Usage of LS-DYNA® in the Development of Professional Hammer Drills

A. Syma[1]
M. Hörmann[2]
[1] Black & Decker GmbH, DeWALT Professional Engineering Center, Germany
[2] CADFEM GmbH, Germany

Abstract

The development of modern electric power tools for professional use requires special attention. Characteristic aspects such as efficiency and user comfort along with robustness and durability are always of importance to the manufacturer. For the fulfillment of these attributes computer-aided simulation combined with the finite element software LS-DYNA® is a central point during the development process at Black & Decker GmbH, i.e. from the predevelopment phase up to testing near series prototypes.

The area of application of LS-DYNA® is not limited to classical drop test cases for devices (see Figure 1), but goes far beyond that. DeWALT uses LS-DYNA® for their hammer drill development in order to account for different hammer sub-assemblies and various structural mechanical concerns. Particularly during the hammer work interpretation regarding unwanted idle impacts, LS-DYNA® can simulate harmful shock waves in the drilling spindle and tool holder for the equipment. Further LS-DYNA® allows the computational illustration of the entire hammer drive train (see Fig. 2) as well as the simulation of comprehensive misuse. Based on case examples from the daily employment of LS-DYNA® in development practice the various types of applications at Black & Decker GmbH, DeWALT are shown.
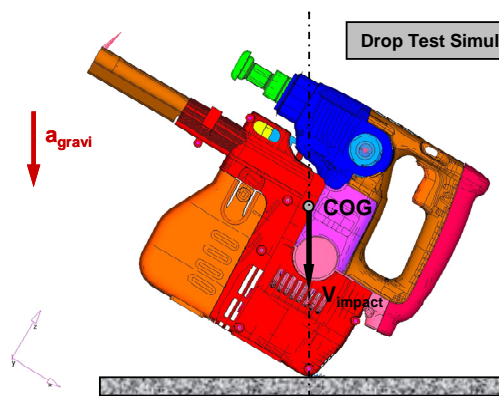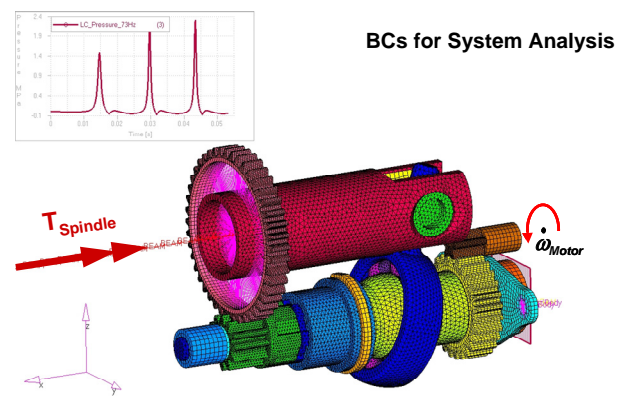
Fig. 1: Drop test simulation of a Hammer drill

Fig. 2: Simulation model of a Hammer drill drive train

1 Introduction

The *Black & Decker Corporation*, Headquartered in Towson (Maryland), USA - founded in 1910 – with a sales volume of $6.1 billion dollars in the fiscal year 2008, is one of the leading power-tool manufacturers in the world. Their product portfolio includes brand names such as *Black & Decker*, *DeWALT*, *Delta* and *Porter Cable* fastener- & lock systems (see Figure 3). As of the end of 2008 the *Black & Decker Corporation* employs 22,100 workers.

Fig.3: Power tool brands made by Black & Decker

The power tools made under the brand of *Black & Decker* and *DeWALT* will be distributed to important markets within North- & South America, Europe and Asia. Locations of *DeWALT*'s production development, in addition to the headquarters in Towson (USA), include Spennymoor (UK) responsible for electric hand saws, and Idstein, near Wiesbaden for its concrete division. The site in Idstein is primarily responsible for the development of hammer drills (DeWALT) for professional use. The DeWALT Hammer Series ranges from the small 2.5 kg weight battery to the larger 30 kg demolition hammer for a total of approximately 20 drilling and chiseling tools (see Figure 4).

Fig.4: Part of the DeWALT drilling and hammering family

The hammer drills within the range of the *DeWALT* label are some of the most technically complex products on the market (see Figure 5). The hammer drill consists of an electric drive including a gearbox, an electronic unit with switch, a hammer, drive clutch, the hammer mill, and outer casing with handle and the tool holder (see Figure 6). These sub-systems operate in the toughest conditions. The complexity in the development of rotary hammers paired with the durability expectations from the customer presents a special challenge. One complicating factor is that the hammer encounters hard impacts through the work of the mechanism, and generates high strains as well as a large amount of dirt. This is essentially a period of "self destruction."

In technical terms this is referred to as the *fatigue life* of the device which could, for example, be designed for 120 hours.
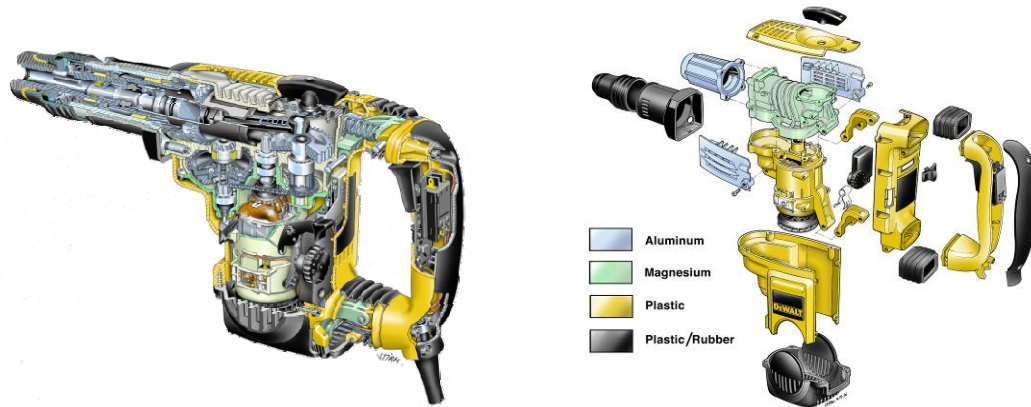

