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DETERMINATION OF CONDITIONS FOR SEARCH OF OPTIMAL PARAMETERS OF RAILWAY CHASSIS SUSPENSIONS

Summary. The efficiency of resilient suspension is usually expressed through various combinations of resilient and viscous elements, defined by dynamic and viscosity coefficients and other parameters. The aim of this article is to identify the components of the objective function, establish their weighted values and parameter regimes, and to determine fluctuation limits, initial values, and speeds of optimization parameters, which cannot be established a priori in advance. Calculations aimed at optimization of parameters show that the stability coefficient should be considered the main indicator of the objective function, as this is the first parameter to limit the running speed. Given the increasing speeds of trains, the presented method is very important in calculating suspensions.

ОПРЕДЕЛЕНИЕ УСЛОВИЙ ДЛЯ ПОИСКА ОПТИМАЛЬНЫХ ПАРАМЕТРОВ ПОДВЕСКИ ЖЕЛЕЗНОДОРОЖНЫХ ЭКИПАЖЕЙ

Резюме. Эффективность упругой подвески обычно выражается через различные комбинации упругих и вязких элементов, с заданными коэффициентами динамическим и коэффициенты вязкости и другие параметры. Цель статьи состоит в том, чтобы найти компоненты целевой функции, установить их весовые коэффициенты и определить пределы изменения, начальные значения и скорости параметров оптимизации, которые не могут быть установлены заранее. Вычисления, направленные на оптимизацию параметров, показывают, что коэффициент устойчивости нужно считать главным критерием целевой функции, поскольку это - первый параметр, который ограничивает рабочую скорость. Учитывая увеличивающиеся скорости поездов, представленная методика очень важна для расчета подвесок.

1. INTRODUCTION

Effective (efficient) suspension of railway rolling stock not only improves comfort in passenger trains but also increases reliability and durability of chassis and all rolling-stock elements, and makes positive impact of railway safety. When making calculation models, efficiency of suspensions is expressed through various combinations of resilient and viscous elements, it is assessed by means of dynamic viscosity coefficients and other parameters. In order to solve the tasks of determination of optimal suspension parameter values, it is first of all necessary to clear out the issues related to technology for solving these tasks. In order to obtain actual results, it is necessary to determine the components of goal function, clarify if priority should be given to some of them or if all the components must have the same influence while forming the goal function. Furthermore, it is necessary to determine calculation conditions, i.e. to select excitation (inequalities) functions and chassis rolling conditions.

When, due to the abovementioned factors, we can a priori choose certain assumptions, which can be specified in the course of calculations, but there are no possibilities to select rolling-stock movement speed and initial values for optimisation of suspension parameters a priori.

The task of this article is to determine components of the goal function, their weighted values, to select parameter modes where calculations will be made, limits of values of the optimised parameters, their initial values and speeds.

2. COMPONENTS OF GOAL FUNCTION

Into the goal function it is necessary to enter (record) the regulated dynamic indices of the stages of axle-boxes and the central suspension [1, 2, 3, 4]:

$K_{dva}^{\max}$ − vertical dynamic coefficient of axle-box suspension,

$K_{dha}^{\max}$ − horizontal dynamic coefficient of axle-box suspension,

$K_{s}^{\min}$ − stability coefficient before crawling-up (climbing-up) of wheel edge onto rail,

$K_{dvc}^{\max}$ − vertical dynamic coefficient of central suspension,

$Akv_{\kappa v}^{\max}, g$ − vertical acceleration of bodywork,

$A_{kh}^{\max}, g$ − horizontal acceleration of bodywork.

