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THE DEVELOPMENT OF INTAKE SYSTEM IN INTERNAL COMBUSTION ENGINE IN STUDENT-CLASS VEHICLE

Master's Program Automation of design and engineering

The abstract of the Master`s Thesis

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INTRODUCTION

Relevance of the work. The formula SAE, better known in Europe as the Formula Student, is student engineering competitions, which were originally organized by the Society of Automotive Engineers (SAE) and included in the SAE Collegiate Design Series. According to the plan of competitions, a team of university students is an engineering company which has to develop, build and test a prototype car of a formula class for amateur racing car market. The challenge for the teams is designing a bolide, which will be able to pass all the disciplines in the competition successfully. And moreover the team has to provide the entire project's design documentation and to prove that the applied technical solutions are optimal.

One of the actual tasks in designing of a car is development of the internal combustion engine power system, taking into account the regulations of the "Formula Student" competition. Formula Student Combustion Rules implies the limitation of the engine capacity, that should be less than 610 cc, fuel type - gasoline, noise level not exceeding the threshold of 110 dB, and also the presence in the intake system of an air flow limiter – restrictor (with a cross-section diameter of 20 mm). The developed air intake system is to increase the engine power by intake manifold mechanical losses decreasing.

The purpose of the thesis – the intake manifold geometry development for FSAE engine with implementation of topological optimization approach.

The main objectives of the research:

1. The internal combustion engine(ICE) intake systems existing designs analysis;
2. Prefeasibility study (ICE parameters, applicable in FSAE, restrictions regulated by the conditions of the competition);
3. Designing and simulation of the intake system with the use of the modern computer simulation software;
4. Topological optimization of the intake manifold geometry;
5. 3d printing the intake manifold and make laboratory tests.

Research Methods:

1) Method of finite-element modeling in the CAE environment STAR-CCM +;
2) Analytical calculations with the use of function-computing packages;
3) Methods of topological optimization (method of control points.);
4) Laboratory tests.

Scientific novelty of the work:

Intake manifold geometry for FSAE internal combustion engine developing technique was improved. The technique based on coupled fluid dynamic analysis method and topology optimization approach aimed to achieve given specification at design stage.

The practical significance of the work

1. An improved technique will be able to develop an intake system for internal combustion engines taking into account the required aerodynamic characteristics and geometric constraints.

Personal contribution of the author:

1. An information review and input data collection was conducted.
2. The project main stakeholders needs were analyzed; scenarios of the system's behavior during exploitation were developed.
3. The 3d model of intake system was designed in accordance with the take measurements.
4. The ICE intake system optimization was provide.
5. The Laboratory test was provide on optimized model.

Approbation of the work

The main provisions of the thesis and its sections were present at:

The All-Russian scientific-technical conference of students, postgraduates and young scientists "Youth and Science", in the section «English for Masters» in 2016 (Krasnoyarsk);

The All-Russian scientific-technical conference of students, postgraduates and young scientists "Youth and Science", in the section "Digital technologies of machine-building production" in 2017 (Krasnoyarsk).

CONTENTS OF THESIS

Introduction. The topicality of the thesis is justified, the goals and tasks of the research are formulated, objects and subjects of research are defined.

In the first chapter of the thesis, the internal combustion engines review was carry out. The task of selecting an engine for a Formula sports car in accordance with the regulations (Formula Student Combustion Rules) was solved.

The purpose of the intake system was consider and conclusions on the design features for later design stages were drawn. The designing intake manifold will have a symmetrical design, since it is more productive. Intersection of the inlet branch pipes and the receiver will be in the form of a trumpet. In addition, at the intersection of runners edges are round to minimize eddies. Throttle valve module should provide easy access for measuring of the restrictor zone. The power injection system with phased injection will be used. For this purpose, when designing the runners at the point of maximum flow velocity, it is necessary to design the holes into which the nozzles will be placed, taking into account the recommended parameters.