Fig. 5: The complex design of the DeWALT hammer drill

The quality of a professional rotary hammer is defined primarily by the performance and robustness of the device. Other aspects of quality include the ergonomic and safety factors of the device. There is a distinction, in this context to the impression of quality, which is mainly influenced by design, material appearance, "operating noise" and the fit of the visible parts.
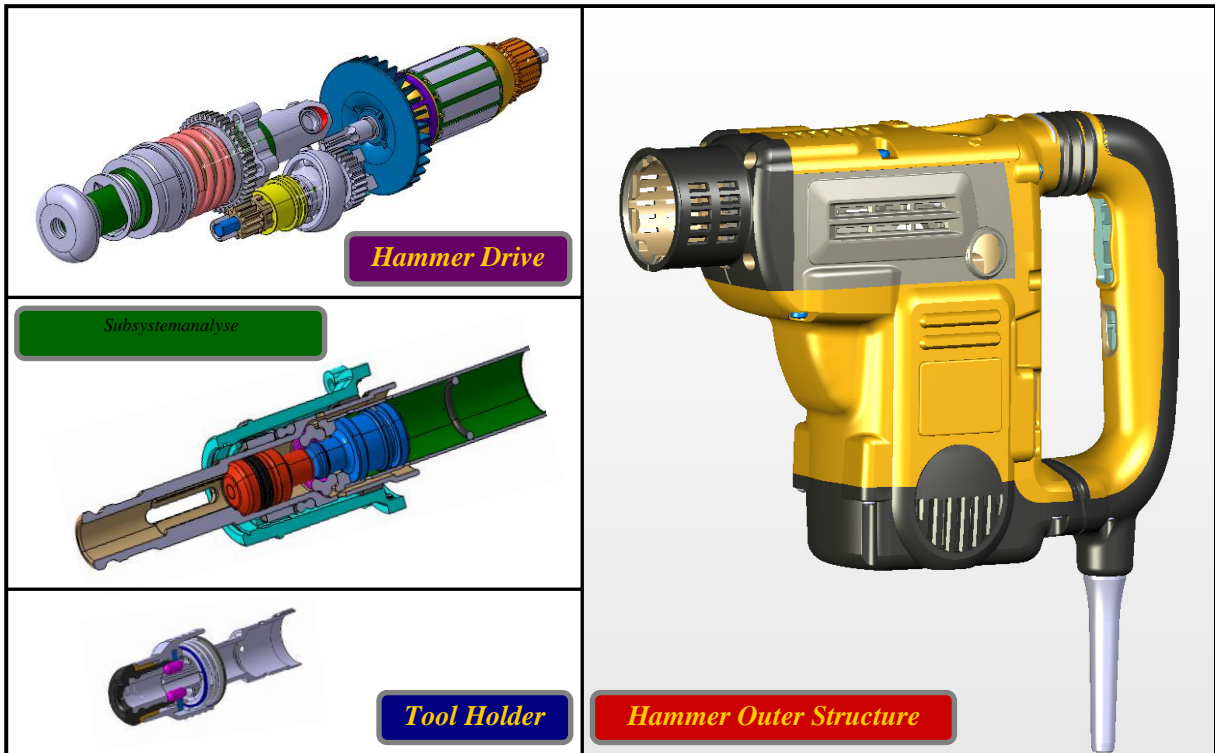

Fig. 6: The components of the rotary hammer

2 Computer Aided Engineering in the DeWALT Hammer drill Development

The engineering discipline of computer simulation is particularly important in the development process. It functions as a tool for the detailed evaluation of prototypes prior to their production. The basis for these supporting functions for the design process are the various mathematical and physical models implemented by means of numerical analysis using high performance computers. The term „Computer Aided Engineering" (CAE) is comprised of the computer-aided modeling, analysis and simulation in engineering practice.

With the help of CAE in the development of the prospective DeWALT-Rotaryhammer, particularly in product functionality, reliability and durability „checks" can be made before the physical product exists. The application of CAE lies mainly in the field of structural mechanics, i.e. in the simulation of static and dynamic loads on the drilling and/or chiseling hammers due to forces, accelerations and shocks. Other applications include multi-body simulation and fluid flow (see Figure 7). Within the structural mechanics field the explicit finite element program LS-DYNA has a special place: it is by far the most important item in the development of simulation software for DeWalt drilling and chiseling hammers.
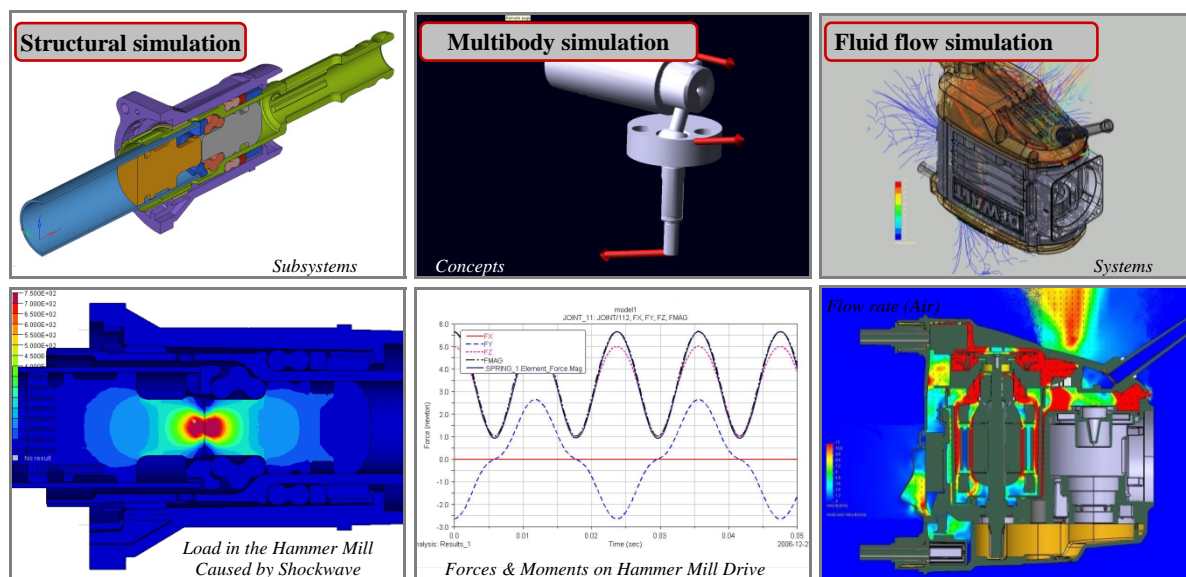

Fig.7: Examples of CAE Applications in DeWALT product development: Structural-, Multi Body- and Fluid simulation – Concept-, Subsystem- and System analysis

In the area of the various product requirements such as quality and functionality enhancement, development time and production costs are required for coordination in addition to determining the appropriate use level and single-rate territory require. The maximum benefit of CAE is the use of dates in the product development process.

The use of CAE in product development process may be divided up depending on the "maturity" of the product in three different areas: concept phase, product development and the prototype testing phase. In Figure 8, the intensity is shown in the three phases of development where the CAE calculations are used, along the DeWALT Milestone Process.
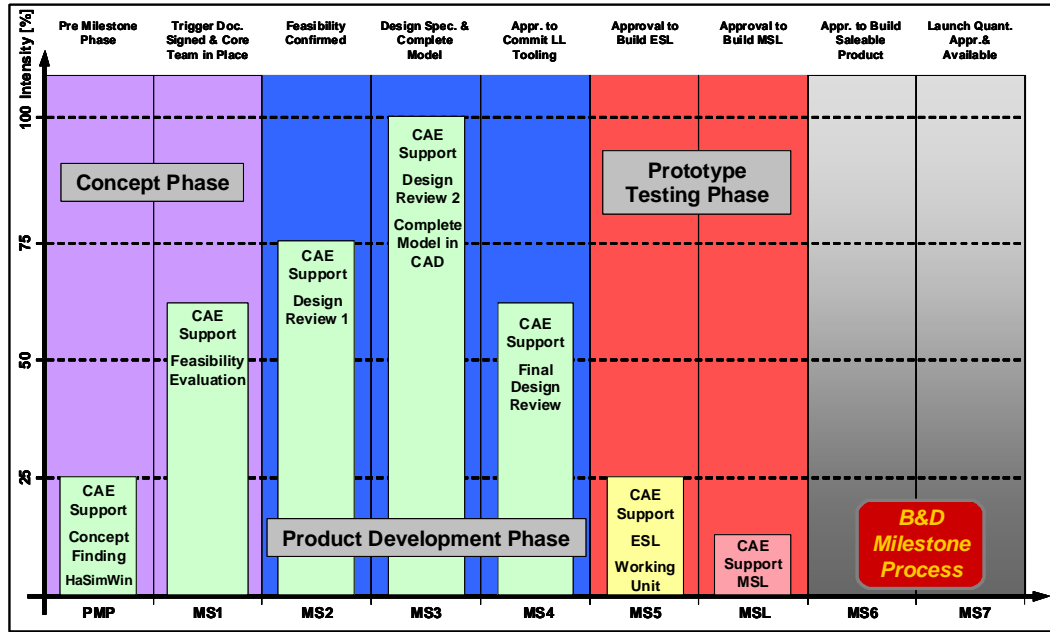
Figure 8: Intensity of the CAE-bit (high) in the product development DeWALT

