MECHATRONICAL AIDED CONCEPT (MAC) IN INTELLIGENT TRANSPORT VEHICLES DESIGN

Pavel Pavlásek
Faculty of Electrical Engineering
University of Žilina

Summary
This article deals with the principles of synergy effect of mechatronical aided concept (MAC) to the design of intelligent transport vehicles products applying CA..technologies and virtual reality design methods. Also includes presentation of intelligent railway vehicle development.

Resume
Príspevok sa venuje synergickým účinkom mechatronického prístupu (MAC) pri návrhu inteligentných dopravných prostriedkov využívaním počítačovej podpory a metodiky virtuálnej reality. Prezentuje praktickú realizáciu vývoja inteligentných rušňov pre železničnú dopravu.

1. Introduction

Fitting the mechanical, electrical and control parts in transport vehicle systems to each other is a complicated task in product development [1]. But **mechatronical aided concept (MAC)** is unique possibility for discovering new way to improve the fit. The effects of MAC to development and modernisation intelligent transport vehicles have immersed benefits compared to other classical approaches in retrofitting technology in railway machinery plants and depots. Therefore the transport vehicles modernisation management should encourage the use of mechatronical-aided concept (MAC) and the staff should understand the importance of improving the product retrofitting with all possible means. There are many arguments for this way of transport vehicles design in old vehicles modernisation and new transport vehicles design [2]. It is today in MAC to talk about virtual reality design and manufacturing and the application of digital tools for the design, development and production of intelligent transport vehicles [3]. MAC is based on invested heavily in computer-aided design and manufacturing technology to improve the safety, quality, cost, and time to market of locomotives and light vehicle railcars. MAC have improved products competitive position in the market place and strengthened position of this new technology as a premier strategy providing high quality jobs and a continuing high level of investment in plants and equipment.

2. Basic principles of MAC

By of MAC definition, the term "virtual reality design and manufacturing" refers to the design, analysis and prove out of the product design and manufacturing processes by use of computers well before any physical products are constructed. Digital computers with the powerful application software are used to define the product functions, properties, geometry, test the product, design the process steps, analyze and simulate manufacturing operations, simulate the ergonomics. Before the MAC, the classical design period, the realization of the designer's styling concepts, the definition of body sheet metal, and the design and assembly tooling relied entirely on **physical models**. The stylist's clay was digitized. Lofted drawings became the basis for the master definition of the part, the **"hard" model**. Duplications of this model were used for the construction of assembly and checking fixtures.

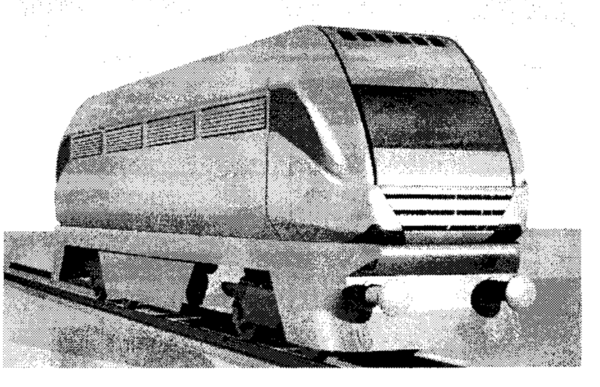

Fig. 1 Early phase of a MAC to generate and evaluate alternative conceptual design (visualisation of future product in virtual model)

Today's design and manufacturing systems, based on MAC, have transformed transport industry. Accuracy and repeatability have been enhanced to a degree unachievable in the traditional concepts. The virtual model (Fig.1) and the analytical tools enabled it improving both the productivity and time to market.

