

## OPTIMIZATION OF COMBUSTION PARAMETERS FOR CI ENGINES BY COMPUTER MODELLING

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**Abstract:** This paper presents scientific studies about optimization models for analysis of processes occurring during simulated operation on single cylinder compression ignition engine. The rate of heat released ROHR was obtained experimentally, and by simulation. For validation of the parameters that influence the shape of the combustion heat, released rate has been optimized by designing and running a set of experiments followed to obtain a range of information about minimum and maximum values of response parameters, where the best have been selected results to obtain the objectives. The optimization process was intended improve the results of simulations by minimizing the distances between the values obtained from model simulations and experimental measurements on the laboratory engine. Working method systematically changing the model parameter values simulated by optimization algorithm selected and the settings specified by this parameter. In our case, the optimization process intended to improve the results of simulations by minimizing the distances between the values obtained from simulations on a theoretical model and experimental measurements of the compression ignition engine laboratory. Optimization method used in our case is Genetic Algorithm and is a global search method in the model based on the analogy of natural biological evolution. A population of solutions is improved by creating the descent from these by applying the survival principle of the solution most adapted to the model. After optimizing, the coefficients of injection cycles have been repeated all the simulations, and results were analyzed using Impress Chart post processing program, which by graphical analysis tools output data obtained allows comparison of simulation results with laboratory measurements and validation results for the rate of heat released. Reduced costs and facilities optimization model offers several advantages in obtaining accurate results from simulations, which relies on accurate data and parameters originally introduced in the simulation program. Using computer simulations to validate the experimental measurements we are sure to obtain accurate results in research work.

**Key words:** simulation, optimization, experiment, rate of heat released, AVL Boost, Design Explorer.

### INTRODUCTION

*Design Explorer* (DE) is a software tool that provides workflow for *Design of Experiments* DoE required for analysis and optimization of simulation models on *AVL Boost*. The program is used in the development of models to investigate dependencies of model parameters and simulation results. This method can be used to improve the quality of a simulation model using a range of optimization algorithms. Optimization parameters are used in the study of fluid flow, heat transfer phenomena and mass transfer [3].

*Design of Experiment* DoE is used to analyze the influence parameters of the model-simulated response and to find optimal values of the starting process. The DoE method generated a number of points that define the best model simulated. An optimization algorithm systematically changing the model parameter values by minimizing and maximizing these values and seeks to set values for the target. In our case, the optimization process intended to improve the results of simulations by minimizing the distances between the values obtained from simulations on a theoretical model and experimental measurements of the compression ignition engine laboratory.

After running a set of optimization experiments to obtain some information about

minimum and maximum values of response parameters, where best results are selected to obtain the proposed objectives [7]. Parameter optimization requires to obtain a precision of 1 to 3% between the results of a theoretical model simulated and measured results for an experimental model [3].

**MATERIAL AND METHODS**

DoE experimental design is a simulation methodology that is used to obtain a maximum amount of information while minimizing the number of simulations. DoE variables are called factors and each factor we defined a specific value called level.

Optimization method used in our case is *Genetic Algorithm* and is a global search method in the model based on the analogy of natural biological evolution. A population of solutions is improved by creating the descent from these by applying the survival principle of the solution most adapted to the model. At each new generation of solutions, optimization points are generated by genetic modification of previous solutions. Genetic optimization algorithms do not use real numbers, but encoding design values (phenotypes) of points character strings (genotypes) of genes defined in binary alphabet 0 and 1 (figure 1) [7].

