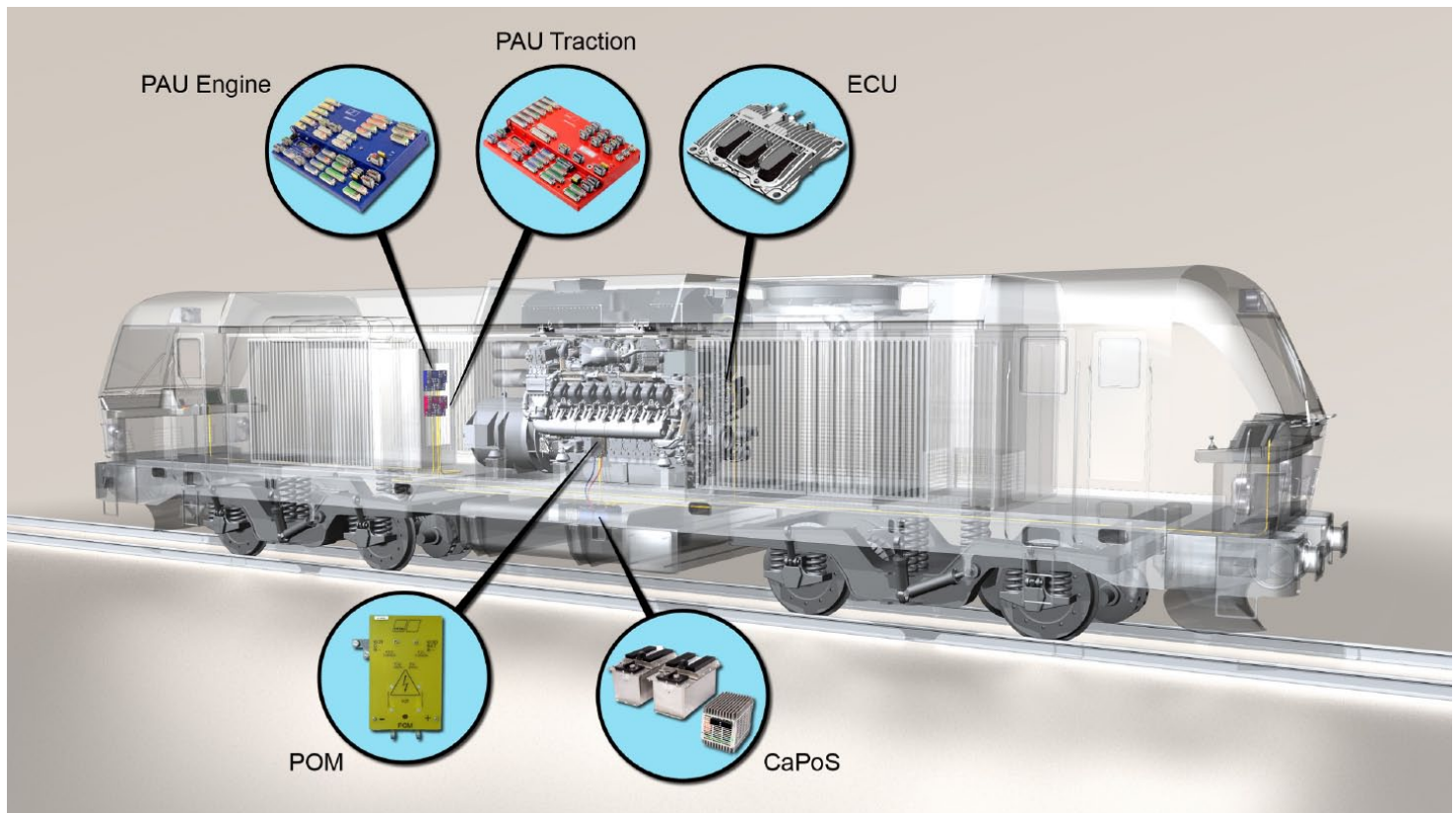


Powerline – Drive automation for locomotives



Authors:

Werner Knoll

Project Manager Powerline Project Engineering

Michael Welte

Project Manager Powerline Development

Powerline is a complete concept for the automation of drive systems in diesel-hydraulic and diesel-electric locomotives. Its modular structure provides a high level of flexibility and ensures straightforward integration in new-builds as well as in locomotive repowering projects. This article describes how Powerline can be integrated in different types of locomotive and explains the functional principles of the individual components.

1. OVERVIEW OF SYSTEM

Powerline was developed as a modular system with various different functional modules in order to support both diesel-hydraulic and diesel-electric locomotives and in order to give locomotive manufacturers a high degree of independence. The concept offers exceptional flexibility in the selection and adaptation of functions to suit individual locomotives. Figs. 1 and 2 provide an overview of Powerline applications in various locomotive types with the focus on the individual electronic components.

