# Methods of building a parametric CAD-model of a piston micromotor with the systems

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**Abstract:** The small-power micro-motors are widely used in different kinds of equipment including unmanned aerial vehicles. However, in the modern literature not so much attention is paid to the issues of parametric modeling of such engines. In this research there has been developed with the use of the "virtual engine" concept and existing parameterization options the method of building the parametric CAD-models of the piston micro-motors for further calculations in the CAE/CAM-suits. The general and specific recommendations have been provided. The efforts by building of such models have been estimated. The method allows simplifying, partially formalizing and parallelizing the piston micro-motors modeling process which allows reducing the time needed for the development thereof.

**Keywords:** Piston motor, virtual engine, parametric CAD-model, hierarchical assembly, micro-motor, parameterization.

## 1. INTRODUCTION

To solve the tasks of designing the complex technical systems today the special algorithms for creation of a "virtual engine" are used in which the CAD-component represents one of the basic stages. This method is based on the following principles: 3D-model of the piece describing the complete structure of the mechanism (or a part thereof) that is sent to kinetic calculation in the course of which all the strokes, speeds and accelerations of all the model items are determined. Then the model is subjected to the dynamic calculation by which the effective forces and moments are specified including reactions in all couplings. At this point one may either return to the 3D-model or continue calculating. This stage is followed by the strength analysis by which the strains in all components are evaluated. If a designer is satisfied with the strength then the model is redesigned for production, for this purpose the existing special programs are used.

If it is possible to ensure the model universality in respect of each program, i. e. free exchange of information between them by means of the dedicated software then one may speak of the algorithm of engine design implemented on the basis of the integrated programs – "virtual engine" [1-9].

The necessary condition for performing calculations with the use of the CAM/CAE-packages such as kinetic-dynamic, thermal, strength one, evaluation of reliability and assessment of life-time, adjustment of the vibrational properties and some other is the designed CAD-model of the engine major components [10-12]. For the purpose of comprehensive analysis consistent with the concept of creation of a "virtual engine" the most comprehensive 3D-model equipped with all the devices and systems ensuring the continuous operation of a real-life engine is required.

The specification of a solid model allow considering the structural features of the specified engine (Fig.1) affecting its performance and relevant for development of the design method.

Fig.1. Appearance of a piston low-thrust engine

The following basic principles may be distinguished in the 3D-modeling of the mechanical system structures: interactivity, self-descriptiveness, parameterization option, ease of transfer to CAE/CAM-packages.

Such features as operational ergonomics, long storage time, ease of copying, visualization and many other also belong hereto.

In an object-driven model, beside the numeric parameters, there are also structural ones. The simplest variant of such parameterization is the object modeling on the basis of the structural components or features (Feature-based modeling) by means of Boolean or similar operations (Add, Extrude, Revolve, etc.). In this case it is possible to manage the object shape by activation or exclusion from the calculation of the particular structural components. I. e., to obtain 3D-variants differing not only by dimensions but by the appearance as well. Within a more complicated variant the “objects” may mean not only relatively simple operations (Extrude, Revolve, Sweep, Shell, etc.), but also more complex combinations. For example, such an object as a “hole” depending on the parameter specifying the hole type may provide the following geometric variations (Fig. 2).

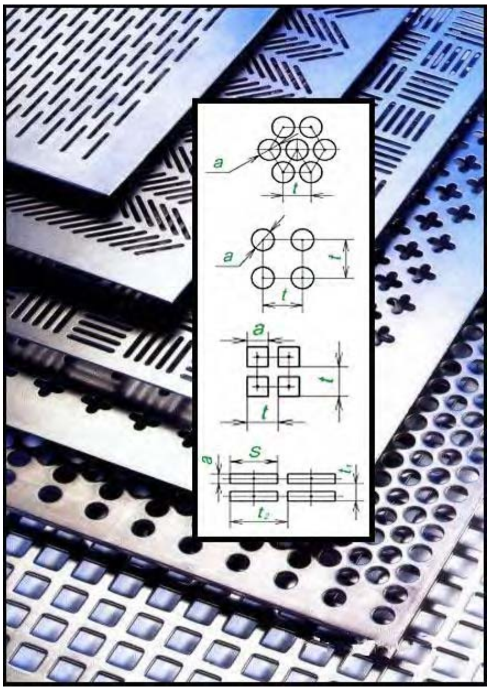



Fig. 2. Variants of the parametric setting of the through-hole type

Another example that can be given is the modeling methods based on the hybrid techniques (sheet metal, pipelines, etc.) as well as various objects allowing creating a model from a set of the production operations (bevels, rounding, slots, grooves, holes, etc.) [9, 13].

