GT-Suite Users Conference

„Automated gas exchange model calibration using optimization tools"

Thomas Steidten

VKA RWTH Aachen

Dr. Philip Adomeit, Bernd Kircher, Stefan Wedowski

FEV Motorentechnik GmbH

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Automated gas exchange model calibration using optimization tools

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Automated gas exchange model calibration using optimization tools

Introduction
Problems during the model build up

Problems when modeling an existing engine:

- **In complex parts not all geometries are known, when no design sketch is given.**
- **Flow path does not follow stringently the geometry.**
- **Several boundary conditions are unknown (e. g. heat transfer to ambient,…).**

→ **To simulate a given engine correctly the calculation model has to be calibrated on measurement data.**

Hereby the cycle average values can be corrected by varying temperatures and setting multipliers in the submodels. More challenging is the tuning of the gas dynamics by varying pipe length and diameter resp. volume.

During the model build-up several problems can occur:

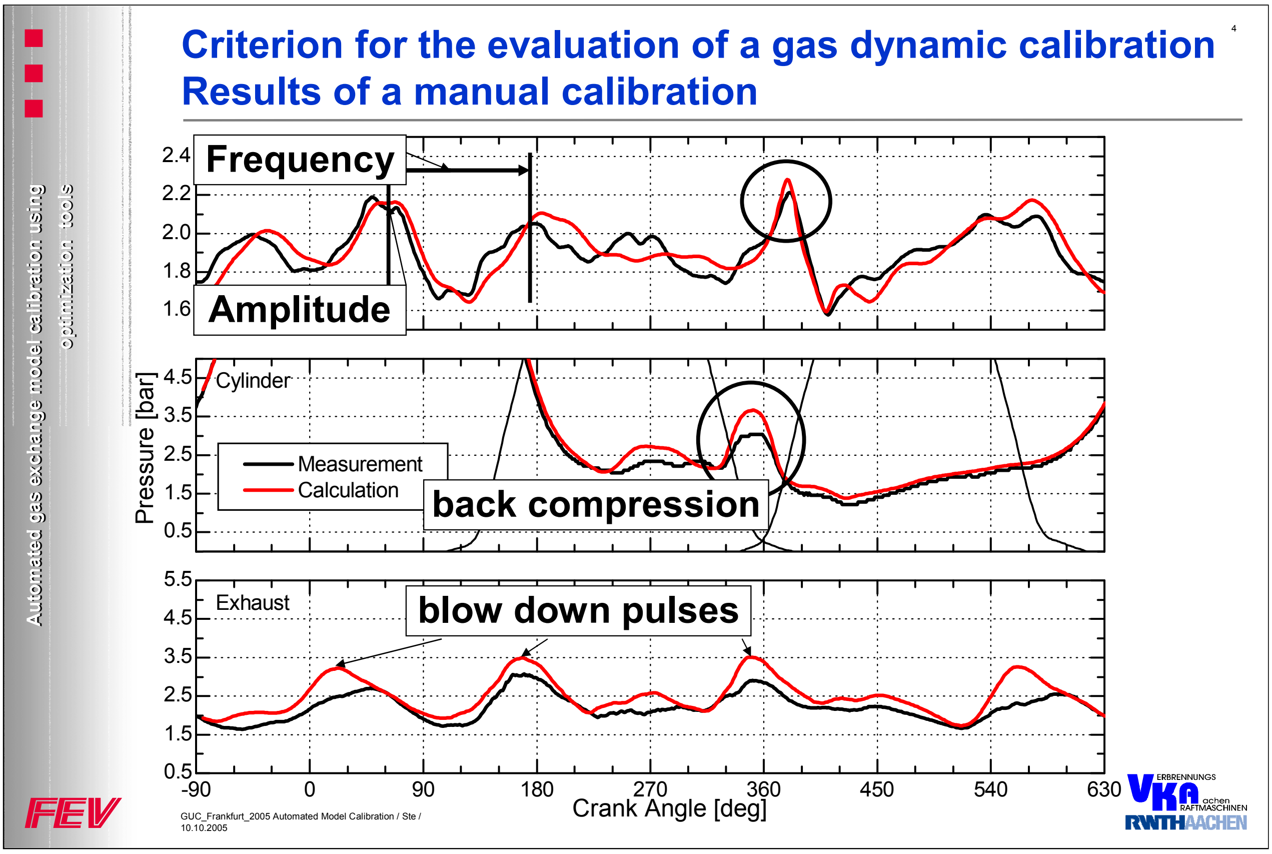
Especially in very complex parts not all geometries are known, when no drawing or CAD data is given and the inner geometry can not be measured. Furthermore the flow path does not stringently follow the geometry. Separation areas in bended pipes or at the connection of pipes and volumes influence the flow path. Finally unknown boundary conditions, e. g. heat transfer to the ambient, lead to uncertainties in the simulation model. detailed measurements can help to reduce these uncertainties, but can not avoid the problem.