While in the early concept phase, only simplified CAE analysis is used for the investigation of different technical approaches, the simulation work in the product development phase is characterized through detailed and complex simulations. The analysis here is for both the individual hammer assemblies (subsystem analysis) and for the entire Hammer drill (system analysis) instead of what we see in Figure 7.

In the prototype testing phase the use of computer simulation is mainly for the efficient and quick investigation of test failures, while developing problem solutions. Often this CAE is the only possible "tool" to demonstrate the physical processes for visualization and understanding, consequently, it can be included (e.g., shock waves in iron works components, Fig. 7). The simulation practices of recent years have shown that LS-DYNA is the appropriate simulation software for structural problems, an explicit FE-code capable in all three phases of development, as we have shown. The following will now highlight case examples demonstrating the diverse applications of LS-DYNA in the Dewalt Hammer drill development.

3   LS-DYNA usage for the simulation of the external structure

Drop-test Simulation

In the design of the external structure of a rotary hammer considerations must be made regarding the ergonomic design and specific aspects such as robustness and safety of the device. For example, a test case of a power tool dropped from a defined height level must survive with no major damage, i.e. after falling from a height of 1 m the device may have no cracks or gaps, which would allow touching electrically conductive elements. In this case, a compact rotary hammers tested under stringent conditions of 2 m height is carried out. As a result of the high profile of company-specific design and long production time of injection molds a relatively early alteration of the basic outside design parameter is required. Potential weaknesses of the external structure must therefore be recognized early in the development which exists at this time without physical prototypes.

With the help of LS-DYNA Black & Decker routinely performs drop and tilt tests of simulated drilling and chiseling hammers. The challenge of a case or tilt test simulation lies less in the actual calculation of the different test case variants, but rather in the provision of a suitable simulation model. A basic simulation model includes not only the external structure but the large parts of the "inner" Hammer modules (see Figure 9). The consideration of the internal components is necessary to depict what the reality is during impact resulting load paths. It can also be high on impact loads on the adjacent inner hammer components that are visible only through a simulation model with detailed interior. Besides the high number of model parts the cost of modeling is enhanced further by the necessary high detail of the outer structure. This is required to map the particularly numerous slug connections and form conclusions of the plastic parts in sufficient detail. Due to the demand for lower mechanical stress on the user decoupled handles are used increasingly these days. The picture of this often very complex geometry drives the appropriate level of detail further. Therefore, a sufficiently accurate model consisting of the external structure with three-dimensional elements (hexahedral, tetrahedral and pentahedron) with small element lengths (0.8 to 2.5 mm) can be constructed. A modeling of the external shell elements is not an acceptable alternative.
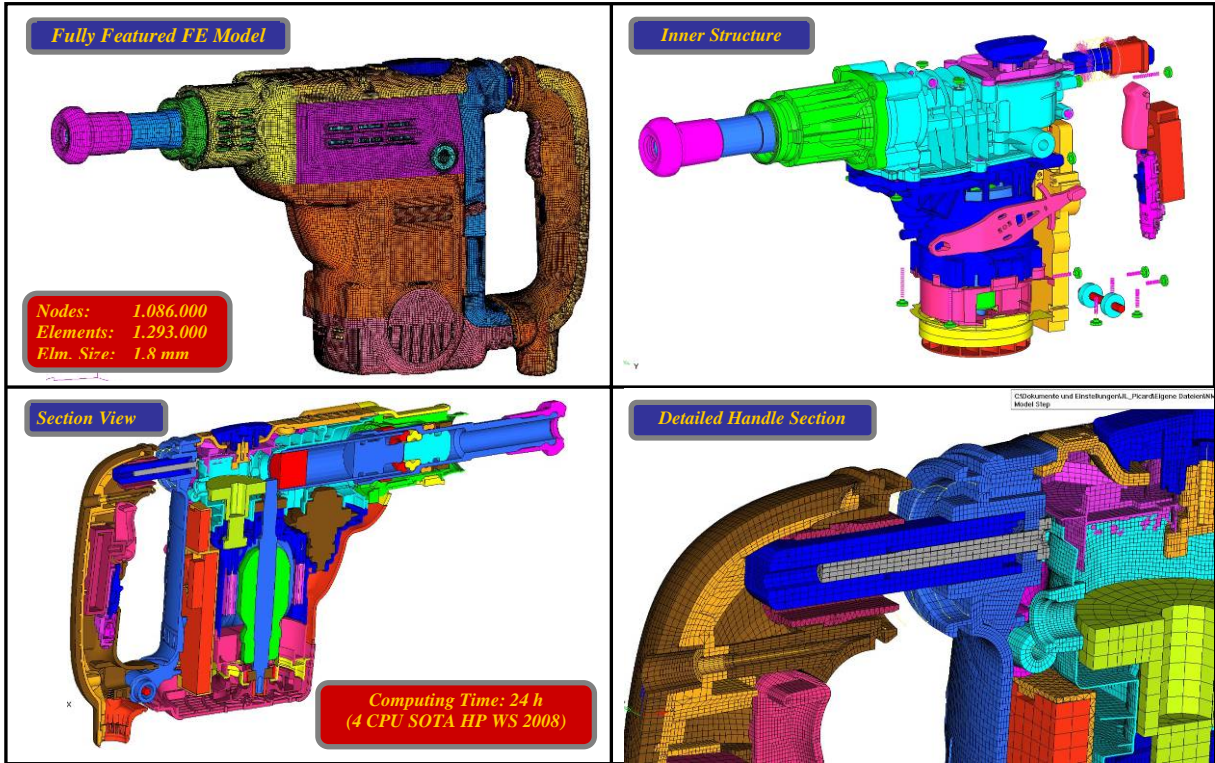
Fully Featured FE Model

Nodes: 1.086.000
Elements: 1.293.000
Elm. Size: 1.8 mm

Inner Structure

Section View

Computing Time: 24 h
(4 CPU SOTA HP WS 2008)