## 2. MATERIALS AND METHODS

The issues of building a parametric CAD-model of an internal combustion 2 h. p. engine have been considered.

The study is performed with the use of the modern methods of engine design on the basis of the high-end CAD-systems used for various technical objects [14-18].

The object of the research is a two-stroke one-cylinder air-cooled internal combustion engine with the air-fuel mixture ignition from a heater plug with a resonant exhaust pipe. Engine capacity - 2,47 cubic cm, cylinder diameter 15 mm, piston stroke 14 mm, weight 180 g,, shaft speed 38000 rpm.

Area of application: cord high-speed ship-, car- and aircraft models, unmanned aerial vehicles.

The building of the particular engine models has been considered: from the simplest piece created by a single operation and not featuring any additional elements (radius , bevels , holes , etc.) to the most complex body parts (Fig. 3) requiring over a hundred of complex operations.

Fig. 3. Operations of rotation , stretching , rounding the fins , beveling  and operations with the edges ( , , ) – modification of the case model

The same piece may be made in different ways, among which there are more or less efficient, labor-intensive and simple ones. There are methods of building that may bring you to a dead-lock at a certain stage. A few simple rules shall be observed for the quick creation of successful models by the sketch design :

1. Before starting working within NX environment you should spell out the detailed sequence of operations in the form of a flow chart that will allow to immediately cut off many of the wrong ways.

2. You should for reducing the number of operations by building of a model that's why all the sketches  maximally information-bearing, especially the first one.

3. Use the simple operations, if possible: stretching  and rotation . This makes the model-building tree clearer , simplifies the process of the model building, eliminates possible errors by the model transfer to the other packages (for production, dynamic, gas-dynamic, strength calculations, etc.) and design of drawings, enables the logical model parameterization. This is with exception of the objects for which special tools are provided, for example, sheet metal  or welding .

After creation of CAD-models of particular pieces they are combined in an engine assembly (Fig. 4) by means of various mating of components in an assembly .

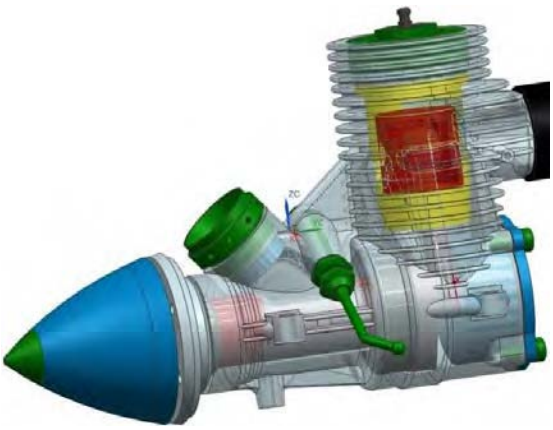


Fig. 4. 3D-engine model without a resonator pipe

For building of the model (Fig. 4) the modular concept or hierarchical assembly was used when firstly the subassemblies of separate units are formed and then they are united in other subassemblies of a higher level up to the assembly of a finished model. This method features a number of advantages:

a) Each separate unit may be designed by a different designer which significantly speeds up the work.

b) Smaller assemblies may be performed with the use of the computers with low RAM- and GPU memory capacity, and the summary one – on a more powerful computer.

c) If needed, modifications can be introduced to separate units without damaging the structure of the entire model.

d) The model structure is strictly ordered which enables quick search and full access to each separate piece (Table 1).

