

INTERACTIVE VISUAL ANALYSIS AS A SUPPORT OF OPTIMIZATION AND ANALYSIS OF INTERNAL COMBUSTION ENGINES

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1. Introduction

Increasing complexity and a large number of control parameters make the design and understanding of automotive engines (and all other complex systems) impossible without simulations today. Strict emission rules and regulations force manufacturers to design improved engines in a very short time. In order to meet those requirements, car manufacturers use simulations as a cost-efficient, and often the only possible way to design systems with desired characteristics. During the design process in car industry many different aspects of new designs are checked using simulation long before a new car is manufactured. Examples include mixture formation and combustion, engine cooling and filter regeneration, air conditioning in the passenger cabin and front shield deicing, and many others. The increasing complexity of automotive subsystems, e.g., the power train, the intake and exhaust system, or the fuel injection subsystem, also require simulation for optimization. Tuning of an injection system, for example, for modern cars is an example of a multiparameter optimization process. The operation of the injection system depends, in a very indirect way, on several parameters. Therefore, optimization by experience and intuition is usually not possible.

The common practice today is to define a model, run the simulation, and study results. Engineers often use diagrams or 2D charts in order to depict various results. In case of 3D CFD, 3D visualization is also used to illustrate results. However, these visualizations are rarely interactive; they are rendered once and explored then. If engineers have to optimize a model, numerical optimization of the underlying mathematical model is usually used. A clear hypothesis is necessary for such an approach.

As data amount and complexity grows, automatic analysis methods are often not sufficient any more. In order to efficiently cope with huge and complex data sets, interactive visual analysis (IVA) tries to balance human cognition and automatic analysis. The power of human cognition is used to guide analysis. The IVA approach provides an interactive discovery framework. It helps the user in getting insight, in understanding the data and complex, often hidden, correlations and interplay between certain data dimensions. The visual information-seeking mantra – overview first, zoom in, details on demand – as defined by Shneiderman summarizes the main idea. Interactive visual analysis is much more than presentation only; it supports users in the analysis of complex and heterogeneous data sets. It is necessary as our ability to understand and analyze data cannot cope with the always increasing pace of data generation and simulation.

In this paper we describe three projects where we have used interactive visual analysis for: optimization and rapid prototyping of a common rail injection system, analysis of a timing chain drive, and analysis and optimization of an elastohydrodynamic (EHD) lubrication bearing. All of these projects have been done in close cooperation between visualization experts and mechanical engineers.

We have used coordinated multiple views for the analysis and three different simulation tools, AVL EXCITE Timing Drive, AVL HYDSIM, and AVL EXCITE Power Unit, for different parts of the engine. In contrast to a conventional way where engineer sets up a model, runs a simulation, and analyzes results then, we have used multiple simulation runs. The main idea is to define a range of control parameters and to run many (up to 20 000 in our case) simulations. Interactive visual analysis will help then to analysis results, to support experts in getting insight and understanding the model. We will describe the coordinated multiple views and the data model used in the section 2, the first case analysis of the time chain drive in the section 3, simulation steering and rapid prototyping of an injection system in section 4, analysis of an EHD bearing in section 5, and finally section 6 will conclude the paper.

2. Data Model and Coordinated Multiple Views

In case of multiple simulation runs we have a complex data set. There is one record, or data item, for each simulation run. It contains independent and dependant variables. Independent variables are control parameters; they are varied in order to create multiple runs. For each unique set of control parameters a set of dependant variables is computed. The control parameters were always scalars in our case, and output parameters were scalar or function graphs. Having function graphs as output makes the data model more complex. One record, which represents one simulation run, has scalars and function graphs. As we have many records, we call all function graphs which belong to the same output parameter (but different combinations of control parameters) a family of function graphs. We have used a coordinated multiple views (CMV) system, ComVis, in order to analyze our data.

ComVis is an interactive visualization tool based on coordinated multiple views principle. It supports various views, such as, e.g., scatter plot, parallel coordinates, histogram, as well as two special views curve view and segmented curve view used for displaying families of function graphs. The scatter plot and histogram are well known in engineering. Parallel coordinates are often used to explore multidimensional data sets. The main idea is to place more coordinate axes parallel to each other and to connect points representing values from a particular record on each axis with a line. In this way each record is represented with a poly line. Although it might seem confusing for a novice user, parallel coordinates are certainly very powerful analysis tool. Correlations between neighboring axes are clearly visible, and in combination with linking and brushing many unexpected patterns can be detected.

