Locomotive Diesel Engine Test Stand with Energy Recovery in the Electrical Network

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***Abstract*— The paper presents a test stand for internal combustion Diesel engines, for testing and break-in of locomotive Diesel engines, used in railway traction, with energy recovery in the electrical network. Its realization was carried out by modernizing the test stand of Diesel engines for locomotives from Remarul "16 Februarie" in Cluj-Napoca, resulting an experimental model presented in this paper. The stand is designed for verification and monitoring tests of technical parameters (electrical, hydraulic, pneumatic) for the correct operation of the locomotive Diesel engine. The novelty of the stand presented in this paper, consists in the automation of the entire testing process of the Diesel engines for the realization of the mentioned stand as well as the energy recovery in the electrical network. The stand includes modern equipment and components, data display and storage equipment for the main measured parameters as well as software dedicated to the application.**

***Keywords*—test stand, locomotive Diesel engines, energy recovery, energy efficiency, automation, static power converters.**

I. Introduction

Conventional stands, most common in testing locomotive engines, were made by coupling the Diesel engine to a direct current generator, which delivered energy dissipated on power resistors, cooled with water, a solution that allowed difficult adjustments and small load variations applied to the motor shaft. Starting from these classic ways, it was pass to essentially different solutions [1], new at national level, with a high degree of technology, through the use of static power converters (inverters). This method makes it possible to recover the electric energy delivered by the generator and also to inject it into the local or national power supply network [2]. Also, the monitoring of the internal combustion engine (ICE), engine parameters and of the medium voltage network with a network of sensors and transducers connected to a calculation system with specialized software [3], which finally provides a measurement bulletin, is a modern, the latest generation testing method.

The paper has a multidisciplinary character (energy, electrical engineering, electronics and automation) and involves a complex approach, with studies in all directions mentioned above, establishing the operating diagram with main functional blocks, analyzing all implementation solutions and finally design, implementation and testing a new stand with superior features (with energy regeneration into the network, digitization, human-machine interface).

The result of the stand installation in the Remarul "16 Februarie" hall consists in coupling the Diesel engine with the direct current generator by mounting on a fixing platform, mounting the blocks of electronic power converters - excitation rectifier and three-phase inverter, circuit connection of the three-phase voltage transformer, installation of the circuit breaker and the measuring cell and of the connection with the 10kV network of the beneficiary, mounting and testing equipment of the command, control, protection and signaling panel of the booth.

Important for the stand modernization is the development and the testing of a software program dedicated to the application for monitoring electrical parameters and data acquisition from all stand equipment, monitoring environmental conditions, control of various electromechanical devices, compliance of testing procedures and operation diagrams $M = f(n)$, $P = f(n)$ and $P = f(U, I)$.

The tests of the Diesel engines on the stand are long (it can take up to 24 hours in the case of a Diesel engine running-in that has undergone a major repair), and the evaluation of fuel consumption and energy savings are processes that require long-term measurements in different charging conditions and are related on the network-connected consumers. After the tests completion, will follow the interpretation of the results, the completion of the test method, the finalization of the operating and the maintenance procedures of the stand. An optimization of the Diesel engine settings has been considered to maintain constant speed [4], but the open loop control

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monitoring solution is preferred, as functional changes of the engine can be easily observed during the running-in procedure.

II. The Operation Principle Of The Locomotive Diesel Engines Test Stand

Fig. 1 shows the block diagram of the locomotive Diesel engine test stand. The tested Diesel engine (DE) is mounted on a fixing platform, and is connected via a cardan shaft to the DC generator (G) with its excitation winding (GE). The DC voltage control, generated by the generator G, aims to keep the voltage *Ug* at a constant value. This adjustment is made by means of the Rectifier, respectively by controlling the excitation current, *Iex*.

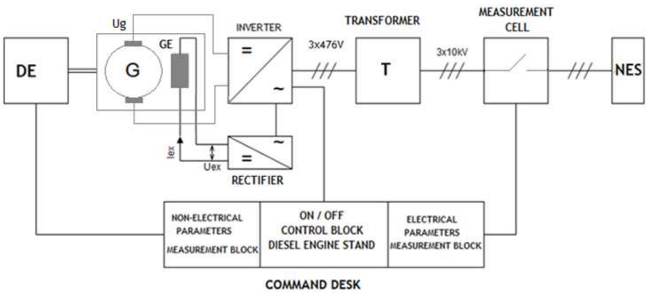

Fig. 1. Diesel engine test stand block diagram.