Detailed Handle Section

Figure 9: Design and detail of a complex FE-model for the drop test simulation

COG

V_{impact}

Handle Drop
Test Case 2m

Strain During Drop Phase

Strain During Drop Phase

Rigid Wall Force - Normal Force

F_{Rigid Wall}
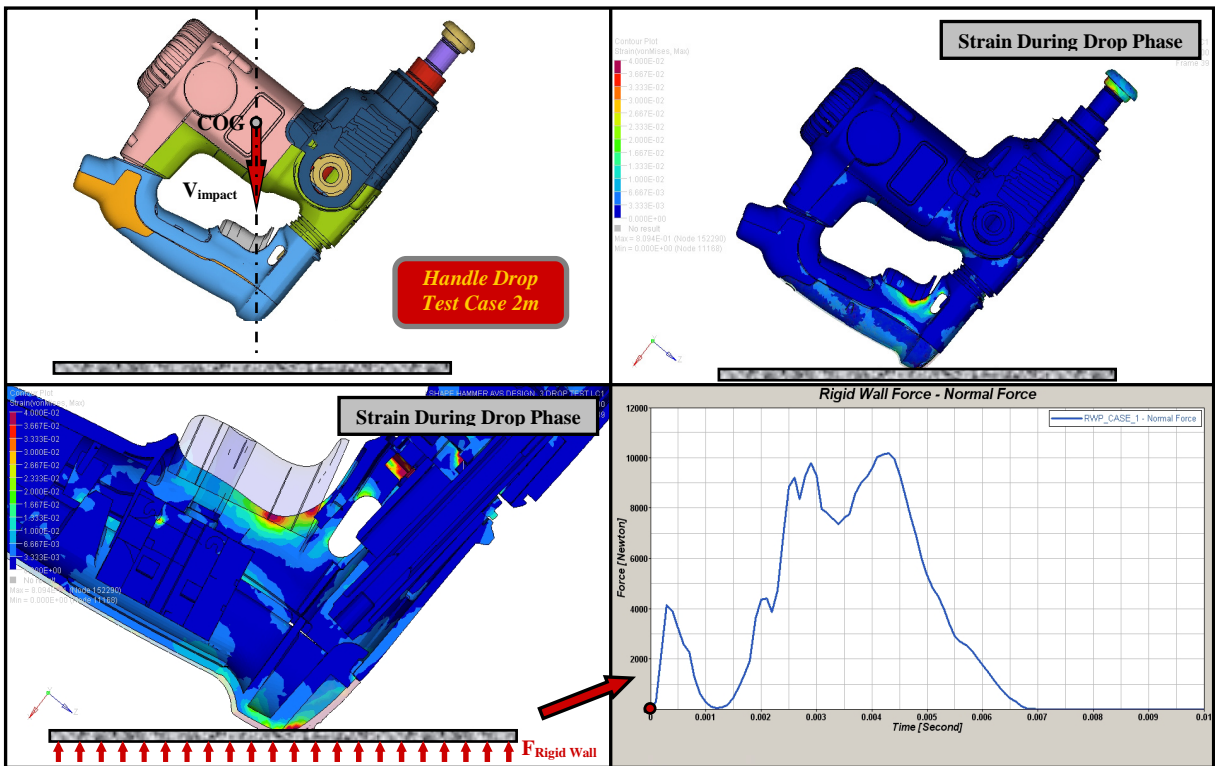
Figure 10: Typical drop test simulation of a rotary hammer with anti-vibration handle

If there is a powerful simulation model created beforehand, we can locate the virtual prototype with high predictive accuracy and potential vulnerability for the external solution to be worked out. The evaluation criterion for the identification of potential weaknesses in plastic parts is the

strain (comparison and main strains), and the following isotropic material models are destroyed (see Figure 10 & 11). For an exact prediction of plastic parts from the advanced material model it is necessary to know both the fiber orientation (directional modulus) and enlarged failure criteria (e.g. strain-pressure difference, strain rate sensitivity). The advanced material models are already in selected cases in the house and Black & Decker, in cooperation with the plastic supplier to use.
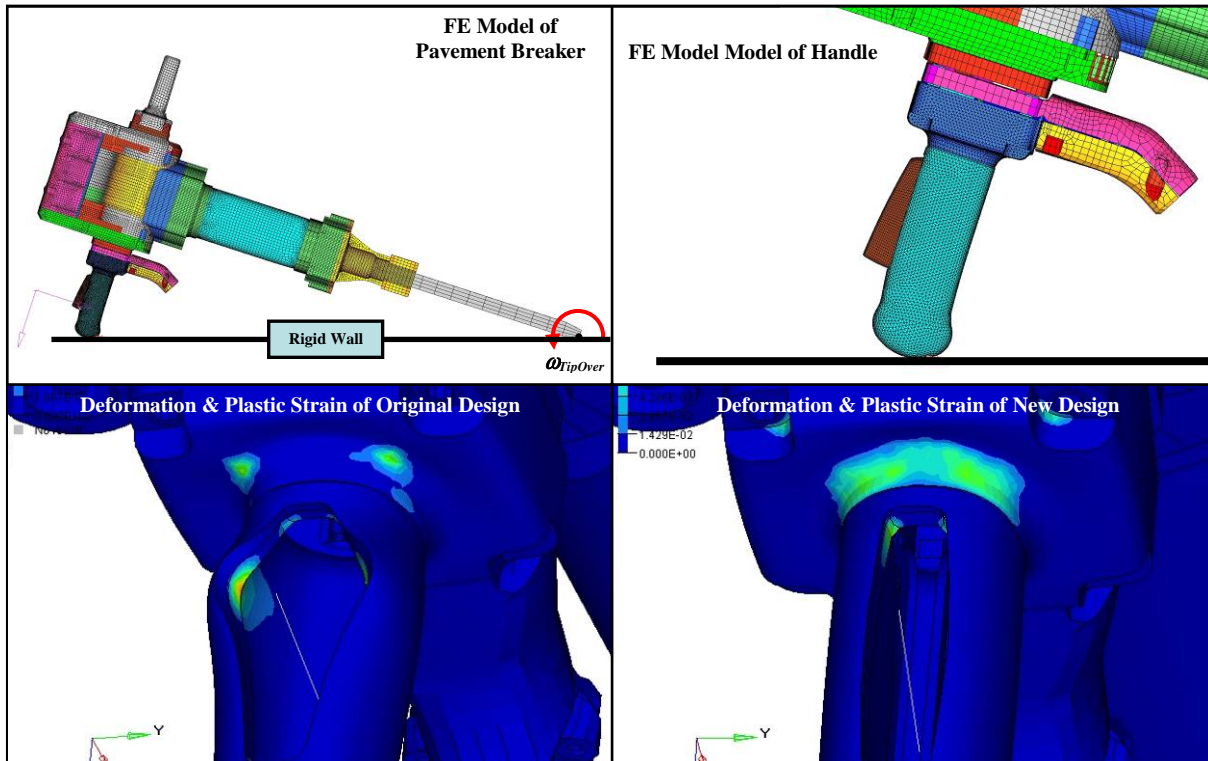

Figure 11: Typical tilt test simulation a chisel hammer with anti-vibration handle

Abuse Simulation

Another aspect concerning the interpretation of the external structure is the robustness of the connection with misuse. In particular, those electrical appliances that are designed for professional application should survive abuse due improper handling without damage. For example, a drill or hammer should resist large pull-out and bending forces introduced into the handle from say, improper release clamping of a drill or chisel.