The central interface in the Powerline system is the 'Power Automation Unit, Engine' component (PAU Engine) (Fig. 1) which has the primary tasks of linking various locomotive control systems to the MTU diesel engine – via bus technology or hardwired signals – and of adapting external engine peripherals. PAU Engine also looks after the complex task of managing the locomotive's cooling plant (control and monitoring) in order to ensure that the diesel engine operates in compliance with emissions certification standards. In addition, PAU Engine also has a standardized Ethernet service interface

Typical signals between the locomotive control and PAU Engine include engine start, engine stop and target speed but the component also processes other vital information such as speed, lube oil pressure and coolant temperature and makes them available for display on the driver's

Other electronic components such as 'PAU Traction', current and voltage transformers and a power output stage are also available for AC/DC locomotives (*Fig. 2*). In this system, PAU Traction acts as an interface with the traction generator and its associated components.

The primary functions of PAU Traction are to monitor and control the traction generator and to provide additional monitoring, protection and control functions. These include an anti-slip function in which PAU Traction detects wheel-slip on the locomotive and initiates appropriate countermeasures such as reducing the power available to the traction motor. Other important functions include field weakening for the traction motors, i.e. electrical gear change, and rectifier monitoring.

In order to implement these functions, PAU Traction registers and processes the currents and voltages for the traction motors and the traction generator using current and voltage transformers to measure them in isolation so that PAU Traction is not open to high-voltage signals. PAU Traction then controls the excitation of the traction generator via the power output stage.

PAU Engine and PAU Traction, the main modules in the Powerline system, thus provide all the interfaces needed to link the relevant components and integrate external peripherals. The interfaces in both modules are fully matched to the requirements of rail applications.

In order to meet other important requirements and to safeguard the flexibility needed, Powerline components also offer the possibility of adapting and parameterizing all software functions to suit the relevant locomotive environment. This provides an exceptionally flexible system which can be customized to match each individual locomotive type.

2. INTEGRATION IN DIFFERENT LOCOMOTIVE TYPES

The system components described can be integrated in three different locomotive types.

2.1. DIESEL-HYDRAULIC LOCOMOTIVES

Fig. 3 shows one possibility for integrating Powerline components in a diesel-hydraulic locomotive.

Apart from the core drive components (diesel engine and hydraulic drive), this configuration shows the core Powerline components and the lo-

The diagram illustrates the PAU engine system components and their connections. On the left is the PAU Engine (1), which includes a yellow box representing the ECU (8). To its right is the Driver's cabin, which contains the MTU Series 4000Rx4 (6) and the Locomotive control panel (7). The Locomotive control panel is connected to the PAU Engine. Below the Locomotive control panel are four sensors: the Coolant level monitor (5), the Cooler fans (2), the Fuel management (3), and the Air filter monitor (4). The PAU Engine is connected to the Driver's cabin and the Locomotive control panel.

1	PAU Engine	5	Coolant level monitor
2	Cooler fans	6	MTU Series 4000Rx4
3	Fuel management	7	POM
4	Air filter monitor	8	ECU (Engine control unit)

Locomotive control Driver's cabin

1 2

3 4 5 6 7 8 9 10 11 12

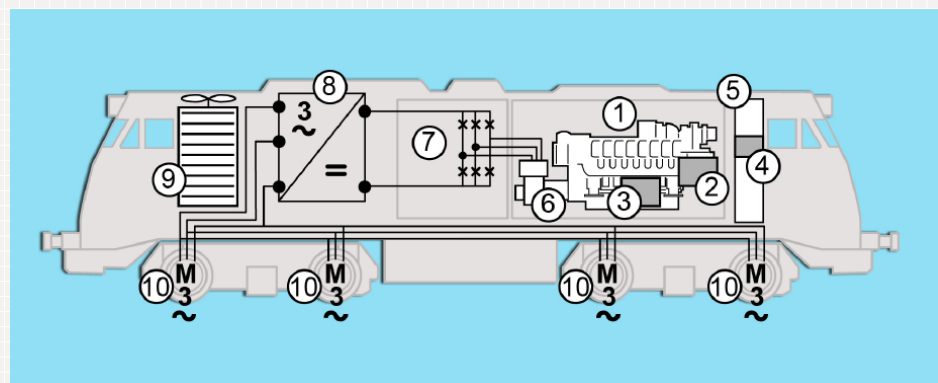
1 PAU Engine	7 MTU Series 4000Rx4
2 PAU Traction	8 Fuel management
3 Current-voltage convertor	9 Air filter management
4 Power output stage	10 Coolant level monitor
5 Traction generator	11 Cooler fans
6 POM	12 ECU (engine control unit)