The generated DC voltage is applied to the three-phase Inverter input, which generates at the output an alternating voltages system that are synchronized with the main supply voltage which is measured by means of the measuring block from the Measurement Cell. The output of the Inverter is connected to a step-up transformer (T) which has the double role of galvanic separation from the main power supply network, and of adapting the voltage level from his primary winding of 476 Vac to his secondary winding at 10 kVac.

Fig. 2 shows the 10 kV measurement cell, which is composed of two compartments:

1. Input-output compartment with serial medium voltage circuit breaker SION 3AE5105;
2. Measurement and protection compartment.

Fig. 2. 10 kV measurement cell.

The energy regeneration and its use in the supply of other consumers of the beneficiary or, externally, by using the National Energy System (NES), increases the energy efficiency of the stand and can reduce testing costs. During the operation of the stand, the overall energy consumption of the entire workshop is reduced and the voltage drop on the electrical energy supply network are avoided.

III. Description Of Electronic Equipment With Energy Efficiency For Testing ICE engines From Rolling Stock Endowment

A. Description of components, equipments, parameters, performances and power diagrams

The two converter`s command, measurement control, protection, signaling modules are based on microcontrollers performing current and speed regulators, gate control of the thyristors by using information collected from current and from voltage transducers [5-7]. The measurement and control elements of the conversion parameters represent analog and digital quantities which are digitally transmitted by PROFIBUS for the central control and measurement panel.

As previously presented, in the current situation, to perform the tests of engines, in general, and of ICE engines in particular, the loading solutions are based on DC machine connected as generator, which provides at the rotor winding output a power proportional to the speed for a certain excitation current *Iex*. On a regular equipment, this energy is to be consumed on a load resistor [8, 9]. Thus, the mechanical torque developed by the ICE engine, converted through the DC generator in electrical energy, turns into heat that is lost in the environment (in water basins).

To eliminate these losses, the new proposed solution consists of the following:

At a certain static operating point, the Diesel engine will rotate in one direction (the direction of Diesel engine rotation in operation) at a *nx* speed, driving the DC machine with the same *nx* speed in the same rotation direction.

The electronic equipment with energy efficiency (Fig. 3), selected a two quadrant DC-AC converter which can be used as inverter during energy regeneration and as rectifier for Diesel motor start. Static tests of the converter are performed being supplied from the AC voltage source of 1800 kVA, 3x476 V, 50 Hz, together with the supply of the DC excitation, with load a DC motor-generator group. Power converters are made according to the rules specific to the field [10-19].

In Fig. 3 is presented the static power converter which is composed of 3 compartments:

1. Supply-selection compartment:
   - By external transformer of 1800 kVA, 476 Vac;
   - By internal 400 kVA transformer; 476 Vac.
2. Static power converters compartment:
   - Rotor inverter;
   - Excitation rectifier;
   - Automation and controls.
3. Transformer ICE engine test selection compartment.

Fig. 3. Static power converter.

In this way, the DC generator becomes the brake for the Diesel engine with the following difference: if we virtually impose a speed *ny* <*nx*, where *ny* is the speed imposed by the electric converter powered from the network, and *nx* is the target speed imposed by the Diesel engine to the same DC machine, it results that the difference in voltage described by (1), is a power *P* that is injected into the power supply network and where can be consumed by the beneficiary's applications or in NES.

$$P = (E_{nx} - U_{ny}) \cdot I_R \quad (1)$$

In this situation, apart from the fact that there is no longer need the load resistors, during the endurance tests is regenerated an important energy into the network, energy proportional to the parameters of the test point (*n, P*).

The description of those components, equipment, parameters, performances and main electrical diagram of the power converters are presented in Fig. 4. One can see that the stand can be configured for the tests of two alternate Diesel engines MD1 or MD2.

