 4. Impact of development based on virtual testing and on real testing on the Engine Development Process

3. Integration of the virtual test into the development process

The applicability of the virtual test to reliability engineering and therefore the integration in the development process is still seen with some scepticism by engineers. Reasons for that are missing expertise in interpreting results and therefore

difficulties to communicate results,

easy to use software (lack of training) and

links to different software to perform multidimensional simulation,

confidence in mathematical simulation.

In order to establish virtual testing and – as a precondition – to overcome the fore mentioned scepticism it is essential to develop measures which form a “simulation environment” consisting of:

Software capable of predicting the behaviour of complex systems under real operating conditions with the highest accuracy. It must be ensured that software packages based on different physical or mathematical models are combined in the best suitable way via interfaces, co-simulation or simultaneous simulation.

Workflow management hiding the complexity of the simulation system from the engineer. This includes model generation including load definition and material data acquisition and result presentation in a task oriented manner.

Computer power to achieve sufficient turnaround times for the virtual testing to effectively drive the development process and

Educating engineers to understand different engineering disciplines and to make use of complex interrelations of numerous design parameters. Apart from the technical aspect this human factor is the key to employ such sophisticated and extensive simulation procedures in a successful way.

4. The AVL platform concept

Based on the definition of AVL´s engine development process and on the capabilities of AVL´s and third party simulation software products a “platform concept” was worked out and turned into reality. Fig. 5a shows the components of the platforms and Fig 5b shows examples for various platforms which are developed to support the engine development process with simulation and test procedures. The following example of the “Durability and NVH Platform” emphasises the mathematical simulation part of the platform.

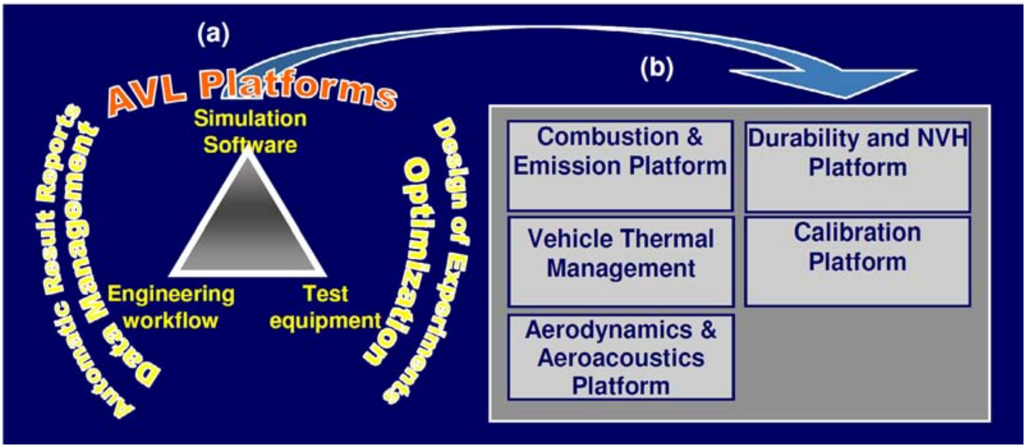

Fig. 5. AVL´s Platform Concept

5. Durability and NVH platform applied to crank train design

Traditionally the crank train layout was based on rough calculations, afterwards e.g. crankshaft and connecting rod were simulated with FEM (quasi-static) and optimised separately.

Increasingly structures and systems of products become more and more complex. It appears that when various reliable components are combined into a system, the result is not necessarily a reliable system. Subsequently, the complexity of today’s powertrains does not allow component level simulation and component level test as the only scrutiny. It is also compulsory to do simulation and testing on the system level. Fig. 6 shows the modelling of the entire engine system and the displaced results for a part of the engine block.