The main available methods of manufacturing parts were defined, as well as the materials that can be used. The optimal way of making a layout is the method of extrusion printing using ABS material, which is the most suitable for making a model for testing. The method of powder printing is the most preferable for the manufacturing the parts when using reinforced fiberglass, which combines heat resistance and is not adversely affected by gasoline vapors.

Methods of topological optimization were also considered and the most appropriate method was determined - method of control points. Such working principle is used in the CFD simulation software.

In the second chapter implementation of the project within the framework of the system-engineering approach was described – stakeholders, their impact and value for the project were defined. The functional and non-functional requirements for each module of the system were systematized, taking into account the limitations by the regulation of the competition. The technological and constructive schematic diagrams of the inlet system were constructed. Modular and layout schemes of the inlet system were present, as well as the layout scheme in the formula car system. DSM physical link matrix of components of the inlet system was composed and their ordering and clustering were carried out. After that, 4 modules were received: suction module; air supply regulation module; transmission and mixing module; distribution module. The planning of stages of the project implementation was carried out taking into account the time limits of the entire product lifecycle.

A mathematical method for solving adjoint equations was also considered, which working principle is used in the Fluent software - where it was decided to optimize the topology.

In the third chapter in accordance with the previous review, proceeding from the data of the four-cylinder engine Stels 600 benelli BJ465MS-A obtained on the basis of the measurements of the inlet channels, and measurements of the geometry of the car, in the CAD environment of COMPASS 3D an intake system was designed. (Figure 1)

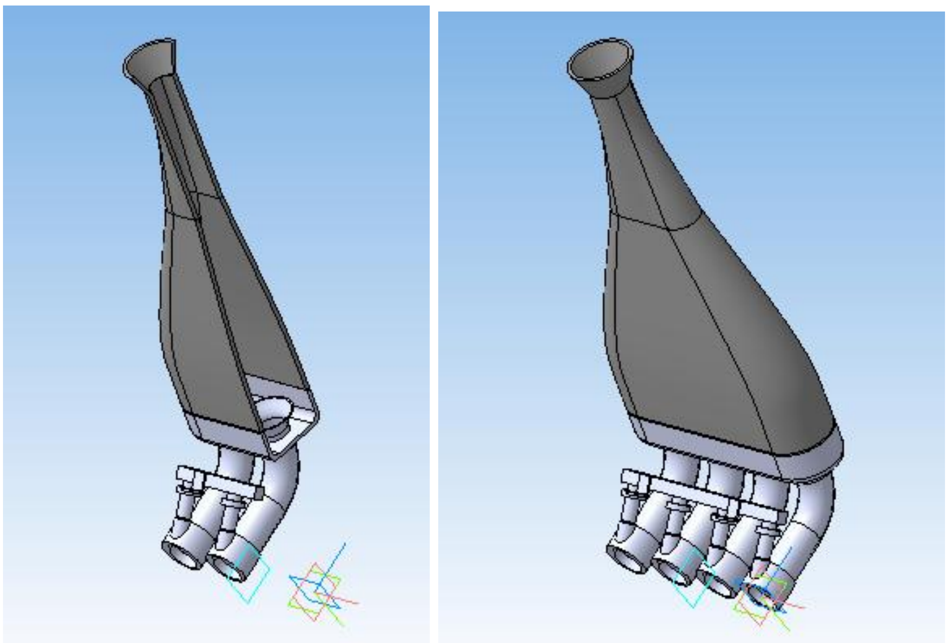

Figure 1 – The intake system

Numerical simulation of flow in the intake system in CAE environment was carried out. As the boundary conditions, at the outputs of the runners pressure as a function of time was set, corresponding to the engine pressure at the intake strokes according to its modes of operation. At the inlet to the collector, atmospheric pressure is set. As a solver we used the bound flow method that takes into account the gas compressibility (ideal gas model) and its temperature. Also, the SST turbulence model was used. The objective was modeled in the nonstationary regime.

