2.5. CALCULATIONS OF KINEMATIC AND STATIC PARAMETERS OF STRUCTURAL ELEMENTS OF A FORMULA RACING CAR

Before starting the design of the suspension, it is always necessary to conduct a kinematic calculation. Thus, the most important vehicle parameters are determined that affect stability, handling, fuel economy and rubber.

Note that car and suspension settings are always a compromise. Either the car is comfortable, or it is well-driven, or it behaves well on straight lines, or it maintains balance when cornering. And there are many such factors. The choice of one or another option depends on the original purpose for which the car is being created.

Since in our case we are designing a sports car with open wheels, accordingly, when calculating, we will neglect such qualities as comfort, smoothness, but at the same time pay great attention to handling, the ability to adjust parameters, shock absorber stiffness, lightness and structural strength.

The most important aspect of a project of a sporting car of the class "Formula SAE" is a frame. The frame contains operator, engine, brake system, fuel system and steering mechanism, and must be of adequate strength to protect the operator in the event of a rollover or impact.

Planning and calculation of these constructions is mainly carried out on the basis of calculation formulas of resistance of materials, not taking into account interaction of the elements, the peculiar features, of thin-walled bars. All of it results in overrun of the metal and, as a result, to influences on the weight.

The piston, piston pin and piston weight of 25 to 30% relate to the piston parts. Reducing the weight of all these parts leads to the fact that with frequent revolutions, the inertia of the crank rod decreases, and as a result, mechanical losses are reduced. In this case, it is important to balance the weight of the pistons, piston pins and connecting rods in order to avoid various loads on the crankshaft journals and, therefore, reduce the dynamic load from torsional vibrations.

In the work, the optimal size ratio of a simplified model with a piston rod is selected, which ensures a reduction in the volume of the structure and, as a result, the mass within the permissible voltage limits. The optimization algorithm is implemented in the Ansys finite element package.

Calculation of the kinematics of the suspension. In the kinematic calculation, as a rule, three parameters are calculated:

- change of way with the full course of the suspension;
- change in the transverse angle of inclination of the wheel at full travel;
- determination of the center of the roll of the car.

In this paper, only the first two parameters were considered. SolidWorks (3Dsketch) was used as a research tool.

SolidWorks features 3Dsketch function allows you to simulate rod spatial systems, and with the correct installation of joints, you can calculate the kinematics of movement of any design. This is done by setting the coordinates of the studied point of the structure, and after changing the location of the point (and the entire structure associated with this point), you can analyze the changes in any points of the structure.

When calculating the kinematics of the suspension, we used the “3dsketch” function. The initial geometric data was taken from the prototype car.

The constructed model consists of straight lines in a 3D sketch. Despite the fact that we calculated kinematics, the geometric dimensions of the pipes, steering knuckle and shock absorber, it was decided to neglect. Thus, the initial model was built in SolidWorks (fig. 1)

