Train Driving Parameters Optimization to Maximize Efficiency and Fuel Consumption

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Abstract: Progress in air and fuel management has greatly increased the efficiency of modern automotive train diesel engines, also achieving significant reductions of pollutant emissions. The increased flexibility of the air and fuel management systems also means a higher number of control parameters and complex interactions between different parameters. The task of tuning the engine control parameters to find the right combination to maximize the efficiency and reduce pollutant emissions is referred to as engine calibration. The task of engine calibration for modern automotive diesel engine has become extremely challenging, requiring large amount of time and money to be spent on engine test bench. The main aim of the study was to test and evaluate driving quality of train diesel engine. The subject of this test is a diesel engine train. The diesel engine train series was made with respect to running safety and dynamic behavior, under the test conditions fulfilled. It meets the prescribed requirements of the standard EN 14363: 2005.

Keywords: train; diesel engine; engine calibration

1 Introduction

Energy consumption is one of the focus points of modern train operation. In the last decade, almost every train company has taken measures to diminish its carbon footprint, and to save energy. Railways are considered energy efficient compared to other transport modes such as air travelling. These energy reduction goals also affect high-speed railways (HSR), which are expanding throughout the world. The progress in air and fuel management has greatly increased the efficiency of modern automotive train diesel engines, also achieving significant reductions of pollutant emissions. Many studies have been carried out with regard to this issue, in order to reduce the HSR energy consumption. As the operational speed of HSR is much faster than metro train, the efficiency of the HSR can't be ensured only by traditional automatic driving methods, which increase the energy consumption and impair the intelligence of train operation. Increased flexibility of the air and fuel management systems also means a higher number of control parameters and complex interactions between different parameters. The task of tuning the engine control parameters to find the right combination to maximize the efficiency and reduce pollutant emissions is referred to as engine calibration. The task of engine calibration for modern automotive diesel engine has become extremely challenging, requiring large amount of time and money to be spent on engine test bench.

The study [1] defines a set of key performance indicators (safety, timeliness, energy consumption, workload of the driver, environment, cost of maintenance and brand image) relevant to train operation that are specific, measurable, assignable, realistic and time-related, and that are influenced by the driving strategy of the driver. The results show that a maximal coasting strategy causes the least environmental pollution, and in most scenarios its energy consumption coincided with the optimal energy-efficient train control strategy or it had an energy efficiency close to the optimal one. Eco-driving is an energy efficient traffic operation measure that may lead to important energy savings in high-speed railway lines [2, 3, 4]. Rail operations are housed inside a complex and extremely dynamic system where work is distributed in time and space [5]. Finding the way to reduce environmental impact and to produce cleaner energy is the main task of engine manufacturers. Hence, the paper [6] presents different methods and systems of diesel emission control, especially exhaust gas recirculation (EGR) techniques that regulate emissions during their formation, as well as exhaust after treatment techniques which reduce already generated harmful emissions based on the catalytic effect of precious metals, various catalytic converters and particle filtering (DPF). The article 7 has developed and evaluated two models to predict instantaneous exhaust emissions of CO_2, NOx, particle number concentration and geometric mean diameter in accumulation mode (30-560 nm) and in nucleation mode (5.6-30 nm) of a 2.0 euro 4 diesel engine fueled with pure diesel and animal fat in different proportions. Today, diesel engines are no longer mentioned for generating huge amount of soot and high-level of noise. These achievements have been made owing to the employment of numerous mechatronic systems implemented in the engine [8]. Potential of an artificial neural network platform to emulate the performance, emissions and stability indices of an existing single cylinder diesel engine operating in dual-fuel mode with methanol port injection under varying fuel injection pressure has been explored in articles [9, 10, 11, 12, 13, 14]. The main aim of the study was to test and evaluate driving quality of train diesel engine. The subject of this test is a diesel engine train - DMV manufactured in "Metrovagonmaš" for Serbian Railways. Testing was conducted in respect to a vibration dumping based on research [15, 16] in order to determent driving stability as well as vibration.

2 Methodology

2.1 Experimental Testing Procedure of Diesel Engine Train Series 711

The subject of this test is a diesel engine train - DMV conducted by simplified method and partial procedure according to standard: EN14363. This test was conducted in accordance with the methodology and criteria of the standard: EN14363 -testing for the acceptance of running characteristics of railway vehicles.