A side-view diagram of a diesel locomotive with the following numbered components:

- 1: Diesel engine
- 2: Piston
- 3: Crankshaft
- 4: Coupler
- 5: Cab
- 6: Fuel tank
- 7: Water tank

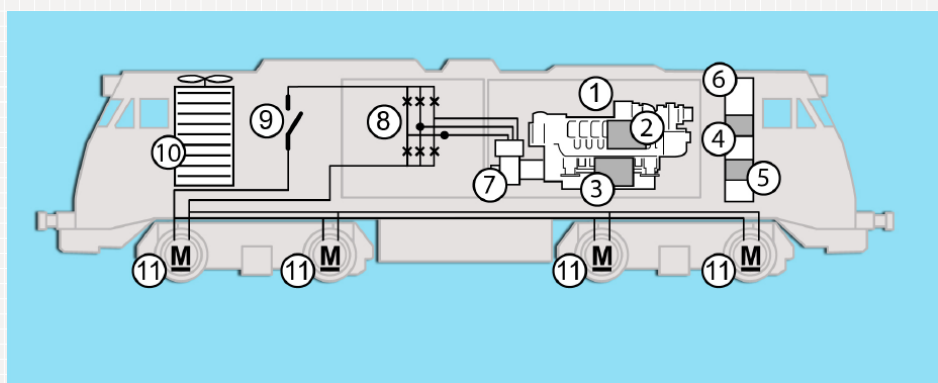
- 1 Diesel engine
- 2 ECU (engine control unit)
- 3 POM
- 4 PAU Engine
- 5 Electronics control cabinet
- 6 Cooling plant (cooler fans)
- 7 Fluid transmission

Fig. 4: Locomotive with diesel-electric AC/AC drive



- 1 Diesel engine
- 2 ECU (engine control unit)
- 3 POM
- 4 PAU Engine
- 5 Electronics control cabinet
- 6 Three-phase synchronous generator
- 7 Rectifier
- 8 Converter
- 9 Cooling plant (cooler fans)
- 10 AC traction motors

Fig. 5: Locomotive with diesel-electric AC/DC drive



- 1 Diesel engine
- 2 ECU (engine control unit)
- 3 POM
- 4 PAU Engine
- 5 PAU Traction
- 6 Electronics control cabinet
- 7 AC synchronous generator
- 8 Rectifier
- 9 Traction motor contactor
- 10 Cooling plant (cooling fans)
- 11 DC traction motors

comotive control system. For the sake of simplicity, individual sensors and actuators such as hydraulic fluid level sensors and fuel pumps are not shown.

2.2. DIESEL-ELECTRIC AC/AC LOCOMOTIVES

Integration of Powerline in a diesel-electric locomotive with AC/AC technology (Fig. 4) involves the same components as for diesel-hydraulic locomotives. The drive units on this type of locomotive are three-phase AC motors fed via the converters as shown.

2.3. DIESEL-ELECTRIC AC/DC LOCOMOTIVES

Powerline also supports diesel-electric AC/DC locomotives which operate with DC traction motors (Fig. 5). In addition to the Powerline com-

ponents already mentioned, this configuration also involves PAU Traction for generator control.

3. POWERLINE AS AN ELECTRONICS PLATFORM

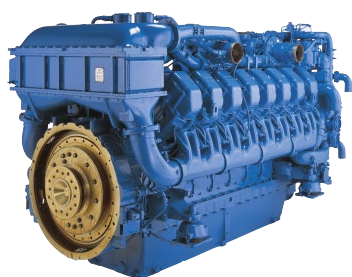
The flexibility of the rail automation system can also be described in terms of platform electronics where a universal electronic module utilizes standardized interfaces to link the engine controller with the locomotive control system, thus functioning as a central linking element. In the case of Powerline, PAU Engine is the central electronic module which facilitates linkage with the electronic engine controllers (ECU) for the various MTU rail diesel engines as well as providing a standardized interface with the locomotive control system. In this way, the PAU Engine electronics plat-

form facilitates linkage between a range of MTU engines and various different locomotive control systems, e.g. 8, 12 and 16-cylinder Series 4000 R41 engines (UIC II, 850–2,200 kW); 8, 12, 16 and 20-cylinder Series 4000 R43 (EU IIIA/UIC IIIA, 1,000–3,000 kW) and 4000 Rx4 engines (EU IIIB/UIC IIIB, 1,000–2,700 kW) as well as 12-cylinder model 1600 R50 engines (EU IIIB/EPA Tier 4, 690 kW) (Fig. 6). Whilst PAU Engine links MTU diesel engines with the locomotive control systems, the electronic module PAU Traction performs the same function in respect of the various traction generators. PAU Traction also has standardized interfaces and facilitates the connection of various traction generators with the locomotive control system so that DC traction generators as well as three-phase synchronous generators with rectifiers can be linked to locomotive control.