Due to these uncertainties and problems a calibration of the simulation model onto measurement data is necessary.

Typically the calibration process is divided in two parts:

Part one is the matching of the cycle average values like air/fuel ratio or power. Hereby e.g. wall temperatures and multipliers in the sub models can be used (beside the main measures fuel mass, FMEP,…) to tune the model.

The more challenging second part of the calibration process is the matching of the gas dynamics. Herein the complex pressure traces in the intake manifold, in the cylinder and the exhaust system have to be matched to measurement data by varying pipe lengths and diameter as well as flow split volumes and discharge coefficients. The occurring phenomena are nontrivial and demand high effort.



This figure shows pressure traces of the intake manifold, the cylinder and the exhaust manifold in dependency of the crank angle for a full load operation point at 3600 rpm. The black line represents measurement data while the red one is from a manually calibrated simulation model.

In a classical manual calibration process several significant points of the pressure signal are matched. These are for example:

the pressure rise in the intake runner when the intake valve opens, induced by the back compression in cylinder with the coupled high in-cylinder pressure in comparison to the boost pressure

the frequency of the free vibration. Here it can be seen whether the lengths and diameters in the intake runner are set well.

beside the frequency the amplitude should be matched, too. The amplitude indicates if the damping behavior of the intake system (induced by friction or volume) matches the real engines characteristic. In this example the fit between measurement and calculation of the pressure trace between 180 and 360 °CA (while the exhaust valve is opened) is only low.

looking on the in-cylinder pressure signal the above mentioned back compression is another significant point. Here the valve timing and the valve flow coefficients can be checked.

The last example should be the blow down pulses in the exhaust pressure trace. With these pressure peaks the matching of the exhaust system pipe lengths and diameter can be proved.

All in all it can be said that no objective criterion can be given to prove the quality of the calibration process. Furthermore this method leads to a huge number of targets which can not be implemented in an automated optimization process.

A more feasible method for finding targets for the calibration process can be found using the Fourier transformation.

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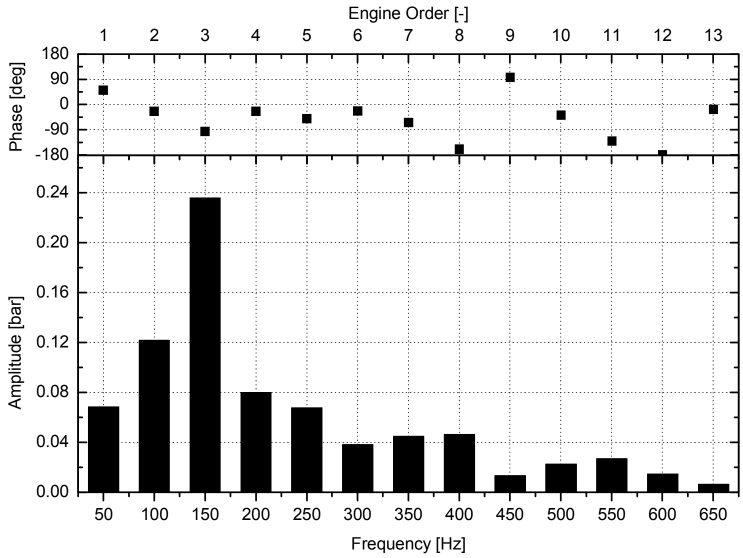
Criterion for the evaluation of a gas dynamic calibration
Result of a Fourier Transformation

$$f(t) = a_0 + \sum_{n=1}^{N} \left(a_n \cos(n\omega t) - b_n \sin(n\omega t)\right) \qquad a_n := A_n \cos\varphi_n \qquad b_n := A_n \sin\varphi_n$$



