CAD PROCEDURES USED IN THE DESIGN OF AUTOMOTIVE COMPONENTS

Eugen-Madalin GALITU [1], George CONSTANTIN [2]

Rezumat. *Piesele din aliaj de aluminiu din industria auto sunt piese de dificultate înaltă datorită procesului de obținere al piesei brute. Pentru ca piesele să răspundă cerințelor impuse în funcționare, se dezvoltă prototipuri virtuale care sunt analizate prin simulare numerică în condiții de funcționare. Lucrarea de față aduce în discuție un studiu de caz privind modelarea cu elemente finite şi simularea comportării termice şi analiza dinamică a unei componente corp by-pass EGR aflate în faza de proiectare. Analiza termică şi dinamică permite determinarea câmpului de temperatură şi a frecvențelor proprii, precum şi a modurilor proprii de vibrații care sunt analizate prin prisma cerințelor funcționale ale componentei. Se prezintă modificările realizate asupra modelului CAD pentru aducerea parametrilor termici şi dinamici în limitele acceptate. Simularea prototipului virtual corectat conduce la validarea modelului.*

Abstract. *The parts of aluminium used in the automotive industry are highly difficult to obtain due to the process of casting. For the parts to meet the requirements imposed in running, virtual prototypes are developed that are analyzed by numerical simulation in operating conditions. This paper brings up a case study on finite element modelling and simulation of thermal behaviour and dynamic analysis of a components body EGR bypass in the design and optimization phase. The thermal and dynamic analysis enables the determination of temperature field and natural frequencies and modes of vibrations that are analyzed in terms of the component functional requirements. The modifications made on the CAD model for bringing the thermal and dynamic parameters within acceptable limits are presented. Virtually corrected prototype simulation leads to model validation.*

Keywords: virtual prototype, FEM, thermal analysis, dynamic analysis, EGR (Exhaust Gas Recirculation) component, modifications, model validation.

1. Introduction

In the design process of the cast components used in the automotive industry there are several design stages that have to be considered [1]:

- Specification of the component (input and output temperature, frequency in running, etc.);
- Structural CAD design;

[1]Eng., PhD Student, Engineering and Management of Technological Systems, Politehnica University of Bucharest, Romania (eugen.galitu@gmail.com).
[2]Prof., PhD, Engineering and Management of Technological Systems, Machines and Manufacturing Systems Department, Politehnica University of Bucharest, Romania "Name" Institute, City, Country (george.constantin@icmas.eu).

- Creation of virtual prototypes and their analysis;
- Finite element analysis (FEM) of the components and of the assembly (static and dynamic);
- Finite element analysis (FEM) of the thermal behaviour;
- Changes of the real prototype.
- Virtual prototype validation.

Some components included in the whole assembly have to meet some functional requirements. Generally, these requirements are quantities of different types such as temperatures of the gas that flows inside the component, static quantities such as tensions or deformations under static loads (forces and torques) and also dynamic quantities, taking mostly the form of natural frequencies and natural frequency modes.

Starting from the initial requirements and following some calculation procedures, along with some dimensional conditions, the first stage of CAD modelling is achieved. In this stage, a virtual prototype is prefigured with a relative precision regarding the initial required quantities. Therefore the CAD model is the "source" for a set of Computer Aided Engineering procedures including some numerical simulation of thermal and dynamic behaviours.

The numerical simulations of the virtual prototype under different types of loads lead to a set of values of the discussed quantities that are compared to the required one [2, 3]. Moreover, in this stage of virtual prototype simulation one can take into account the optimization procedure considering one criterion or more than one criterion.

The comparison leads to some corrections (modifications) of the CAD model made in order to bring the discussed quantities in the required range. Most of the modifications are of dimensional type (modifications of the component volume in some areas) or addition of some volumes or subcomponents that modify the behaviour of the whole component. All these modifications are part of the virtual prototype change. Thus, a new model is defined, improved in order to meet the requirements.

The simulation procedures should be resumed and the validation procedure completed.

2. Case Study on a New Component of EGR Type

Exhaust gas recirculation – EGR used on large scale in diesel engines is a system that enables the recirculation of the gases resulted during combustion and redirecting them into the intake manifold. This procedure allows significant decrease of NOx emission due to the decrease of the two elements that are underlying its occurrence.