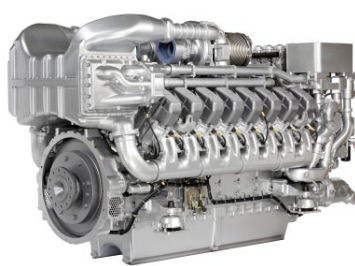
Fig. 6: MTU engine series for rail applications



Series 1600 R50 (EU IIIB)



Series 4000 R41 (UIC II)



Series 4000 R43 (EU IIIA/UIC IIIA)



Series 4000 Rx4 (EU IIIB/UIC IIIB)



The ECU is MTU's electronic engine controller with integrated engine management. The primary tasks of the ECU include speed control and engine monitoring.

4. CORE POWERLINE COMPONENTS

4.1. ENGINE CONTROL UNIT (ECU)

The ECU is MTU's electronic engine controller with integrated engine management. It is mounted directly on the diesel engine. The ECU is a standard MTU component which is used in a range of different applications including the rail, marine, distributed power generation and C&I sectors. Adaptation to the relevant application is achieved using different parameter sets depending on the engine type and application sector. The primary tasks of the ECU include start sequence control, speed control and engine monitoring. The ECU also has an engine safety system.

4.2. POWER OUTPUT MODULE (POM)

POM is an optional module for starter control and also functions as a terminal board for the starter cables. Like the ECU, it is mounted directly on the engine. The POM is controlled directly via the ECU.

4.3. POWERLINE AUTOMATION UNIT ENGINE (PAU ENGINE)

PAU Engine is the central link element between the locomotive control system and the MTU diesel engine control. It is an automation module with interfaces and functions specifically developed for rail applications. Unlike ECU and POM, PAU Engine is not engine-mounted but is located in the locomotive's switch cabinet. PAU Engine is used in applications ranging from locomotive new-builds to locomotive repowering projects and special-purpose vehicles.

In order to achieve the level of flexibility already described, PAU Engine has around 140 hardware channels in various forms. This allows straightforward adaptation to different new and repowered locomotives as well as to various special-purpose vehicles. Each of these hardware channels is supported by tested and proven rail software. The function is activated and parameterized via internal PAU Engine operating parameters.

This modular system utilizing pre-allocated hardware channels and pre-defined standard software functions facilitates fast and straightforward adaptation to different locomotives from different manufacturers.

For connection to the locomotive control system, PAU Engine provides numerous rail-specific hardware interfaces in the form of binary and analog signals as well as standardized bus interfaces such

as CANopen. The module also benefits from additional interfaces for linking external engine peripherals such as fuel pumps, air filter monitoring, diesel engine cooling plant control and additional coolant level sensors.

PAU Engine also has an interface with the driver's console in the locomotive. This allows it to provide a range of data such as control signals for alarm lamps and display instruments covering engine speed, coolant temperature and lube oil pressure etc. Obviously, PAU Engine also provides an interface with the ECU in the form of a further CAN bus.

In order to guarantee this extremely high level of flexibility and functionality, PAU Engine also facilitates the transmission of diagnostic data for commissioning. This allows access to various diagnostic and commissioning functions via a standard Ethernet interface and a web browser without the need for special-purpose diagnostic tools. Commissioning and troubleshooting throughout the entire Powerline system is thus considerably simplified.

4.4. POWER AUTOMATION UNIT TRACTION (PAU TRACTION)

PAU Traction is the link element between the traction generator and the locomotive control system. Like PAU Engine, PAU Traction is an electronic automation module with rail-specific interfaces and software functions and is located in the locomotive switch cabinet. PAU Traction has the task of linking traction generators from different manufacturers with the locomotive control system. Unlike PAU Engine, PAU Traction is normally used primarily for repowering projects and for special-purpose vehicles. Obviously, PAU Traction is always used together with PAU Engine in these types of locomotive.

PAU Traction provides around 90 hardware channels for linking different traction generators and their associated peripherals to the locomotive control system. This allows straightforward adaptation to the conditions prevailing in repowered locomotives and special-purpose vehicles. As with PAU Engine, each hardware channel is supported by tested and proven standard rail software which can be activated and parameterized via PAU Traction operating parameters.

The concept of using prefabricated function modules allows simple and fast adaptation to locomotives from different manufacturers and also accom-

modates different types of traction generator.