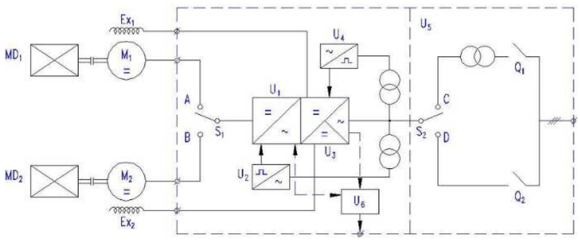

Fig. 4. Wiring diagram of the electronic test equipment.

a) **U1** - The power module for rotor converter with the following characteristics:

- Rated power: 1500 kVA;
- Rated input voltage in the DC: 0-800 Vdc;
- Rated output voltage: 3x476 V, 50 Hz, with safe phases synchronization output converter AC/DC with output phases transformer of medium voltage network;
- Rated current DC: 2000 Adc;
- Rated current AC: 1600 Aac

b) **U2** - The command, control, measurement, protection, signaling module for the rotor converter with the following characteristics:

- Supply voltage: 400 Vac, 50 Hz;
- Rated supply current: 1 Aac;
- Output voltage: 24 Vdc;
- Output rated current: 5 Adc.

c) **U3** - The excitation converter power module with the following characteristics:

- Rated power: 6 kVA;
- Rated supply voltage: 476 Vac, 50 Hz;
- Output rated current: 35 Adc;
- Output voltage: 0-170 Vdc.

d) **U4** - The command, control, measurement, protection, signaling module for the excitation converter with the following characteristics:

- Supply voltage: 400 Vac, 50 Hz;
- Rated supply current: 1 Aac;
- Output voltage: 24Vdc;
- Output rated current: 5 Adc.

e) **U5 -** Power supply equipment in AC with the following characteristics:

- Rated power: 400 kVA;
- Rated supply voltage: 3x476 Vac, 50 Hz;
- Output rated voltage 1: 3x476 Vac, 50 Hz;
- Output current 1: 1600 Aac;
- Output voltage 2: 3x600 Vac, 50 Hz;
- Output current 2: 385 Aac.

f) **U6** - Measurement and control elements of the conversion parameters with the following characteristics:

- Local and remote control of the output voltage of the rotor converter and of the excitation converter;
- Control of the output current of the rotor converter;
- Operation of the rotor converter in two quadrants;
- Voluntary and emergency shutdown of the rotor converter operation.

B. Conditions for integrating the presented components:

1. The electrical energy source consists of an 1800 kVA 3x10 kV / 3x476 V transformer, connected to a 3x12 kV / 630 A medium voltage cell with a medium voltage switch.

2. The stand is able to alternately test two types of Diesel engines. The load for the electronic equipment depends on the tested ICE engine, as follows:

- Diesel engine with a maximum power of 374 HP (275 kW) with idle/max speed equal to 800/2000 rpm and DC generator of 800 KW, 750 Vdc, 1152 Adc, 1800 rpm, Uex = 170 Vdc, Iex = 35 Adc, step and/or continuous load;

- Diesel engine with maximum power of 1250 HP (920 kW) with idle/max speed equal to 350/750 rpm and DC generator of 1280 kW, 800 Vdc, 1600 Adc, 1080 rpm, Uex = 170 Vdc, Iex = 30 Adc, step and/or continuous load.

3. The load of the two Diesel engines is applied in steps and / or continuous between 0 and P_{emax}, for the engine running-in.

4. Constructively, the static power converters for the rotor and for the excitation are equipped with fully controlled thyristors.

IV. Test Procedure For Locomotive Diesel Engines

The working procedure, implemented in the control software which running on the computer from **U6** (Fig. 4), follows the functional organizational chart of the activities necessary to carry out in good conditions the various operations performed on the test stand.

The test stand is intended for repair shops in order to test and run-in the ICE`s after major repairs and can be used for an unlimited number of engine types. Testing an engine involves measuring of a large number of parameters, processing the resulting values and comparing them with the values imposed by the manufacturer, also preparing the written reports.