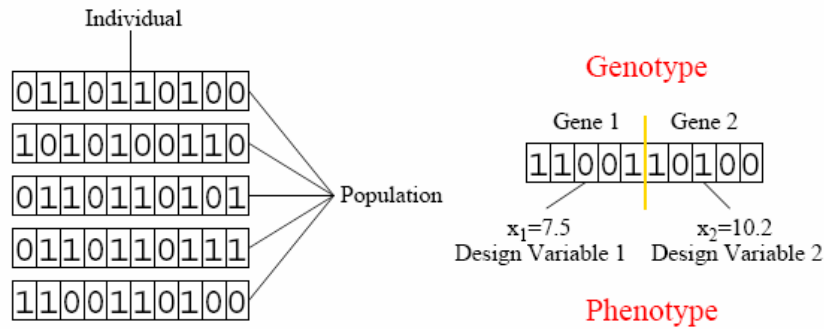


Figure 1. Genetic Algorithms

*Genetic Algorithms* use a discrete search space. The strongest genotypes are selected for use in the next generation of solutions. Each of the original character strings is used to form two character strings that are combined to generate two new generations of solutions. By random mutation genotypes are changes in each genotype by which a gene is replaced by another more powerful to produce a new genetic structure. Therefore, a mutation 0 is changed to 1 and vice versa, to introduce additional variability among the next generation of solutions in order to avoid local minima of the solutions values. The initial generation of solutions is generated randomly, and ends when the performance criterion is fulfilled initially defined (figure 2).

To optimize a single objective method for obtaining a weighted sum  $F_{WS}$  the following formula is use:

$$F_{WS} = \sum_{i=1}^k w_i F_i(x); \tag{1}$$

The user determines weighted amounts. Generally, the relative importance of various objectives is described by the weight values.

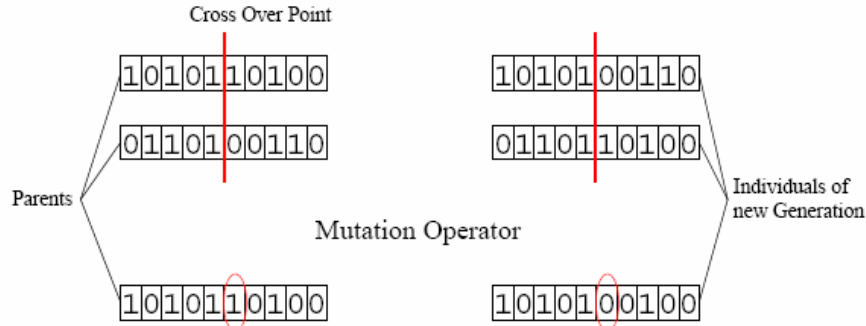


Figure 2. Methodology of genotypes formation

To optimize the parameters of injection that depend on results of the simulations, has been used to optimize the *Design Explorer* program, a method that consists in finding optimal coefficients by running a series of simulation results so as to identify the precise measurement results experimental [9]. In the tools *Impress Chart*, was loaded the simulation results and defined schedule for the rate of heat released for the two combustion models [1], *AVL MCC* model for simulated model, and *Two Zone Table* for experimental model (figure 3(a), and figure 3(b)):

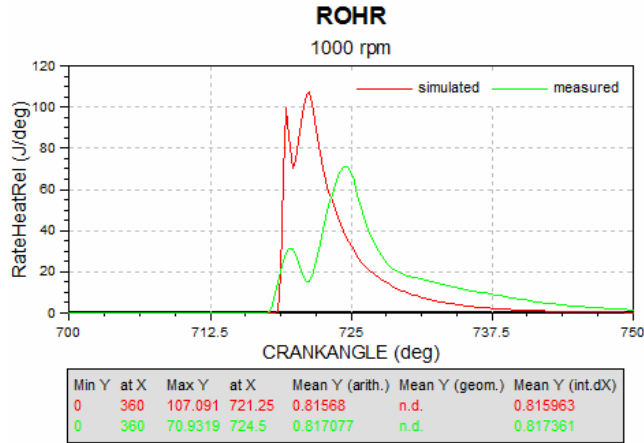


Figure 3(a). Rate of heat released ROHR for 1000 rpm

From the chart above shows, the surface that defines rate of heat released (ROHR) is approximately equal for the two combustion models (simulated model and experimental model), differ only in shape of the curve and maximum peak combustion values (Y max). The optimization process were selected four control parameters, specific for *AVL MCC* combustion, and model have been optimized [4] to change the rate of heat release ROHR:

▪ *Ignition Delay Calibration Factor* = *mcc\_igndel*, which controls the fuel mixture ignition delay;