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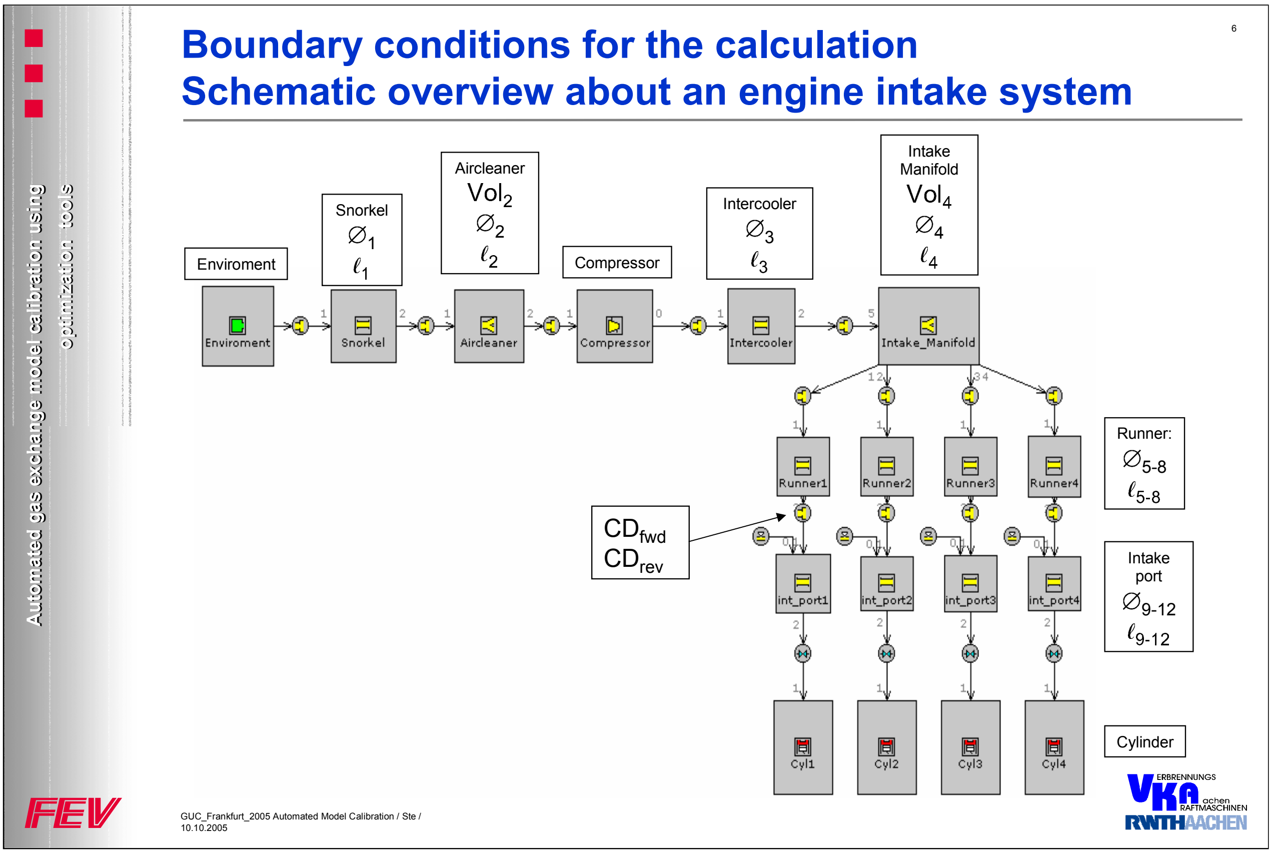
With the Fourier transformation the complex periodic pressure signal can be splitted into simple harmonic oscillations.

The results plotted here are the amplitudes and phase angles of the intake pressure signal at 6000 rpm in dependency of the frequency resp. the engine order.

It can be seen that the first 8 frequencies have got the major influence on the pressure signal, due to the highest amplitudes in the spectrum. The following 3 engine orders with amplitudes around 0.04 bar have got minor influence, while the amplitude and therefore the influence of the higher frequencies is negligible.