The initial procedure involves performing the engine`s preparation operations, as described in diagrams from Fig. 5 to Fig. 7:

- Mounting and fixing the powerpack on the stand;
- Oil supply for the Diesel engine;
- Connection of supply installations with fuel, coolant, electrical energy and air;
- Checking and eliminating any leaks;
- Coupling the installation in order to bring the Diesel engine to working temperature;
- Coupling the sensors and transducers of the measuring stand to the tested motor;
- Heating the Diesel engine to the optimum operating temperature;
- Final verification and remediation of possible malfunctions;
- Connect the Diesel engine to the electric generator by means of a coupling;

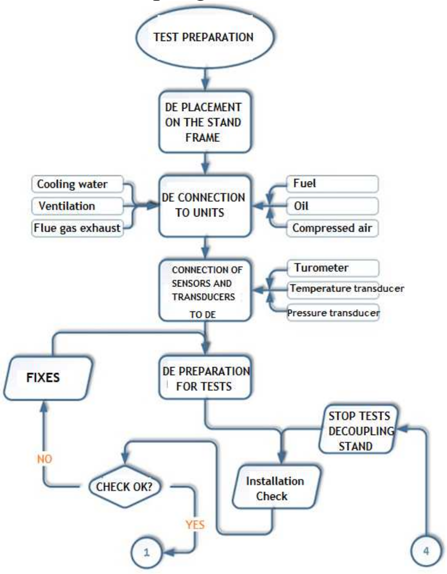

Fig. 5. Flowchart for testing locomotive Diesel engines I.

- Connect the electronic converter to the local medium voltage supply network;
- The Diesel engine is started by means of the electric generator functioning as a drive motor powered by the converter from the local electrical network and it is stabilized at idle speed, in a maximum allowable prescribed time of N seconds; if this time is exceeded, the generator is stopped and, after a stabilization time, the operation is resumed;
- If the Diesel engine does not start and does not stabilize at idle speed after a number of tests, the tests are stopped and any defects or malfunctions of the ICE engine or stand are sought and remedied;
- The function of the converter is switched to the inverter (in this way the electric generator switches to active load mode for the Diesel engine with electric power cutting in the medium voltage network);
- The functional tests to which the Diesel engine is subjected are selected, in turn, and the values measured by the measurement systems of the stand are acquired;
- The measured values are individually stored and processed, and the obtained results are compared with the reference values for the selected engine type;

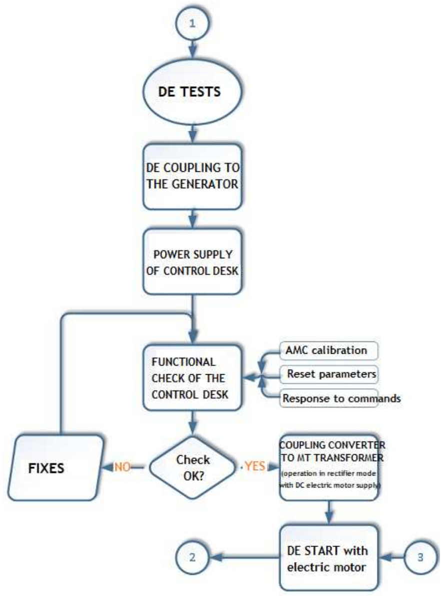

Fig. 6. Flowchart for testing locomotive Diesel engines II.

- If the values obtained during the test are outside the acceptance range for a correct operation of the Diesel engine, the tests are stopped and any problems that lead to its improper operation are sought and remedied;
- After tests and obtaining of the results consistent with the correct operation of the Diesel engine, the tests are stopped and the test bulletins with the obtained results are printed and the power diagram function of speed is made (P = f(n)).

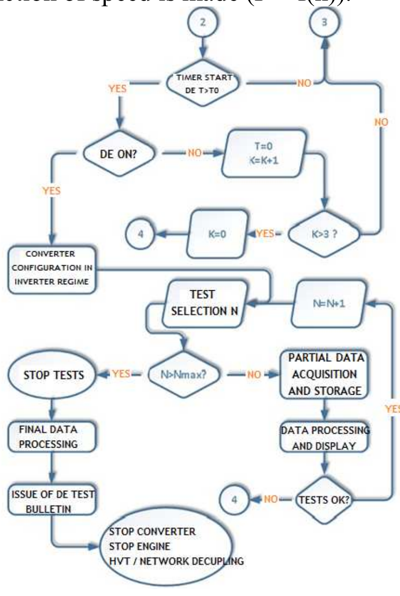

Fig. 7. Flowchart for testing locomotive Diesel engines III.

