Title:
Methodology of Modular Design of Construction Machines

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Introduction:
The following paper describes a method of structural design of modular mobile working machines, specially wheeled telescopic excavators. Today in the automotive industry, engineers prefer modular design, platform vehicles, to increase the efficiency of the process of designing newly released models. In the design of construction machinery, it is also possible to choose a common platform for a group of devices. For the research of modular design methodology, it was drawn up several excavator options. Students of engineering study have modelled within two years, the conceptual study of wheeled telescopic excavator of weight category up to 14 tons. Some design solutions and used components cannot be presented in this work, because of patent protection. The design of the selected components is also in ownership of manufacturing company, the potential machine manufacturer. This model of wheeled telescopic excavator presents proposal of new size range of universal finishing machine, which will appropriately complement the company manufacturing program. For this machine, there were selected variants of different chassis, various powertrain systems and work equipment's. The chassis options include wheeled chassis, tracked chassis and self-propelled chassis with its own power unit, which generally replaces drivetrain in excavator upper body. Work equipment, telescopic boom as a set of modules provides many more design variants. Base variant, wheeled telescopic excavator is shown on Fig.1.

Fig. 1: Wheeled telescopic excavator based on a platform.

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The design of these machines was made in CATIA V5. Intuitive work, with tree structure of assemblies, enable to create a common platform for all variants of machine. All parts, components and modules are connected, and each design change on modules is reflected in all machine variants. Subject to research design methodology was also the possibility of using methods of generative engineering design in process of construction machines designing. With parametric modeling methods, there was ensured technological modularity. Defining common parameters, such as a sheet thickness, radiuses and angles of bends, allows the use of the same manufacturing technology in several parts of the machine.

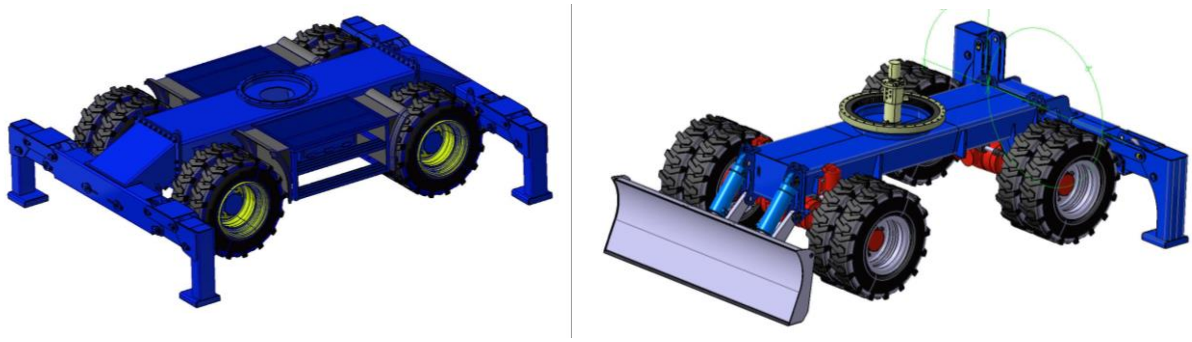

Fig. 2: Wheeled chassis with two modules of stabilizers and with one front blade.

Structure:

Before the design, there were predetermined rules for structuring the different sub-assemblies and parts. All manufactured parts have a common coordinate system positioned on the axis of rotation of the machine upper-body and are fixed to the zero point of space. Each assembly and sub-assembly includes own part entitled skeleton. All skeletons, parts, assemblies and sub-assemblies have the same 8 numerical labeling XX_XX_XX_XX. The first two numbers indicate the part of excavator (01 - chassis, 02-upper-body, 03 - work equipment). The next two numbers identify variant of a part (01_01_ - wheeled chassis, 01_02_- tracked chassis…). The third and fourth numbers indicate the level of subassembly of individual modules, components and their order. Module, forming a platform for a given level, is indicated by two characters _XX_ in corresponding level. This means, part is used in other variants of the machine at the same level.