The curve view depicts all curves simultaneously, and user can intuitively select a subset by simply drawing a line across curves. All curves which cross the line will be selected. The segmented curve view divides the horizontal axis in discrete steps. For each step a bar divided in bins is drawn. In this way a distribution of values for each step on the x-axis can be seen.

The combination of views makes it possible to analyze wide variety of data sets. The main idea of coordinated multiple views is to display more views simultaneously. Every view can be of any supported type. Figure 1 illustrates basic views.

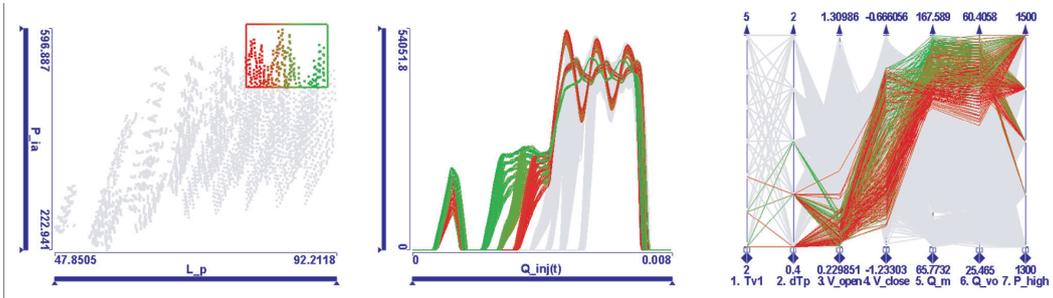


Figure 1. We investigate the conditions when fuel is injected deep in the combustion chamber and with high power. The corresponding items are brushed in the scatter plot diagram. The linked injection rate function graphs show that this requires boot-shaped main injections. The desired needle opening and closing velocities are highlighted in the parallel coordinates view

ComVis pays great attention to interaction. Linked views enable user to easily select a subset of data points in any view and all corresponding items in other views will be highlighted. This offers significant advantage compared to static views. Figure 1 illustrates the basic idea. User brushes (interactively selects) the items with high P_{ia} and L_p output values by simply drawing a rectangle in the scatter plot. The curve view shows all possible curves in gray as a context, and selected curves as curves in focus. Finally, parallel coordinates view shows the values of control parameters which correspond to the selection and all values in gray. We can immediately see that, e.g., V_{open} (the 3rd axis) has to be low if we want P_{ia} and L_p to be high.

Besides simple brushing ComVis supports composite brushing. Multiple brush mode makes it possible for the user to combine various brushes. The user selects brushes and Boolean operations between them. AND, OR, and SUB are supported. Furthermore the tool creates composite brush in an iterative manner. This means that user selects current operation (AND, OR, or SUB) and draws a brush. The previous brushing state is combined with the new brush. The new state is computed and the new state is used when user draws a further brush. In this way user immediately gets visual feedback, and can very easily broaden his selection (using OR), or can further restrict selection (using AND or SUB). Although this mechanism is less formal than a real Boolean editor for brushes it is very efficient and allows very fast information drill-down. We will illustrate how such a system can be used to support mechanical engineers in various tasks during a design of an IC engine.