2.1 MAC Product Concept, Design, Development, Manufacturing

Starting in the MAC design, where new model of intelligent transport vehicles are conceived, digital tools are used to model vehicle shapes (sketching tools emulate the paper, pen and colour). Photo-realistic models give the designer an almost true to life view of the new model. The vehicle component design is today done entirely in MAC (in MAC we use Pro/Engineer system by intelligent transport designed vehicles in this case). Digital assembly of the locomotives insures that the parts will fit and function together. The development process is optimized which may include minimizing the number of operations within "the loosing time and money process". New analysis tools are being developed to further enhance this process. The software for MAC is parametrically based, meaning the designers can vary the design parameters and reuse existing designs. Standard parts, modules and features are used from the library. Casting configurations are customized within the MAC system. The finished design is inspected and adjusted in 3D virtual reality environment before assembling period begins.

2.2 Assembly process in MAC strategy

Computer based decision support tools in MAC strategy are used extensively to capture process information prior to the actual modelling of the intelligent railway vehicle assembly operations. These include assembly sequence studies based on the use an automated manufacturing planning system to define the sequence of operations for each assembly process – mechanical, electrical, control. MAC use CA..technologies for the design of assembly tools. Things like gripper fixtures, holding fixtures and other tooling are designed in Pro/Engineer. Once these tools are designed in 3D, we can use simulation software to validate the whole process. This reduces time of manually teaching the assembling team during the assembling period. MAC also uses digital tools to design and simulate the production process. Assembly systems, manual workstations, conveyors, piping, and safety work envelopes are maintained within a CAD facility layout of the entire plant. The facility layouts are maintained on MAC network so that any technology process module can access the files immediately when there are changes. These parameters assist in understanding causes of "bottlenecks" and the impact of new technology in the production logistics. Finally, because of intelligent transport vehicles, process and resource models are contained within the same data environment; MAC can generate the control code used to program the rapid prototyping from process and resource models. MAC control designs are generated from the sequence of operations defined in the process model. MAC validates the generated control code by means of simulation.

2.3 Virtual manufacturing

Assembly tool design and construction have undergone truly significant in intelligent transport vehicles design. Most of these have come about because of the change from physical models to digital models both for the product and tooling definition. This single master definition, mathematically precise and available to all downstream applications, has virtually eliminated geometric errors due to design ambiguity and misinterpretation. The extension of MAC into manufacturing has enabled the use of simulation to predict parts and modules performance before significant investment needs to be made. In the future, as MAC gain a better understanding of the design processes, generative design software will become available for both product and process. Finite element methods (FEM) and dynamic simulation tools will reduce the cost and improve the performance of manufacturing tooling. Database tools will provide for easier access to digital designs and equipment performance histories, which are essential for a learning organization. And on the factory level, intelligent processes will monitor and self-correct to virtually eliminate the kinds of the whole design process (Fig.2).

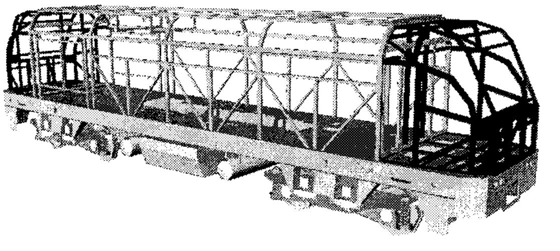

Fig. 2 Sophisticated model of locomotive mechanical modules – frame and skeleton

2.4 MAC in electromechanical system design

MAC brings major improvements to electrical parts and systems design with a comprehensive set of industry-leading Pro/Engineer CAD/CAM/CAE software. Electromechanical design solutions can help improve electrical components, configurations, customizations and parts structure through tools that offer greater functionality and efficiency in the design process. Using MAC design, electromechanical design solutions give electrical and electronics designers and engineers an uncompromising tool to create digital models of electrical machines, boxes, electronic modules, circuit breakers, fuses, and other electrical components and equipments, as well as consumer products at all levels. MAC technology can not only be used to create 3-D geometry of a product, but also to simulate, test and analyze the product's behaviour throughout the design, manufacture and life cycle. MAC offers:

a) a large product portfolio covering the whole product development process,
b) a process-oriented spectrum of applications,
c) a core product for core processes.