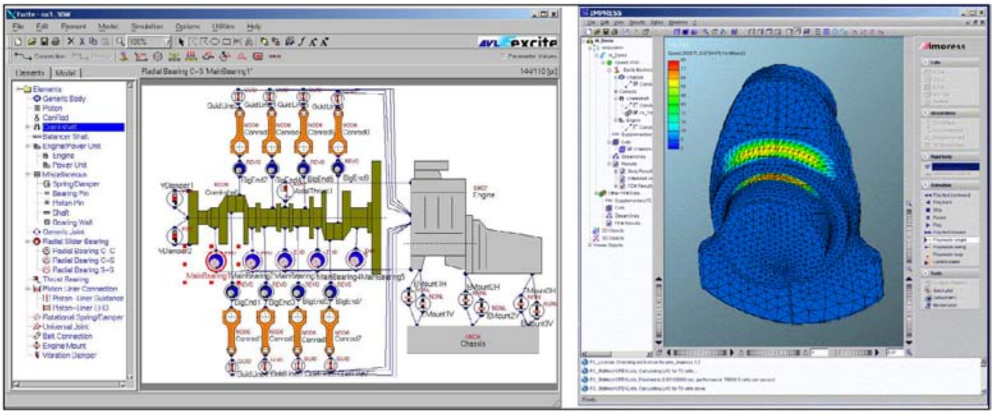

Fig. 6. System modelling and result evaluation for engine durability simulation

The increasing level of teamwork required in today's development process, and the corresponding holistic thinking leads to the fact that engineers are engaged in several and differing levels of the process at the same time. As a consequence, they have to use different programs, which requires a graphical user-interface (GUI) which is as simple and intuitive to use as possible.

The analysis of the results, apart from the specialised knowledge possessed by the engineers, demands visualisation software that enables fast interpretations of the results.

In addition to the "static" result representations, video animations are created because they permit reliable result interpretations. This is especially important for structural and fluid flow simulation.

Fig. 7 shows the workflow for the durability evaluation of the crankshaft. This new approach starts with the layout of the crank train using flexible MBS simulation under real operating conditions. The calculation model for the system is steadily refined, the durability of the components (crankshaft, con-rod, main bearing wall, etc.) are optimised within the system simulation.

The project lead-time is steered by the fact that the creation of the flexible MBS-model takes a considerable effort and also the calculation of the stresses has to be done externally with a commercial FE solver.

As the generation of the flexible MBS crankshaft model (structured model) takes a lot of modelling time considerable effort was invested to reduce this part of the workflow by an automated procedure that at the same time maximises the reliability of the calculation model to avoid hard to detect errors.

In a first attempt the creation (generation) of the flexible MBS model (crankshaft structured model) was automated as this is the most time intensive work, Fig. 8.The steps of the automated procedure are: Based on a CAD-STL file the crankshaft is separated by the AutoSHAFT into simple units (e.g. cylindrical parts like journals, crank pins) and complex units (e.g. webs). In the next step a FE meshing of the complex parts is done, a mass partitioning calculation is performed, followed by an elasticity evaluation using a static analysis with an integrated FE-solver with all necessary boundary conditions and load cases set up automatically.

Finally the complex parts represented by the numerically derived mass and stiffness matrices and the analytically calculated pins and journals are assembled together using the tool Shaft Modeller to form the structured model of the crankshaft.