3. Case 1: Timing Chain Drive

A timing chain drive (or a belt drive) is found in most production car engines. The purpose of the timing chain drive is to transfer motion from the engine's crankshaft to the camshaft. The camshaft actuates valves that must be synchronized to the piston's motion. Therefore, precisely two crankshaft rotations are needed for a single camshaft rotation. The chain's motion deviates from its ideal kinematic path especially at high engine speeds. Dynamic and inertial phenomena cause vibrations that increase noise levels and mechanic wear. The vibration causes the accuracy of the motion coupling to deteriorate. The camshaft's rotational velocity does not remain constant and undesired high frequency components are added. This induces rougher and less controlled valve operation which can reduce fuel economy and power output. This can be simulated in software thus simulation tools are used extensively in the design of timing chain drives. The basic approach is to model each chain link as a single rigid mass connected by spring/damper units to neighboring chain links and simulate the resulting multibody system based on the Newton-Euler laws. The motion of the chain is computed only in the y-z plane. The motion perpendicular to the plane can be ignored without influencing the validity of the simulation. Therefore, each chain link has three enabled degrees of freedom (DOF): translations in y and z directions and rotation around x- axis. Sprockets are modeled as generic mass elements with only one DOF: rotational around x-axis. In a simulation the objects are described using their contact contours. The contours of sprockets and guides reflect their actual shapes. However, the contours of chain links consist of circles around the pins that interconnect the chain links, because these are the surfaces in contact with the sprockets and guides. There are two circular contours at both pins of the chain links. The smaller circle is the surface that comes into contact with the sprocket. The larger circle is the outer surface of the link sliding on guides. The simulation computes (among other attributes) forces between elements. There are two classes of forces: (a) contact forces between chain links and the sprockets/guides, and (b) connection forces between neighboring chain links. The contact forces act when a link comes into contact with a sprocket or guide. The algorithm for computing contact forces is based on evaluating the size of the overlap area between the contact contours of the two objects, the stiffness of materials, the relative velocities and the damping properties of the materials. The connection forces act between neighboring chain links and are computed in a similar way. Figure 2 illustrates the corresponding connection and contact force models.

We used a model of a basic type chain drive system which consists of two sprockets, the camshaft sprocket (38 teeth) and the crankshaft sprocket (19 teeth). Additionally, two fixed guides lead a bushing chain along the chain path to reduce vibrations. The constant load is applied at the camshaft sprocket and a constant rotation is prescribed at the crankshaft sprocket. Lash in the chain and friction

in contacts between the chain and sprockets are not considered. A commercially available software package, EXCITE Timing Drive from AVL, was used for the timing drive simulation.

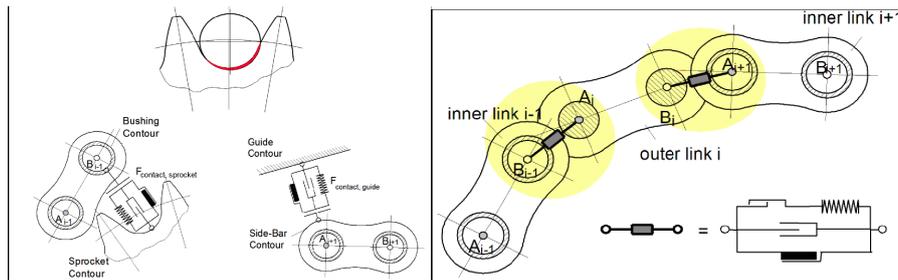


Figure 2. (left) A model of the contact forces between chain links and sprockets. The red region indicates the overlap area of the contact contours. Each chain link has smaller circular contours at both ends that model the bushing which comes into contact with the sprockets. The side-bar contour is the outer edge of the chain link that slides on guides. (right) A model of the connection forces. Each chain link is connected to its neighbors via stiff spring and damper elements

Numerous control parameters can be defined in the simulation software. In the scope of this case study we varied engine speed and four design parameters: sprocket stiffness, guide stiffness, chain preload, and camshaft sprocket offset from the designed position in the z direction. A positive offset means that the camshaft sprocket is further away from the crankshaft than its kinematically ideal position; therefore the chain becomes relatively short. In our case, there are 1,152 possible combinations of these parameters or 1,152 simulation cases. A simulation run is performed for each case with a simulation period that is sufficient for all chain links to complete a full revolution. Five response parameters were computed for each case:

1. Maximum contact forces [N] for each chain link. This is a function graph where the independent variable represents a chain link (1 to 100) and the dependent variable represents the maximum of the contact forces that act on the link in the simulated time span.
2. Maximum connection forces [N] for each chain link. This is a function graph similar to the previous one.
3. Overall maximum contact force [N]: scalar.
4. Overall maximum connection force [N]: scalar.
5. Fourier Transform of the camshaft sprocket's rotational velocity [rad/s vs. orders]: function graph.