By reintroducing the burnt gases in the intake, a part of the oxygen needed for combustion is replaced by the burnt gas that leads to decreasing the amount of oxygen in excess [4, 5]. On the other hand, because the flue gases absorb some of the heat generated by the combustion, the maximum temperature on the cycle is reduced.

The case study treated by this paper considered the component support by-pass EGR used in the automotive industry. It is the subject of the CAE procedures applied on the virtual prototype used in simulations before producing the component. The component should have the following characteristics [6, 7, 8]:

- Redirecting the burnt gas in the intake manifold at the required temperature about 200ºC;
- The minim natural frequency accepted on the components of the automobile should be of 260 ±20 Hz.

For the evaluation by finite element analysis, some features of the body EGR by-pass are presented in Figure 1. The numerical simulation consists of the determination of the temperature distribution as a result of the thermal analysis during operation and also the natural frequencies and modes of vibration. The analyses were performed using the program Nastran.

The recessed areas are represented in Figure 2.

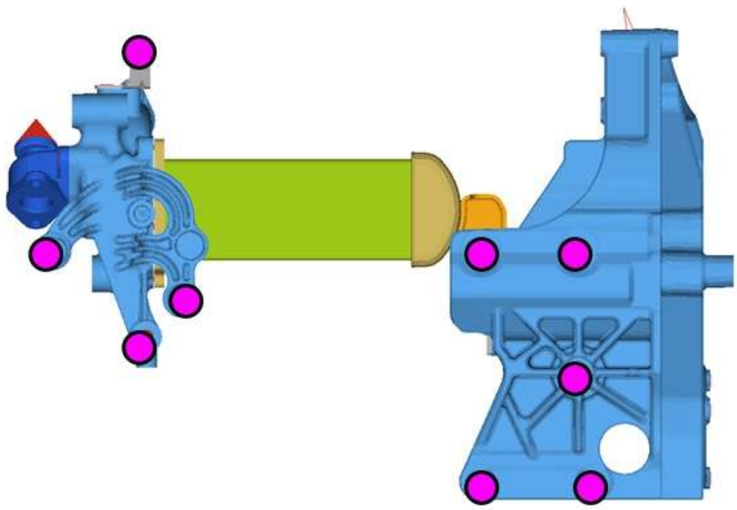

Fig. 1. Body of by-pass EGR.

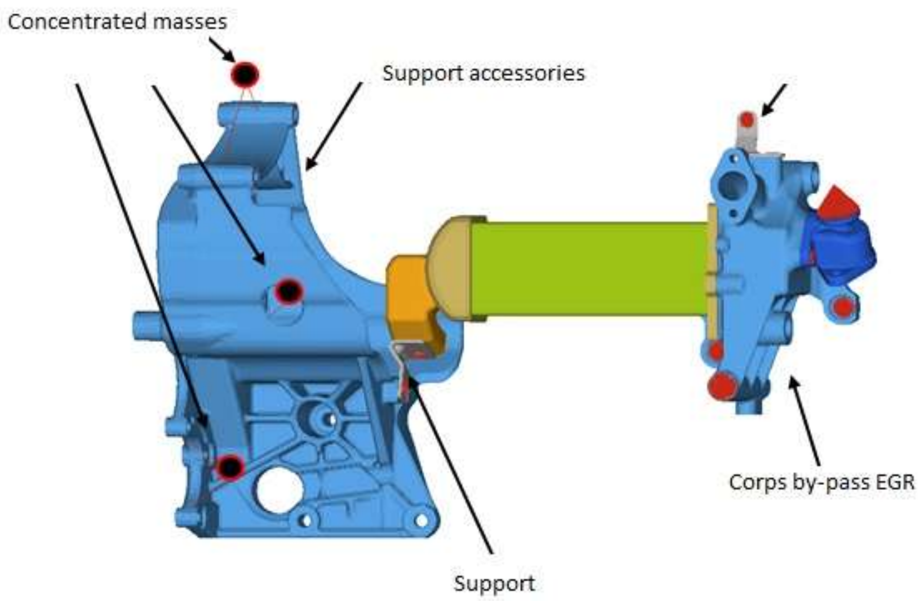

Fig. 2. Recessed areas of body by-pass EGR.