The abuse simulation used by LS-DYNA has a limit as calculation software. Although the pull-out and bending forces are in practice applied abruptly, the resulting structural loadings are not uniquely static or dynamic in character. The accuracy of the expected stress results would require an implicit FE-calculation software (e.g. Ansys). But this has the crucial disadvantage of an already existing drop test simulation model having to be completely rebuilt for an *implicit* calculation. The calculation in practice has shown that with careful coordination of the calculation parameters (network density, element type, contact definition, load application, accuracy), a sufficiently accurate prediction of the respective voltages (Conciliation and principal stresses) is possible. Consequently, the use of LS-DYNA, both the test case and the abuse of simulation are performed with the same simulation model.
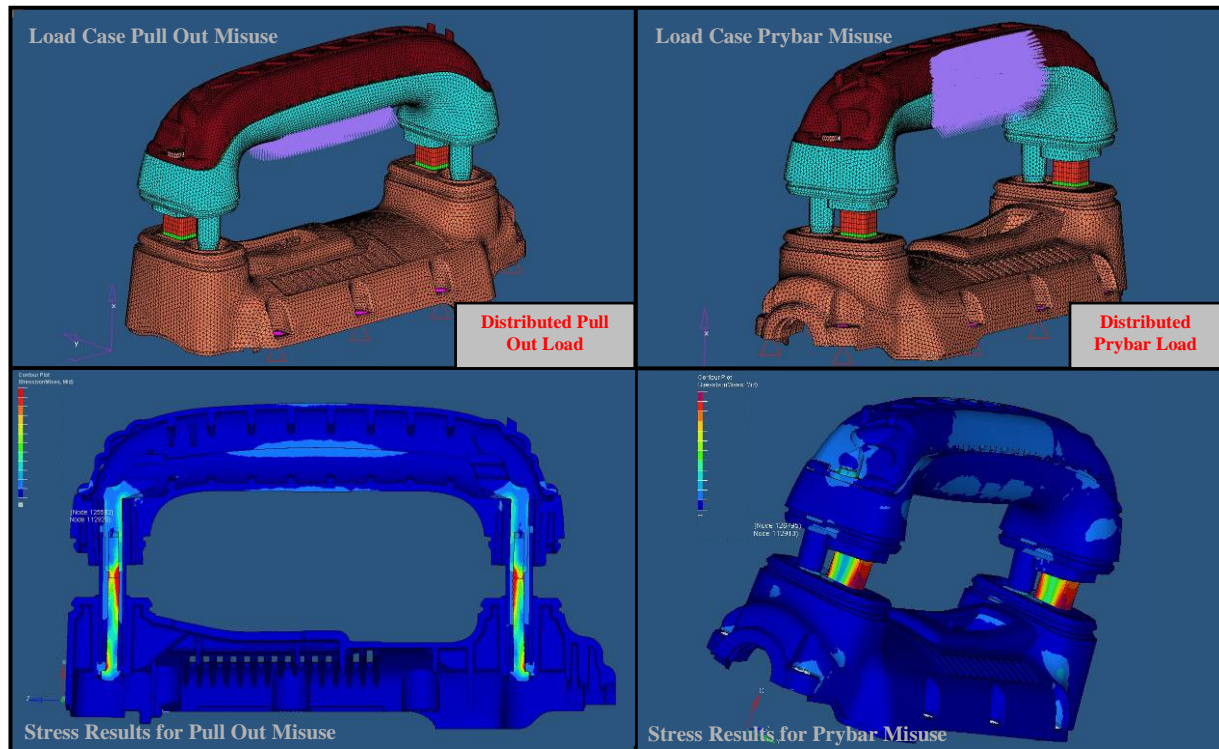
Figure 12: Typical simulation for an abuse hammer handle

4   LS-DYNA usage for the simulation of hammers and hammer drive

Blank Space Simulation

The pneumatic hammer mechanism must recreate the task of the actual blow. In iron-operation with this chisel meets the impactor on the so-called anvil, which then hits the chisel again. However, if there is no chisel in the device or is there is no load (the user does not generate pressure force on the hammer), there may be spaces in the device. In a blank space which produces impact energy that is not transferred over the device to the concrete. The anvil is moving unabated in the spindle, resulting in a longitudinal oscillation and is highly dynamic (generated in the axial direction). Also known as a shock wave, this oscillation produces, among other things, high-frequency voltage within the spindle structure. This can lead to cross sectional jumps in the particular structure and micro-damage in the component (see Figure 13). To eliminate spaces a catching device holds the anvil. In practical use the device cannot avoid all the spaces, so this load should be considered when interpreting the hammer mill components.

To simulate the spaces and the resulting tensions LS-DYNA offers high-performance algorithms and contact and parabolic tetrahedron for fast and accurate modeling of the blank space problem. Furthermore, damping of the hammer mill is provided by built in rubber rings with viscoelastic properties material-models are mapped depending on thermal expansion rate.
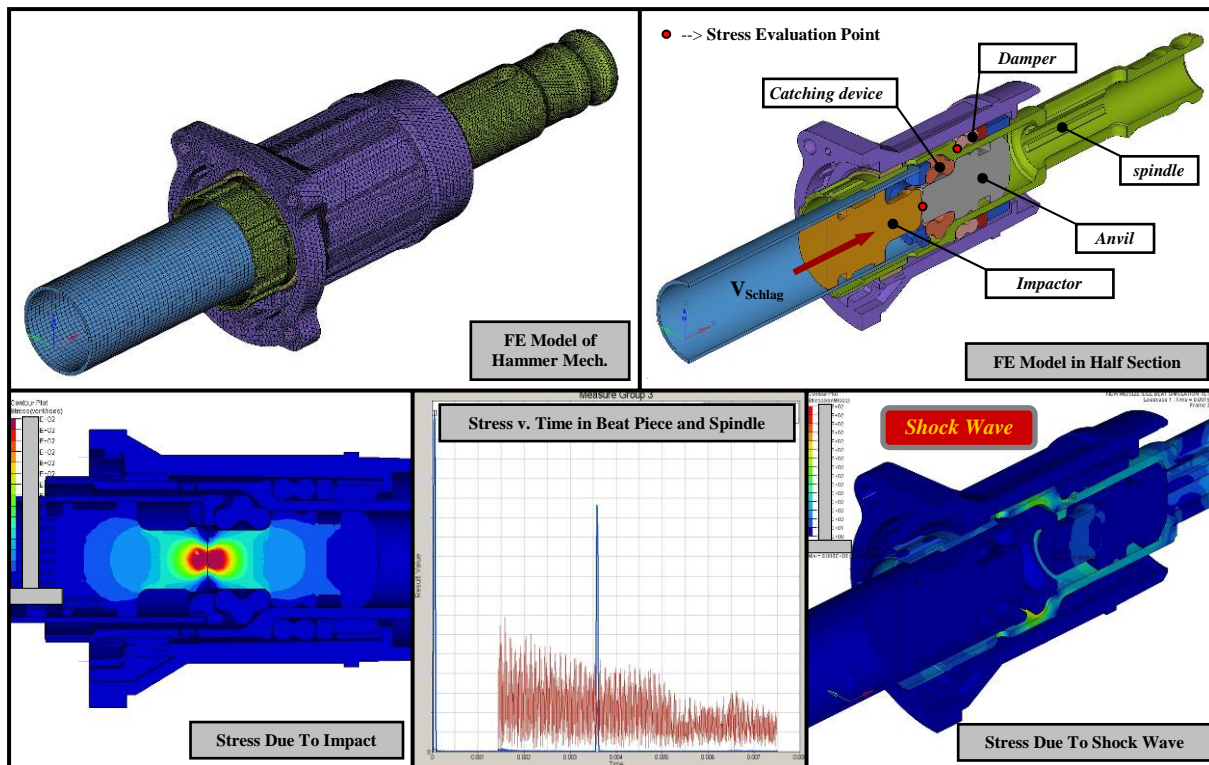
Figure 13: Blank space simulation in the hammer mill without a chisel