Standard tools for the analysis of chain drive simulation data include 2D charts and animated 3D representation. Those methods are sufficient if engineers want to analyze one or only a few simulation runs. With increasing computer power it is possible to run multiple simulations (several thousands of them) in order to tune design parameters for optimal results. However, the analysis of many simulations requires a different approach. For example, studying one thousand 2D charts describing connection forces is not practical, nor is an elaborate 3D rendering of one thousand cases with many geometric details. Interactive visual analysis offers new possibilities for analysis of multiple simulation runs. Engineers generally face four main tasks in the analysis of chain drive simulations:

1. finding invalid parameter combination,
2. parameter sensitivity evaluation,
3. reducing chain noise, and
4. keeping contact and connection forces within a range.

The CMV system is used to support the engineer in all of these tasks. Figure 3 illustrates a snapshot from analysis, where engineer selects a combination of sprocket and guide stiffness in order to see maximum contact force. Note the low values of the contact force (in Figure 3 top) for selected case compared to the gray part of the segmented curve view shoeing the range of maximum contact forces for all combinations of control parameters. The distribution of forces is very even across all links (x -axis in the segmented curve view). If the user simply moves the selection to another combination of stiffness parameters, situation changes significantly (Figure 3 bottom). Interested reader can find more details in [Konyha 2007].

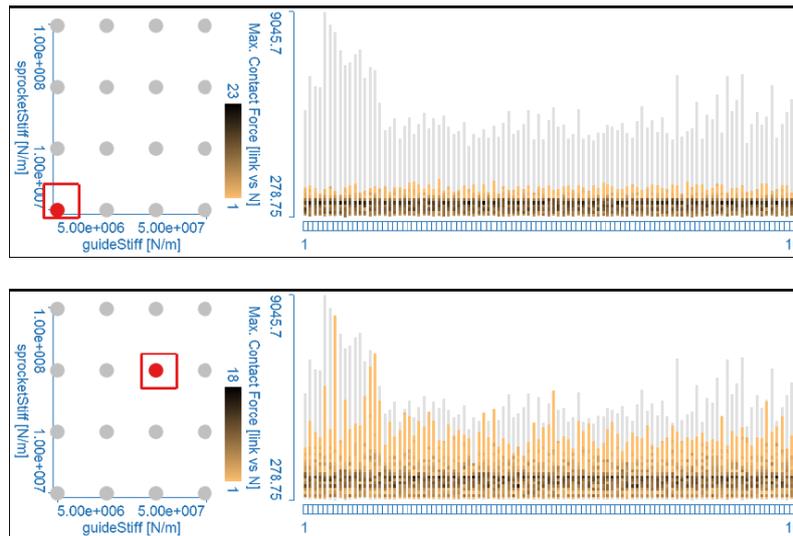


Figure 3. (top) Low guide and sprocket stiffness produces low contact forces. The distribution is very even, which means similar forces act on all chain links. (bottom) Stiffer guide material also increases the contact forces, but it also makes their distribution more varied. Some chain links often suffer considerably larger than others

4. Case 2: Simulation Steering and Injection

There are many (often conflicting) goals of diesel engine design, including the need for high power and good fuel efficiency, meeting emission regulations, reducing noise, and improving drivability. The fuel injection system is the key diesel engine component to achieve those goals. There are several properties that are considered important in the injection system: flexible timing of the injection, accurate control of injected fuel quantity and opening and closing times, and the ability to inject small amounts of fuel to achieve economical operation and good emission properties. The common rail injection system, can be controlled in a very flexible way. Injection pressure and quantity can be controlled with a high degree of flexibility, multiple fuel injections are possible within one injection cycle, and the time and duration of the injections can be controlled precisely by the engine control unit based on the engine speed and load. The simulation of injection system used is based on the theory of 1D fluid dynamics and 2D vibrations of multibody systems. There were multiple simulation runs again. The injection shape depends mainly on three factors: the nozzle geometry, injection pressure, and timings for valve opening and closing procedures. The nozzle geometry is optimized and the injector is produced then. The other two parameters, pressure, and timings for valve opening and closing procedures, are changed during the engine runtime depending on current load and speed. We focus on analysis of those parameters. Therefore, the independent variables in our current investigation are related to injection pressure and injector valve timings. The injection pressure is controlled by the injection pressure modulation device [Konyha 2006], which is positioned between the rail and injector. In our investigations, this device is not modeled in detail, but we take the modulated pressure as input. The characteristics of the pressure on the injector's inlet are described by three independent variables. The injector valve actuator that controls the injection timing is described by its opening/closing times and velocities. Therefore, we have five independent variables. We have varied those five parameters and computed 4,375 different simulation runs. For each combination of the independent variables, the simulator computes three sets of time-dependent results: injection rate, injection pressure, and needle lift. Each of those three creates a family of function graphs.

