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Improving efficiency of train traction operational standards: an approach with usage of simulation

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Summary. The paper gives the results of the research on the correction of the train operation model by means of test data. Simulation makes it possible to replace long-term test cruises by relevant calculated data, allowing to reduce the fuel and energy consumption, improve transportation of cargo and passengers.
Key words. Train traction, efficiency improvement, operation standards, test cruises, simulation.

INTRODUCTION

The introduction of the new series of locomotives is connected with forecasting the train traction operational standards. Such standards include the train weight standards Q, train schedule $\{T\}$ and train control modes by he established schedule $\{u\}$, and their corresponding rates of traction fuel and energy consumption E.

The effectiveness of transportation process is highly dependent on the values of the given standards. This accounts for the objective of efficiency improvement of these standards. It can be formulated as a specific energy resource discharge function minimization:

$$e = \frac{E(Q, \{T\}, \{u\})}{Q} \to \min . \qquad (1)$$

This objective is topical for the replacement of engine stock by new series, for which the set of standards must be specified for the first time. Under conditions of Ukraine's railways, such objective is still topical both for the existing and the modernized locomotives.

RESEARCH ANALYSIS

The solution of the given objective is based on the identification of the actual traction and power characteristics of locomotives in operation. Besides it is necessary to know the operational conditions of a specific site, which causes a choice of driving modes of trains.

Traditionally the solution of similar objectives have relied on two approaches. According to the first one, models with various specifications which then were used for estimation and optimization of standards of train traction were formed.

Train movement simulation leans on classical postulates of the theory of locomotive traction [11, 18]. More detailed models for the solution of specific objectives are known as well: efficiency specifications [7], mode of electrodynamic braking [15], for diesel engine with sequential turbocharging [2] and for two units system locomotives [12].

Researchers have accumulated high scientific potential with the solution of train dispatching optimization tasks [1, 8, 20]. It led to adaptation of specific technical systems for locomotives performance improvement [4, 16].

However researchers note considerable divergence in the results of simulation, which can be explained by deviations in the real train characteristics [14]. Therefore a skilled control of the results in the course of test cruises is required [17, 21]. The technological level of modern measuring systems allows obtaining exhaustive data about the traction-energy processes in the train [19].

But in the long-term perspective a great number of test cruises is economically inefficient. Besides, the necessity of the modes and conditions constancy during the test is still difficult to achieve.

RESEARCH OBJECT

Therefore the authors of the article assumed that the efficiency of train traction process experimental studies can be increased by the addition of computer simulation to the full-scale tests, which simulate the conditions of test cruises. For this purpose it is necessary to correct the design model, in order to achieve its adequacy, and then to use this model in simulation.

In order to determine the optimum train locomotives operational standards a new approach has been developed [9]. According to it a set of correcting factors is used as an assessment of divergence between ideal (passport) and actual model characteristics. These factors are found out as a result of measurement data processing. The approach, stated in [3], can be used for measurement database processing.

In order to estimate the divergence of power characteristics (traction power, specific resistance and braking forces) the external parameter as of the train system has been chosen as a reduction factor, while the correction factors are to be calculated under condition of a minimal divergence line between the estimated and the actual profiles of the site [12].

The advantage of such a method is a linear accumulation of divergences, estimated to determine if the adjustment is necessary, and the calculation of correction coefficients with the use of simple algebraic operations. This makes it possible to control parameters of the train in real time during a cruise which is essential for the onboard locomotive decision support systems.