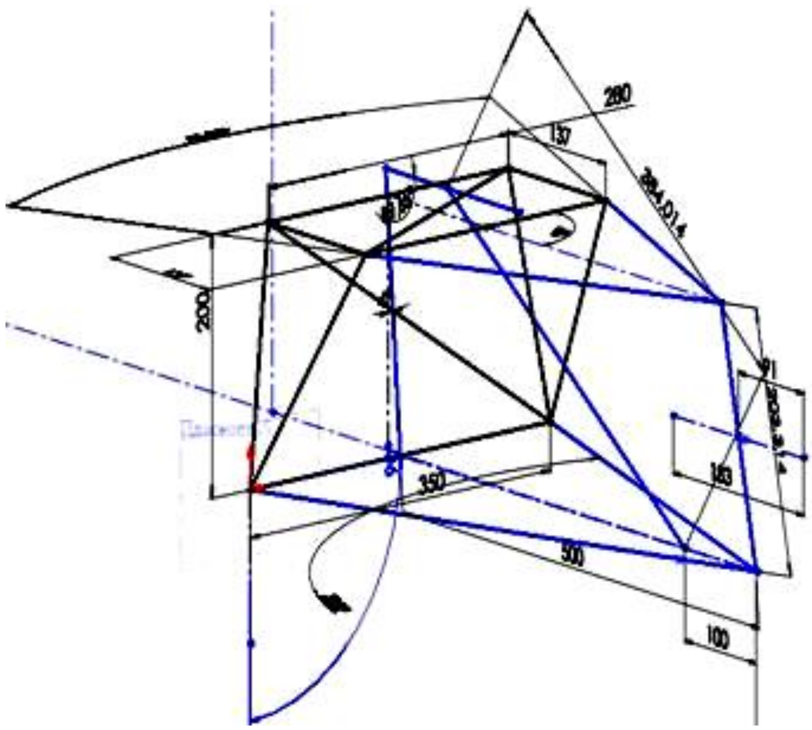

Fig. 1. Initial suspension scheme in Solid Works

In the Solid Works program, only one suspension parameter was calculated – this is a change in the path. For this purpose, the movement of the extreme point of the suspension A was studied along the movement of the extreme point of the wheel along the Y axis. As can be seen from figure 2, the coordinates of point A along the X axis were entered with an interval from 0 to 60 (including the suspension travel of the prototype – 60 mm). Next, the change in the motion of point B along the X axis was measured.

The ratio of coordinates at the initial location of point B, at the initial location of point A and at the location of point A for the maximum suspension travel just characterized the change of path along the length of the suspension travel to "breakdown".

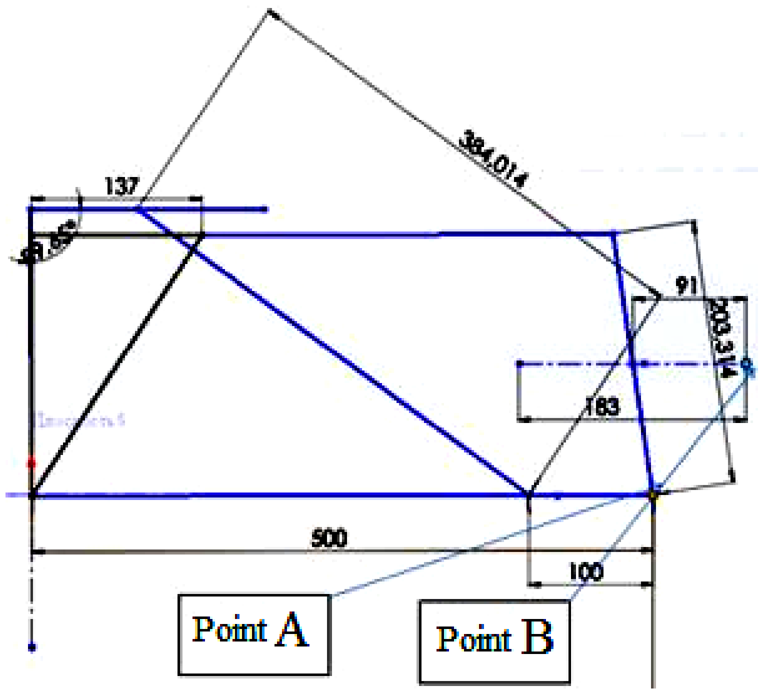

Fig. 2. Suspension scheme in the Solid Works program for determining the position of points

Despite the fact that the “3dsketch” function is not intended for detailed calculation of kinematics, it accordingly gives visualized results of studies. For this purpose, I had to use the Microsoft Excel program additionally. As a result of the suspension kinematics study in Solid Works, the following results were obtained (Fig 3).

