PRINCIPLES OF MODULARITY IN DESIGN AND MAINTENANCE OF LOCOMOTIVES

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ABSTRACT

Thematic patent search was performed that determined design directions for modular systems in transport and industry. The largest percentage of use is characteristic of: railway, agricultural, power engineering, space industry and shipbuilding. To a lesser extent, the modular design principle is involved in medium heavy and precision engineering.

A new concept of application of modules of the main and auxiliary equipment on locomotives is considered, in which key attention is paid to the components of modules and unification of their components. It is necessary to change the philosophy of design and creation of modules, taking into account all possible risks and organizational hazards during modernization of production. The use of modular equipment layout in the engine compartment can significantly reduce operating costs and speed up the service operations during locomotive maintenance. A comparison of operations of current maintenance of Formula 1 cars and modular locomotives has been made.

Keywords: locomotive, patent search, modular design, transport engineering, operation, railways.

Background. *Thematic patent search showed that modular design in the last decade has become widespread in various industries: automotive and shipbuilding, railway engineering, energy, aviation, aerospace, radioelectronic industries. Pic. 1 shows a diagram of patenting of methods for designing devices based on modularity in mechanical engineering.*

As can be seen from the diagram, the largest percentage of use of modularity is related to heavy engineering, and railway agricultural, power engineering, space industry and shipbuilding have the most significant share. To a lesser extent, the modular design principle is involved in medium heavy and precision engineering. There can be identified: automotive industry, machine tools, robotics, radio and electronic products.

According to the search results for ten years, 48 Russian patents related to the topic under research and meeting key parameters were identified. Pic. 2 is a diagram illustrating the dynamics of domestic patenting.

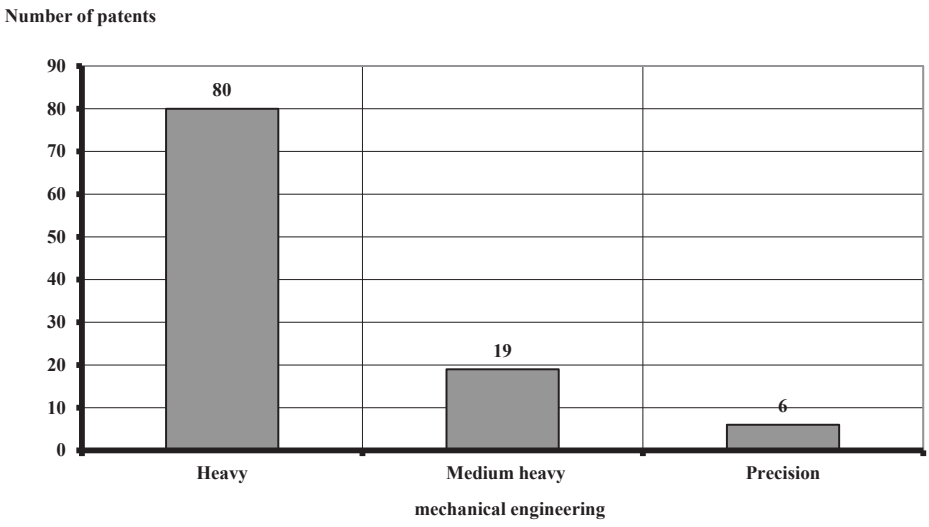
From the diagram it follows that the peak of activity in this area took place in 2007–2010. Currently, inventive activity is also beginning to noticeably intensify.

Modularity in locomotive building. Block-modular design of aggregates and systems is widely used on vehicles for various purposes. Locomotive building is no exception. Leading global locomotive companies create traction rolling stock on the basis of unified platforms [1, p. 45].

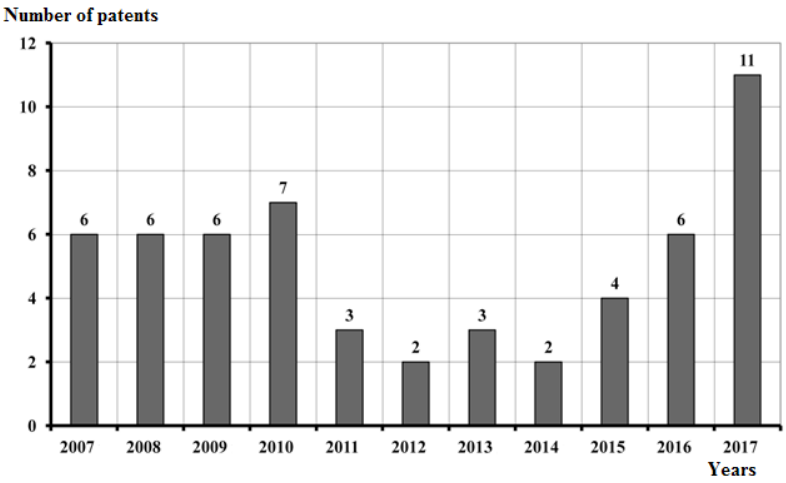
The modular locomotive design is a quick-detachable frame, inside which compact equipment single-purposed equipment is installed. The locomotive contains separate, individual bases, with modules embedded in them. Next, the modules are arranged in sections that are located in a certain way in the engine compartment and are designed to perform a clearly defined group of main and auxiliary (serving) operations.