Bundled within the electromechanical design solutions are applications allowing simultaneous design and integration of ever more complex electrical systems. Design engineers can work within a 3-D digital data and tools that allow for the important function of space allocation optimizing for EMC [4]. MAC system of combined products and services can help improve overall production processes to accelerate product development and achieve greater functionality:

a) integrate with electrical specifications such as wire and component lists,
b) associate electrical behaviour to mechanical parts and assemblies,
c) build libraries and catalogues of standard electrical parts (modules),
d) capture electrical specifications through text formats,
e) reserve space for electrical, hydraulic and air systems,
f) design 3-D of the electromechanical systems driven by electrical specifications and created by electrical schematics,
g) define command systems and related reports for review and documentation,
h) create 3-D implementations of electrical cabling systems,
i) generate 2-D views of wire harnesses for wire bundle manufacturing.

3. MAC impact on intelligent railway vehicles

Of the industries that utilize MAC solution, one example includes the leading developer of railway products producing three different prototypes of intelligent railway prototypes. MAC system in design of intelligent railway products allows designers to create virtual reality prototypes, helping them cut long time period off the development cycle for most new products. MAC gives a quality result on the first trial, further increasing their speed to market. Overall, it has had a major impact on the productivity, competitiveness and in the end, profitability. MAC system facilitates the transition of a product from design to manufacturing, cutting weeks off the processes and reducing costs. Heightened functionality, offered by electromechanical design solutions, can help to improve the design and production process and therefore positively impact profit margins:

a) complete the concept phase more quickly,
b) increase accuracy and reduce the time it takes to perform detailed processes,
c) streamline design modification efficiency,
d) optimize the manufacturing process to increase capacity without increasing production costs.

MAC integrates CA..technologies and FEA within main frame (chassis) and bogies retrofitting and auxiliary frame development. MAC realizes considerable timesavings in development and testing of a vehicle by the first creating a purely digital form on the computer. Hard prototypes are increasingly built only after each individual component is checked and analyzed with the help of computer-aided simulation. MAC allows the technological progress fully to be able to react quickly and flexibly to global needs and local customer requirements. The time required for development and testing of an intelligent railway vehicle can be reduced considerably if it is first created in a purely digital form of virtual vehicle on the computer (Fig.3). Hard prototypes are increasingly built only after each individual component has been checked and analyzed with the help of computer-aided simulation [5].

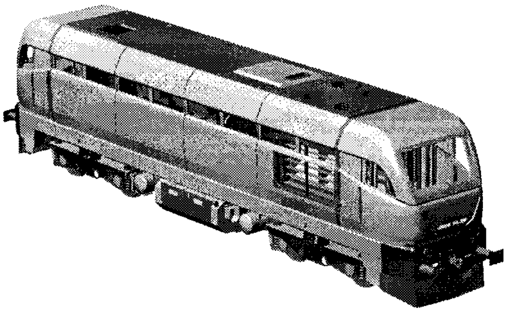

Fig.3 Virtual reality sophisticated model of DEL

3.1 Integration of design and analysis

In contrast to a sequential test-based verification process, the computerized analysis can largely be performed simultaneously with the design progress. The objective is a design process governed by analysis, in which the designers themselves perform the essential Finite Element Analyses (FEA) for their specific component designs. This requires an analysis tool which is integrated into the CAD system and which can also be operated reliably by the occasional user. The introduction of the Finite Element Analyses (FEA) product now enables these analyses to be integrated much more effectively into the design process. FEA enables simpler components such as frames, axles, bogies, or wheels to be analyzed in just a few steps. Pre-optimized component designs represent a sound basis for further development of locomotive characteristics, which is accomplished by design, analysis and test departments operating closely together. Special FEA applications, for example to study the component fatigue or crash behaviour, are indispensable for this purpose. CA..technologies offer a rich set of functions for the designer, including 3D solid, surface and wire frame modelling (Fig.4). The MAC innovative technology automates parameterization of the 3D geometry, provides a wealth of capabilities, including flexible hybrid modelling, the virtual product development, process driven applications and the design-point finite element analysis.