As a result of the modeling, the quasi-static state of the flows at 5000 iterations was achieved, which corresponds to 0.08 seconds of the engine operation from the moment of launch in real time and includes 5 working cycles. The main criteria necessary for optimization were identified and analyzed (pressure drop in the system and air mass flow).

According to the criteria, the results were obtained: 0.055 kg / sec flows into the working cylinder at the intake stroke – air mass flow rate at steady modes of operation. The maximum pressure and velocity are created in the restrictor zone. In runners the velocity and pressure are much lower.

Then topological optimization of the intake collector geometry was carried out in the Fluent CAE environment with the use of the method of control points. The specified control points are shifted by distances calculated with the use of the mesh sensitivity parameter to the specified objective function, which is calculated by the Adjoint Mesh solver. The moved positions of these control points are set in such a way as to minimize the resistance of the system. In the optimization of the model geometry, 11 iterations were carried out. The optimization schedule is shown in Figure 2.

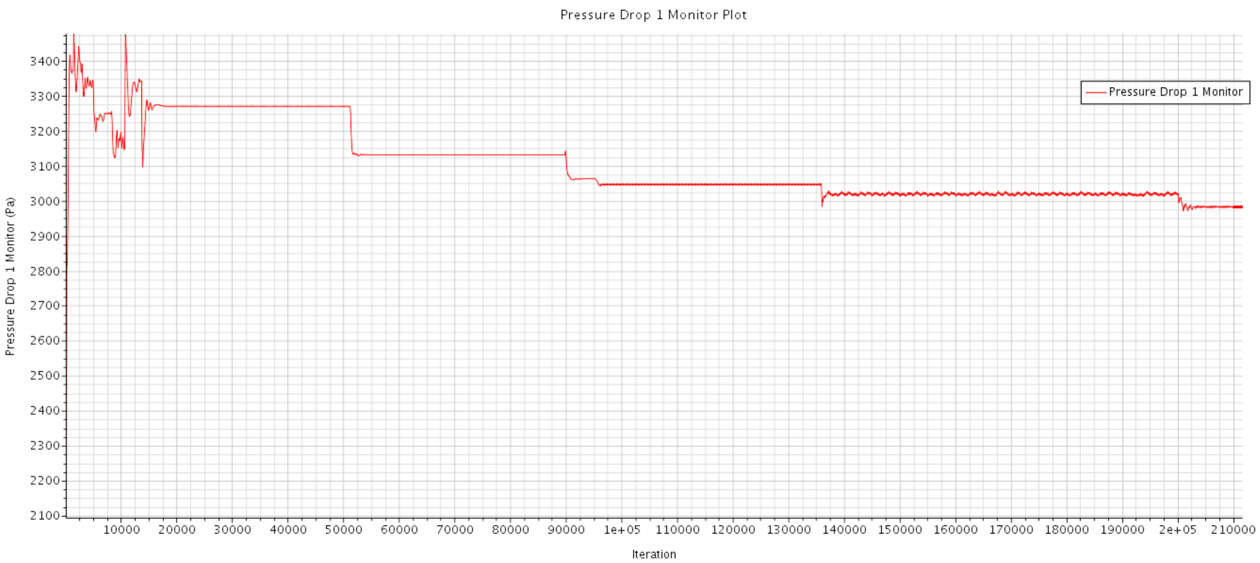

Figure 2 – Pressure drop due to optimization process

An optimized model of the intake system was obtained. In Figure 3 you can see that the design of the collector and the diffuser was changed.

The obtained results correspond to the calculated ones, which indicate correct calculation and optimization results.