The test was conducted on the first train set in the series. Set of diesel engine train is composed of two motor wagons for passengers. Each of the two motor wagons have two axle bogies and the control room in front. Bogies in frontside of the driver's cabs have driving axels, while the axels at the side of the clutch are not driving. Train has four bogies in total. Acceleration in the lateral direction was measured on the two bogies frame.

2.2 Test Conditions

The test was carried out by a simplified method, i.e. measuring vertical and lateral acceleration of the bogie frame.

The procedure was applied according to the standard EN 14363. The test speed of train in both directions, while large radius track (R > 2500 m) was:

$$V_{isp} = 1{,}1 \times V_{\max} = 1{,}1 \times 100\,\text{km/h} = 110\,\text{km/h} \tag{1}$$

If it was not possible to achieve testing speed since the maximum speed allowed, in some sections, was considerably smaller. Maximum lateral acceleration at the level of the upper edge of rail needs to be in the limits of 0.81 ÷ 1.19 m/s^2, for this type of train and the range of speeds according to EN 14363, annexes G.

Running safety and ride quality testing was performed according to EN 14363. Information about the test:

- Train number: 711 - 001/101
- Type of vehicle: Two diesel engine train
- Manufacturer: "Metrovagonmaš"
- Net weight train: m_0 = 87.663 t

- Maximum train speed: V_{max} = 100 km/h
- Centre bolt distance: 2a = 15,000 mm
- Number of driving units: 2
- Number of bogies by driving units: 2
- Type of bogies: Twin axle with two-stage suspension
- Primary suspension: Double coil springs
- Secondary Suspension: Air
- Primary oscillation damping: Vertical hydraulic dampers
- Secondary oscillation damping: Vertical and horizontal hydraulic dampers
- Leading axle: Pivot

2.3 Geometric Quality of Track

According to EN14363 quality rail track for testing is evaluated through a standard deviation prominence of the left and right rails by profile (vertical deviation - z) and deviation per direction (lateral deviation - y). Levels of quality tracks are marked with QN1, QN2 and QN3. The recommendation of EN14363 of the test track includes:

– 50% of quality sections better than or equal to QN1,

– 40% of the quality sections between QN1 and QN2,

– 10% of cut quality between QN2 and QN3.

The segments in which the deviation has exceeded maximum allowed by quality QN3, was not considered in the assessment of the results. The value of 1.3xQN2 was taken as the limit of QN3. Limit values for evaluating the quality of tracks depends on the maximum constructive speed of the tested vehicle Vmax. In the straight tracks and tracks with large curve radius maximum testing speed was V max + 10 km/h. In the small curves radius ($R \leq 600$ m), a testing speed of 80 km/h < $V \leq 120$ km/h was applicable. An overview of the relevant track parameters is shown in Table 1.

Railways Serbia used for measuring the geometric parameters gauge measuring the round: Plasser & Theurer type EM - 80 L. Assessment of the geometric quality of the tracks on Serbia Railways is performed according to: "Instruction 339 on unique criteria for the control of the condition of the railways, while recording the following parameters: stability of the left and right rails, which corresponds to the parameter of uneven rail profiles in the vertical direction.

Table 1
An overview of the relevant track parameters

parameters track	Limits for quality of tracks in curves of small radius			Limits for quality of track in the corners of a large radius and the direction		
	QN1 [mm]	QN2 [mm]	QN3 [mm]	QN1 [mm]	QN2 [mm]	QN3 [mm]
Standard deviation by profile (z-deviation, irregularities): - σz	1.8	2.1	2.73	1.4	1.7	2.2
Standard deviation in direction (y-deviation): - σy	1,2	1.5	1.95	1.0	1.3	1.7
Maximum single deviation per profile, irregularities: Zmax	8.0	12,0	15.6	6.0	10	13,0
Maximum single deviation per direction - Ymax	8.0	10,0	13,0	6.0	8.0	0.4

The geometric quality of the track from the standpoint of maintenance criteria is defined in three levels:

- QN 1 value, which results from the track control or from the rate of maintenance in the context of the normal planning tasks of maintenance rails.
- QN 2 value, which results from short-term measures to maintain track.
- QN 3 value, in which exceedances are observed, track segment is excluded from the tests because the geometrical quality of track is not typical of tracks quality. This value still doesn't correspond to the most unfavorable condition, but it is an allowed form the aspect of maintenance.