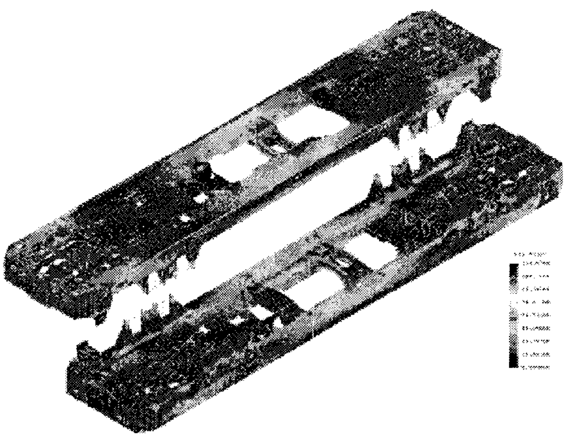

Fig. 4 Sophisticated model of locomotive main frame FEM analysis

3.2 MAC of locomotives design mission and strategies

The mission of MAC is to position developer and producer as world's most competitive and innovative locomotive firm by offering the best high-quality/low-cost solutions. Competitive strategies of MAC are growth (equity investment, partner co-operation, profit re-investment), market development (geographic and economic focus), product differentiation (flexibility to adapt designs to customer needs), research and development (integrate available technologies to expand product line offering and business services).

The ability of the product designer to understand complementarities of design tools, development procedures and manufacturability is a decisive factor for hi-tech intelligent product. Classical and widely used methods of locomotives modernisation are based on serial line logistics - process specific tools and guidelines on the component fabrication and assembling process. The objective of MAC is to help the designer to find the best conceptual product design with assistance of specific process design tools. MAC in the intelligent locomotives design is based on linking the development system that can be seen on several levels – **customer, company, family, structural and component level**.

On **family level**, we considered how various product variants could be related (benefits from unification of several types of diesel electric locomotives with the same or similar performance and service conditions – 98 units of DEL Code 750, 752, 753 and 754 in ŽSR). On **structural level**, we solved the interaction between the product structure and manufacturing system (manufacturing system consists of a number of separate operations – component fabrication in different OEM facilities with the different data management design systems), sub-assembly, final assembly, testing, etc., as well as a number of support activities (logistics, storage).

We have to know and check the critical operational conditions and starting points of development and after the evaluation of this conditions we solved to use a new generation of design and development tools (CAD system Pro/Engineer) which gave us systematic and concurrent methods of dimensional fitting, mechanical, electrical and other multi-stress testing (including the ability of changing many different variants of solutions according to the customer needs in the process of development – we derived many benefits of the virtual reality design with sophisticated model of locomotive before fitting all parts and all function of the whole product including embedded all parts for the complete locomotive control.

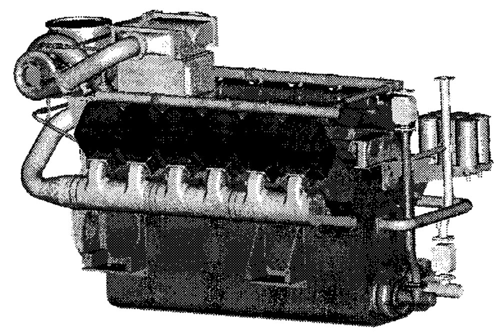

Fig. 5 Unified diesel engine units developed as modules (standardisation on component level)

On the **component level**, it was necessary to concentrate to critical components in term of high costs in order to save development time and that the OEM supplier often had a more in-depth knowledge of some manufacturing operation (this way we developed in relatively short time and low costs new locomotive version of diesel engine PA 4-185 LOCO (Fig.5) with excellent technical parameters in cooperation with the traditional engine producer. In similar way and as parallel process, we developed traction and auxiliary generators, auxiliary drives for ventilation of the diesel engine space, cooling of the electric dynamic brake components, etc., as well as the complete locomotive control system on the world-leader hardware platform.