Table 1. Suspension calculation results

Suspension movement mm	zn	yt	½ colies mm
-59	496	40,2	570
-55	446	45,2	571,19
-50	497,49	50	571,8
-45	497	55	572,46
-40	498,4	60	572,99
-35	498,8	65,1	573,47
-30	499,1	70,11	573,88
-25	499,37	75,13	574,22
-20	499,6	80,13	574,5
-15	499,78	85,14	574,72
-10	499,9	90,14	574,88
-5	499,98	95,15	574,97
0	500	100,15	575

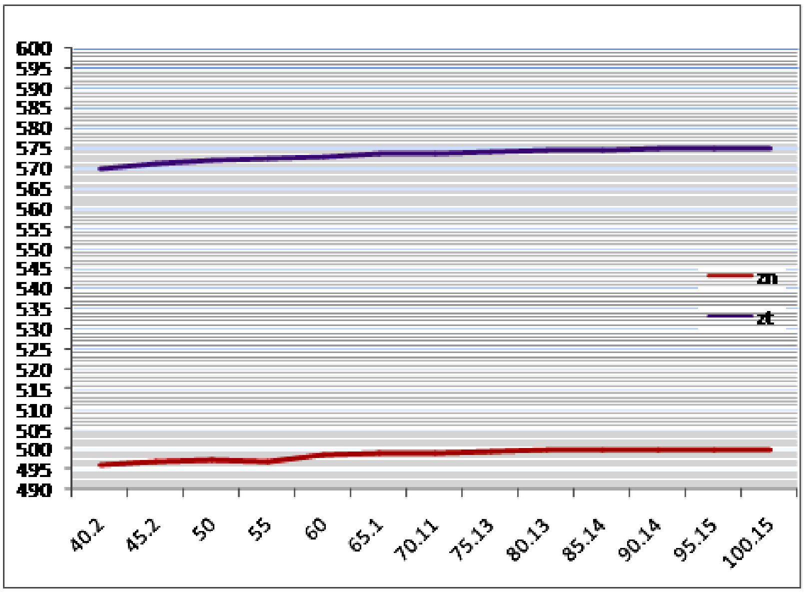

Fig. 3. Schedule changes during full suspension movement

Frame calculation and car body shaping. The frame shown below was designed and constructed at the department of Dynamics, durability of machines and resistance of materials, Odessa National Polytechnic University. For creation of mathematical 3D-models of the framework of the car, it was required to measure sizes and shape-generating elements of the engine and the seat of pilot. The configuration of the frame of the car depends on these knots. All tubes are round and made of steel (module of resiliency $E = 2{\cdot}10^5$ MPa, coefficient of Puasson $\mu = 0.30$). All tubes with the exception of the diagonal braces have 27 mm in OD and 2.5 mm in wall thickness. The diagonal braces have 25 mm in OD and 2 mm in wall thickness.

To study the frame, the finite element method was used according to the method described in the article by Limarenko A.M.[36]. The static loading on the frame was 900 kg, the frame was fixed in the places of joining of levers of pendant in order to prohibite any moving. The computer simulation and calculation of frame were done using the cored finit element from the library of bundled software Ansys — Beam 188 (fig. 4).

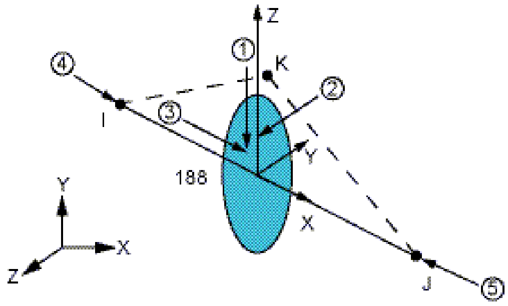

Fig. 4. Beam188 geometry

Beam188 is suitable for analyzing moderately stubby-thick beam structures. Shear deformation effects are included as in the studies of professor Orobey V F[37].

The finite-element model of the frame consists of 385 elements and 352 nodes (fig. 5).