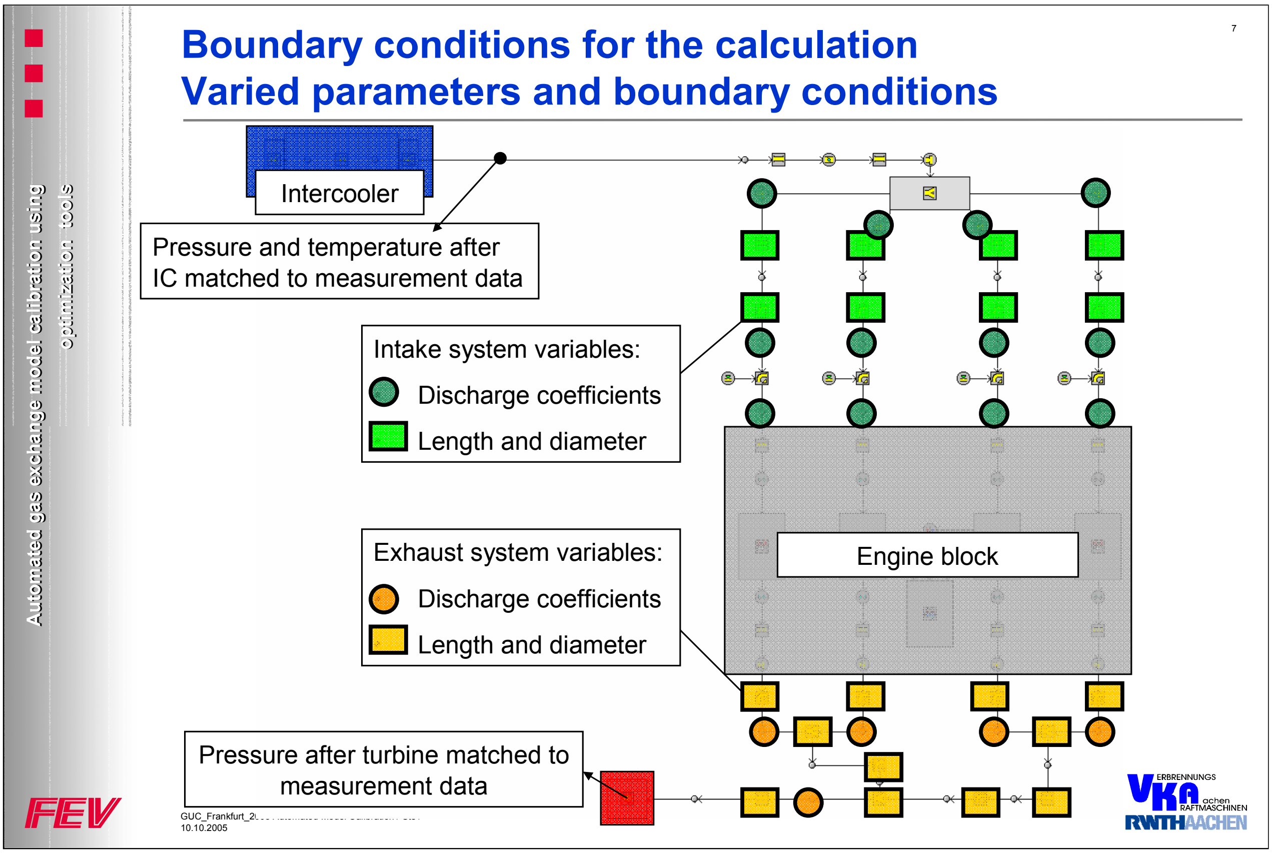
As a results of this investigation the first 10 engine orders will be set as target for the automated calibration process for the intake system.



After setting the targets the input variables have to be chosen. This slide shows a schematic overview of the intake system of a turbocharged engine.

Starting at the inlet ambient the intake snorkel has to be dimensioned. After this pipe the diameter of the air-cleaner as well as its length and volume have to be defined . After the compressor, which is normally described by maps, the pipe bundle of the intercooler has to be dimensioned. The next geometries which have to be set are the plenum volume, diameter and length and the corresponding data of the intake runners and ports. Furthermore several flow coefficients between the parts or end flow corrections at the connection plenum-runner can be defined. All in all again a huge amount of influencing measures. Moreover the exhaust system is not part of this simplified overview.

The DoE tool DesignExpert, which was used for this investigation, can only handle up to 10 input variables. Among and above implementing all these parameters in an optimization process will lead to very long computation times. Therefore a pre-selection of the most important variables is necessary.



Having a look on the calculation model it can be seen that the investigation concentrates on an "inner" system. At turbocharged engines the gas dynamics before IC has got only minor influences on the gas dynamics after IC. Furthermore the turbine isolate the system on the exhaust side.

At the beginning of the calibration process all temperatures, multipliers, etc. were set on default resp. reasonable general values. In a second step the pressure and temperature after IC as well as the pressure after turbine were matched to measurement data.