Hammer Drive Simulation with LS-DYNA

The hammer is used to generate the drive's reciprocating motion and the production of spindle rotation. From a rotation-translation converter for the piston actuator, a safety clutch and two gears in the gearbox, one of which is switchable to Hammer drills, are connected. The switchable gear stage is used to adjust the various device models in Hammer drills (only for chisels, chiseling and drilling, and simple drilling). A hammer on the other hand requires no switchable gear and no clutch, as this only has one working mode and produces no rotation.

The hammer driving a drilling hammer and chisel must be designed for durability. In the development phase it is therefore necessary to know the burden of the individual components and to assess the long term strength. The simulation of single-hammer mill components (e.g. Ansys) would first require the development of the system with a multibody simulation program to determine the necessary boundary conditions of the individual components. Furthermore, it would be necessary for some components of the hammer drive's boundary conditions to be calculated based on flexible body, as a rigid body would reflect this poorly.

With the help of LS-DYNA, it is possible to simulate the hammer drive in a "working performance". By using selected joint definitions (joints), manual definition of the surface contacts (including friction), and time-and travel-dependent definition of the other conditions (such as pressure, displacement, etc.) is a very possible to map performance-efficiency of the hammer drive with elastic bodies. It allows for the calculation of the required voltage characteristics simultaneously for all components and for a full stroke cycle. It should be noted here that this type of simulation requires the use of double exact code, as it would otherwise occur *after* the first shock cycle to numerical instability of the simulation. The total reaction of

the tapping machine continues to deliver significant added value to an "on-accumulated" consideration of part simulations, it provides comprehensive system understanding (see Figure 2, 14 & 15).
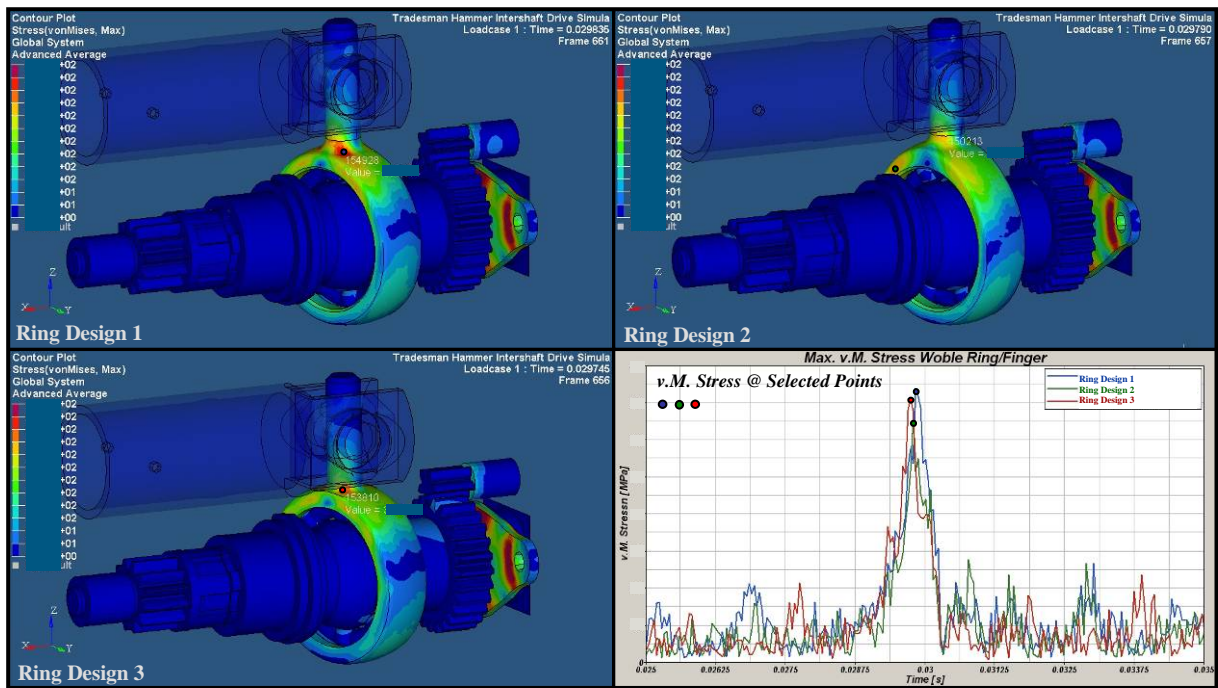

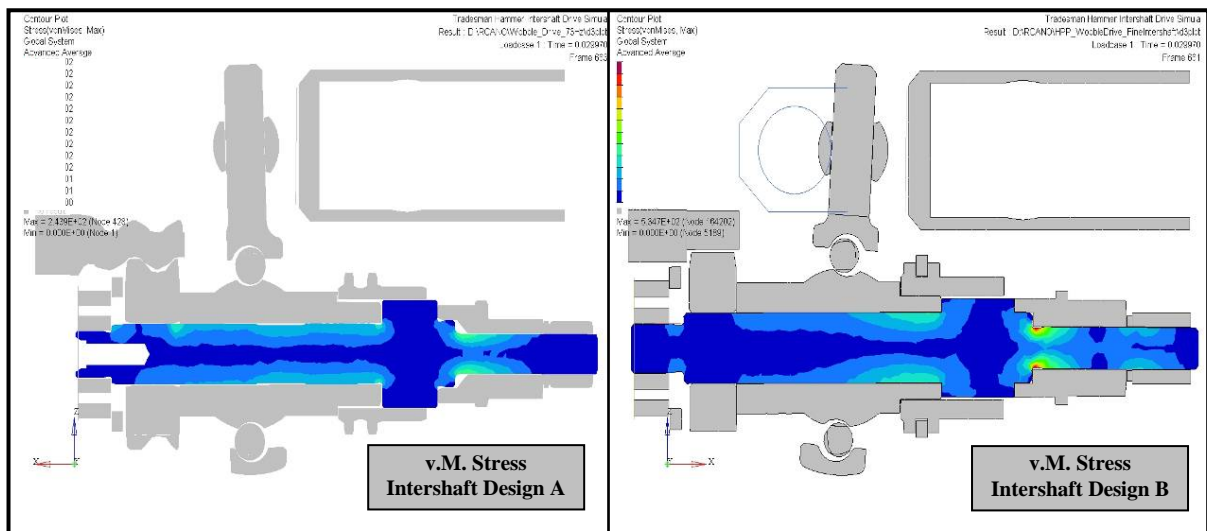*Figure 14: Results of a hammer driving simulation for different designs of the wobble ring*