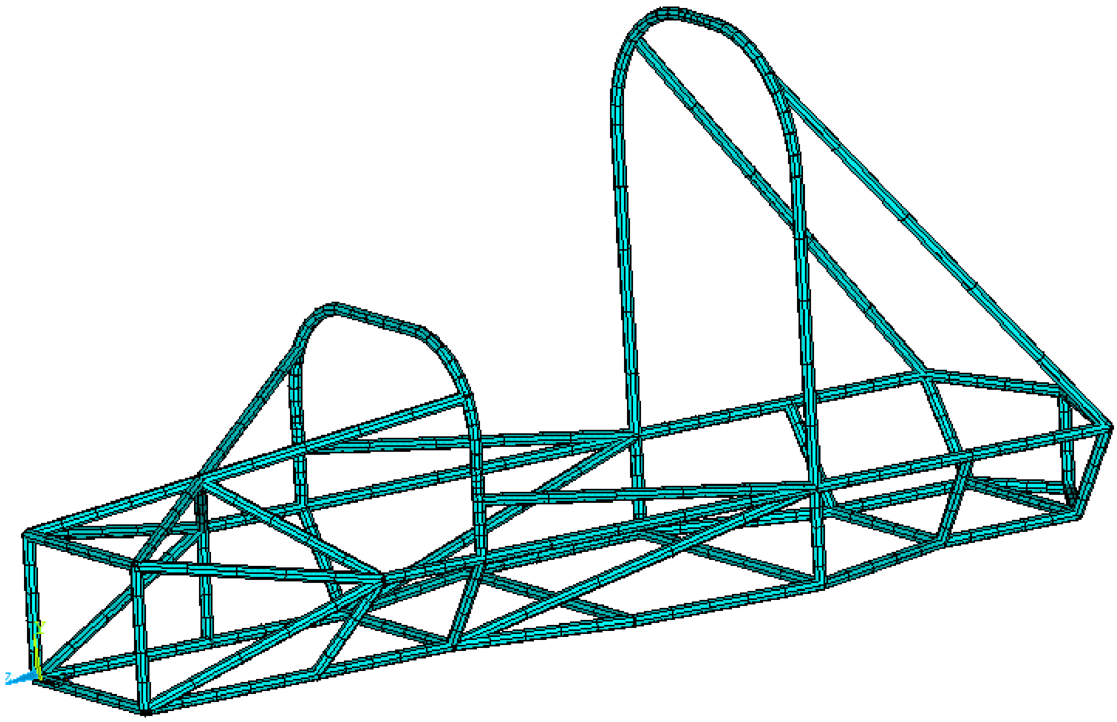

Fig. 5. The finite-element model of the frame

As a result of the calculation of the frame of a sporting car of the class "Formula SAE " by the method of finite elements, it was determined that the maximal equivalent tensions on the basis of the hypothesis of Huber-Mizes were $_{max}\sigma_{экв}$= 70 MPa, not exceeding the legitimate value [σ] = 160 MPa. The analysis of the linear moving ($_{max}f$ = 5 mm) has also confirmed sufficient inflexibility of the construction of the frame. The fields of equivalent stresses that arise in the frame are shown in

[36] Limarenko A.M. The optimization of car engine piston-rod by numerical method. / A.M. Limarenko, V.V. Khamray, A.A. Druzhynin. Вісник Одеської державної академії будівництва і архітектури – 2015. ч.1 вип 51, – С. 586-589.
[37] Оробей В.Ф. Основи розрахунку машинобудівних конструкцій. Навчальний посібник / [В.Ф. Оробєй, Л.В. Коломієць, О.М. Лимаренко]. – О.: ТОВ "ПЛУТОН", 2015. – 48 с.

(fig. 6). Having finished the analysis of the stress-strain of the frame, the results were processed in the CAD – system.

This allows us to see the general structure forms of the bolide, whereupon a designer can make his work over the elements of aerodynamics and over the general composition of the car (fig. 7, 8).