First the intake system was automatically calibrated. For this purpose nine measures were set as input parameters for the DoE tool.

•forward and backward discharge coefficients at the connection plenum-runner

•length and diameter of the primary runner

•inlet/outlet diameter and length of secondary runner

•forward discharge coefficient at the connection plenum/spacer

•forward discharge coefficient at the connection spacer/port

After the optimization of the intake system the exhaust system was calibrated. Here the following variables were set:

•length of the primary exhaust pipes for cylinder 1/4 and 2/3

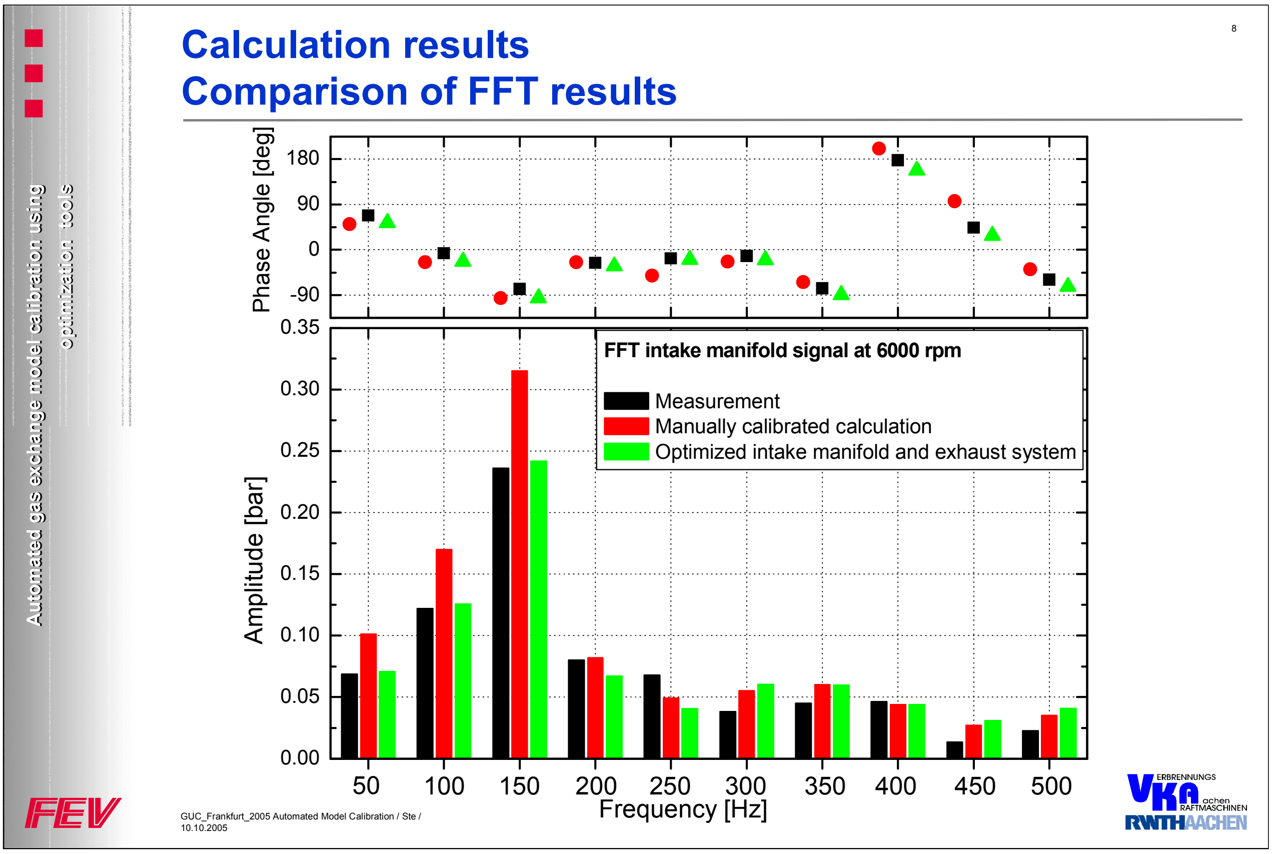
•diameter of the whole exhaust system down to the 2 in 1 junction