EGR body is subjected to thermal stresses because inside the component there is a variation from a large temperature about 500-600°C to a temperature of 200−240°C in a short time for achieving the engine cycle.

The critical area of the casting is the wall that separates the gas inlet in the body EGR and EGR gas output of filtered that should be reintroduced into the combustion chamber.

Analysis was performed by imposing a thermal convection heat exchange between the different surfaces shown in Figure 4. The reference temperatures and the heat transfer coefficients are shown in Table 1.

Table 1) Reference temperatures and heat transfer coefficients used in FEM modelling

	T [°C]	*HTC [W/m^2 °C]*
Input surface EGR	550	750
Surface output EGR	206	550
Outer surface	70	10,000
Water soul	90	100

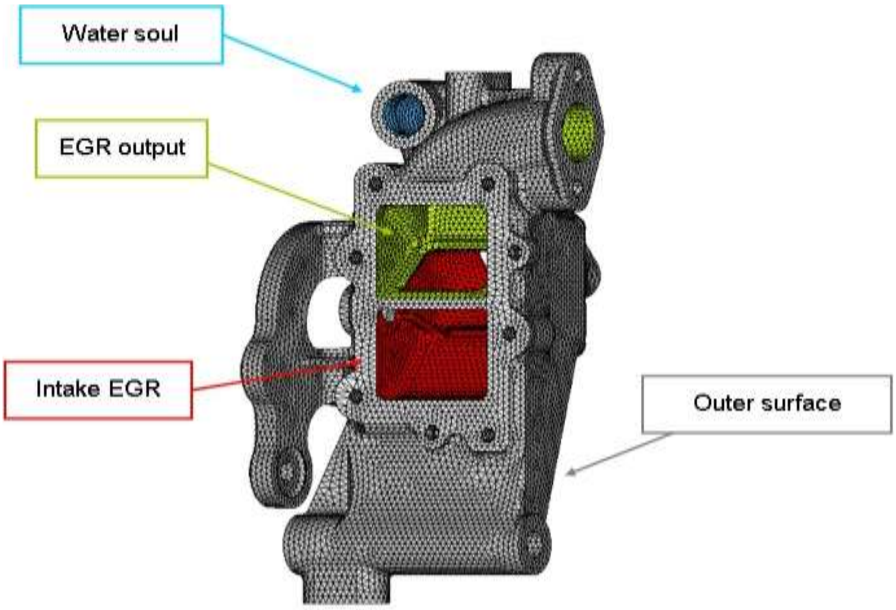

Fig. 3. Meshed structure of the component.

Table 2) Material characteristics used in FEM modelling

Component	*Material*	*Modulus of elasticity [MPa]*	*Coefficient Poisson*	*Density [kg/dm³]*
Corps by-pass EGR B0511441C	EN 1706 AC 46400 ST6	76,000	0.3	2.7
Stiffening brackets	Steel	206,000	0.3	7.85

The analysed meshed structure has 59,000 nodes and 380,000 elements. The number of nodes should be as great as possible due to the increase in precision of the simulation. There are a lot of areas of interest and the simplification of different zones is not required. The mesh of the component Support by-pass EGR is presented in Figure 3.

The analysis was performed taking into account the material having the characteristics given in Table 2.

2.1. Thermal analysis

The thermal analysis was achieved for the running characteristics of the component support by-pass EGR taking into account the intake temperature in EGR of 550ºC and also the output temperature of EGR of 206°C.