The three levels of the parameterization depth may be distinguished:

1. When a particular variable is assigned to each unique parameter in a model, then they are added to the parameter table. This method provides the lowest gain as compared to the non-parameterized model only due to the centralized variation of parameters since if it is needed to modify the model all parameters shall be pre-computed and changed independently.

2. When the independent (primary) and dependent (secondary) parameters are distinguished. The values of the dependent parameters are either calculated according to the expressions set at the parameterization stage or computed by the program on the basis of the specified geometric constraints (free dimensions). The smaller the number of independent parameters is the more complicated is the parameterization because of the necessity to identify the functional relations between the parameters which may require deep knowledge of the processes (physical. chemical, etc.) taking place in an engine, necessity to take into account the variations impact on the strength, producibility, etc.

Table 1. Composition of the engine component models

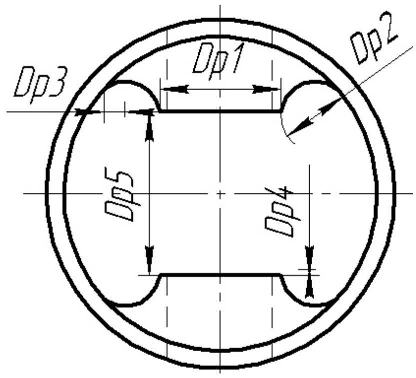
| | | | |
|---|---|---|---|
| **Crankshaft** | | 1 | Rotation |
| Code | | 2 | Rotation |
| Operations | 6 | 3 | Rotation |
| Key | | 4 | Rotation |
| Additional geometry* | 12 | 5 | Stretching |
| Arrays | 0 | 6 | Stretching |
| Threads | 1 | | |
| **Piston** | | 1 | Stretching |
| Code | | 2 | Stretching |
| Operations | 6 | 3 | Stretching |
| Key | | 4 | Stretching |
| Additional geometry* | 0 | 5 | Stretching |
| Arrays | 0 | 6 | Stretching |
| Threads | 0 | | |
| **Piston pin** | | 1 | Rotation |
| Code | | | |
| Operations | 1 | | |
| Key | | | |
| Additional geometry* | 0 | | |
| Arrays | 0 | | |
| Threads | 0 | | |
| **Connecting rod** | | 1 | Rotation |
| Code | | 2 | Rotation |
| Operations | 5 | 3 | Stretching |
| Key | | 4 | Combining |
| Additional geometry* | 10 | 5 | Rotation |
| Arrays | 0 | | |
| Threads | 0 | | |

* radius, bevels, holes, etc.

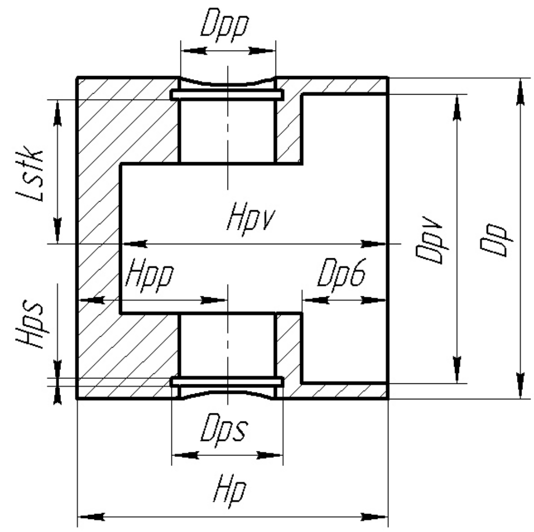
3. When the target functions are the integral engine characteristics: power, torque, fuel consumption, weight. At this point we go beyond the scope of geometric parameterization and this study. In respect of an engine as a whole such parameterization may be performed to a certain extent only by means of using a model set within the frameworks of the "virtual engine" concept of the necessity to combine in a single model all the processes in the engine for maintenance of which the parameterized geometry is created.

Further we are going to consider the second and partially the third level of the parameterization depth. Thus, in a parametric model both the dependent and independent variables shall be selected as well as there shall be present the table of dimensions of pieces making a single assembly, at the same time it is suggested that by further optimization the dimensions of parts will not change by more than twice. Let's consider as an example the piston group including along with the piston itself the piston pin and locking rings (Fig. 5).