•forward and backward discharge coefficients at the 4 in 2 junction

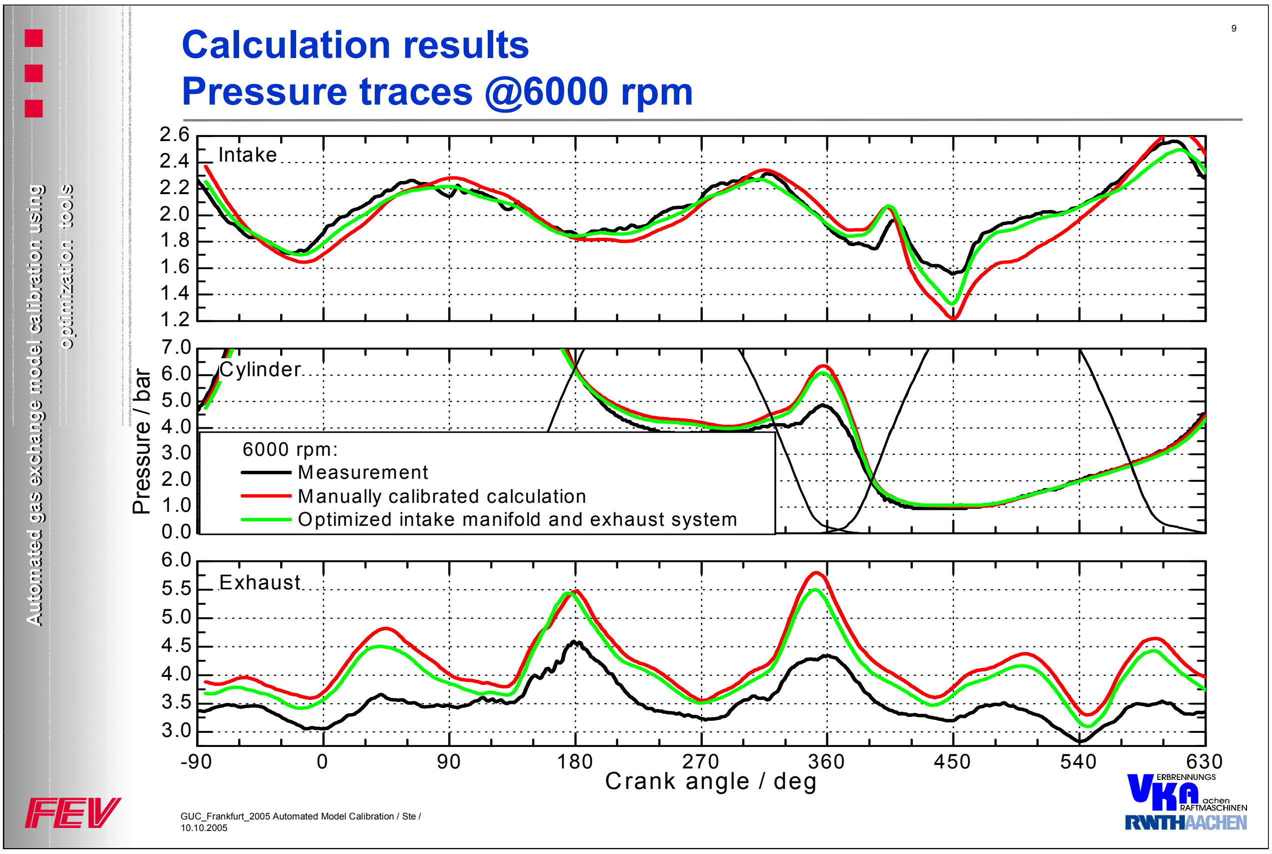
•forward and backward discharge coefficients after the 2 in 1 junction

•diameter of the pipe before turbine

With the target parameters mentioned above and these input variables a DoE investigation was done. A D-optimal design space was chosen and a cubic model was assumed. To estimate the lack of fit the amount of calculations was doubled.