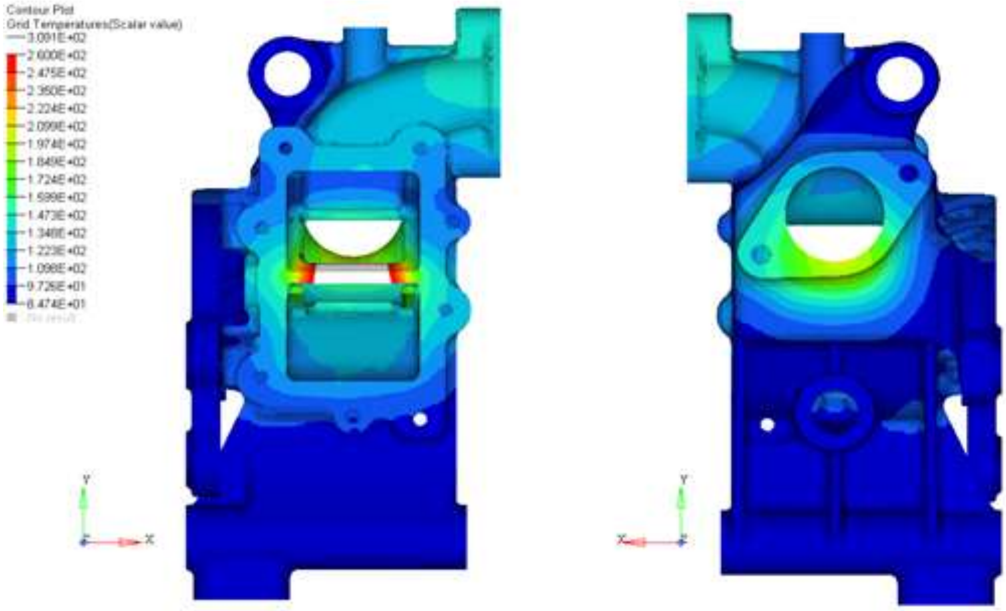

Fig. 4. Distribution of temperature after thermal simulation.

The temperature distribution after thermal simulation is shown in Figure 4.

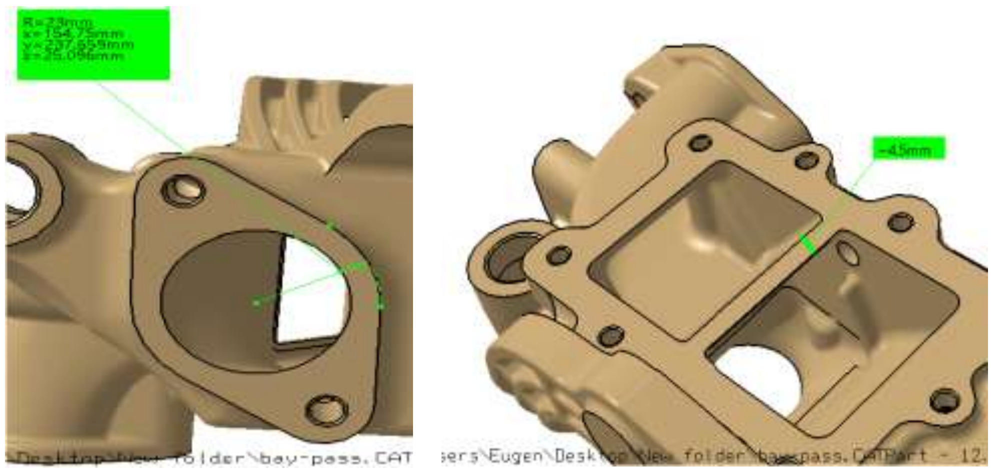

Fig. 5. Dimensional modifications of the CAD model after the initial simulations.