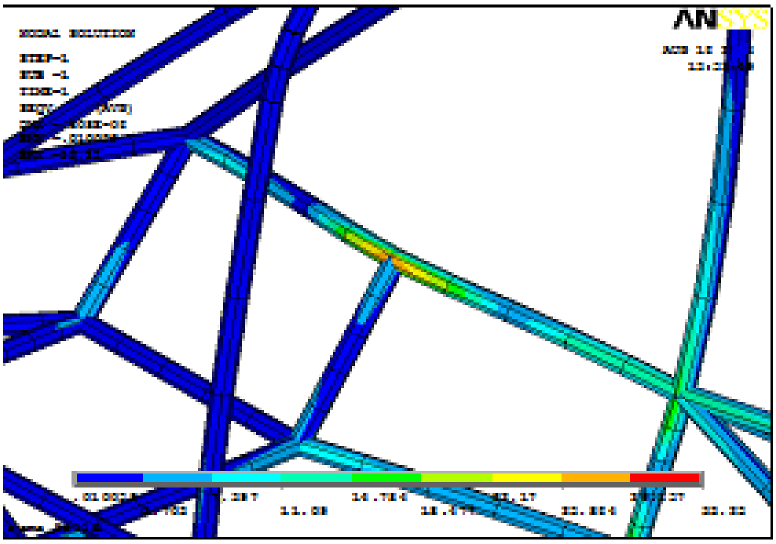

Fig. 6. Normal stresses in characteristic sections

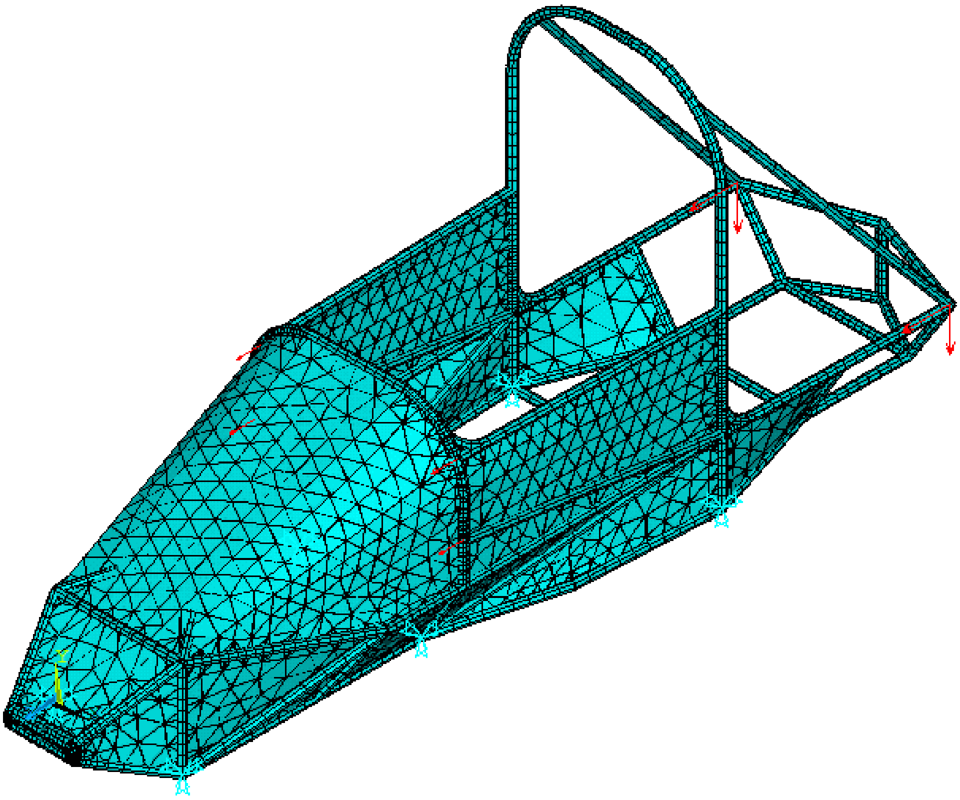

Fig. 7. The general composition of the forms surfaces

Fig. 8. Prototype race car

Calculation of the piston rod. Taking into account the connecting rod symmetry only one half of construction is considered.