Besides function graphs, simulation computes following scalar values: amount of fuel injected during pilot injection, amount of fuel injected during main injection, amount of fuel flowing back to the fuel tank, needle opening velocity, needle closing velocity, spray penetration depth, and average injection power. Once the data was computed we have used the CMV tool to analyze the data. Figure 1 shows one stage of the analysis. During the analysis we found that the amount of injected fuel in the main injection stage can be controlled by adjusting highest pressure on the injector inlet. The amount of

pilot injection is controlled mostly by the lowest pressure on the inlet, but injector valve opening time also has some influence on it. We observed that choosing proper timing is the key to achieving the desired injection shapes for various engine operating conditions. When pressure increases too fast on the injector's inlet, then the resulting wave can be reflected into the fuel line, which impairs our control over the injection's shape. By studying the needle lift function graph and the related needle opening and closing velocity, we can define the desired needle characteristics for specific injection shapes and see how tightly the injection rate and the needle lift function graphs are correlated.

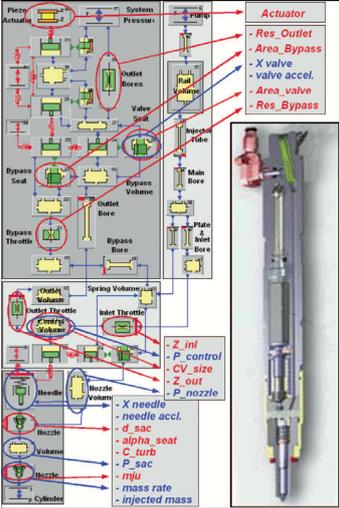


Figure 4. The final injection simulation model and the four main blocks. The blocks represent logical grouping that has no influence on the model topology. An actual injector is shown on the right. The control parameters are shown in red, and the output parameters in blue

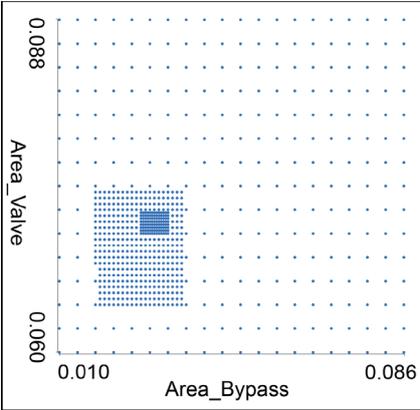


Figure 5. Combinations of the control parameters as created during the analysis. We have a coarse mesh of parameter values at the beginning, and we refine them twice during the process

In the next stage we wanted to analyze a more complex injector model (Figure 4). The parameters depicted in red in the figure are control parameters, and those depicted in blue are output parameters. One design option is to run the simulation for all possible combinations of parameters and to explore the system. If we use ten values per control parameter, there are 10^{11} possible combinations of control parameter values. Since we can run about ten simulations per minute (for our model), we would need 10^{10} minutes, or more than 19,000 years to complete all simulation runs. It is clear that this is not feasible. Instead, we propose to start with a simplified model, use interactive visualization to refine the control parameter space, and once the initial control parameters are fixed, the simulation model is extended. The four blocks shown in Figure 4 represents four stages of model complexity used in this case. The whole process is controlled from visualization. Our new framework makes it possible to define new simulations using the visualization tool. The visualization tool is used for the analysis and

for the steering of the simulation. That makes it easy for the domain expert to generate new simulations and to refine or to filter the simulation dataset. We provide four basic operations: refining or coarsening some control parameters (changing the step); narrowing down the control parameter interval (changing boundaries); adding new control parameters; and removing some existing control