Figure 15: Results of a hammer driving simulation for various wave designs

The safety coupling with a Hammer drill is used to decouple the drive spindle from the actual hammer drive in case of overload. It is classified as a safety critical component and is designed to protect users with a clamping drill from injury by a sudden occurrence.
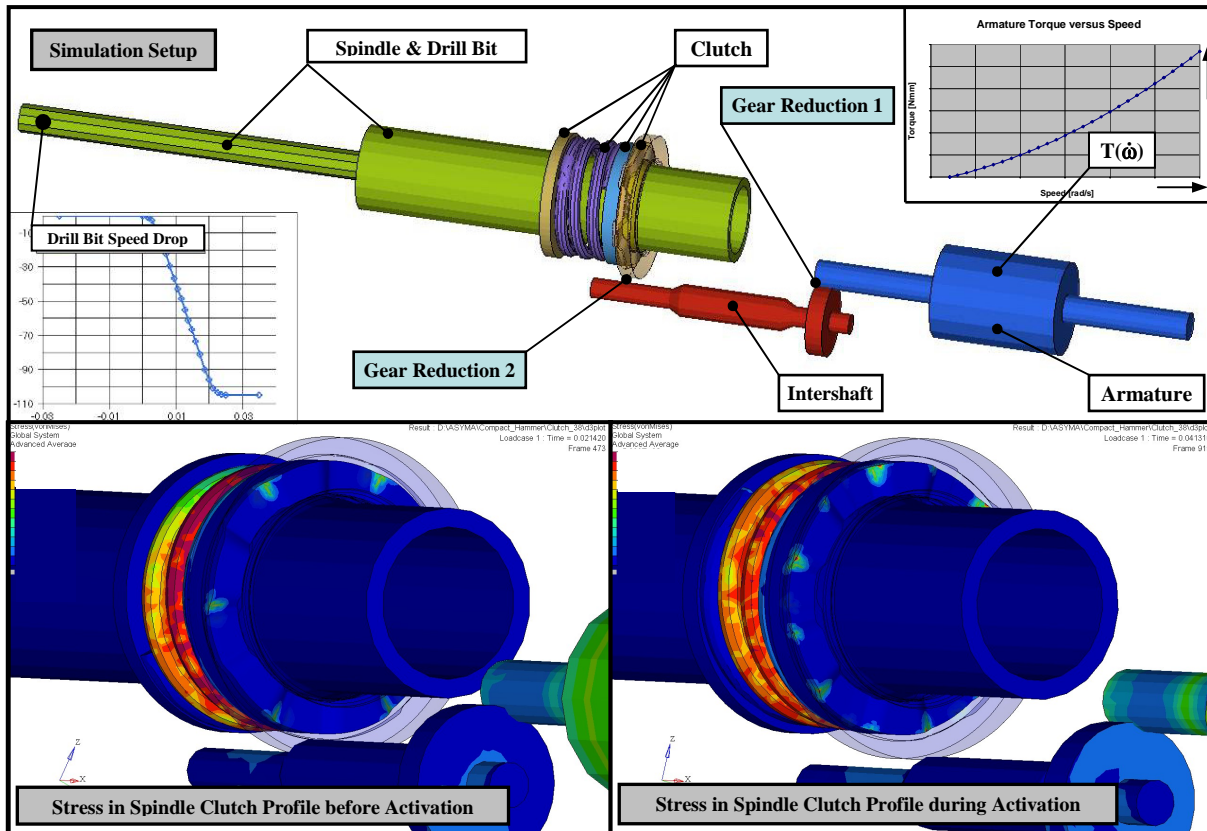
Figure 16: Setup and results of a coupling with LS-DYNA

A Hammer drill coupling is designed as a spring-loaded positive locking clutch. It is subject to mechanical wear in the use of equipment that would change the release torque of the coupling both upward and downward. In the design of the clutch, it is therefore necessary to understand the triggering dynamics.

With the help of LS-DYNA, it is possible for the triggering of a Hammer drill to simulate coupling relations. For this purpose it is necessary to take into account the entire drive train (motor armature, gear, intermediate shaft and spindle) with its stiffness and inertia in the overload simulation. Furthermore, one must adapt the engine torque-speed dependent on the specific rotating speed of the engine (see Figure 16). The evaluation criteria are clutch simulation, the release torque, the surface pressure measurement between the form-fitting parts and the stresses in the form-fitting parts.

5   LS-DYNA usage in simulation of the tool holder

The tool holder - also called feed or chuck - is used to hold and lock the drill and the chisel. A feed is subject to frictional wear with diverse loads, resulting primarily from hammer blows (especially spaces) and misuse (impact and bending forces). Similar to the hammer mill the tool holder will also be reviewed with LS-DYNA on the blank space load (see Fig.17). Similarly, the feed is subjected to abuse by a default simulation to identify potential structural weaknesses. The example of the tool-holder here is a running LS-DYNA simulation according to the feeds that are shown.
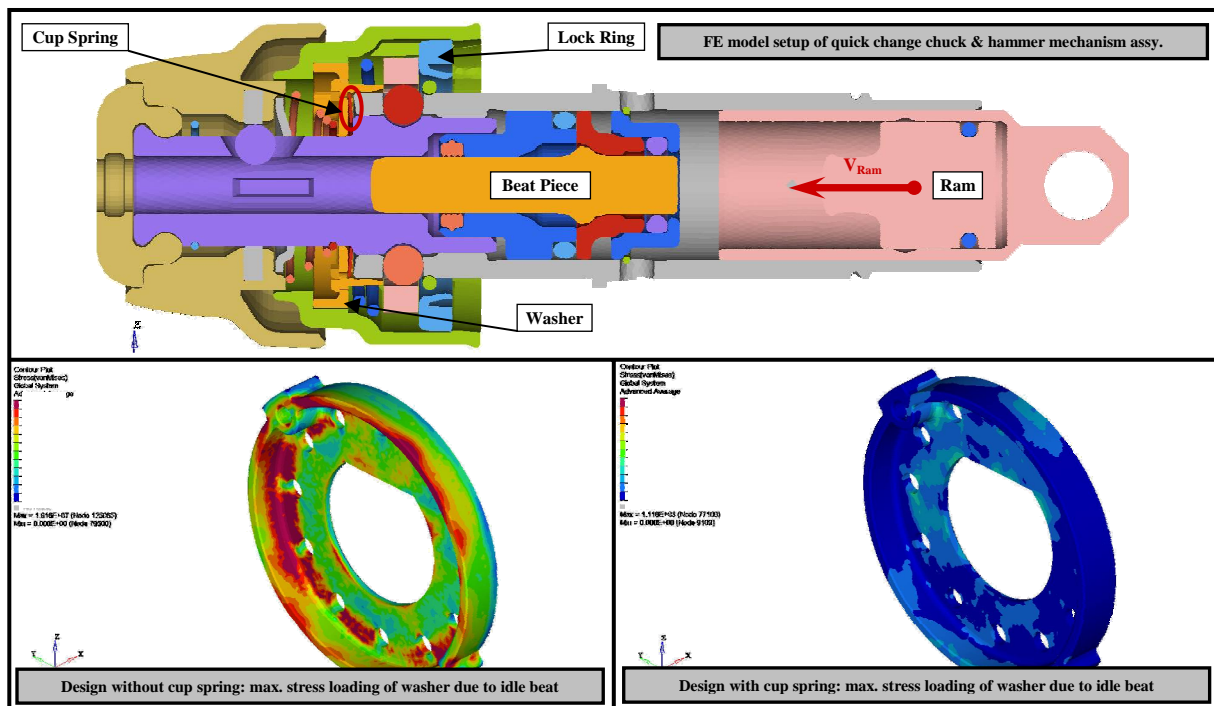