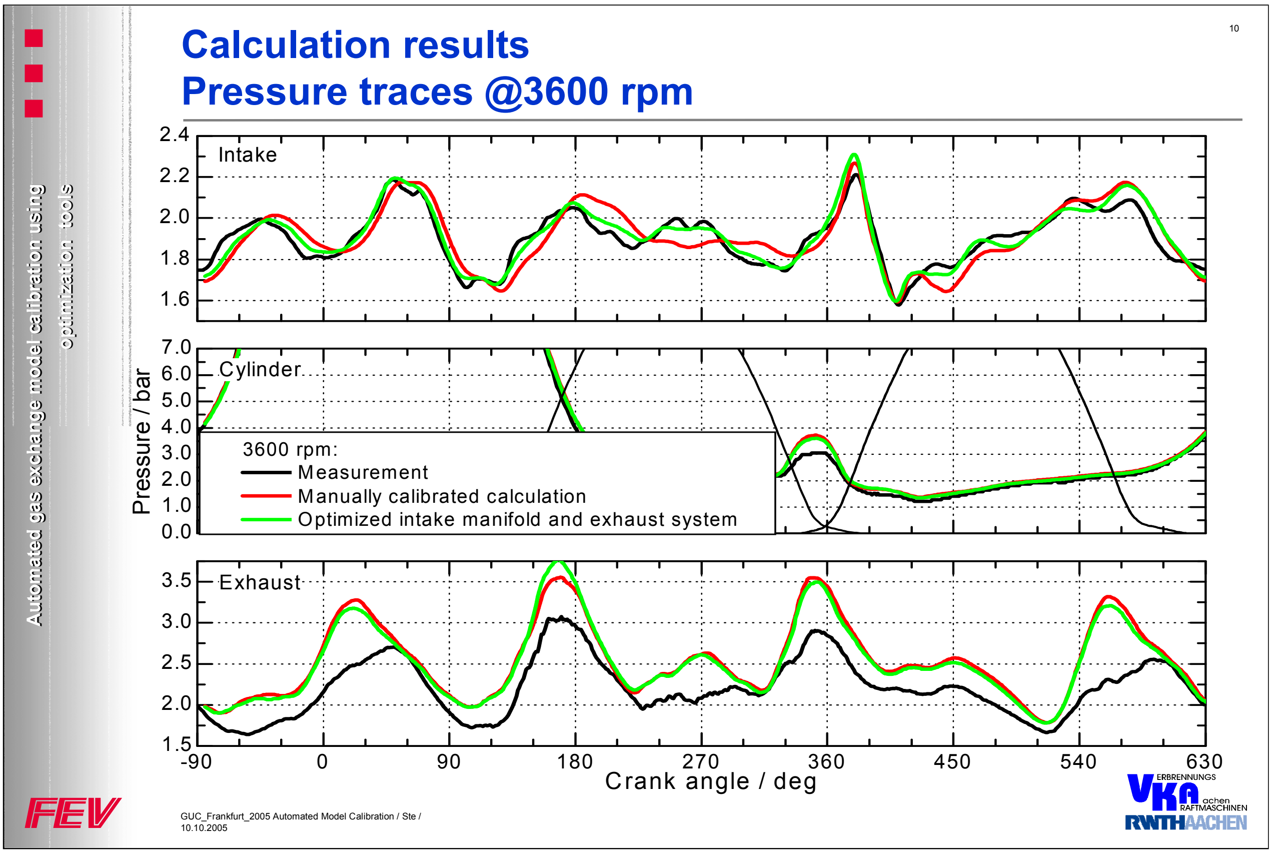


Comparing the FFT transformation results of the measurement, the manually calibrated model and the automatically optimized model, it can be seen that a significant improvement of the degree of fit can be reached for the first three frequencies. Here the fit of the automated calibration is nearly perfect. For the higher frequencies with minor influence a partly improvement was achieved.