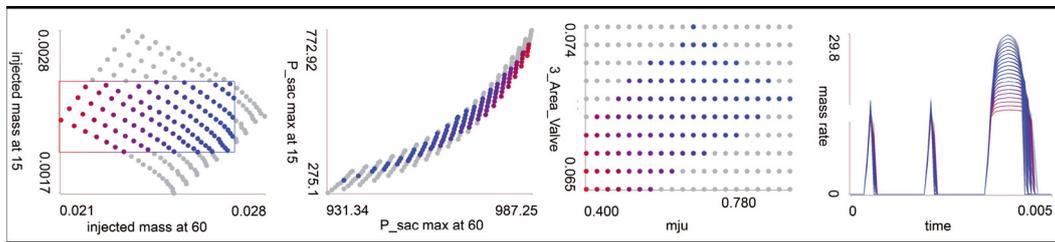


Figure 6. The final model. The target injected mass on the left is defined using a quite narrow range here. The user zoomed in at the final stage of analysis and selected only a narrow range in the leftmost scatter plot. The corresponding parameters are shown in other three views

parameters. The domain expert estimates the coarse boundaries of the parameters, runs a sufficient number of simulations and sees what parameter values make sense and what values are not allowed. In the case of fuel injection systems, the injected fuel mass was one of the output parameters often used to identify parameter values that are not allowed. If there is not enough injected fuel or if there is too much injected fuel, the engine will not run properly. We use the simulation tool to create the initial simulation model, specify the initial control parameter values and produce simulation results. Only a part of the injection system is modeled in detail while the rest is replaced with modeled “ideal” values. These ideal values became the target when we refined the model. The goal is to create a simulation model and to determine the control parameter values that produce the simulation results that are as close as possible to the idealized result. We repeat the process at three different levels. The user first designs a very simple simulation model and sets the parameters. The user then extends the simulation model and provides the parameters for a more complex model that represents the second level. Finally, the user defines the complete simulation model. Of course, it is always possible to go back and forth between different levels (as it is often the case during prototyping) and to change already tuned parameters. The domain expert carries out the interactive steering process at three different levels. The first level focuses on the already generated simulation results. The expert uses the visualization tool to investigate the simulation results and, by extensive use of brushing and linking, can get first insights. This is the same as in our previous case. If the current simulation results are not sufficient, the expert can proceed to the second level. The second level of iterative prototyping involves refining the control parameter values, generating new simulation results using the current simulation model and then returning to the first level of prototyping. The expert can do it in an interactive way and request new simulation results from the simulation tool. As new simulation results are computed, the data in the visualization tool is automatically updated. Figure 5 shows a scatter plot of two control parameters. There was a coarse grid of values in the beginning, the engineer requested new simulations using a finer grid for a subset of ranges, and finally the parameters were even further refined. At the third level the simulation tool is used to update the simulation model itself. We have used such a scenario for rapid prototyping of a common rail injector. The thigh interplay between simulation and visualization made it possible to pursue a deep analysis of the complex model. Without interactive steering it would be impossible to understand the model and complex correlations between various input and output parameters. Using here described system we were able to find an optimum set of control parameters relatively quickly. Konyha et al [Konyha 2007] and Matkovic et al. [Matkovic 2008] give a more detailed description of interactive visual analysis of above described technology.

5. Case 3: Families of Surfaces and EHD Bearing

The data model used in previous cases contained families of curves. We have extended this model further, and allowed single attributes to be surfaces. These surfaces form a family of surfaces now. Analysis of such data is a challenging task. We have applied this technology to the analysis of

multiple simulation runs of a slider bearing. For the design of internal combustion (IC) engines, the reliability of the crank train slider and thrust bearings and the piston to linear contact is of central importance. Its design affects key functions such as durability, performance, wear and engine noise. Due to increasing specific loads, all physical effects have become important and they have to be considered by an advanced simulation tool: structural elasticity and dynamics, energy flow, mixed friction, and the