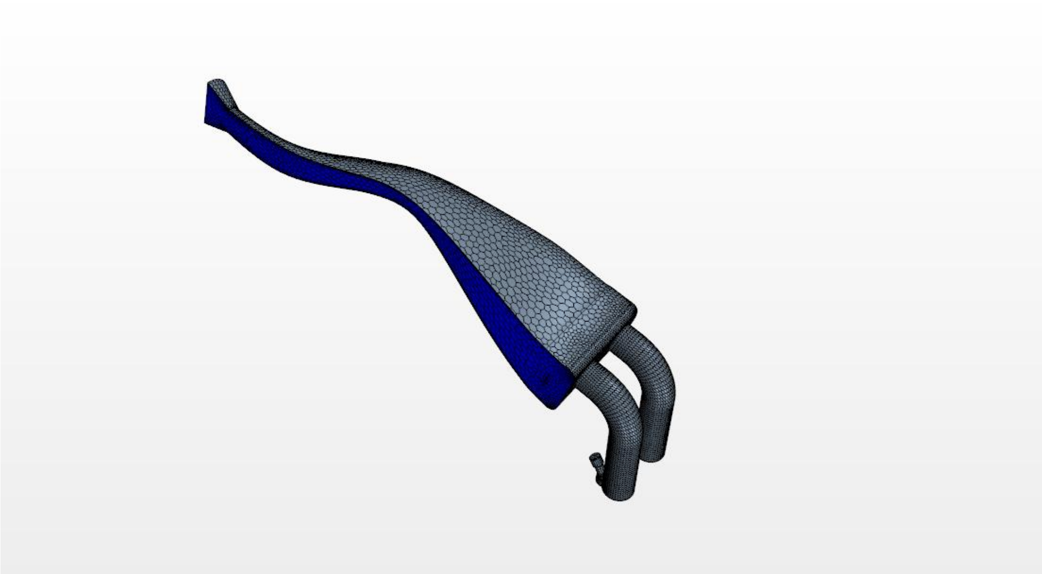

Figure 3 - Topologically optimized shape

The air flow velocity and pressure in the system were also analyzed, and vector flow visualization for the optimized model was carried out. Following the results of optimization it was possible to increase the mass flow by 15%.

Then the layout of the intake system was created by 3d printing technology. After that, the air intake system was tested at the flow bench. The obtained results correspond to the calculated ones. The difference between simulation and measured mass flow values at the model was 6%. It indicates the correct calculation and optimization results.

In the conclusion the main findings and results of the work are presented.

MAIN RESULTS AND FINDINGS

1. Existing designs of ICE power systems were analyzed;
2. The collection of input data for designing was carried out (ICE parameters, applicable in cars of «Formula Student» class, restrictions regulated by the conditions of the competition);
3. Designing and modeling of the ICE power system with the use of the modern means of computer modeling were conducted;
4. Topological optimization of the ICE power system model was carried out;
5. A layout by means of rapid prototyping was created and an ICE power system test was conducted. The obtained results were adapted.

CONCLUSIONS

The geometry of the intake collector for FSAE was developed with the use of the topological optimization approach. The design optimization model had allowed to increase the design productivity and, in separate elements, to form the optimal topology, according to which, hereafter, the model was designed.

Improved method of ICE intake system designing based on geometry topology optimization approach was developed.

The main publications on the subject of the thesis:

The main provisions of the thesis are reflected in the publications: total number of works - 2. List of scientific works:

1. Tolstykh I.I. METHOD FOR TURBOCHARGING SINGLE CYLINDER OF FOUR-STROKE ENGINES // The collection of materials of the International Conference of students, postgraduates and young scientists "Prospect Svobodny-2016" dedicated to the Year of Education in the Commonwealth of Independent States in the section "English for Masters" in 2016 (Krasnoyarsk);

2. Tolstykh I.I. COMPUTER MODELING OF AERODYNAMICS IN THE INTAKE SYSTEM FOR BOLIDE OF «FORMULA STUDENT» CLASS// The collection of materials of the International Conference of students, postgraduates and young scientists "Prospect Svobodny-2017" in the section "Digital technologies of machine-building production" in 2017 (Krasnoyarsk).