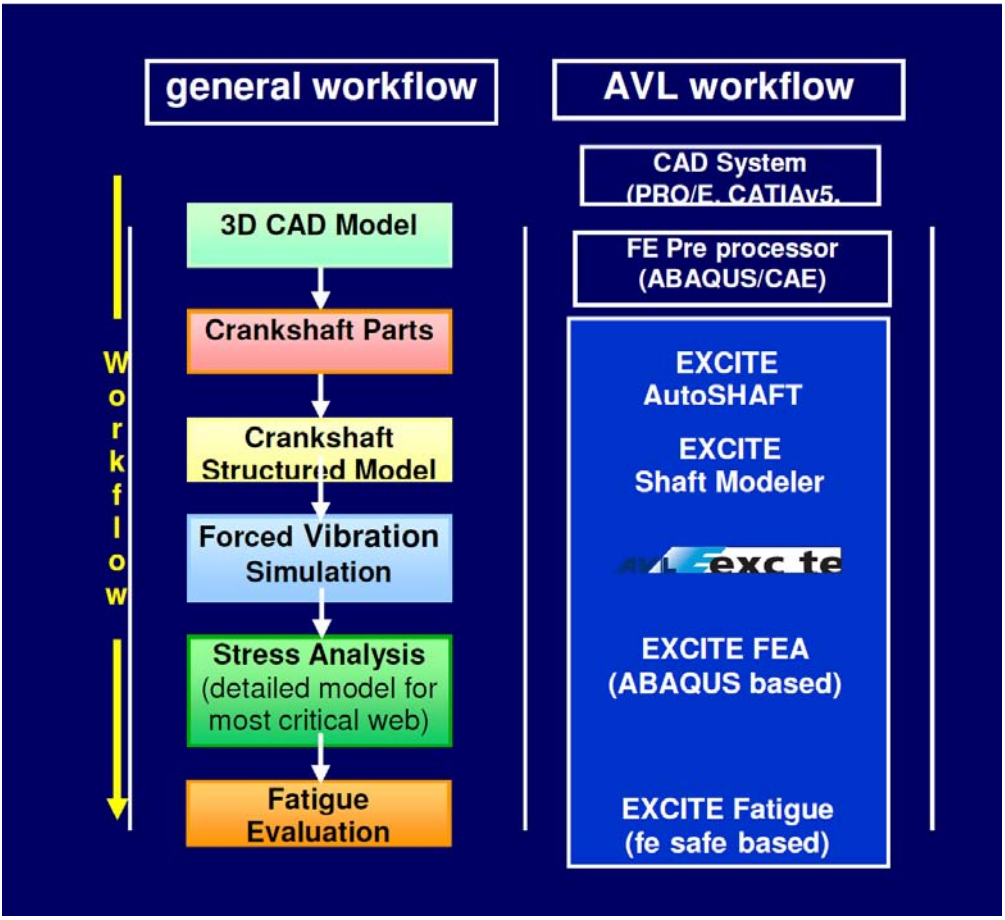

Fig. 7. Workflow for durability of crankshafts (structured model)

AVL's solution includes also all post-processing steps of the crankshaft analysis (stress calculation and fatigue evaluation) to offer the complete analysis workflow.

To make this sophisticated multidimensional mathematical simulation a part of the standard engine development process for durability and NVH applications additional measures were taken to reduce the overall CPU processing time. Especially time consuming "manual" work steps like the parameter identification for the engine mount model for NVH applications have been automated based on measured stiffness values.

As mathematical optimisation becomes increasingly important simple models for e.g. considering the oil film in the bearings as well as fast solvers were introduced. Finally the procedure had to be verified by real testing. This is done comparing many measurement results gained by power train development projects which are performed either in AVL or by customers. This is the final step to establish the procedure as a "virtual test" within the development process. The simulation results displayed in Fig. 9 show a very good correlation with the experimental results.

Now the virtual tests can be reliably applied in a very early phase of the product development and lead to a reliable development status creating confidence in the quality of the product. Sothis leads to a decision making process which gives the right answers beforehand.