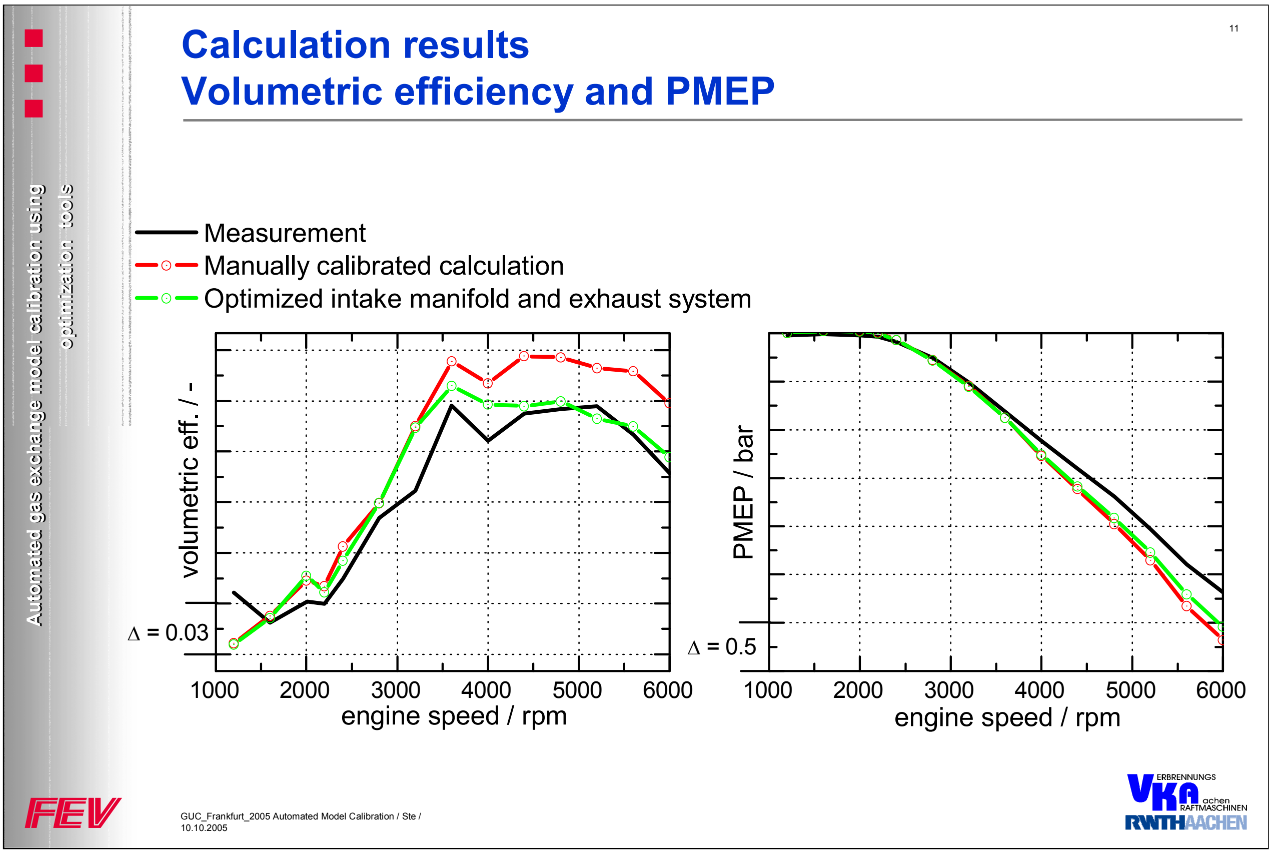
Corresponding to the FFT results, the pressure traces show a significant improvement, too. At 6000 rpm especially the suction spike during the intake phase is much closer to the measured signal compared to the manually calibrated model curve.

The optimization of the exhaust system shows only small potential for improvement. Here the optimized parameter set leads to a slight decrease in pressure over the whole cycle. Parallel to this decrease the back compression in-cylinder becomes smaller.



Keeping in mind that the target of the optimization was only the frequency spectrum of one engine speed, the results of other engine speeds are interesting.

It can be seen that with the optimized parameter set not only the frequencies resp. the pressure traces which were part of the optimization could be improved. The exemplary results at 3600 rpm also shows a significant improvement. At the intake pressure trace the gap between measurement and calculation decreases across the whole cycle. Moreover the frequency of the free vibration is matched very well in comparison to the base calculation which was manually calibrated.



Another measure, which was not part of the optimization is the volumetric efficiency. The calculation results of the optimized model show that this measure can be improved up to 3 % in comparison to the manually calibrated model. Furthermore the pumping work could be decreased which leads to a better fit to the measurement data.

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Summary

- **A method for an automated calibration process has been presented, using the DoE tool DesignExpert.**
- **The example of an automated model calibration shows that a significant improvement in the degree of fit can be reached in comparison to the manual calibration.**
- **The calibration, which was part of this paper, covers only a part of the whole calibration process. Beside the geometries also e.g. temperatures can be used to fit measurement data.**
- **Target of further investigations can be the focus on a standardization of the full calibration process.**

Summary:

1. A method for an automated calibration process has been presented, using the DoE tool DesignExpert.
2. The example of an automated model calibration shows that a significant improvement in the degree of fit can be reached in comparison to the manual calibration.
3. The calibration, which was part of this paper, covers only a part of the whole calibration process. Beside the geometries also e.g. temperatures, valve timing can be used to fit measurement data.
4. Target of further investigations can be the focus on a standardization of the full calibration process.