In skeletons, there are modeled a wireframe geometry, planes, shape geometry and parameters in ordered geometrical sets. Created elements are published and copied sequentially to the last parts, where they are used to create final weldment. For example, sheet plates manufactured by bending, trimmed etc., are modeled in the skeleton with shape design as surfaces. In the resulting part, we determine the thickness parameter of the sheet to dimensionless surfaces and carry out changes as chamfers, fillets, symmetry, drilling holes etc. In each of the resulting Part, there are Part Bodies, which represent final components. In welded parts, one PartBody represent one single sheet. Whole Part then represent a weldment. Some assemblies, which also serve to be analyzed in regard to the kinematics, are created with different structure. Each independently movable part is a separate part or sub-assembly and does not contain any external references and publications. The reason is that while we move parts, we change the coordinate system against to the original system. It would be then impossible to move published geometry.

All parts and assemblies, with XX in label, constitute the platform of the machine. It is possible to separate modules for each kind of machine variant. Platform size affects the price of manufactured machines. For all machine variants, we can determine how many modules are common. We determine the coefficient of modularity for each excavator. Defining certain parameters in the CAD model allows us to analyze the various cost options. Accordingly, it is possible to choose variants, which should be produced or not.

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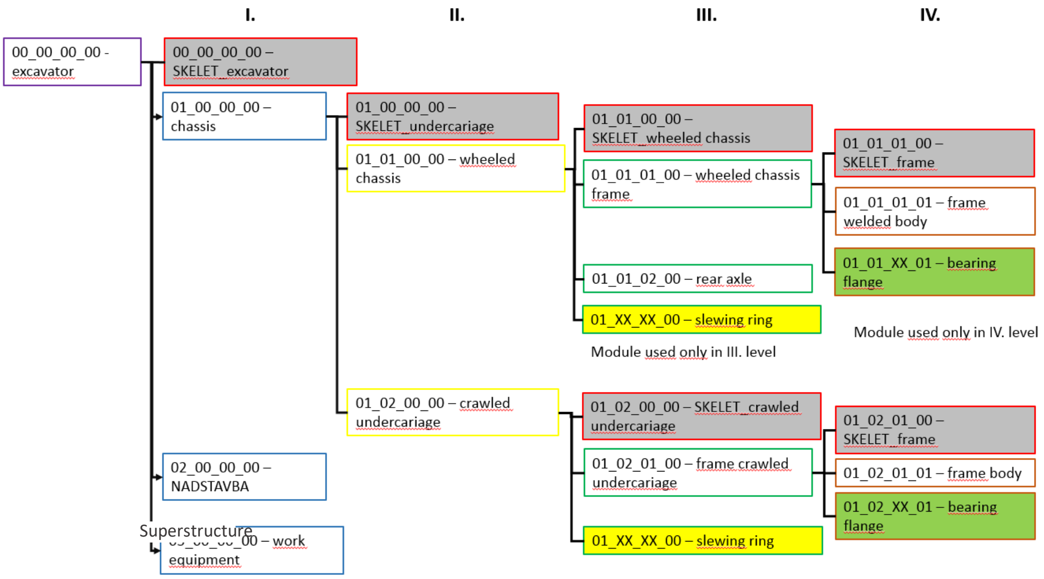

Fig. 3: Tree structure with modules and skeletons.

Front blade kinematic system was created otherwise. Blade was made in the skeleton blade assembly. The finished geometry of sheets was copied into the final weldment assemblies, but without link to the original geometry in the skeleton. After any change of geometry, it is necessary to copy isolated geometry once again into the final weldment. This method has been proved to be slow. Because of that, it was used only for kinematic parts, which do not require many design changes. Such parts as axles, which are purchased as complete parts. They should be modeled as movable for purpose of a collision analysis. Therefore, movable components of the axle are published and isolated in a separate part. These parts create a movable assembly of axles.