Firstly, we need to make a table with descriptions and the table of parameters (Table 2) sufficient for describing all the part dimensions and specifying the independent variables, and regarding the dependent variables - to specify expressions by means of which they are related to the independent variables. By doing so it is understood that such division is conditional and if necessary at the finishing stage the dependent variable may be assigned a numerical value where the connecting expressions will be deleted and further on it will be considered as an independent one.




a)




б)

Fig. 5. Scheme of piston parameterization:
a) bottom view; б) longitudinal section

The parts making the other groups are parameterized in a similar manner whereas the carter parameterization involves the biggest difficulty (Fig. 3). Because of their volume the corresponding parameterization patterns and tables are not presented in this paper.

Table 2. Table of the piston parameters

| **(Porshen) (Piston)** | | | |
|---|---|---|---|
| No. | Name | Description | Value, mm |
| 1 | **Dp** | Piston diameter | 15,0 |
| 2 | **Hp** | Piston height | 14,5 |
| 3 | **Dpv** | Piston inside diameter | 13,5 |
| 4 | **Hpv** | Height of the internal piston part | 12,5 |
| 5 | **Lstk** | Distance from the piston centerline to the locking ring of the piston pin | 6,5 |
| 6 | **Dp1** | Piston boss width | 5,2246 |
| 7 | **Dp2** | Diameter of the sidepiece of the piston boss | *Free 3* |
| 8 | **Dp3** | Diameter Dp2 center shift along X | *Free 0,923* |
| 9 | **Dp4** | Diameter Dp2 center shift along Y | 0,1755 |
| 10 | **Dp5** | Distance between the piston bosses | 7 |
| 11 | **Dp6** | Distance from the piston top to the piston boss | 4 |
| 12 | **Dpp** | Diameter of the piston pin hole | 4,5 |
| 13 | **Hpp** | Distance from the piston top to the piston pin axis | 7 |
| 14 | **Dps** | Outside diameter of the lock ring | 5,2 |
| 15 | **Hps** | Lock ring width | 0,4 |

## 3. RESULTS

1. The parametric CAD-model of the internal combustion engines has been built. The specific issues of the procedure of performing 3D-operations, making the split-level engine assemblies and the combination thereof, hierarchic model structure have been considered.

2. The basic principles of the parametric modeling of mechanical systems have been specified.

3. The procedure for building a parametric CAD-model of a 2 h. p. internal combustion engine for the use in the standard procedure of “virtual engine” construction has been developed.

4. The labor content has been evaluated. It may be noted that the total time of building a 3D-model of an internal combustion engine makes about 200 hours, of which for building a model of the cranking mechanism – 12%, VVEL – 5%, base members – 72%; for the assembly – 5%. The rest of the time is spent on the small pieces and other operations.

## 4. DISCUSSION

The ability to abstract and generalize allows solving a great number of various tasks including engineering challenges since any of them may be reduced to a set of a few standard situations. Thus, creating of a parametric 3D-model of an internal combustion engine may be rather difficult until a designer does not abstract from the particulars and does not reach the primitives underlying the model basis. This is because the very essence of a geometric model is a certain degree of simplifying the source physical object.

At the same time the use of parameterization allows to significantly reduce the time for the parts adjustment, the time of the engine structural optimization and the total development time, to increase the optimization quality due to the extension of the number of options considered with the use of the optimization automation, for example, using the IOSO PM software.

## 5. CONCLUSIONS

It should be mentioned that the present paper overlooks such issues as specific features of transfer of the created geometry to CAE/CAM-packages which relates to its overall simplification, for example, removal of small components for FE-analysis or grouping of the parts for the purpose of dynamic analysis [7, 10, 12].

The process of optimization itself and the automation thereof is not considered [5].

The logical continuation of the given study is the deepening of functional relations between variables due to a better understanding of the physical links between them which should result in the reduction in the number of independent variables up to a certain minimum of parameters that are really relevant for the structural optimization [19-23].

## CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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