3.3 Unification and modularity

All the parts and units were developed as unified parts and modules for the company level of design (Fig.6), where it was calculated with a multiplication effect for other types of DE locomotives with different volume and different performance (but tuning the software there is possible to change the service regime of any type of locomotives – we made an expert system for evaluation and as the result of this we calculated for the customer needs 3 different types of locomotives for all services instead of 13 different types used in ZSR today with myriads of spare parts, service works, etc. for app. 500 units) [6].

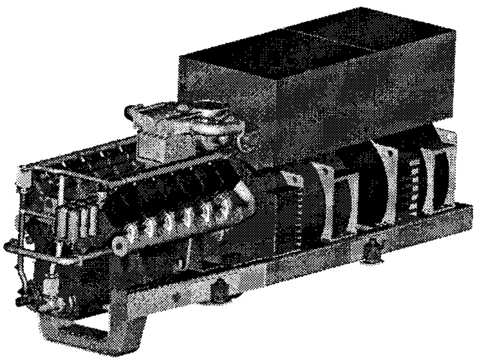

Fig. 6 Unified power-pack unit developed as unified modules for company level of design (standardisation on family level)

MAC, as can be seen from the previous part of this article, is addressed to product the functionality. This idea is based on the list of product main functions. Other evaluates parameters of design were: production costs, the quality, flexibility, and short time of development, risk, efficiency and environmental effects (Fig.7). The production costs of a product cannot objectively be understood by looking at the design itself, but only by investigating the developed methods of the design (all benefits of design).

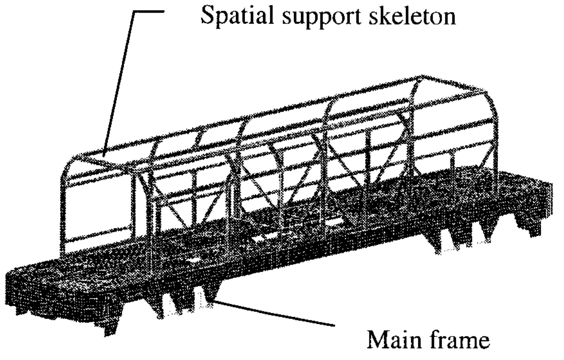

Fig. 7 Sophisticated model of locomotive main frame and skeleton

During the early phases of a mechatronical approach concept the design team must generate and evaluate alternative conceptual design [7]. Due to limited time and resources, the team in a classical approach of design normally reduces alternatives, but MAC enables to evaluate and change the design solution in the later phase - in some cases it was in the beginning of detailed design – changing in standards in ergonomics of drivers cab (Fig.8) [8].

MAC is based on trying different methods (VRD enables e.g. to demonstrate a sufficient assembling process), and brought not only the primary effect, but also the secondary benefits – new tools, new materials, new technologies, new methods, new quality of documentation and data management (Fig.9).