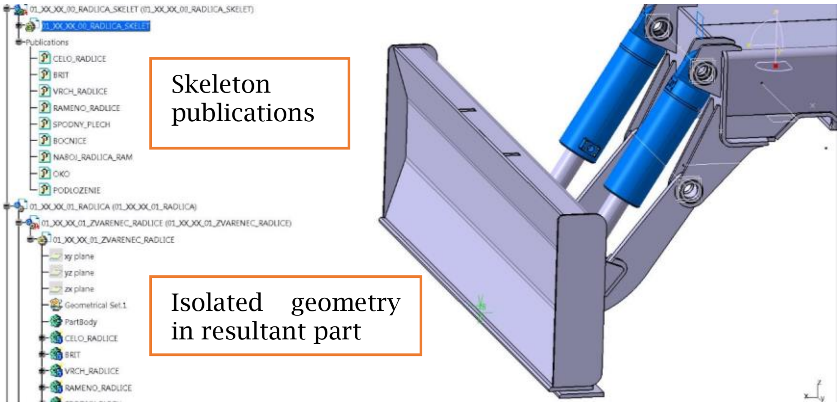

Fig. 4: Isolated geometry of front blade weldment published from front blade skeleton.

To explain the function of publications hierarchy, the connection between axle and chassis frame is defined in the 01_01_skeleton wheeled chassis, to which belong both mentioned assemblies. In this skeleton is defined exact position using the points, screw axes and planes. Such a geometry is then, using CATIA publications, copied to the required sub-assemblies as an external reference with links to the original skeleton. Here we use the geometry to create very parts. If we change the position of the connection defined in the skeleton chassis, changes are reflected in both dependent assemblies.

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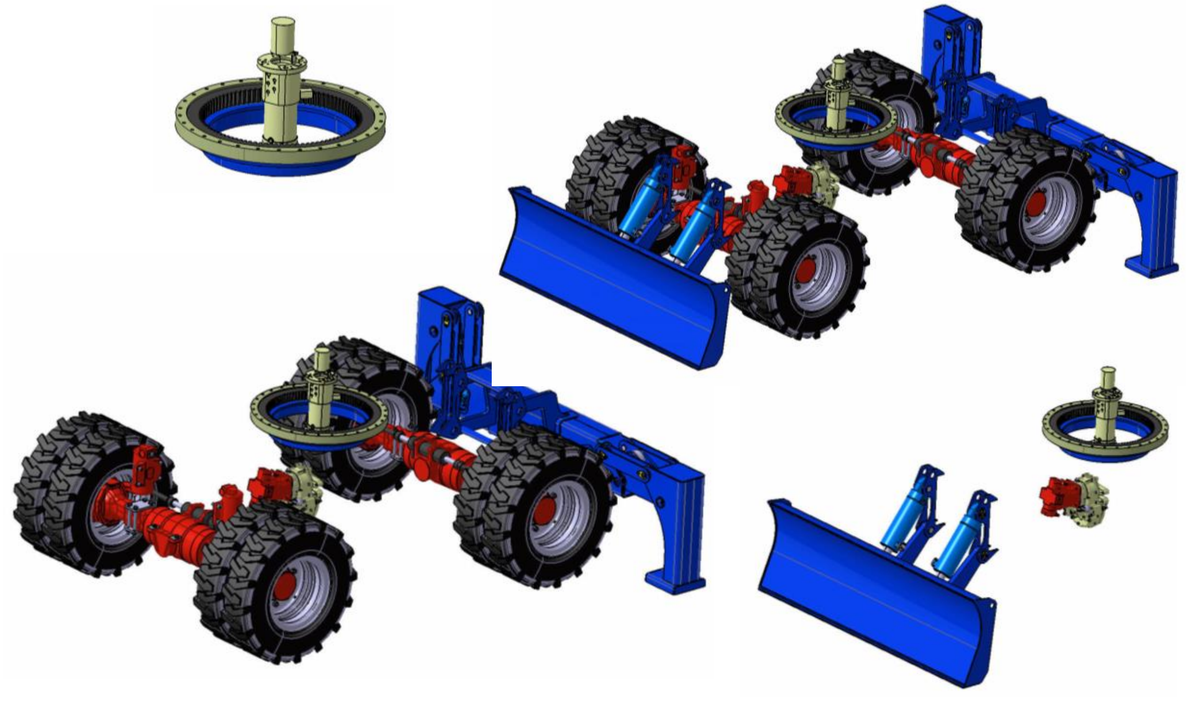