In Fig. 8 is presented the control desk for the locomotive Diesel engines test stand with energy recovery in the electrical network.

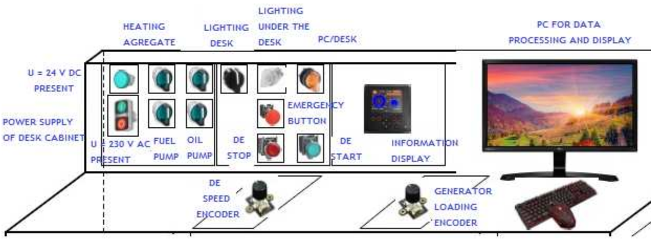

Fig. 8. Control desk for Diesel engine test stand.

V. Data Monitoring Software Program

The data recording software program shown in Fig. 9 was written in LabVIEW [20] due to its technical database dedicated to functions, his availability, but mainly because of his compatibility with the NI USB-6003 data acquisition board, produced by the same company.

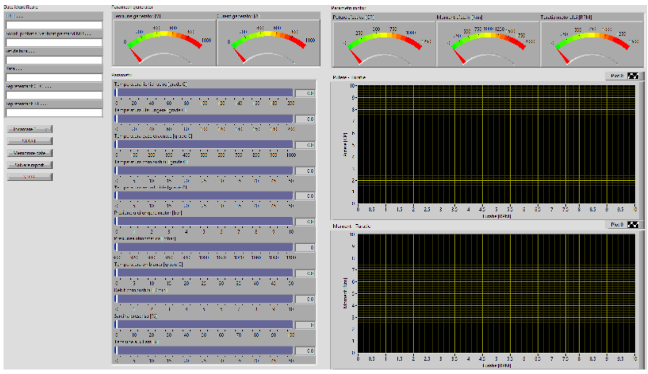

Fig. 9. Monitoring and reporting program interface.

The software program (Fig. 9) is intended to provide visualization of the values measured by the sensors that ensure the system monitoring, such as pressure, temperature, current, voltage, etc., as presented in Table I.

TABLE I. Measurable / Determined Parameters

No.	Measurable parameters	DE 1 Value	DE 2 Value	MU	Obs.
1.	Engine speed n	350-750	800-2000	[rpm]	acquisition with encoder
2.	Engine coolant temperature T_{water}	80	Max. 98	[°C]	
3.	Oil temperature in engine lubrication system T_o	85	Max. 115	[°C]	Max 110 °C
4.	Fuel temperature T_{fuel}	20	20	[°C]	100 °C
5.	Permissible air temperature T_{air}	70	Max. 55	[°C]	115 °C
6.	Oil pressure in the lubrication system p_o	4,5	Min. 2.5	[bar]	10 bar
7.	Overflow protection	880-900		[rpm]	2000 rpm, with encoder
8.	Fuel pressure	Min 2,8		bar	4 bar
9.	Water pressure	1,5-2,5		bar	4 bar
10.	Over supplying air pressure	0,75+/-0,15		bar	4 bar
11.	Air pressure	3.2-3,3		bar	4 bar
12.	Effective engine power P_e at a certain operating speed	1250 920	374 275	[HP] [kW]	$P = f(n)$; by calculation

The graphical interface can display the output values provided by the sensors and the current values of power, torque, current, voltage [21].

The interface reads input data from the operator, from the tested engine and allows registration, on request. The recorded data can be displayed as Power vs. RPM or Torque vs. RPM.

The output of the software is a continuous log from the start of the program till the end of the measurement, saved in SCV format, and the output file for the report is saved in HTML format. This allows the export of the operation diagrams.

Due to the fact that the number of parameters acquired from the sensors exceeds the number of the input connector of the NI data card, the inputs were multiplexed using an analog multiplexing circuit. To obtain analog data with the selected DAQ (Data Acquisition) board, a hardware multiplexing had to be made. This allows the reading of up to 32 analog channels, signals from transducers or useful voltage / current values. The electrical diagram for acquired signals transmitted to the ports of the NI acquisition board is presented in Fig. 10.