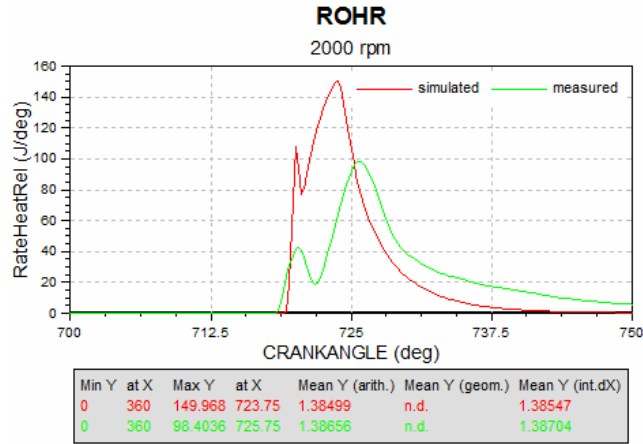


Figure 3(b). Rate of heat released ROHR for 2000 rpm

- *Combustion Parameter* = *mcc\_compar*, which has the greatest influence on the shape of rate heat release curve and a higher value of this parameter leads to a faster combustion process;
- *Turbulence Parameter* = *mcc\_turbpar*, which controls the influence of kinetic energy density;
- *Dissipation Parameter* = *mcc\_disspar* that have an influence over the kinetic energy dissipation.

### RESULTS AND DISCUSSIONS

By optimization have been modified the values of the combustion parameters (defined to obtain a form similar for the two curves of ROHR), but also to retain the size of areas defined by these curves, which means the same amount of heat released for each of models studied [4].

Using mathematical operator *Linear Combination* from *Impress Chart* [9] the two features of rate of heat released ROHR were combined in an single curve (figure 4):

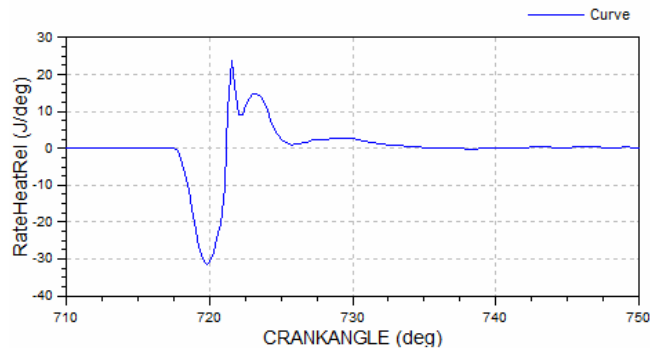


Figure 4. Linear Combination for rate of heat release ROHR

Applying the mathematical operator *Polinoms and Fractions* was define a single characteristic for the rate of heat released ROHR for both cases studied (figure 5). This operation generates a curve resulting from the combination of two polynomials [9].

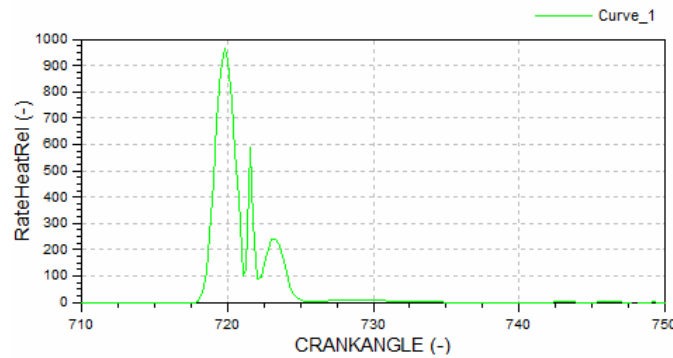


Figure 5. Combined characteristic for the considered cases

Using mathematical operator *Integration* was integrated the characteristic for rate of heat released ROHR for the integral value 0 [9] (figure 6).

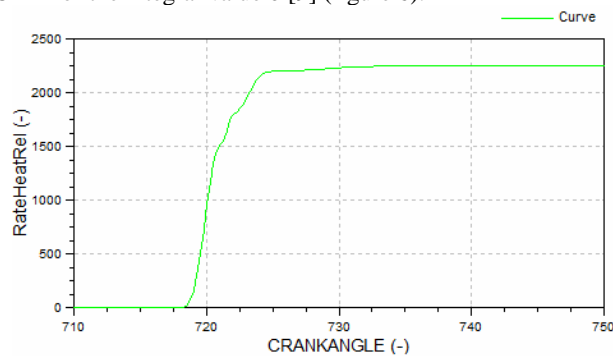


Figure 6. Integrated characteristic for rate of heat released ROHR

All mathematical operations performed above were extended for the results of a number of simulation processes 27 (figure 7 a, b, c) applying the command *Expand Wildcards* in *Case Selection* [8], so that the optimization process to include all the 27 cases studied.