The corrected model of the train taking into account correction coefficients is the following: upon transition from step n to $n+1$:

$$f_\kappa(v_n,u_n)=\frac{F_\kappa\big(k_I(u_n)\cdot I_d(v_n,u_n),u_n\big)}{(P+Q)g}, \tag{2}$$

$$\left.\begin{aligned} s_{n+1}&=s_n+\Delta s,\\ v_{n+1}^2&=v_n^2+2\Delta s\zeta[k_f f_\kappa(v_n,u_n)-k_w w_o(v_n)-\\ &\qquad -k_w b(v_n,u_n)-i(s_n)],\\ \Delta t_n&=\frac{2\cdot 60\Delta s}{v_{n+1}+v_n},\quad t_{n+1}=t_n+\Delta t_n; \end{aligned}\right\}, \tag{3}$$

$$\begin{aligned} \tau_{n+1}={}&\tau_\infty(k_I(u_n)\cdot I_d(v_n,u_n))\frac{\Delta t}{T(k_I(u_n)\cdot I_d(v_n,u_n))}+\\ &+\tau_n\left(1-\frac{\Delta t}{T(k_I(u_n)\cdot I_d(v_n,u_n))}\right), \end{aligned} \tag{4}$$

$$E_n=\left[\begin{array}{l} \dfrac{k_I(u_n)I_\partial(v_n,u_n)U_e(s_n)p(u_n)\Delta t_n}{6\cdot 10^4},\\ G(u_n)\Delta t_n, \end{array}\right. \tag{5}$$

where: P – locomotive weight [t]; k_I – engine characteristic change correction coefficient; k_f, k_w, k_b – traction change, resistance and braking correction coefficients; I_∂ – engine current [A]; s – train track [km]; v – speed [kmph]; ζ – proportionality coefficient [kmph^2/(N/kN)]; w_o and b – specific resistance and braking forces [N/kN]; t and Δt – operation and move out time [min]; τ – engine superheat temperatures [°C]; T and τ_∞ – engine thermal characteristic; U_e – supply voltage (for electric locomotive) [V]; p – the number of engine bypassing; G – fuel consumption (for diesel locomotive) [kg/min].

At each “run” of the model, the optimum mode of train operation is used according to the criteria:

$$H^*=E+\lambda_1 T+\lambda_2 M+\lambda_3\tau\rightarrow\min, \tag{6}$$

where: T – travel time through the site; M – the number of controller switches by train-operator; λ_1, λ_2, λ_3 – corresponding factors estimation coefficients.

The discrete variant of dynamic programming was used as a working optimization method, as it does not require the models simplification. According to this method the authors developed the corresponding computing algorithms.

RESULTS OF RESEARCH

Basing on numerous calculations the authors have found out that the results for the corrected model differed from the data of full-scale measurements within 1,5%. For the same operation modes calculations for ideal model gave divergences to 5% on energy consumption and 7% on track time [10].

Thus the implemented correction of the model allowed achieving its adequacy to specific operational conditions, and then the model can be used for train traction power optimization.

The simulation process can be presented as follows:

1. Estimation of the train weight critical norm Q,
2. Distribution of the train diagram betweenspans $\{T\}$,
3. Efficiency improvement of the operational modes on every span $\{u\}$,
4. Calculation of the fuel and energy consumption.

Such program includes all tasks defined by the regulatory requirements.

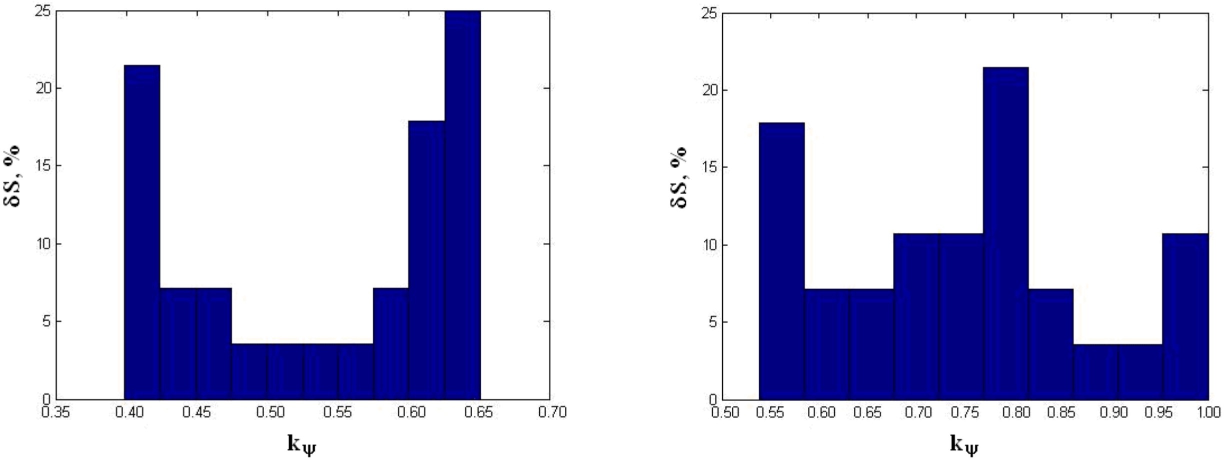
According to the methods [Enterprise standard 2010 “Arranging rolling stock operational tests”], the estimation measure for train weight critical standard is the rates for the locomotive wheel creep on the calculated ascent. They were estimated with the simulation results depending on the coefficient:

$$k_\psi = \frac{F}{1000\psi P g}, \qquad (7)$$

where: F – traction force implemented without critical creep;

ψ – creep coefficient of traction.

The example of k_ψ coefficient distribution according to two train weights is shown in fig. 1.



a

b

Fig. 1. The k_ψ coefficient distribution along the length of ruling gradient for train with Q=4200 t (a) and Q=5400 t (b)

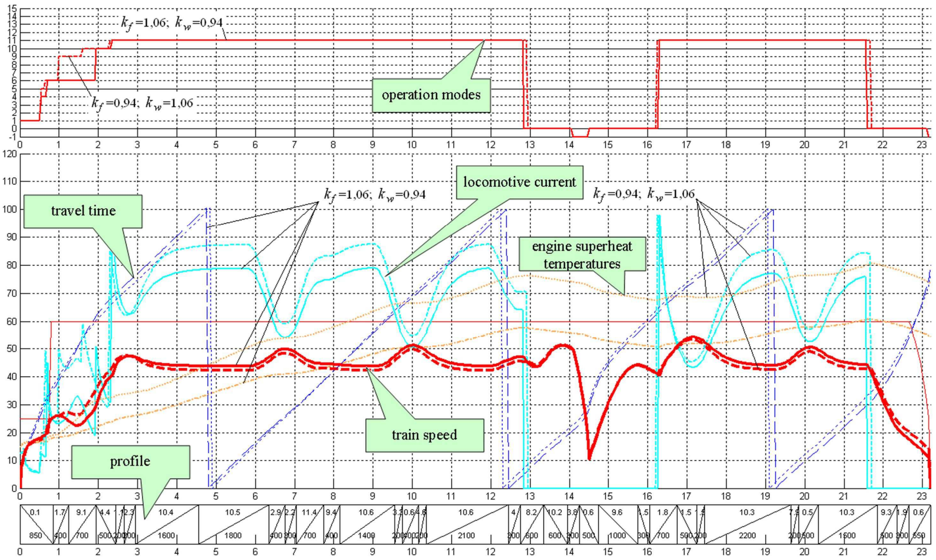


Fig. 2. Determination of optimum operation modes for different operational conditions

As you can see, for the train weight of 4200 t (existing standard) the k_ψ coefficient has values up to 0,65, which considers a reserve on locomotive traction force. With the increase of train weight up to 5400 t, on the most part of calculated ascent (about 54%) the locomotive goes with k_ψ>0,75, and site extent with k_ψ>0,85 and k_ψ>0,95 doesn't exceed respectively 22% and 10% of the calculated ascent. The results of the simulation were confirmed during test cruises, thus the model yielded reliable result.

The application of simulation with estimation of the influence by variation of operational factors can be especially effective (in comparison with full-scale tests). In fig. 2 the optimum operational modes for tow extreme possible variants of combination k_f and k_w coefficients are presented. According to calculation results, this optimum operation mode can be recommended as stable.