Like PAU Engine, PAU Traction provides rail-specific interfaces in the form of binary and analog signals for locomotive control and has CAN bus communication with the engine controller (ECU). However, it also has additional interfaces for linking external traction generator peripherals such as current transformers for measuring traction motor current and voltage transformers for measuring generator voltage and monitoring rectifier fuses, rectifier temperature and traction generator winding temperature. PAU Traction also has interfaces with the driver's console in the locomotive. These can be used to transmit various signals including, for example, generator voltage, generator current and mean traction motor current to analog display instruments.

Likewise, PAU Traction provides an Ethernet interface facilitating fast and simple diagnosis and commissioning without the need for special-purpose tools. Function and application of the Ethernet interface have the same 'Look and Feel' for PAU Engine and PAU Traction so that diagnosis of an entire Powerline system is straightforward and intuitive.

5. POWERLINE ACCESSORIES

Additional MTU components are available to extend the Powerline system and cover supplementary requirements.

5.1. REMOTE SERVICES

An optional data acquisition module can be installed in the locomotive which makes it possible to transmit all important measuring and diagnostic data to an MTU remote server via GSM modem. The rail operator's service staff can then access the data on the locomotive worldwide via an encrypted Internet link.

Scanning the locomotive data means that preventive action can be taken in good time on the basis of fault reports. Downtime and faults on the locomotive can thus be considerably reduced and even avoided completely. Running scans on current diagnostic data also makes it possible to optimize service and maintenance scheduling for the entire fleet of vehicles.

5.2. CAPACITY POWER SYSTEM (CAPOS)

CaPoS is an alternative to starter batteries and is based on high-performance capacitors or 'Ultra-

cap' modules. The significant benefits of these maintenance-free modules include their outstanding cold-start capability (down to -40°C) and their longevity (service life: approx. 15 years). In addition, CaPoS contains no heavy metals – a further considerable advantage in environmental terms.

5.3. INDIVIDUAL SOLUTIONS

Customized solutions are also available on request – for example, a completely prefabricated switch cabinet with integrated, wired MTU electronics for installation in the locomotive. This significantly simplifies installation of the Powerline system as the entire switch cabinet is fully tested in advance and is supplied ready for installation. This particular solution is frequently used in locomotive repowering projects.

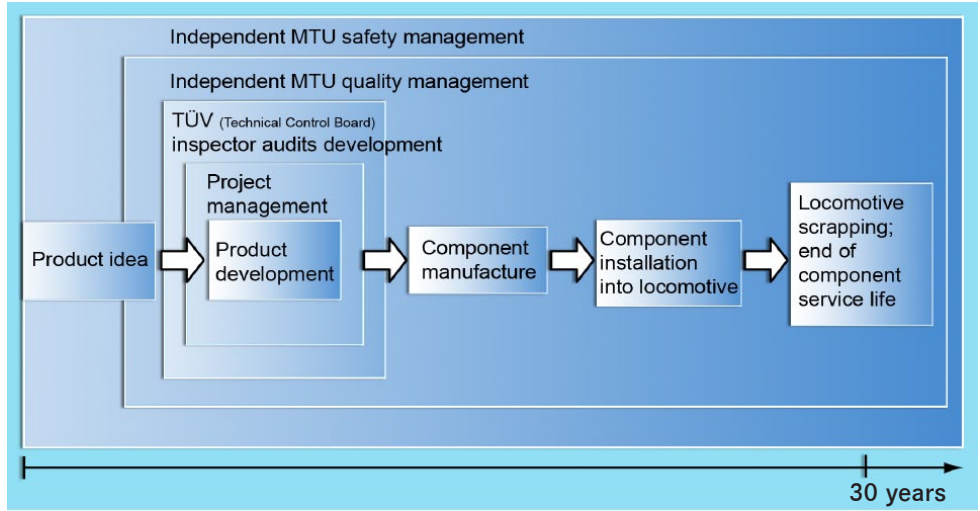
6. DEVELOPMENT IN LINE WITH RAIL STANDARDS

To obtain approval for locomotives, manufacturers have to submit comprehensive documentation to the relevant rail traffic authorities such as the Eisenbahnbundesamt (EBA) in Germany. This includes verification documents for sub-systems on the locomotive such as the MTU diesel drive module.

The locomotive approval process is considerably easier if the manufacturer is already in possession of the verification documents required. MTU Friedrichshafen is one of the first suppliers to be able to provide certificated rail automation systems for a diesel drive module as part of the package.

The rail standards EN50126, EN50128 and EN50129 are fundamental to the development of rail components. These European standards are based on the international standard IEC61508 'Functional Safety'.

Fig. 7: Organisational structures for rail standards compliance



To achieve compliance with the specifications of these rail standards, rail component manufacturers must be able to call on a particular level of organizational structure which covers the entire process from the product concept through to completion of the life cycle of the locomotive after around 30 years (Fig. 7).