Applying the operator of mathematical, *Statistics* were defined for the 27 cases (CaseNo) size of the optimization process [12] for the parameters selected by the maximum value of X for Y\_OF\_XMAX (figure 8).

Using mathematical operator *Store Statistics* was set the maximum for the number of simulations [9] to be developed in the optimization process (figure 9).

For the next stage of optimization after initial data were defined by which we will optimize selected parameters [7], launched the process of optimization by the connection between programs *AVL Boost* and *Design Explorer (Connect to Design Explorer)*. For this in *Design Explorer* program menu were loaded with initial data files that have been processed in *Impress Chart* and were chosen global parameters that have been optimized and values within

the area of design *Design Variables* including simulations were run [2]. The limits for optimized parameter values were set between 0.1 (1.000e-001) and 10 (1.000e+001).

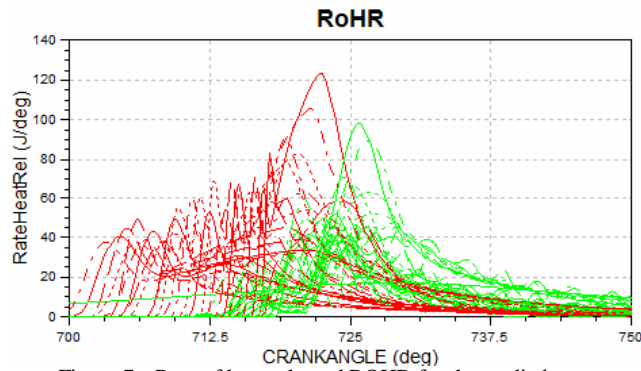


Figure 7a. Rate of heat released ROHR for the studied cases

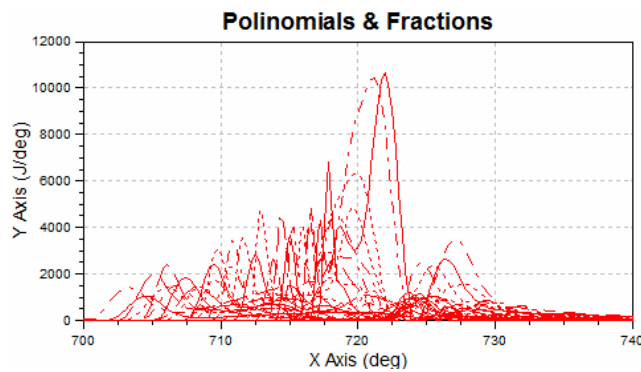


Figure 7b. Expanding the operator Polinomials & Fractions in the series of results