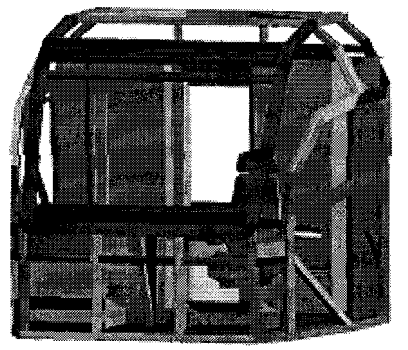

Fig.8 Virtual reality sophisticated model for evaluation drivers cab ergonomy

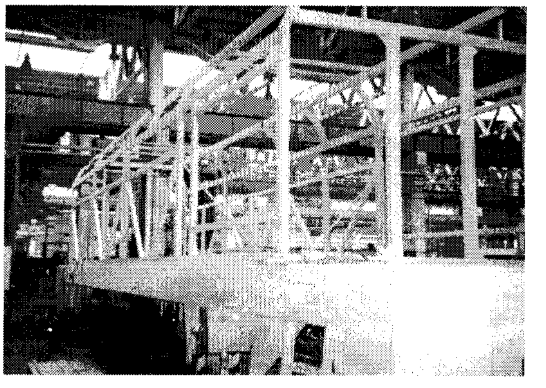

Fig.9 Real mechatronical approach based main frame and skeleton of locomotive

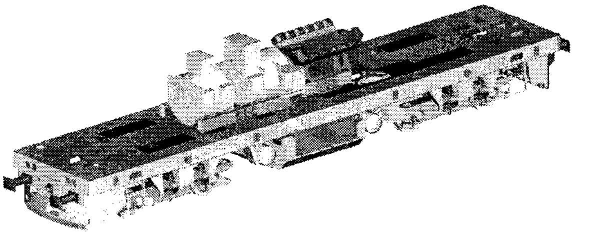

Fig. 10 Unified power-pack modules on main frame and bogies (standardisation on structural level)

MAC uses a cross-functional team. This team approach performs modernization of diesel electric locomotives (DEL) and diesel multiple units (DMU) for the customers using their own technology and assembling capacity or customer's technology and assembling capacity. Locomotives are determined for universal, manipulation (shunting) and freight transportation - light manipulation/light freight with 600 kVA, heavy manipulation/heavy freight transport 900 kVA, universal locomotives with 1200 kVA traction AC generators (Fig.10). Modular diesel electric multiple units with the power of diesel engine from 600 to 1500 kW are determined for passenger's transportation [9].

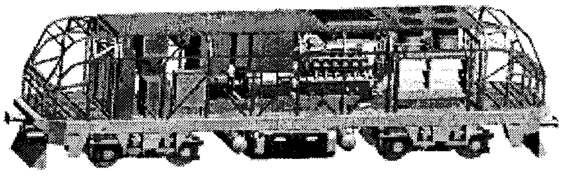

Fig.11 Virtual reality design of sophisticated model of universal DEL (standardisation on customer level)

The value-added that MAC provides can be defined by its work in the field of mechatronics. It is this highly VRD design (Fig.11), a specialized skill, combined with the cheap labour dynamics and developed plants and factories that separate a mechatronical team from its competitors in the area of intelligent railway vehicles. Also, the drag force on the hook is increased remarkably (Fig.12).

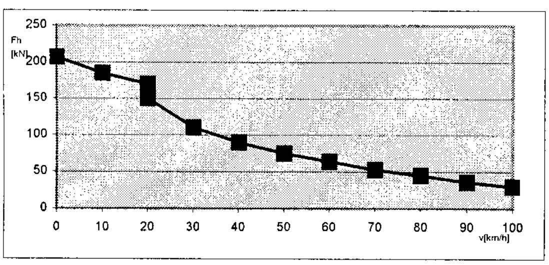

Fig. 12 Locomotive drag force measured on the hook

3.4 Advances of the MAC due to electronics and cognitive unit

Therefore the cognitive control of transmission from the combustion engine up to the wheels of locomotive makes possible maximal saving of energy and reduction of fuel consumption in any operating mode, increasing traction force on the hook, continuous measurement, diagnostics and data notation from all the aggregates, accessories and operating conditions of the locomotive (on - line information about accident, notation and review accessible data, etc.). Locomotives have ultra high adhesive properties, anti wheel-slip protection (under any conditions works on effective verge of adhesion) that improve traction attributes of the locomotive under any operating conditions. Drag force on the hook is increased in 30%, traction force increased remarkably (during acceleration up to 50%). Powerful computerized control system also enables serial connection of locomotives into the couple with optimization of their performance (up to 6 locomotives in one train). Diesel electric locomotives do not contain vulnerable neither mechanical nor hydraulic controllers, the number of relays and contacts is minimized. Many functions are controlled via software; the system has built-in diagnostic and monitoring. On a big screen many variables are displayed - oil and water temperature and pressure, voltage and current in electric equipment, speed and revolves for individual axle. Data is recorded for diagnostic use, revisable, printable and useful for reparation and checking out and also possible transfer to laptop or hand-held computer. Because of sophisticated adhesion system, cognitive unit assures maximum power and fuel economy for all operating conditions allowing mechatronical product to pull more weight per locomotive (or reduce the number of locomotive for operator). Enhanced adhesion and more efficient fuel usage (optimal engine performance in all notches) helps to reduce fuel costs (more than 10%).