The product development process for Powerline components takes place in a project team whose various members are closely involved with software development as well as hardware development. A TÜV (Technical Control Board) consultant recognized by EBA (German Rail Authority) is involved throughout the entire development process.

7. QUALITY AND SAFETY MANAGEMENT

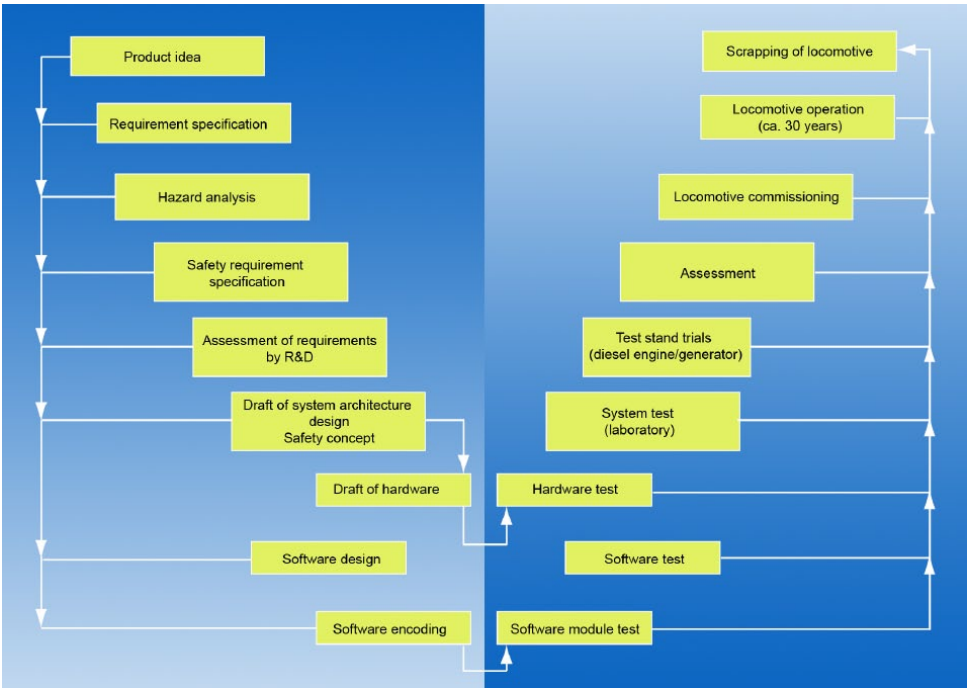
In compliance with ISO9000, the product is monitored throughout its 30-year (approx.) service life by MTU's separate and independent Quality

Management System with the primary emphasis being placed on maintenance of MTU's high standards of product quality.

Another MTU Safety Management System, which is likewise independent, follows the product throughout its life-cycle to monitor compliance with all technical safety issues including, for example, the feedback of information from the field via the hazards log book supplied with the product.

The quality and safety management systems implemented by MTU Friedrichshafen are clear indications that the product development process for applications in the rail sector is subject to requirements which are considerably more stringent than in many other fields.

Fig. 8: Detailed diagram of the product development process up to safety test completion

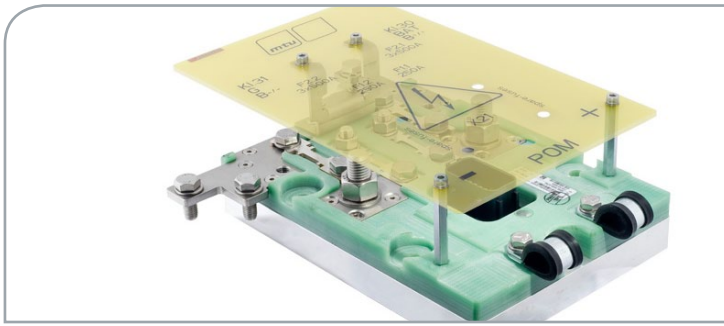


8. DEVELOPMENT BASED ON THE V-MODEL

MTU develops all its hardware and software components on the basis of the widely recognized V-model (Fig. 8). This procedure helps to avoid system-based faults during the product development process. As the entire development process is accompanied by a TÜV consultant, the V-model provides auditable documentation verifying process-compliant development. These documents are the credentials which verify the safety of the rail components and sub-assemblies which will one day be used in rail systems transporting both passengers and hazardous goods.

The following typical requirements are of primary importance: The customer ordering the product to be developed formulates all product requirements in a computer-administered system. This process is known as 'requirement engineering'. Each individual product requirement is allocated a unique ID number which appears in all development documents. All of the development phases must be implemented in line with the relevant development schedule and phase procedure – including receipt review, implementation and conclusion review.