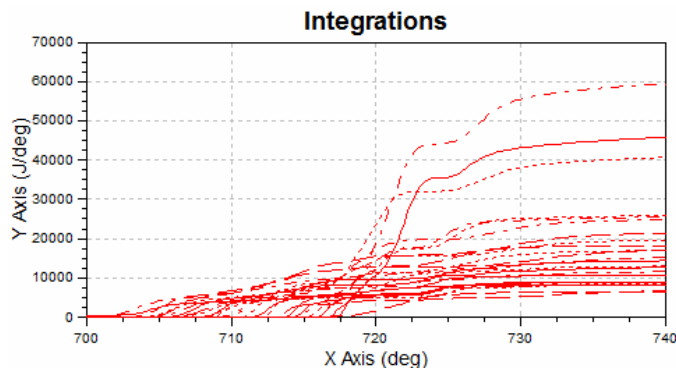


Figure 7c. Expanding the operator Integrations in the series of results

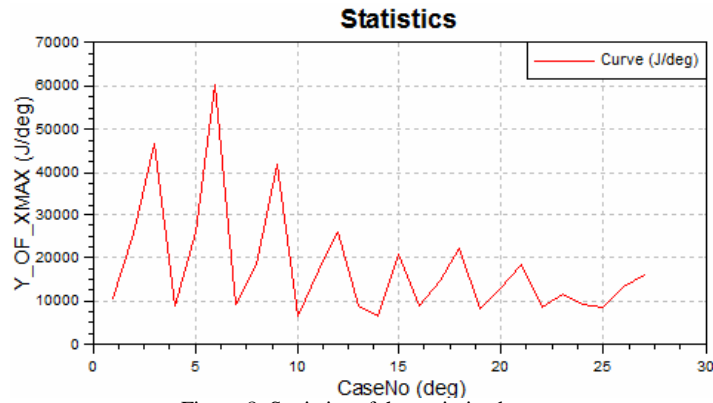


Figure 8. Statistics of the optimized cases



Figure 9. Store statistics for the number of simulations

Next was defined the nonlinear restrictions of the design space, and was set the objectives and constraints have been validated for response values *Objectives / Constraints* by loading the stored value application in Store of Statistics. Was selected the optimization method was used, for our model called *Genetic Algorithm*, which after running to about 600 simulations for each of the 27 cases studied, has retained only 25 of the best results obtained from the optimization process. After running the optimization, process was generated values of optimized parameters [5].

*Ignition Delay Calibration Factor* = *mcc\_igndel* for which the optimization was obtained and validated from 0.350 values (figure 10).

*Combustion Parameter* = *mcc\_compar* for which optimization was obtained and validated from 0.685 values (figure 11).

*Turbulence Parameter* = *mcc\_turbpar* for which optimization was obtained and validated from 1.380 values (figure 12).

*Dissipation Parameter* = *mcc\_disspar* for the following optimization value was obtained and validated 0.675 (figure 13).