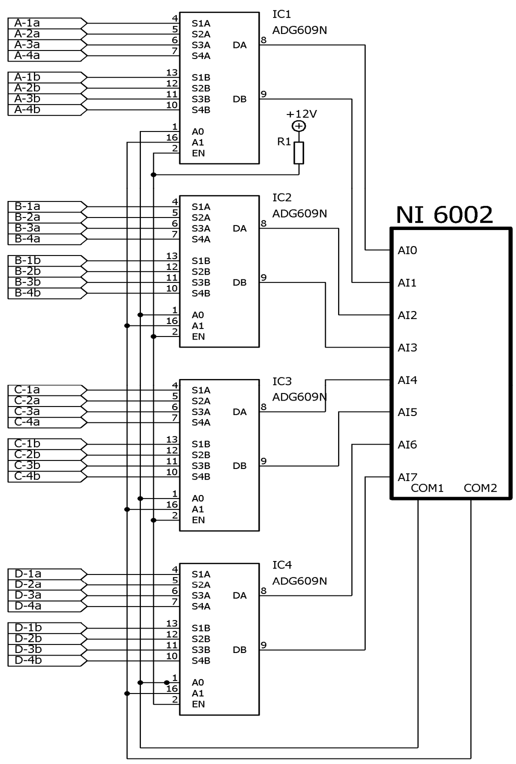

Fig. 10. Wiring diagram for the transmission of the acquired signals to the ports of the NI acquisition board.

The values are transmitted to the data processing modules and to the acquisition board type NI USB-6003 connected to the computer system on which is running the software application specialized for monitoring and control in the LabVIEW language.

Fig. 11 shows the process of determination of the mechanical characteristic of the stand $P = f(n)$ for different loads applied to the Diesel engine.

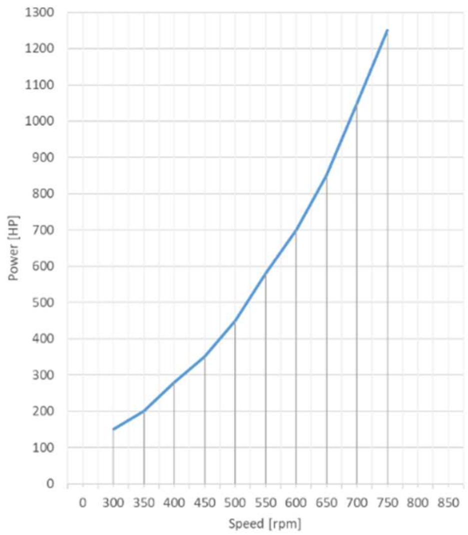

Fig. 11. The mechanical characteristic chart for locomotive Diesel engines.

VI. Conclusions

The stand is the result of a technology transfer contract with the practical implementation at SC "Remarul 16 Februarie" Cluj-Napoca, Romania.

The test stand for ICE engines is intended for the testing and running-in of locomotive Diesel engines, used in railway traction, with energy recovery in the electrical network.

The stand is designed for verification tests of the technical parameters for the maintenance (electrical, hydraulic, pneumatic) in the optimal operating parameters of the Diesel engine. The stand includes modern equipment and components, data display and storage devices for the main measured parameters, and specialized software.

The proposed complex system is an innovative product at national level, competitive at European level, that ensures maximum energy efficiency in the testing process by recovering energy in the electrical energy network.

The specialized software program ensures the creation of a database with the coordinates of the measured parameters. The system can also be used to measure other types of engines with the modification or completion of the stand. This ensures the acquisition, storage and processing of test parameters information, as well as activation and creation of an electronic database with tests results, also ensures the traceability, the created database ensuring the identification of the reference test.

The results had been followed:

- modernization of the locomotives Diesel engines test stand from Remarul "16 Februarie" in Cluj-Napoca resulting in an experimental model;
- automation of the entire testing process of Diesel engines for the realization of the above-mentioned stand;
- energy recovery in the electrical network.

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