New software functions under development are checked by an independent 'verifier' to confirm



The Power Output Module (POM) is an optional module for starter control and also functions as a terminal board for the starter cables.

that all of the specified requirements are covered and to verify compliance with the development process. In addition, during the system test, a 'validator' checks to ensure that the function, as it is implemented in the product, meets the specified requirements. An independent, external consultant analyzes the development process and the safety functions it incorporates. If the relevant development standards and procedural models have been complied with, the consultant then issues a safety certificate for the system.

9. SOFTWARE ADMINISTRATION

Flexibility through parameterization as mentioned above, also involves a further aspect relating to the product life cycle: software administration. During production, it is essential that each electronic component receives the correct software and the correct parameter set for the application in question. This requirement applies not only for series production but also for any replacement parts which may be needed. In this context, the use of a software configuration management system ensures compliance with the specifications of standards EN50128 and EN50129.

ECU software and order-specific parameter sets for each individual engine (e.g. engine-specific performance maps and order-specific plant parameters) are stored in a central MTU database. Identification is effected by means of globally unique engine numbers.

Software administration for PAU Engine and PAU Traction also utilizes a central MTU-wide database where the order-specific parameter sets and the relevant PAU software for each order are stored. This system makes it possible to clearly identify the software and parameter sets for each individual device in operation in locomotives throughout the world at any time.

10. REPLACEMENT PARTS

The availability of replacement parts must, of course, be guaranteed throughout the service life of the locomotive, which may be up to 30 years. MTU gives the rail operator a warranty that replacement parts will be available for 30 years. And in order to make sure that this can be reliably implemented, all electronic components are developed, further developed (if necessary), tested and manufactured at MTU.

It is, of course, possible that manufacturers of

electronic sub-components such as capacitors or ICs, could discontinue supplies during the lifetime of the warranty. In such cases, all electronic devices affected are further developed by MTU's in-house R&D section to make them compatible with the new sub-components available on the market.

In order to ensure a swift response to such changes, MTU's quality management system continuously monitors the availability of all components used. If a supplier announces the discontinuation of larger electronic components, the assemblies affected are completely redesigned and, if necessary, any software modifications needed are implemented. The interfaces with the locomotive environment, such as housings and connectors etc., remain externally unchanged.

11. ELECTRONICS PRODUCTION AT MTU

MTU's electronic components are manufactured in-house and are fully tested for functionality. To ensure that components deliver a long service life and high quality, all production processes are strictly linked to ISO9000 and IRIS (International Railway Industry Standard) and are audited at regular intervals by external certification companies.

Inspection of the electronics components manufactured takes the form of automated tests using devices which safeguard consistent and reproducible test quality. All of the test results for each individual component are recorded in a test log which can be accessed at any time. The relevant test logs can be identified using unique part and serial numbers allocated to the electronic components thus guaranteeing reliable identification and traceability at all times.

12. CONSULTATION, PROJECT ENGINEERING AND COMMISSIONING

Expert knowledge and experience are particularly vital during the planning, design and calibration of the individual components. MTU offers its customers comprehensive support to ensure that the final outcome is an ideal drive concept with the best possible balance between the individual components.

This support is available right from the quotation phase in the form of consultation on all of the standard functions required, selection of suitable standard components and important information on the safety functions of the MTU

system. Customer-specific solutions obviously also play a central role in these consultations. In the project engineering phase, the next step is detailed consultation on the functional integration of the electronic components from MTU in the locomotive control system. The various different technical solutions available are also compared and evaluated in order to identify the best possible system solution.

During commissioning of the locomotive, MTU offers wide-ranging support in areas such as engine start, static and dynamic engine load tests, generator testing and cooling plant testing. Prior to engine start, checks are run to confirm that all MTU electronic components have been correctly installed. The plant's signal interface is then tested before the engine is started up. Locomotive-side auxiliaries such as compressors, battery charging and cooler ventilation undergo tests during engine start-up.

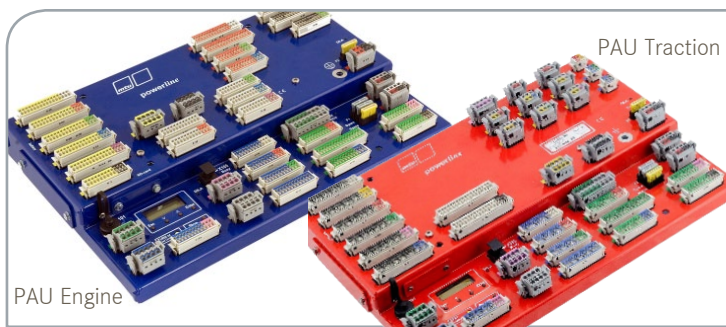
During the static load tests, specific engine performance points are checked at specified engine speeds. To achieve the best possible balance for the locomotive drive module, the parameter values for the electronic MTU components are optimized. During the dynamic load tests, these parameters are then suitably modified in the context of 'locomotive performance characteristics'.