Fig. 5: modules of each variants a) top left – common chassis platform, b) top right – wheeled chassis c) bottom left – self-propelled chassis, d) bottom right – crawled chassis.

Technological modularity:
Each part produced need to be optimized in terms of cost of production and considering the technological possibilities of the manufacturer. In the design of machines, we are trying to reduce the diversity of technologies and materials used. Working with parametric modeling in CATIA helps us analyze this factor. One of the technological modularity conditions is a usage of the same thickness of sheets. Thickness was added for each sheet as a separate parameter. We can then analyze their diversity. Another condition is to use the same bending parameters for metal sheets. During design, several different bends has been defined, and they were preferably used. Technological modularity, however, is contingent on the strength and functionality of the structure. FEM analysis showed inappropriate places in the design of weldments. When removing these places, we were looking for ways that would not significantly affect both modularity's - technical and general.

Methodology of Generative Engineering Design:
From [1,3] " Generative Engineering Design is a process in which the draft or model is made based on quantitative and qualitative parameters or aesthetic inputs, using algorithms created by individual human intervention for the purpose of generating a variable set of subsequent models following accurate relations and according to hierarchical connections." Modular design can be considered as an important section of the Generative Engineering Design methodology, even though it is mainly linked to parametric modeling.
In field of modeling welded structures of machinery, it is possible to apply new methodology in sections in which design is often changed, based on inputs. The reason for redesigning results may be an evaluation by using kinematic and stress analysis. It is necessary to determine the structural hierarchy of design nodes that can and cannot be affected by such a change. As an example, this process changes the structure of clamping brackets for Front blade (the green parts). To optimize kinematics of the front blade is often necessary to change the position of individual pins. This change cannot affect the design of frame weldment (gray parts) Fig. 6.

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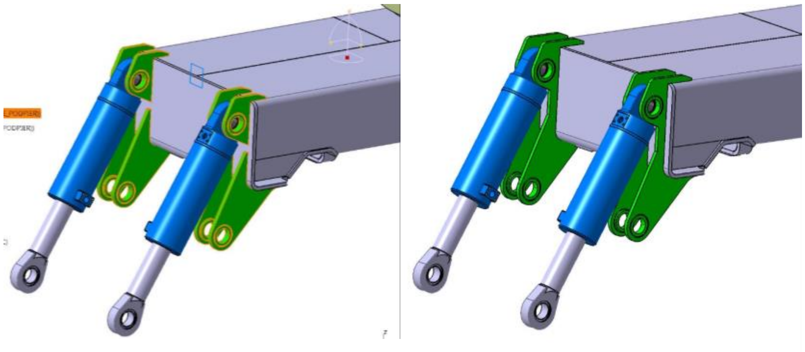

Fig. 6: Design change.

Conclusion:
The most time-consuming part of engineer's work is to change overall design of the component or to check mistakes. The new Generative Engineering Design methodology describes links and tools, which should be involved in the designing process to reduce time for development. Also, intuitive assembly structures and their connecting can improve engineer's work. In practice, the decisive factor in the production, is price of production itself. With the help of parametric modeling in various CAD software we can analyze and optimize pricing complexity of the project.

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