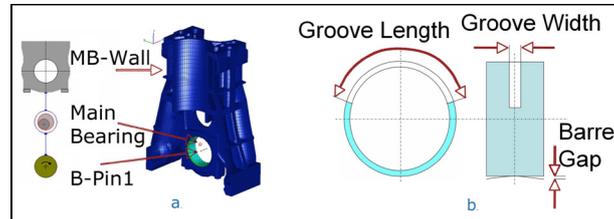


Figure 7. EXCITE Power Unit Main Bearing EHD Model used in the simulation. Topology view on the left showing main bearing wall, EHD joint, and journal and geometry view on the right. b. Parameters which were varied in the simulation. Front view of the bearing on the left, and side view on the right. The groove is used for oil supply

influence of temperature and pressure upon oil viscosity. The IC engine main slider bearing is simulated with the AVL EXCITE Power Unit solver. The corresponding model is shown in Figure 7. Numerous control parameters can be defined for a simulation. We varied three design parameters, length and width of the oil groove (used for oil supply in the slider bearing), and height of the gap in the barrel shape of bearing profile (Figure 7b). We have 225 possible parameters combinations, resulting in 225 simulation runs in our setup. A simulation run has a simulation period of two engine cycles which, for a four stroke engine, results in four complete revolutions of the crankshaft, or a revolution for 1,440 degrees around the rotational axis. Due to numerical instabilities in the first calculated engine cycle, only the second cycle is used for results evaluation. Seven response parameters were computed for each of the 225 simulation runs. The simulation tool computes the distribution of the response parameters over the entire bearing shell surface. The values are computed for every degree of crankshaft revolution using regularly spaced points across the bearing shell surface. Therefore, each of response values can be seen as a data surface, spanned by two independent variables, bearing shell angle and bearing width. We have a family of surfaces now.

We have used the CMV setup again. The engineer reduced the set of control parameters by excluding maximum asperity contact pressure. By analyzing the results from the simulation runs we saw that asperity contact is reduced in general by increasing oil groove length. At the same time asperity pressure can be reduced by decreasing oil groove width. The most interesting region is identified: groove length of 180 degrees which is preferable from production point of view and small groove width. Figure 9 shows four stages of the analysis. We first brush the region of interest in the scatter plot. This brush in the left scatter plot in Figure 9a remains the same throughout the analysis. In the first steps (Figures 9b–d) we also focus on one value of the barrel gap. Later we refine the selection using a histogram brush on the barrel gap histogram (second histogram in Figure 9a, active only for Figure 9e). Results for those six combinations of groove size (as selected in the scatter plot) and always the same barrel gap (as selected in the histogram) are showed for complete engine cycle – for all crankangles. To look at the results in more detail, the distribution of asperity contact and hydrodynamic pressure is also shown as a 3D surface, plotted over the bearing shell angle and the bearing width for all crank angles throughout Figure 9. Figure 9b shows that maximum asperity contact pressure for selected cases is less than 50% of the maximum pressure in all simulation runs (PRSA-MAX graph) and maximum hydrodynamic pressure is also reduced by approximately 10% (PRES-MAX graph). The user likes the 3D surface view in wire-frame mode. He always uses it in order to see if there is some strange behavior. As this view depicts many data surfaces simultaneously all we see is a kind of envelope. He can hardly see the interior of the family of surfaces where many data surfaces are possible (and can be clearly seen in function graph views). By looking at the 3D

surface distribution one can see that asperity contact appears at bearing edges and mainly at one side of the bearing due to the distribution of applied bearing moments (Figure 9b). The PRSA 3D surface view shows all peaks at one side. At the same time, the distribution of hydrodynamic pressure has a peak in the central bearing region (PRES 3D surface view and function graph view). When we apply the third brush (Figure 9c) and show only the maximum values of hydrodynamic pressure, one can see that the maximum appears at only one crank angle near to the top dead center, where maximum bearing forces are acting due to the combustion in the particular cylinder. At this crank angle, the distribution of hydrodynamic pressure (PRES) is regular and asperity contact pressure is near to zero (PRSA). Therefore, further decreasing of the hydrodynamic pressure will probably be not feasible