When installing modules from the outside, hatches with guiding lead-in chamfers and tapered surfaces should be provided to ensure smooth, quiet running of joining parts when docking the quick-detachable couplings and the modules themselves to the base. To align the modules when they dock with the base, technological mandrels, hangers and other related equipment are used.

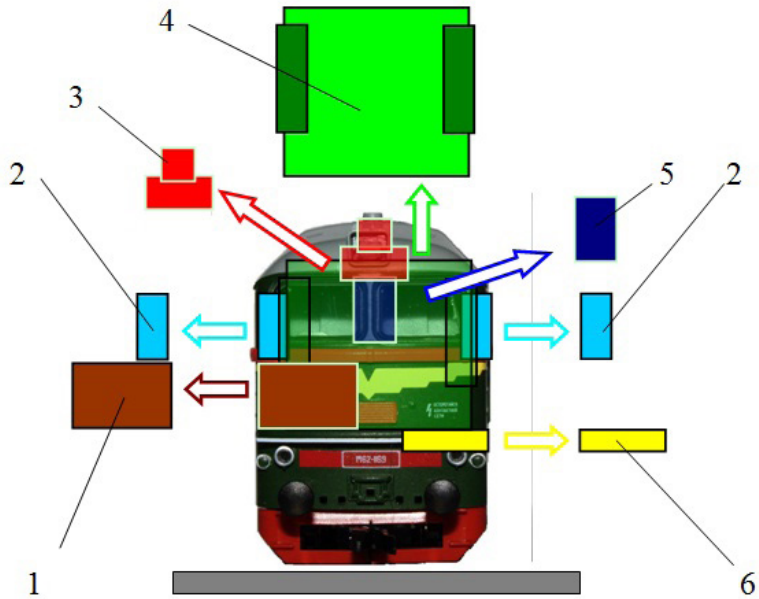
Objective. *The objective of the authors is to consider principles of modular design and maintenance of locomotives, and to study the advantages there-of.*



Pic. 1. The number of patents on modularity of equipment in mechanical engineering.



Pic. 2. Dynamics of patent activity in Russia by year.



Pic. 3. The main modules of auxiliary diesel systems.

Methods. *The authors use general scientific and engineering methods, comparative and patent analysis, evaluation approach, graph construction.*

Results. *In Russia, experimental design of modular locomotives began to be practiced from 2004–2005. A pioneer in the use of modular design and technological solutions is Kolomna Machine-Building Plant with its passenger diesel locomotive TEP70BS and a cargo analogue – two-section 2TE70[1]. The plant develops this expertise regarding design, construction and maintenance of modular locomotives.*

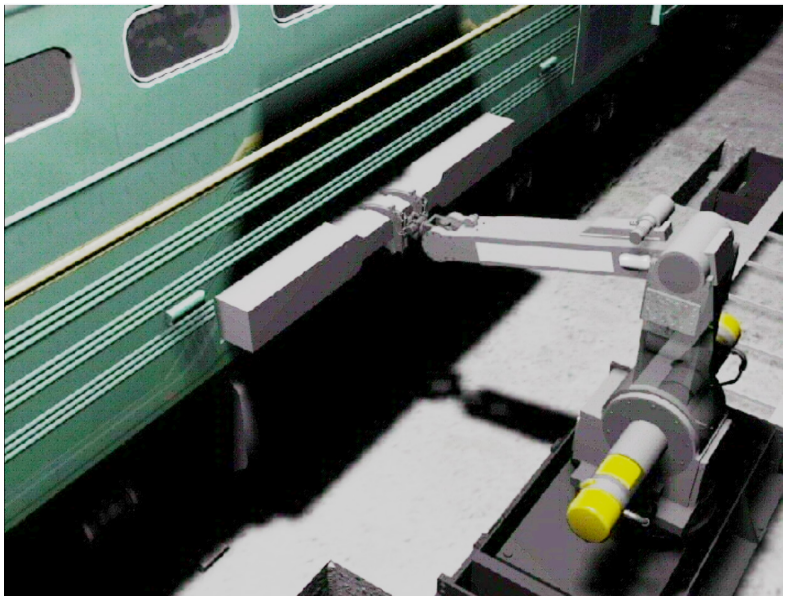
Today, in accordance with the strategy of improving piston engines and autonomous locomotives, participation of all the developers of component parts for the main and supporting modules should be coordinated. It is necessary to fundamentally change the existing outdated concept of designing locomotives, paying key attention to components of modules and unification of their components. The whole philosophy of design and creation of modules needs to be corrected, which is designed to take into account all possible risks and organizational hazards during production modernization.