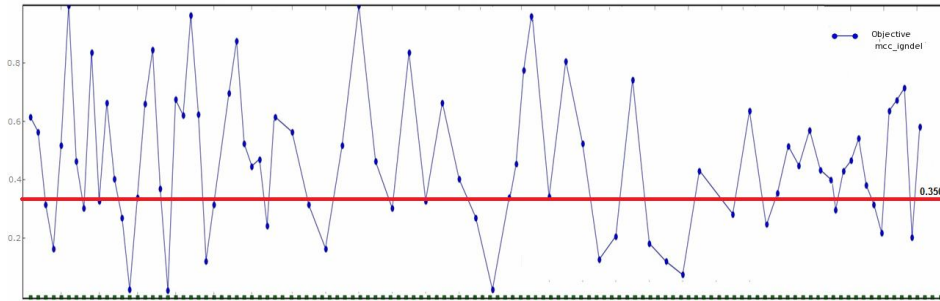


Figure 10. The variation of Ignition Delay Calibration Factor = *mcc\_igndel*

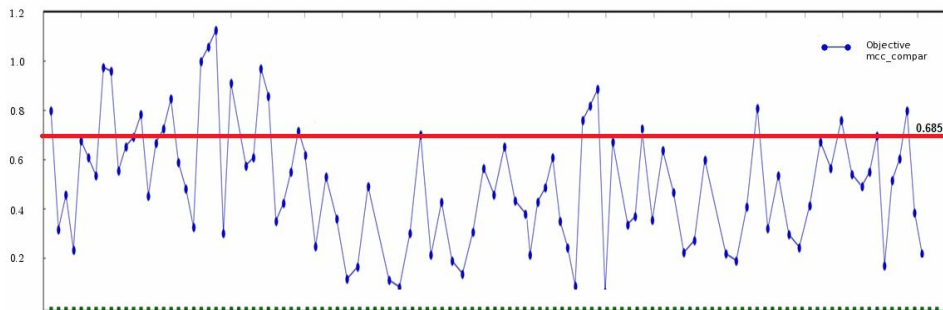


Figure 11. The variation of Combustion Parameter = *mcc\_compar*

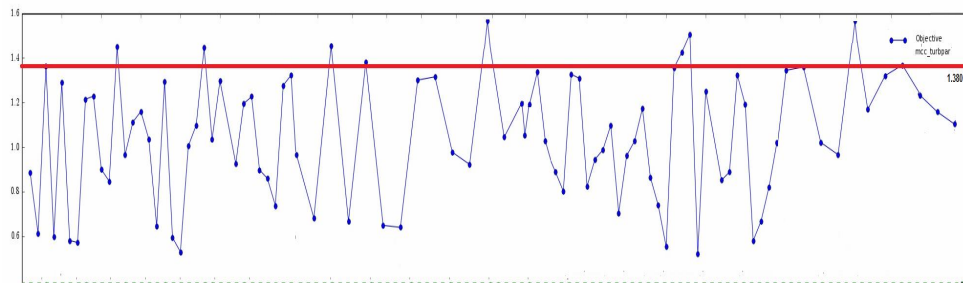


Figure 12. The variation of Turbulence Parameter = *mcc\_turbpar*

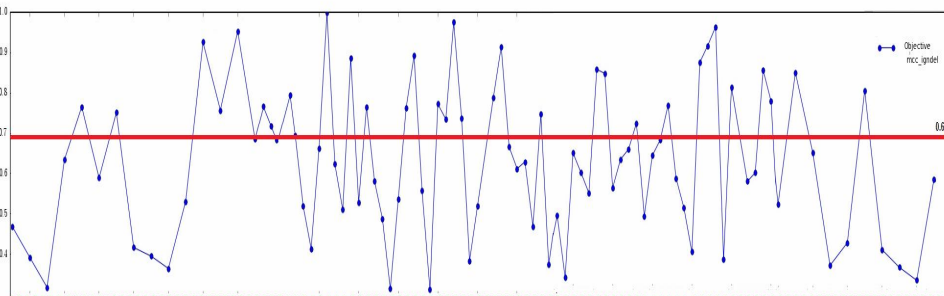


Figure 13. The variation of Dissipation Parameter = *mcc\_disspar*



After optimizing, the coefficients of injection cycles have been repeated all the simulations, and results were analyzed using *Impress Chart* post processing program, which by graphical analysis tools output data obtained allows comparison of simulation results with laboratory measurements (figure 14(a), and figure 14(b)) and validation results for the rate of heat released ROHR [6].

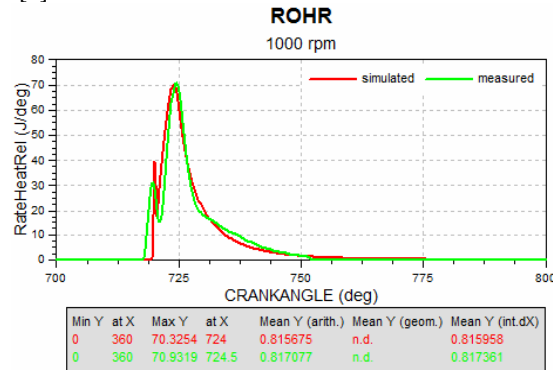


Figure 14(a). Validation of results for ROHR at 1000 rpm

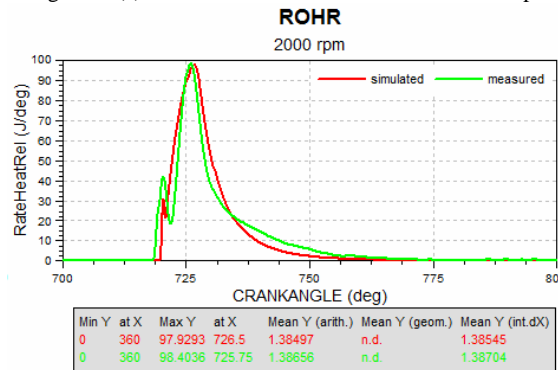


Figure 14(b). Validation of results for ROHR at 2000 rpm

### CONCLUSIONS

Through the optimization of the combustion model parameters studied was determined a range of optimal values were within the range of tolerance required to achieve some results of process simulation as close to the results obtained by experimental measurements. The methods for determining the combustion parameters significantly influence the results of simulations.

Reduced costs and facilities optimization model offers several advantages in obtaining accurate results from simulations, which relies on accurate data and parameters originally introduced in the simulation program. Using computer simulations to validate the experimental measurements we are sure to obtain accurate results in research work.

The experimental design DoE is used to analyze the influence of parameters of the model-simulated response and to find optimal values of power processes. The DoE method generated a number of points that define the best model simulated.

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