Figure 17: Results of a voltage blank space load on a tool holder for different designs of a plate-like component (Washer))

Figure 18 shows the configuration of the calculation, Figure 19, the strain results for different designs of the locking ring.
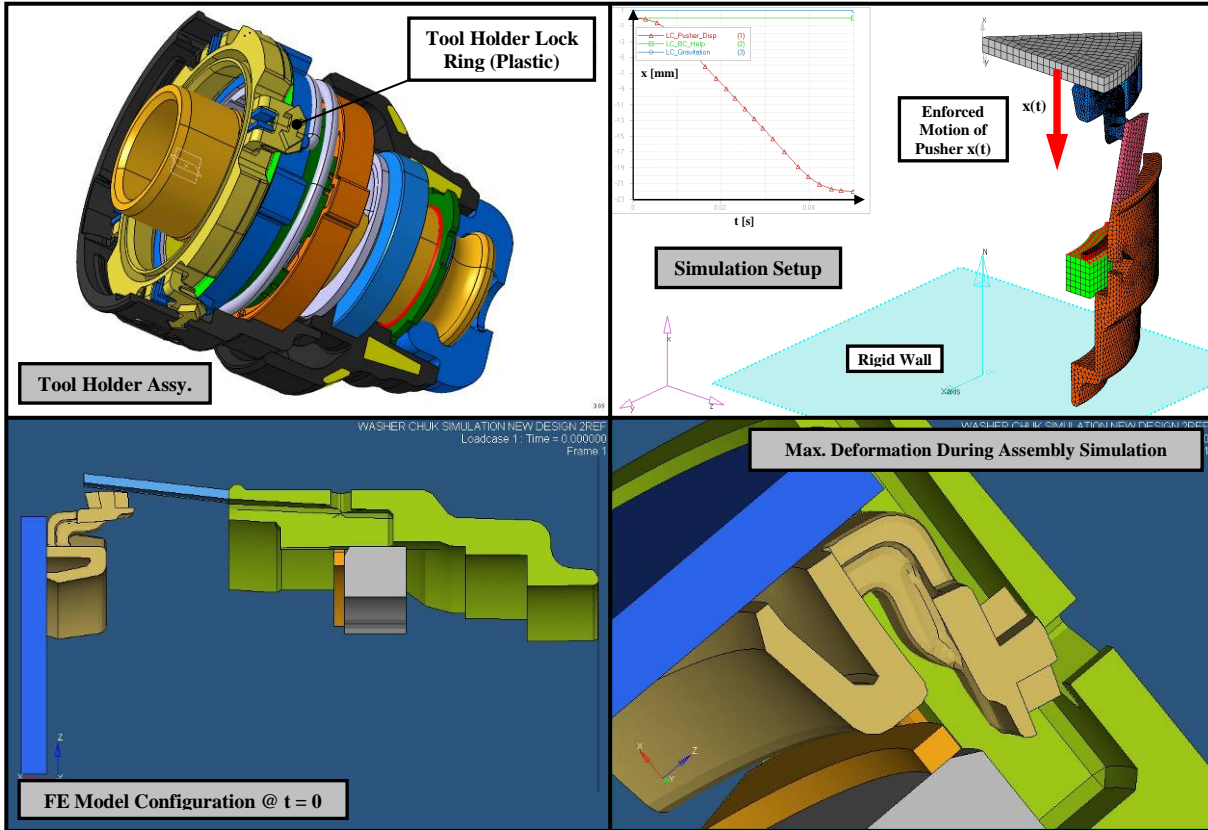
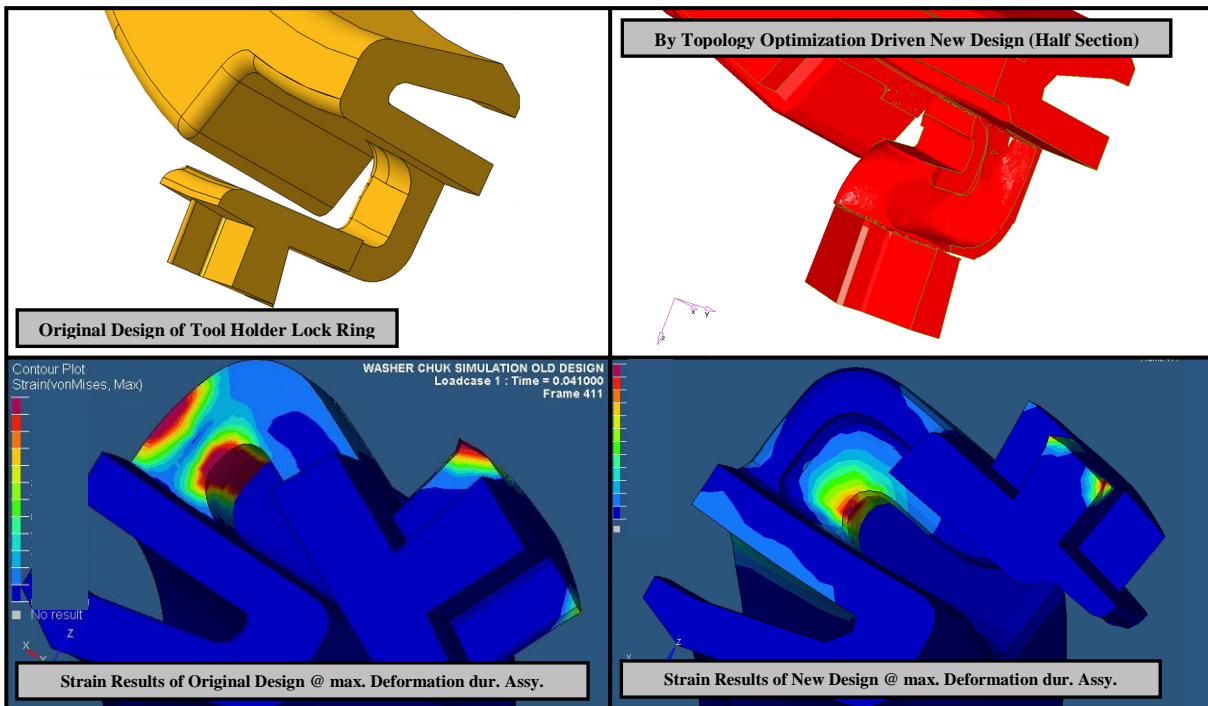*Figure 18: Configuring a simulation with LS-DYNA for a tool holder*

Figure 19: Results of a simulation with LS-DYNA for a tool holder