Of course, the standard dimensions of assembly units should not be directly specified, but in the form of a parametric series, establishing dimensions of sections and blocks for locomotives of different designs and purposes. For example, for diesel locomotives with a full-carrying closed body and a truss-diagonal frame system, assembly and

[1][Electronic resource]: http://kolomna.supportix.ru/about/history/2005–2010.

Table 1

Pit stop of Formula 1	Pit stop of a locomotive
	
Message about a pit stop	**Message about a pit stop**
• The information to the driver about the readiness to take the car to the pit stop is communicated by radio. • The second option: the driver himself tells the team that a quick, unscheduled pit stop is required.	• In accordance with the train schedule, information about the readiness to accept the locomotive for the planned pit stop is communicated. • On-board diagnostics revealed the ultimate, pre-emergency condition of the locomotive equipment, requiring an unplanned pit stop.
Preparation for a pit stop	**Preparation for a pit stop**
• Service team comes out from two sides in the pit lane with the necessary equipment. • Racer turns into a pit lane and with reduced speed follows on the equipped and designated place.	• Expected information about the exact time of arrival of the locomotive in the pit lane is communicated. • In accordance with the regulations, logistic unit modules or individual elements – micromodules in the module are prepared. • Robot manipulators undergo operational testing for compliance with the work performed.
Stop on a pit lane	**Stop on a pit lane**
• All external operations of the service crew are prohibited until the car is completely stopped. • The driver's task is to stop as precisely as possible in the allotted space. • When stopping, it is necessary to focus on either the mechanic holding the lifter of the front end of the car, or the mechanic who holds his hand in such a way that when the car is properly stopped, the middle of the front tire will be exactly under his arm.	• All operations are prohibited until the moment of a complete stop and fixation of the locomotive. • The locomotive crew turns off and de-energizes all systems of the locomotive (turns off diesel, turns off the battery, etc.) in accordance with the adopted regulations. • Switching on the drives of robot manipulators is performed only after the crew leaves the service area of the locomotive. • The movement of staff is monitored by the presence sensors in the service area.



Pic. 4. The moment of installation of a fuel system module in a diesel locomotive.

Table 1 (continued)

Work on the car	Work on the locomotive
• Two mechanics, front and rear, raise the car. • There are three mechanics next to each wheel: one picks up the removed wheel, the other gives the wheel from a fresh set, and the third one directly removes and puts on the wheel. Having fixed the new wheel, the mechanic raises his hand, signaling the end of work. Usually, with coordinated actions of mechanics, replacement of rubber takes 2,5–3 seconds. • After completion of replacement of the wheels, the lifters lower the car onto the road. • Two more mechanics quickly clean the air intakes of the car from both sides. • One mechanic rubs the racer's visor. • Mechanics also perform other operations, such as: filling the tank with fuel, changing the angle of attack of the rear wings, recording the tire characteristics by the sensor, and so on. Plus, one mechanic stands with a portable starter in case the car's engine suddenly stalls.	• At the signal of the siren in repair zone, robot manipulators begin to work. • Work is performed in parallel by several manipulators. • The manipulator-refueling unit No. 1 connects the hose to the fuel tank neck, the second hose to the neck of the diesel engine crankcase, the third hose to the expansion tank of the cooling system module. • Manipulator No. 2 provides for replacement of the fuel system module, or replacement of an element of this system. • Manipulator No. 3 works with the lubrication system module, or with elements of this module. • Manipulator No. 4 performs necessary replacements of the cooling system module, or elements of this module. • Manipulator No. 5 provides replacement of the high-voltage camera module. • Manipulators No. 6 and No. 7 produce work with sand bunk modules at the ends of the cab and body. • Manipulator No. 8 provides routine replacements for the modules of motor-compressors, air preparation systems and diesel gas outlets, as well as controls the crew part and other modules of auxiliary systems (batteries, cabin equipment, etc.). • In case of failure of manipulators (from one to seven), all maintenance work can be performed sequentially by the remaining manipulators with a corresponding increase in the duration of the locomotive stay at the pit stop. • Usually, in case of coordinated normal operation, according to the regulations, replacement of modules with subsequent diagnostics takes 2,5–6 minutes (without time spent on equipment).
Car readiness.	**Locomotive readiness**
• Responsibility for car release onto the track is borne by a senior mechanic of the group. Once this person is convinced that all work over the machine has been completed no one is in the way of its movement and no one drives on the pit lane near the boxes, he raises stock with a sign releasing a racer from pit stop.	• After work is completed, dimensional positioning of the robotic arms is performed and their actuators are turned off. • All systems are diagnosed in installed locomotive modules. • At the end of the diagnostics and on receiving the permission signal, the diesel engine is automatically started and its operation is diagnosed at idle. • A dead endless adjustment of the drive train is made. • Sequencing of devices and power circuits is performed. • A signal is received about the end of the service-module maintenance of the locomotive and the the locomotive crew is called.

disassembly of modules on the side is complicated by triangular braces. Operating and test diesel locomotives: TEP70BS, 2TE121, TE136, 2TE126, TE127, TEP75 had and still have the whole-carrying closed body.