2.4 Test Train Composition and Condition

Set of diesel engine train is composed of two motor wagons for passengers, which are attached by clutch. Figure 1.

Figure 1
Diesel engine train series 711, equipped with measuring devices

The train was tested in the ready for service mode. The mass of a motor vehicle with toilet is 44.019 kg. Mass of train without toilets is 43,644 kg. Total train mass is 87,663 kg.

For testing purposes, 18 people boarded the train. If the average mass of passengers with luggage is 80 kg, total mass of passengers was 1440 kg, thus, the total mass of the train during testing was 89 103 kg. The rolling surfaces of wheels on a train have a UIC - ORE profile. Before the test, the train has passed about 1500 km so that the profiles of rolling surface of the wheels were a little worn. On Figure 3 is shown measuring points from acceleration.

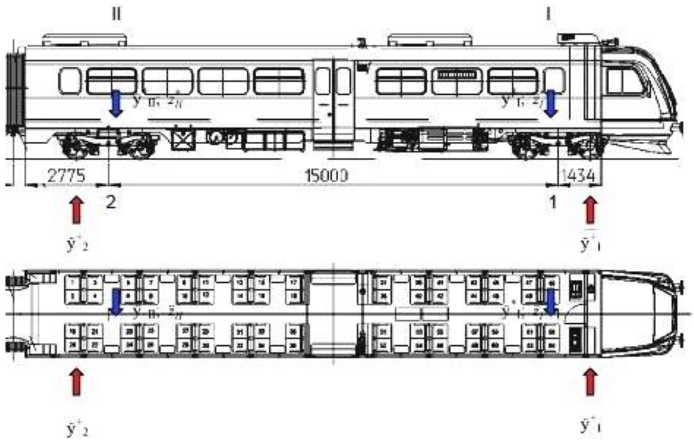

Figure 3

Sensors for acceleration setup

Red arrow are marked measuring points on the bogie frame abovethe axle and, a blue arrow are marks measuring at floor level above the central bogie pivot.

Lateral acceleration of bogie frame was measured (Figure 2), as well as lateral and vertical acceleration on train floor Figure 3. The measuring signals from the channels are shown in Table 2:

Table 2

Measuring signals from the channels

Sizes	Units	Measuring locations	Filter when recording to computer
Transverse acceleration of the frame rotating stand above the front axle assembly lead (drive) rotating stand	m/s^2	1	50 Hz
Transverse acceleration of the frame rotating stand above the rear axle assembly medium (free) working pedestals	m/s^2	2	50 Hz

Sizes	Units	Measuring locations	Filter when recording to computer
Transverse acceleration in the axis of the crate above the lead (drive) bolt rotating stand	m/s2	I	50 Hz
Transverse acceleration in the axis of the crate above the rear pivot of the middle (free) pivot pedestals	m/s2	II	50 Hz
Vertical acceleration in the axis of the crate above the lead (drive) bolt rotating stand	m/s2	I	50 Hz
Vertical acceleration in the axis of the crate above the bolt of medium (free) rotating stand	m/s2	II	50 Hz
Driving speed	km/h	-	50 Hz
Road trip	m	-	50 Hz

During the recording, measurement signals were sampled at a frequency of 300 Hz. Measurement signals of acceleration and speed are provided in Table 3.

Table 3

Measuring equipment

Name	Type	Number	Manufacturer
Encoder acceleration 1	V 12/200	074510716	HBM
Encoder acceleration 2	V 12/200	7321	HBM
Encoder acceleration 3	V 12/200	3047	HBM
Encoder acceleration 4	V 12/200	3052	HBM
Encoder acceleration 5	V 12/200	3290	HBM
Encoder acceleration 6	V 12/200	074510708	HBM
Impulse encoder	Faively	5030	ESPAS
Measuring acquisition system	Quantum X MX 840	0009E5001B2D	HBM
Computer	Notebook	-	DELL

Figure 2

The encoder of acceleration on the frame rotating by - century and above the outer shaft signal

Figure 3
Sensors of acceleration above the main pivot

The characteristics of the measuring equipment used are given in Table 4.