For the research on the stability of optimum operation modes for this site the simulation was carried out for various combinations of coefficients of k_f, k_w and λ_1, that corresponds to various technical condition of the locomotive, train and the time taken (fig. 3, 4). The real-life cruises would require considerable time and constancy adherence of all external conditions.

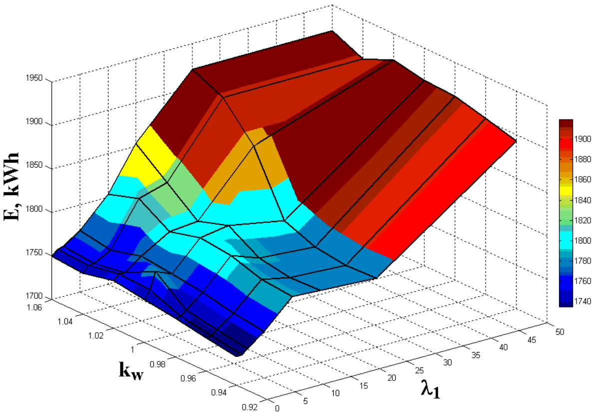


Fig. 3. Power consumption *E* depends on λ_1 and k_w (with fixed value k_f=0,99)

It has been stated that at fixed values of λ_1 of time table and k_f coefficient value *e*can change due to the resistance characteristics of structure up to 3%.On the other hand, due to the change of k_f coefficient (a technical condition and locomotive tracking characteristics) the divergence of consumption *e* (at preservation of optimum operation mode) can reach 16%. The obtained data allow to specify local traction power consumption standards and analyze the results of introducing the train automated control system.

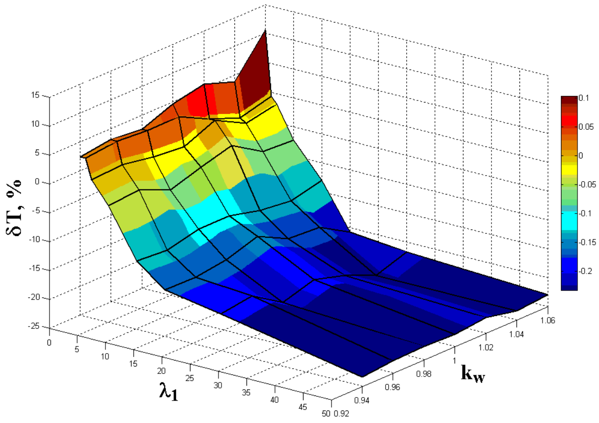


Fig. 4. Timetable lag δT depends on λ_1 and k_w (with fixed value k_f=0,99)

CONCLUSIONS

1. General principles, algorithms and software have been developed to make corrections to the characteristics of ideal train model by test results and calculate the optimal operational standards for trains.
2. This method can be applied to improve efficiency of train traction standards at certain parts of Donetsk Railway.
3. The simulation according to the programme of test cruises showed positive results, making it possible to reduce the fuel and energy consumption.
4. Moreover the test quality improves, because the simulation determines the use of modes and parts of the railway to study during the real cruises.

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ОПТИМИЗАЦИЯ ЭКСПЛУАТАЦИОННЫХ ПОКАЗАТЕЛЕЙ ТЯГИ ПОЕЗДОВ: ПОДХОД С ИСПОЛЬЗОВАНИЕМ МОДЕЛИРОВАНИЯ

Александр Крашенинин, Юрий Осенин,
Сергей Матвиенко

Аннотация. Изложены основные принципы построения адекватной модели тяги поезда, скорректированной на основании данных опытных поездок. Использование такой модели позволяет определить рациональные значения эксплуатационных показателей и нормативов тяги поездов с учетом местных условий, и, следовательно, повысить эксплуатационную и энергетическую эффективность перевозочного процесса.

Ключевые слова. Тяга поездов, оптимизация, эксплуатационные показатели, опытные поездки, моделирование.