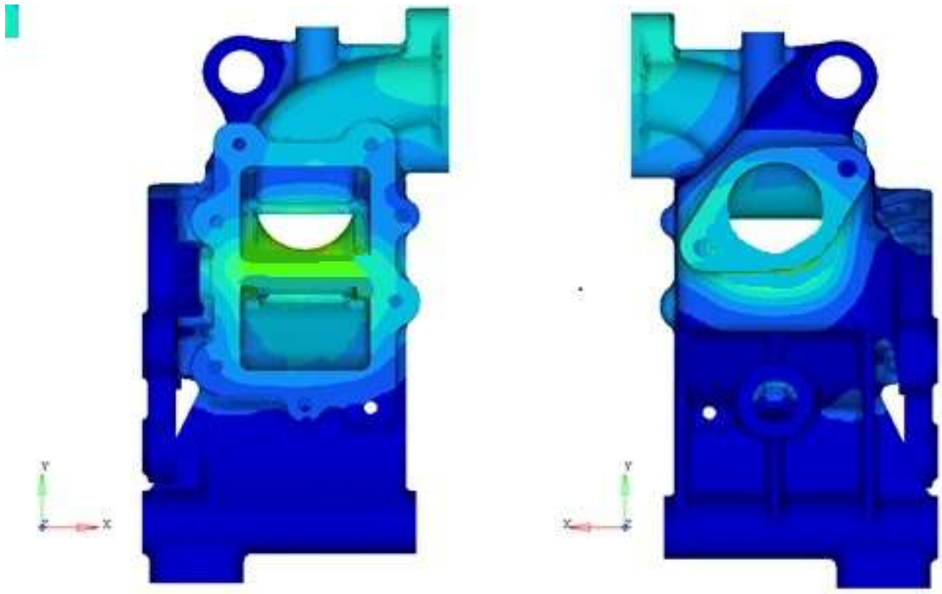

Fig. 6. Thermal analysis after modifications.

The thermal simulation reveals a temperature distribution that shows an increase of temperature in the flange area (about 220ºC) and also at the wall level (max. 260ºC) as shown in Figure 5.

To reduce the temperatures in these areas the flange diameter was increased from R = 23 mm to R = 24 mm. Also the wall thickness was increased from 4.5 mm to 5.8 mm (Figure 5).

The thermal analysis simulation results are shown in Figure 6. The critical temperature was reduced and brought to the required limits (below 200ºC).

2.2. Dynamic analysis

A second stage of the model validation is the dynamic simulation for determining the natural frequencies and also the natural modes of vibration of the component EGR. Some supplementary elements were introduced into the assembly for vibration reducing. The same meshed virtual prototype was used as in thermal simulation.

Table 3 shows the natural frequencies of the pattern seen in the EGR support different configurations.

Table 3) Natural frequencies for different configurations of EGR after dynamic simulation.

	Natural Frequency I [Hz]	*Natural Frequency II [Hz]*	*Natural Frequency III [Hz]*	*Natural Frequency IV [Hz]*
Support by-pass + bracket B0511463A e B0511466B	387	413	470	605
Support by-pass + bracket B0511463A	200	443	781	853
Support by-pass + bracket B0511466B	277	461	545	566

This model has also another solution to increase natural frequencies. They are not reported because it is a matter of bracket accessories and not of the EGR group (Figure 7).

The deformed structure relative to the first mode of vibration of the assembly support by-pass + B0511463A brackets and B0511466B is shown in Figure 8.

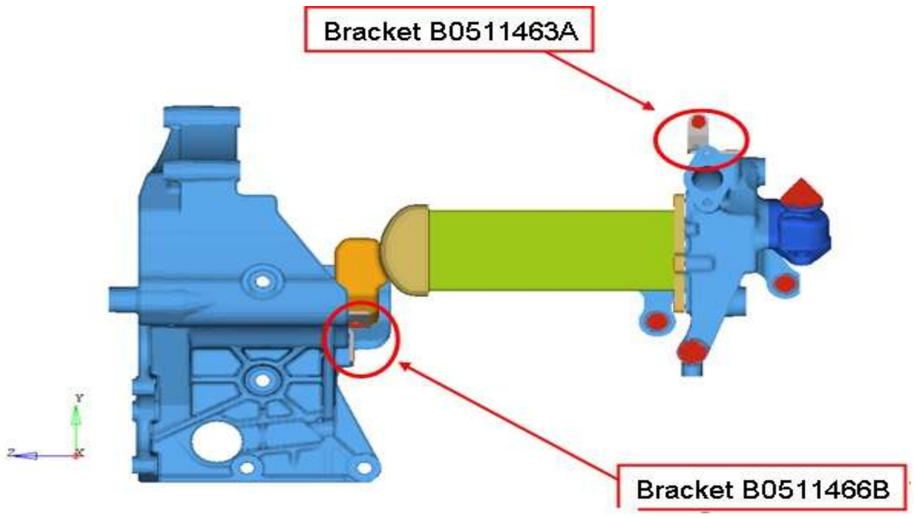

Fig. 7. Assembly of EGR with supplementary elements for reducing vibrations.