The geometric model includes lower and upper head in the form of half-rings (Fig. 9, a), connected by the edge with a T3 thickness and a wall with a T4 thickness. Despite of thicknesses T3 and T4 properties, the connecting rod model includes 6 more design properties (the thickness of lower and upper head – Dt1, Dt2, the angles of orientation of the edge — Ug11, Ug21, Dug1, Dug2), which are in optimization process vary in set restriction limits. Letter designations (T, Ug, Dt) are used for parametric programming of the values, which are used in calculation.

There is a carried out loading effect on the connecting rod, gone out of the gas tension forces from combustion chamber and crankcase sides, viewed in this work. In order to simplify, it's assumed, that on lower and upper head there is a equable tension of 60 °C in bow limits.

The tensions, acting on upper head are selected that way so to make the summarized loading equal the summarized force, that's acting on lower head. The mounting of the bundles towards X axis creates the symmetry condition. One of the bundles is mounted towards Y axis in order to compensate small difference in summarized loads, acting on the lower and upper head.

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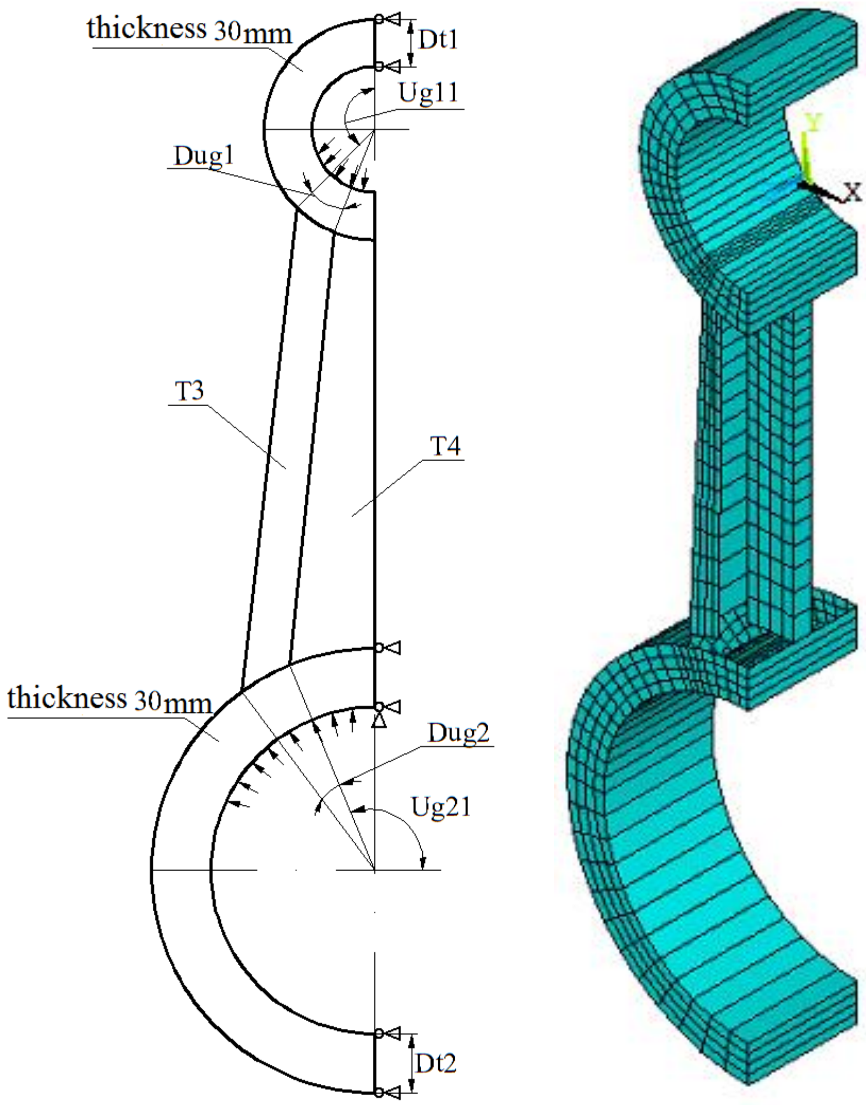
The piston-rod finite-element model consists of 368 elements like Solid45 and 445 bundles. For the calculation it was used a regular scheme of separating into finite elements. The material of the model is a an elastic modulus $E = 2{\cdot}10^5$ MPa and the Poisson's ration μ – 0,28.

