Analysis of the frame design of the subcompact racing car of go-kart class

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Abstract. The article presents the design features of subcompact small-capacity racing car of kart class. The issues of the strength of the supporting structure are considered. The main strength characteristics of the material AISI-1020 are presented, which was used in the design of the frame chassis. A conceptual block diagram of a methodology for designing a supporting structure model using engineering analysis methods (finite element modeling) is presented. The analysis of structural strength using ANSYS software is carried out. The rode type finite element model of the frame is presented. The directions of application and values of the resulting loads are determined taking into account the overloads experienced by the pilot in collisions. The boundary conditions and the deformation pattern of the frame structure when applying the deforming forces to the front beam along the longitudinal axis of the car, outside the longitudinal axis of the car and on the lateral truss of the car frame are given. The engineering analysis data show a good coincidence of the modeling results with the experimental data.

1. Introduction
Karting is one of the most popular types of motor sport. As a sport, karting has been known for a long time - many famous Formula 1 racers began their career in karting. But recently karting is gaining more popularity and goes beyond the boundaries of professional sports. In cities, car rental stations appear, small race tracks for active recreation are being built. Entertainment is one of the most important areas of everyday human life, which, along with education, can significantly affect the state of society. For society, an indicator of the economy development of the city and the country as a whole is a high level of the entertainment industry.

In general, karting is a kind of racing on subcompact racing cars of open type. Go-kart can reach speeds from 60 to 260 km/h, depending on the type and class. This type of road transport has no body, elastic suspension and differential.

Cars go-kart class of amateur series are easy to manage, thanks to the absence of a gearbox. The structure of the standard go-kart includes 7 components: the frame; protection elements (the so-called front box and lateral protection); chassis; steering part; engine (usually two-stroke gasoline, with a capacity of 5 to 7 HP); cooling radiator; driver seat made of hard plastic. It should be noted that recently the direction of electric driving go-kart has been actively developing, which has undoubted advantages, such as the absence of exhausts, a low noise level, all-seasonality, and the absence of the need for additional ventilation in the room of the track circuit.
2. Relevance
The relevance of the go-kart design development is confirmed by increasing the number of studies of various factors aimed at increasing the dynamic stability of the go-kart on the racetrack. It is known that the production of any car of go-kart class begins with the frame or the supporting structure. Analysis of the strength of the car frame is one of the first steps in designing a car of any class [1-11]. Both the dynamic characteristics of the machine and the operational safety of the pilot depend on a properly designed frame. This is confirmed by the number of works [4-11], in which the main emphasis is on modeling and analysis of the supporting structure of the go-kart. The studies of the best arrangement of the frame supporting structure, that is, directly the configuration of the frame itself, frame materials, thickness, cross-sectional parameters of the frame tubes and methods of fixing the basic units of the go-kart are considered. In addition, in [11], the influence of the elastic features of the go-kart frame on the dynamic characteristics of the vehicle at different speeds and steering wheel angles was investigated, and the authors of [12] modified the standard transmission and designed a hybrid type transmission including an electric motor and an internal combustion engine.

As can be seen from the above, the designing of the optimal configuration of the supporting structure of a small-sized car of the go-kart class is one of the main tasks faced by the designers.

3. Materials and Methodology
The choice of the supporting structure material has fundamental importance in terms of pilot safety and vehicle reliability. As a frame material for a small racing car, tube rolled steel AISI-1020 is used, which is the optimal choice in terms of strength characteristics and material cost. The main strength properties of this material are presented in table 1.

| Material Property          | Values     |
|---------------------------|------------|
| Material type             | Steel      |
| Tube shape                | Round      |
| Material name /grade      | Steel      |
| Youngs Modulus, E         | 2.00E+11   |
| Yield strength, Pa        | 3.05E+08   |
| UTS, Pa                   | 3.65E+08   |
| Yield strength, welded, Pa| 1.80E+08   |
| UTS welded, Pa            | 3.00E+08   |

Design development always begins with the analysis of already known design solutions, identifying the advantages and disadvantages, as well as the choice of material and methods of joining the elements. On the basis of these data, a CAD-model of the supporting structure is created, taking into account the requirements of safety, reliability and the possibility of installing all the necessary components of the go-kart on the frame. To identify weaknesses in the design, a finite element analysis is carried out, for which the numerical frame model of the go-kart is created. According to the results of the comparison of the simulated values and the values obtained experimentally, the conclusion is drawn about the reliability of the supporting structure. In case of unsatisfactory results, an in-depth analysis of the design of the frame is carried out - the areas with maximum deformation and areas of poorly deformed are identified. Next, it is necessary to change the frame design in such a way as to redistribute the stressed areas with an increase in structural strength in problem zones. Figure 1 shows a conceptual block diagram of the design methodology.
4. Finite element analysis

The structural strength analysis was performed using the ANSYS software based on the finite element analysis. The finite element model of a go-kart frame developed by the student design bureau at Togliatti State University is presented in figure 2.

![Finite element model of the go-kart frame](image)

The directions of the loads applied to the frame elements in the analysis of structural strength were chosen similarly to the loads of the frame of racing cars of the Formula SAE series, installed in accordance with the relevant regulations. The value of loads was determined on the basis of the limit overloads in a collision. The exact values of the overloads that the go-kart pilot must withstand are not determined – in various sources [5-7] they range from 2g to 5g.

The go-kart laden mass is 135 kg. The overload value varied from 4g to 5g under various modeling conditions.

![Loading the front beam axially: a - boundary conditions; b - deformation of the frame](image)
Figure 3a shows the points of fixed constraints and the point of load application in the analysis of the structural strength of the frame. The forces are applied along the longitudinal axis to the front beam. The boundary condition is the fixation of the displacement along the X, Y and Z axes and the rotation of the lower nodes at the intersection of the outer tube trusses. This scheme was applied to all simulated cases.

The points of the load application are the actual points around the perimeter of the front beam.

Figure 3b presents a picture of the frame total deformation. It can be seen that the frame deformation was 5.5 mm, which is an insignificant value.

But a frontal impact along the axis, taking into account the peculiarities of the go-kart track, is unlikely. Therefore, a simulation of the impact outside the longitudinal axis of the frame for the car of class go-kart (figure 4) and simulation of lateral impacts (figure 5) were carried out. The load application node was located in the center of the front beam during modeling the impact outside the longitudinal axis.

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**Figure 4.** The loading of the front beam outside the longitudinal axis: a - boundary conditions; b - deformation of the frame.

**Figure 5.** Loading the lateral arc truss of the frame: a-boundary conditions; b - deformation of the frame.
The value of deformation has increased more than three times (figure 4), but nevertheless is within acceptable limits. The value of the resulting force in 7810.2 N was obtained from the efforts on the axes: $F_x = 5000 \, N$; $F_y = -6000 \, N$ according to the location of the coordinate axes.

Figure 5 shows the boundary conditions and the pattern of deformation distribution when applying force to the lateral arc truss of the car frame. The arc truss almost completely absorbs the impact energy and the deformation is negligible.

The data of CAE-modeling showed a good coincidence of the results with the experimental data, which led to selected variant of the frame design for production in the student workshop (figure 6).

Figure 6. Manufactured go-kart frame.

5. Conclusions
The developed design of the supporting structure of a small-capacity racing car of the go-kart class meets the requirements of safety, strength and reliability. The finite-element analysis of the frame showed the permissible displacement under loading, taking into account overloads exceeding 4g. According to the developed CAD-model, a go-kart prototype was made, which successfully passed the dynamic tests on the race track.

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