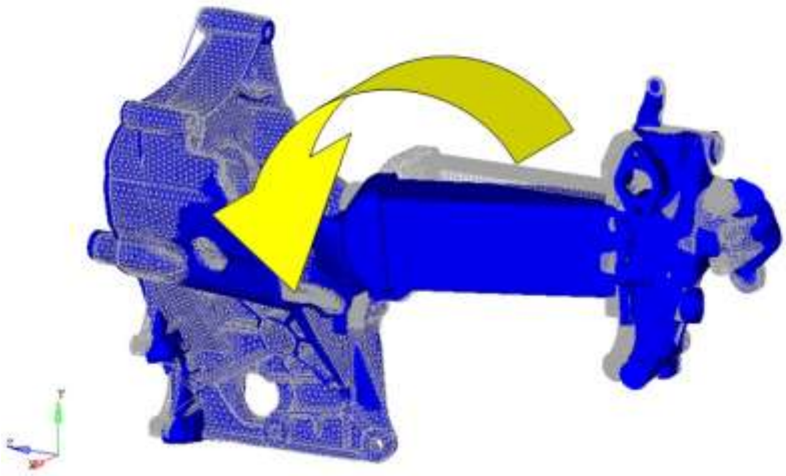

Fig. 8. Deformed structure relative to the first mode of vibration.

Conclusions

The paper proposes finite element analyses for a new designed component of EGR type in order to bring some quantities, such as temperatures and dynamic characteristics during operation, under the required parameters.

The thermal analysis shows that the dividing wall between hot and cold EGR flow reaches very high temperatures (over 230°C) with regard to those accepted for aluminium. The risk is a local softening of the material resulting in permanent deformations.

For meeting the required running temperatures, in the critical zones where the highest temperatures were obtained after simulation, the wall thickness was increased from 4.5 mm to 5.8 mm that determines a volume increase that enables temperature dissipation. Also, the flange diameter is increased to R = 24 mm. The new virtual prototype was validated by simulation, the temperature being brought below 200ºC.

The modal analysis shows that the introduction of B0511463A and B0511466B brackets allows increasing the firs natural frequency of the EGR group up to 387 Hz, which excludes resonance in operation. The minimum frequency accepted for each component of an automotive assembly is of 260 ±20 Hz.

The use of the support B0511466B without B0511463A needs a supplementary analysis because in the three analyses the natural frequencies had values under the minimum accepted value or nearly equal to it.

Acknowledgments

The work has been funded by the Sectorial Operational Program Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/134398

R E F E R E N C E S

[1] S. Viswanathan, A.S. Sabau, Q. Han, A.J. Duncan, W.D. Porter, R.B. Dinwiddie (2001). *Design and Product Optimization for Cast Light Metals*, CRADA final report, http://sbisrvntweb.uqac.ca/archivage/030108382.pdf.

[2] M. Petyt, *Introduction to Finite Element Vibration Analysis*, Cambridge University Press, 2010.

[3] H.F. de Moraes, F.Y., Kurokawa, & L.F. de Mendes Moura (2011). *Numerical Analysis of the Air and EGR Gas Mixture in the Intake Manifold.* 21st Brazilian Congress of Mechanical Engineering, October 24-28, 2011, Natal, RN, Brazil, http://www.abcm.org.br/app/webroot/anais/cobem/2011/PDF/216901.pdf

[4] B.E. Launder, and D.B. Spalding 1974, *The Numerical Computation of Turbulent Flows*, Computer Methods in Applied Mechanics and Engineering, **3**, pp. 269-289.

[5] M. Zheng, G. T. Reader and J. G. Hawley, 2004, *Diesel Engine Exhaust gas Recirculation - a Review on Advanced and Novel Concepts,* Energy Conversion and Management, **45**, pp. 883-900.

[6] L. Andreoni, M. Case, G. Pomesano, *Remplissage de l'empreinte du moule*, Division Leclerc: ETIF, 1993.

[7] *Catalogue: Operating Instructions*, Italpresse Industrie, Brescia, Italy.

[8] *Catalogue: Diecast Machine with Cold Chamber*, Italpresse Industrie, Brescia, Italy.