After the stress-deformation connection rod model state analysis with given boundary conditions there is its optimization process. The main issue of the optimization in this work is an elastic edge orientation and the thickness of ridges between the edges.



a b

Fig. 9. Calculated scheme and parameters to be optimized (a),
finite element connecting rod model (b)

In ANSYS program there are two methods of optimizations: the method of approximation and the first explicit method.

The approximation method – is a method of zero-explicit that provides the effective solving of the majority of design problems. The first-explicit method is based on project sensibility evaluation to certain factors and best fit for solving problems requiring high accuracy.

In this case, the best results were given by first-explicit method. A similar problem was considered in the works of Gnatyuk A.P.[38].

In the Ansys program texts, written on the parametric programming language APDL, set limits on construction parameters and the variable state. As a variable state it was used an equivalent stress, corresponding Huber-Mises criterion. The minimizing object variable was the weight of the structure.

As a result of done optimizations the program displays a message box with a number of best parameters set. In the presented work the convergence was reach at 5 iterations. The equivalent

[38] Гнатюк А.П. Оптимизация толщины режущей пластины в ружейных сверлах / А.П. Гнатюк, А.М. Лимаренко, Е.П. Рябенко // Матеріали XVI Міжнародної НПК "Прогресивна техніка, технологія та інженерна освіта". – Одеса-Київ, 2015. – С. 97-100. [in Ukrainian]

stresses increased from 140 MPa до 157 MPa that is actually located in allowable limits. The changing of the connection rod dimensions after the optimization are shown in the table 2.

Table 2. Optimized parameters' values

Parameter of optimization	Before the optimization	After the optimization	Parameter changings
Piston-rod volume, mm^3	69597,8	59018,9	Decreasing on 15,2 %
Thickness of the edge, mm	20	17,6	Decreasing on 12 %
Thickness of the wall, mm	5	4,82	Decreasing on 3,6 %
Thickness of upper head, mm	10	8,9	Decreasing on 11%
Thickness of lower head, mm	10	10,1	Increasing on 1 %

Conclusion. The results of the kinematic parameter calculations show that the geometry of the suspension under study will not provide good vehicle controllability. Also, there is a likelihood that tire wear will increase, and through the use of soft compounds this can lead to tire breakage when passing a special racing section.

The technique considered in the paper allows to carry out a large number of researches and to find the optimal variant of suspension geometry.

As a result of the car frame calculation, the following results were obtained:

– the international competition rules have been taken into account when calculating the car frame;

– the stress-strain state of the frame is calculated;

– forms for the manufacture of the car body were obtained.

According to the calculation of the connecting rod of the piston group, we can summarize:

– currently, the shape of the geometric parts of a group of piston rods is usually selected using general recommendations that do not take into account the working conditions of certain parts and the requirements addressed to it;

– light weight of rotating masses allows the engine to reach high speeds faster;

– use of modern software systems reduces the time and financial costs for the manufacture or modification of a particular part of an automobile engine;

– the proposed approach allows you to optimize the details of automotive engines with a completely different form of complexity, which creates new opportunities for design, while the shape of the part is determined by the source of ensuring its best performance.

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