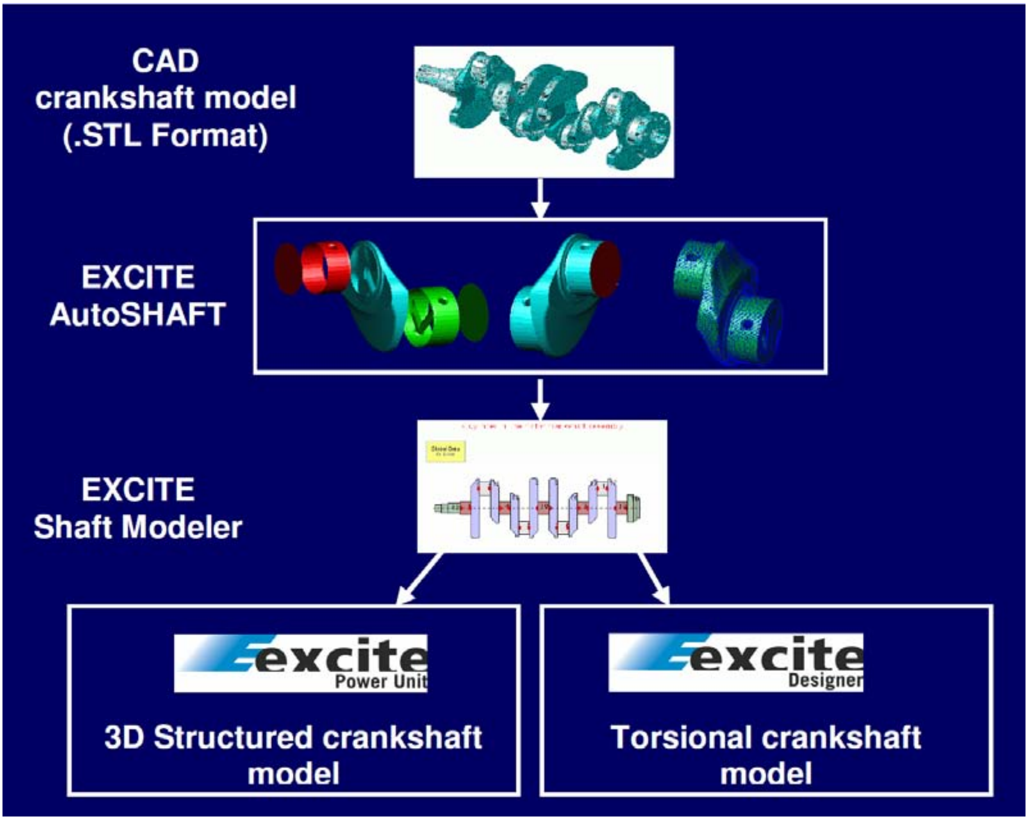

Fig. 8. Flexible crankshaft MBS model for 1D and 3D analysis automated derived from CAD-STL file

An additional fact is that the virtual testing through multidimensional simulation can simulate the real operating conditions before hardware is available. Test equipment often has limited capabilities to simulate real operating conditions if only single components are tested. In our case the test could only consider the torsional behaviour while the simulation included also bending and longitudinal effects automatically.

It is clearly visible that the replacement of testing time by up-front mathematical simulation will reduce the product development cycle time and cost dramatically.

6. Summary

High precision mathematical simulation tools are already available to make detailed investigations on system level deriving accurate results for single components already in an early stage of the development process. This is supporting the reliability engineering already during the concept and design phase.

The effort to develop such tools which are powerful enough to predict product reliability in the early development stage is considerably high but helps to dramatically reduce the costs of change during the prototyping and pre-production phase.

To further improve this way the demands on this process are:

Reliable results for the entire systems provided on time.

Simple handling of the simulation tools.

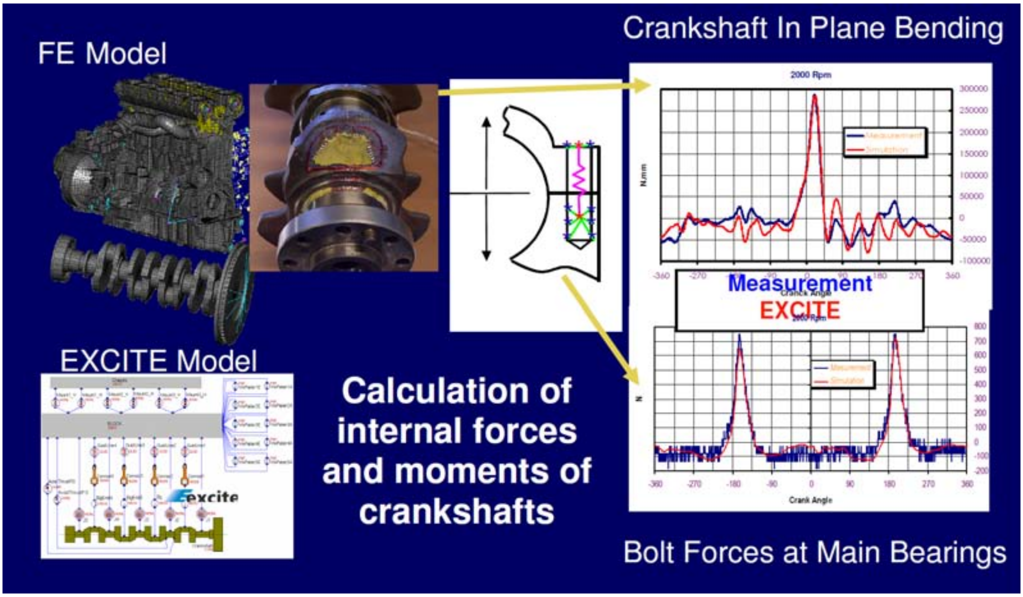

Fig. 9. Comparison of results for a crankshaft of a 4-cylinder engine

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Simple handling of the simulation tools.

Models of the right accuracy and simulation speed for the different development stages (fast models to investigate many variations during the concept phase; in-depth-models for detailed investigations during the layout and prototyping phase)

Integration of all necessary simulation tools into the workflow.

Further steps, required for the integration of the computer simulation tools and tests, will bring together the already existing hardware components of the prototype and the computer models to employ hardware in the loop (HIL) simulations.