Cognitive control unit of the locomotive is a microprocessor-based computer control providing advanced engine and electric power management of locomotives (Fig.13).

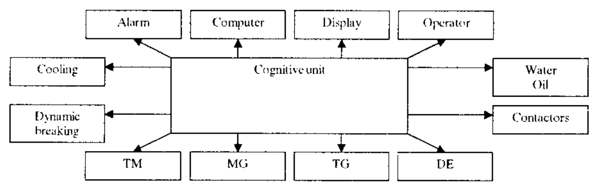

Fig.13 Cognitive control unit developed as unified modules for company level of design (block diagram)

Cognitive control system also provides faster, more flexible and more intuitive computer based troubleshooting technology for quicker and uncomplicated locomotive repair enabling railway transport operator to reduce maintenance costs (more than 20%). An easy to use menu driven large display complete with on-line help and event logging, complements the skills of locomotive maintenance team.

Cognitive control system has numerous user-friendly features and flexibility to operate with more fuel save using optimum engine speeds that correspond to each notch, new dynamic brake with sophisticated control of power-pack proportional to braking effort. Cognitive control system provides maintenance information – pressures, temperatures, positions affecting performance of the vehicle (oil, water, power contactors, control relays, rack), uses standard indicator lights, alarms, and large display alerts to operator important events. In non-volatile memory of control unit are stored parameters associated with trouble events and unconditioned parameters (total monitoring locomotive system). According to intuitive on-line help operator or maintenance team need no computer knowledge – only press a buttons. Sophisticated cognitive unit adds a number of special features to locomotives. System offers expandable and upgraded able hardware and software to give custom locomotive features that operator always wanted (Fig.14).

Fig.14 Final mechatronical approach based product – control panel in the drivers cabin of diesel-electrical locomotive

Fig.15 Final mechatronical approach based product – diesel-electrical locomotive Code 755

MAC performs and offers:

a) the complete modernization of diesel electric locomotives from 600 to 1500 kW,
b) a diesel electric power unit for reconstruction of locomotives – the combustion engine with traction and auxiliary generators on the additive frame (engine, AC generator, sophisticated control system),
c) modern cabins and dash-boards based on firm structures and plastic sandwich windscreens,
d) modular features of locomotive casing based on strong space skeleton and sandwich plastic modules,
e) a mechanical optimizing process (FEM) of construction components of locomotives,
f) the production and assembly capacity for modernization and reconstruction of locomotives used in customer's facility,
g) the production and assembly capacity for the modernization and reconstruction of locomotives (Fig.15).

Technical data of mechatronical product DEL 755

Gauge	1435 mm
Weight	76 tons
Axle pressure	19 tons
Power	1500 kW
Constant traction force	128 kN
Engine	12 PA 4 - 185
Speed (with original bogies)	105 km/h
Length	16,9 m
Width	2,95 m
Height	4,15 m
Wheel diameter	965 mm

4. Conclusion

The mechatronical approach concept - MAC - to the intelligent transport vehicles design is not a simple or complicated "thing" one can buy for money and implement instantly. Mechatronics is a philosophy of thinking and a set of explicit design rules.

MAC philosophy includes following elements:

a) a concurrent interaction between product design and customers needs,
b) a concurrent interaction between mechanical, electrical and cognitive parts and modules (including unification for pre-defined products),
c) the development and prototyping engagement oriented on the industrial and fine art design with related engineering, technical and technological proceedings with exploitation of the concurrent engineering process (mechanical, of construction functionality of all component of locomotives),
d) the conceptual top-down approach at pre-defined product levels (customer, company, family, structural and component),
e) the manufacturability based on virtual reality simulation including optimal assembling process.

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