Table 4
Characteristics of measuring equipment

Size	Extended measurement uncertainty
Speed up	± 0,43%
Speed	≤ 0.1%

3 Test Results

The test results are, in the following order:

1) Track sections with directions and curves of very large radius R ≥ 2500 m
- motor car 1 forward
- motor car 1 back

2) Track sections with curves of large radius 600 m ≤ R <2500 m
- motor car 1 forward
- motor car 1 back

3) Track sections with curves of small radius 400 m ≤ R <600 m
- motor car 1 forward
- motor car 1 back

4) Track sections with curves of very small radius 250 m ≤ R <400 m
- motor car 1 forward
- motor car 1 back

The maximum recorded speed driving on a track section was 112.8 km/h. Since minimum speed of 105 km/h was not achieved at this section, the criterion for running speed in test area 1 was reduced to 103 km/h. Criterion of the overshoot Cd ≤ 40 mm was fulfilled during driving in the right curvature radius of 5000 m.

All mathematical expectations of running safety parameters are well below the limit values. The smallest reached factor of safety - λ min is 2.24 for the transverse acceleration above the central pivot of the bogie.

Measuring sections for statistical processing in the test area are presented in Table 5.

Table 5
Test results, measuring sequences for statistical data analyses

Nr. The sections	Stationary		l [m]	R [m]	h [mm]	In P [km/h]	Cd [mm]
	From the [km.m]	To [km.m]					
Section: A							
1	2	3	4	5	6	7	8
1	61.774	62.524	250	∞	-	111.9	-
2	61.524	61.274	250	∞	-	110.6	-
3	61.274	61.024	250	∞	-	109.2	-
4	61.024	60.774	250	∞	-	107.9	-
5	60.774	60.524	250	∞	-	107.4	-
6	60.524	60.274	250	∞	-	107.5	-
7	60.274	60.024	250	∞	-	107.4	-
8	60.024	59.774	250	∞	-	107.8	-
9	59.774	59.524	250	∞	-	108.8	-
10	59.524	59.274	250	∞	-	110.8	-
11	59.274	59.024	250	∞	-	112.1	-
12	59.024	58.774	250	∞	-	112.4	-
13	58.774	58.524	250	∞	-	112.6	-
14	58.524	58.274	250	∞	-	112.8	-
15	58.274	58.024	250	∞	-	112.3	-
16	58.024	57.774	250	∞	-	112.4	-
17	57.774	57.524	250	∞	-	112.9	-
18	57.524	57.274	250	∞	-	112.8	-
19	57.118	56.868	250	5000 / D	0	111.1	29
20	56.868	56.618	250	5000 / D	0	110.5	29
21	56.618	56.368	250	5000 / D	0	109.7	28
22	56.368	56.118	250	5000 / D	0	109.0	28
23	56.118	55.868	250	5000 / D	0	109.2	28
24	55.868	55.618	250	5000 / D	0	110.0	29
25	55.618	55.368	250	5000 / D	0	110.2	29
26	55.368	55.118	250	5000 / D	0	110.3	29
27	55.118	54.868	250	5000 / D	0	109.2	28
28	219.600	219.850	250	∞	-	104.2	-

Nr. The sections	Stationary		l [m]	R [m]	h [mm]	In P [km/h]	Cd [mm]
	From the [km.m]	To [km.m]					
29	217.100	217.350	250	∞	-	105.3	-
30	216.850	217.100	250	∞	-	104	-
31	215.850	216.100	250	∞	-	103.6	-

All mathematical expectations of dynamic behavior parameters are below the limit values. The smallest reached factor of safety - λ min is 1.39 for the effective value of the transverse acceleration of the bogie.

4 Discussion

Testing of diesel engine train Series 711 working abilities verification was performed by program test security running and the quality of driving. Testing was carried out by a simplified method, by measuring the acceleration on the bogie frames.

Tests have included all test areas, i.e. categories of curves, which are provided by standards EN 14363 considering number and total length of the rail track sequence that meets the requirements of the standard.

Maximum speeds are reaching a value of 112.8 km/h, weather conditions during testing, and the state of rail have been appropriate. All mathematical expectation of parameters for secure train running are below the limit value in all test areas.

On the basis of the results of testing, it was concluded that the diesel engine train series 711, product of "Metrovagonmaš" with respect to operational safety and dynamic behavior, during determined test conditions, meets the prescribed requirements of the standard EN 14363: 2005.

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