If the MTU traction components PAU Traction / power output stage are involved, support is also available to the customer on pre-assembly of the engine and generator as well as on flange-mounting and integration of engine and generator in the locomotive. MTU is also on-hand during testing of the generator at the generator manufacturer's testing facility when procedures such as vibration measurements, torsional vibration measurements and tests on generator self-heating are conducted.

If required, MTU also provides support on cooling plant tests. The procedures involved define cooling control parameters not only to ensure stable temperature regulation for the diesel engine but also to maximize the service life of the cooler. The entire cooling plant is balanced to achieve the best possible operating conditions for the diesel engine.

13. WORLDWIDE SERVICE

When all the tests have been completed and the locomotive has been commissioned, the customer can rely on MTU's global service network



In diesel-hydraulic and diesel-electric AC/AC locomotives, PAU Engine functions as a central linking element between locomotive control and the MTU diesel engine. As an additional component in diesel-electric AC/DC locomotives, PAU engine functions as the central linking element between traction generator and locomotive control. Unlike PAU Traction, PAU engine is typically used in locomotive repowering projects and special-purpose vehicles.

to provide swift and expert support as well as extremely fast spares and logistics services.

14. BENEFITS FOR LOCOMOTIVE MANUFACTURERS

For the locomotive manufacturer, Powerline brings a range of benefits. He receives a certified electronic automation system developed in compliance with current rail standards and covered by a TÜV safety certificate. The predefined, tried and proven software functions incorporated in the modular Powerline system give the locomotive manufacturer maximum reliability coupled with a high level of locomotive availability. MTU support throughout the project allows fast and straightforward integration of the drive module in the locomotive.

Powerline Automation Suite required is provided free-of-charge and can be loaded direct to the laptop onsite for operation. The tool facilitates monitoring of operating and limit values as well as status and fault message information.

In addition, when the diesel engine is not running, stimulation (active switching) of selected PAU Engine output channels is also possible with the tool, making troubleshooting and cable checks simple and easy during commissioning. The range of functions available with the new tool is rounded off by a facility for evaluating and analyzing the CAN bus systems connected with PAU Engine and PAU Traction in the diesel locomotive (primarily CANopen or J1939). PAU Engine and PAU Traction also offer an integrated webserver that provides access to internal data and fault memories via a standard laptop.

Emissions certification involves in-engine emissions control using exhaust gas recirculation (EGR) and externally integrated emissions control using diesel particulate filters (DPF). It also involves adapting fan control to support the diesel engine emissions strategy. On-board and remote diagnosis functions will also be extended in the future with the integration of new engine and periphery monitoring functions already scheduled.

Telecommunications via GSM/UMTS with local connections using Ethernet will be further extended to facilitate access to individual locomotives anywhere in the world.

15. BENEFITS FOR RAIL OPERATORS

During the operational life of their locomotive or vehicle fleet, rail operators can rely on support from MTU's quality assurance and quality management system. This support covers the entire life cycle of the locomotive starting from commissioning and running right through to de-commissioning. And the 30-year spares availability warranty guarantees that the locomotive fleet remains continually available over its entire service life.

17. POWERLINE PRODUCT CONFIGURATOR

To make project planning of Powerline products easier and more effective the new tool 'Powerline Product Configurator' is currently being developed. In future, this tool will automatically generate data records for plants, locomotive cabling configurations and order-specific locomotive commissioning protocols.

16. POWERLINE AUTOMATION SUITE AND WEBSERVER

Introduced along with series start for Powerline, the Powerline Automation Suite tool makes it possible for the customer, the locomotive builder and service staff to run diagnostics on the Powerline plant simply and easily. All that is needed to link up with PAU Engine online is a laptop with an Ethernet connection. The

18. FUTURE TRENDS IN LOCOMOTIVE AUTOMATION

In order to ensure that locomotive manufacturers and rail operators continue to benefit from the latest innovations, functions and technological developments, in future, MTU's electronic automation section will be taking on additional tasks. These include emissions certification as well as remote and on-board diagnostics for diesel drive modules.

MTU Friedrichshafen GmbH
A Rolls-Royce Power Systems Company

www.mtu-online.com

MTU is a brand of Rolls-Royce Power Systems AG. MTU high-speed engines and propulsion systems provide power for marine, rail, power generation, oil and gas, agriculture, mining, construction and industrial, and defense applications. The portfolio is comprised of diesel engines with up to 10,000 kilowatts (kW) power output, gas engines up to 2,150 kW and gas turbines up to 35,320 kW. MTU also offers customized electronic monitoring and control systems for its engines and propulsion systems.



Power. Passion. Partnership.