It is easier to solve design problems on locomotives with bearing, main frames and longitudinal spinal beams. In this case, the closed body, which is a system of frame and side walls, can be easily divided into window cells through which the modules of auxiliary equipment of the diesel engine are loaded.

In combination with aggregation of mechanisms and equipment, locomotive assembly production should be transformed into a separate block-modular installation. And almost all the equipment will be mounted in the form of units during assembly of modules. Accordingly, piping and electrical work with the output to the docking multi-connecting boards with quick-detachable couplings are carried out in full within the modules.

To exclude unforeseen cases and inconsistencies, installation operations in modules should be modeled in a 3D package with optimization of basic coordinate procedures, which will make it possible to find all discrepancies in the installation technology and develop corrective plans as soon as at the first design stage.

After assembly, modules arrive at test stands, with the help of which one can verify operability of the assembled equipment, for which these stands imitate the algorithm of functioning of a diesel engine and other diesel locomotive systems.

The modules for ensuring operation of a diesel generator, refrigerating and high-voltage chambers, cooling fans, a motor-compressor, a battery, sand bins, etc. are assembled.

On locomotives, it is advisable to use functional modules, which are based on known equipment (mechanical, thermal, hydraulic and electrical, microprocessor and electronic, etc.) [2, pp. 15–16; 3, p. 34].

It is possible to isolate and install six main modules for providing a diesel generator (Pic. 3): lubricants – 1, air conditioning – 2, gas outlets – 3, diesel cooling – 4, electric machines cooling – 5, fuel system – 6.

By their functionality modules are divided into standard and original, as well as control and executive ones.

Creating a robotic service-modular point (RSMT). *The sequence of its development is as follows: functional content of RSMT is analyzed and refined, design and*

performance bases are determined, information base is completed, including sensor groups – infrared, movements, touches detectors, etc. From the existing nomenclature, a complex of control of systems and track robots is selected [4, p. 37; 5, p. 30].

A priori compatibility of systems and databases with respect to functional hierarchical features with other automated systems, including those used in related industries, is taken into account. If possible, proven standard, serial devices with a single element groups are used.

The transition to the modular locomotive maintenance system provides for interaction of RSMT with the new structure – the service-modular center (SMC).

SMC will be responsible for all failures detected during unit operation cycle, therefore, a high quality of service and repair of modules is foreseen in the subordinated territory of the center.

The layout of modules in the engine compartment should provide easy access to them both from the outside (from all sides and from the top of the locomotive) and from the inside, as well as whenever possible, should ensure their easy replacement with minimal time and energy.

Pic. 4, for example, shows the moment of installation of a fuel system module in a diesel locomotive [6, p. 145; 7, p. 5; 8, p. 1].

Features of operations of run time service on a modular basis. *For clarity, we compare the main processes performed on the pit stops of Formula 1 cars and the proposed RSMT on locomotives (Table 1) [9, 10].*

Conclusions.

The modular locomotive design allows to:

• reduce operating and maintenance costs when operating locomotives at various landfills and under different conditions;

• reduce the cost of maintenance and repair in operation;

• unify the modules of the main and auxiliary systems for various types and series of locomotives;

• increase all indices of reliability, dependability and maintainability of the component equipment in the modules, to extend the service life of the locomotive;

• reduce unpredictability of the human factor in performance of operations of maintenance and repair;

• use diagnostic methods for equipment modules based on qualitatively new principles;

• reduce the cycle of servicing of locomotives, ensuring replacement of modules within a few minutes with service-modular points [1, p. 48];

• provide logistical programs for efficient transportation of modules between service-modular centers and service-modular points;

• give the engine compartment aesthetic and ergonomic appearance, ensuring installation of all units, pipelines and individual parts within the dimensions of the modules;

• introduce new concepts of manipulators installed in service-modular points, master completely deserted technologies;

• guarantee a high rate of technical readiness of locomotives;

• use advanced design and technological solutions to harmonize locomotives with a focus on customer needs.

Locomotives built on the principle of modularity will have high reliability, manufacturability and harmonization, which will make it possible to implement many innovative technical solutions over time.

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