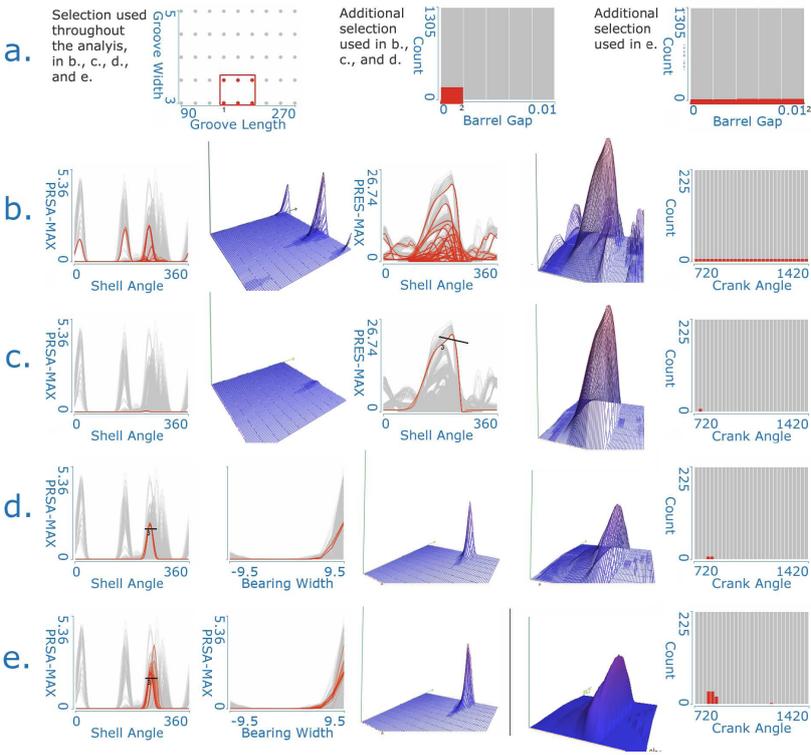


Figure 8a. Groove dimensions are fixed using scatter plot. Barrel Gap is the same for b, c, and d. The extended case is used for e. Three different peaks in PRSA were identified and explored. Selection was refined by selecting high pressure and barrel gap influence was studied. Note the use of 3D surface view and 3D scatter plot which were almost always used by domain expert - mechanical engineer. b. The interesting region of groove size was selected for an in depth analysis. c. Selections were refined by selecting high PRESS-MAX. d. Selections were refined by selecting high PRSA-MAX. e. Finally, gap was extended using histogram selection and high PRSA-MAX was selected

only with selected parameters or without any increasing of the asperity contact pressure. On the other side, when we look at the maximum asperity contact pressure in Figure 9b, (PRSA-MAX views) one can see three groups of characteristic peaks over the bearing shell angle. We select the highest, (3rd,) peak (brush 3 in Figure 9d) and explore the corresponding surfaces. It can be seen that maximum asperity contacts (the PRSA graph in Figure 9d) appear at one side of the bearing but are not the minimum in the crankangle histogram that those peaks appear immediately after maximum hydrodynamic pressure after combustion with shifted maximum values to the bearing edge where solid contact is detected (3D surface views). Typically, the asperity contact pressure at the bearing edges can be reduced by using a barrel profile of the bearing shell. This means increasing the barrel gap as defined in Figure 6b. We tried to see what is happening as we increase the gap, and we expected the asperity contact to decrease. We extended the barrel gap histogram brush over larger values of the barrel gap, the rightmost histogram in Figure 9a shows this selection. Corresponding graphs are

depicted in Figure 9e. Our results show that asperity contact is even increased due to increases of hydrodynamic pressure and the changed distribution, contrary to our first expectations. A more detailed description of the methodology and here described analysis can be found in [Matkovic et al. 2009].

6. Conclusion

We have presented how interactive visual analysis and tight coupling between coordinated multiple views tool, ComVis, and modern simulation software, AVL EXCITE Timing Drive, AVL HYDSIM, and AVL EXCITE Power Unit, can support engineers in the design process. Modern engines are very complex and multiple simulation runs and advanced analysis can significantly improve the standard workflow. Using our new methodology it is possible to check large amounts of results data and identify correlations between design and response parameters. We have also described a complex data model, containing families of curves and even surfaces. The feedback we got from domain experts was always very positive, they were impressed with new possibilities, and they quickly get used to the new way of analysis.

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