Tab. 1

Allowable Values of Principal Dynamic Indices

$K_{dva}^{\max}$	$K_{dha}^{\max}$	$K_{s}^{\min}$	$K_{dvc}^{\max}$	$A_{kv}^{\max}, g$	$A_{kh}^{\max}, g$
0.8	0.38	1*	0.6	0.6	0.25

* When calculated according to forces of relation between rail and axle-wheel

Upper values of all the dynamic indices are limited, except for the value of stability coefficient $K_{s}^{\min}$. For this index, minimum allowable value is chosen. In order to be able to bring the change of dynamic indices into a single range from 0 to 1, they must be regulated. For this purpose, all the dynamic indices except for K_s must be divide from their maximum allowable values. And K_s value must be changed in such a way that the regulated index decreases when increasing the K_s and increases when decreasing it. After assessment of the said changes (modifications), parameter vector of the goal function will look as follows:

$$\overline{\varphi} = \left[\frac{K_{dva}}{K_{dva}^{\max}} \ \frac{K_{dha}}{K_{dha}^{\max}} \ \frac{\left(K_s^{\max} - K_s\right)}{K_s^{\max} - K_s^{\min}} \ \frac{K_{dvc}}{K_{dvc}^{\max}} \ \frac{A_{kv}}{A_{kv}^{\max}} \ \frac{A_{kh}}{A_{kh}^{\max}} \right]^T \tag{1}$$

3. WEIGHTED COEFFICIENTS OF COMPONENTS OF GOAL FUNCTION

Evidently, the influence of dynamic indices is different. This way, it is necessary to have a possibility to change the value of one component of the goal function or another. For this purpose, each component of goal function must have a weighted (importance) coefficient, which allows strengthening impact on its value made by one components of goal function and, and at the same time, to reduce that of others. For the value of goal function to also fluctuate in the range from 0 to 1, the sum of the weighted (importance) coefficients must be equal to one. The final goal function will look as follows:

$$F(\overline{\varphi}) = \sum_{i=1}^{i=6} \lambda_i \varphi_i \tag{2}$$

When calculating dynamic indices of semi-wagon (platform) while increasing the driving speed, all of them approximate the allowable limits. Experience shows that the first of all the dynamic indices to transcend the allowable limits is the stability (running up of wheel edge on rail) coefficient, and therefore the values of all the weighted coefficients λ_i, except for coefficient K_s, are chosen as 0.1, and the K_s as 0.5.

4. PARAMETERS OF CALCULATED STRETCH

In order to perform the calculations, it is necessary to select (install) excitation function in chassis. For such excitations there are geometrical railway track inequalities on vertical plane and on the plane transverse to movement. The inequalities must be such that chassis is acted by excitation forces to all directions and, if possible, by vibrations of all types. For calculations we have selected asymmetric random-type processes, supplemented by asymmetric joints on vertical plane, resulting in lateral swinging. It is expedient to select for the calculations a straight-line stretch, since in curves the driving speed is limited not only by values of dynamic indices, but also by unsuppressed accelerations, which would make selection of parameters difficult.

5. LIMITATIONS OF OPTIMISED PARAMETERS

The main requirement for selection of one or other values of spring sets rigidity must be the possibility to implement these suspension parameters. Furthermore, vertical rigidities of suspensions are additionally limited by differences of allowable heights of automatic clutches of neighbouring chassis.

These limitations will be significant when finally selecting the values of suspension parameters. So far, for determination of conditions, under which the optimisation calculations must be made, we select a relatively wide range of parameters:

Rigidity (*K*)	0 ÷ 60000 kN/m
Viscosity (*V*)	0 ÷ 100 kNs/m
Friction coefficient (*F*)	0.01 ÷ 0.25

6. INITIAL VALUES OF OPTIMISATION PARAMETERS

The goal function as described in expression (2), depends on numerous parameters, therefore it should be expected that the surface described by this function will be of quite complex form. In general case, the surface will have numerous local minimums. It means that in order to determine optimal parameters we first must find the areas where the local minimums are located. When such an area has more than one local minimum, then the result of optimal parameters search will depend on initial values. In this stage for determination of movement speeds in presence of which it is necessary to search for optimal parameters pf chassis suspension stages, we will take standard values of carriage CNII-Ch3, Table 2.

Tab. 2

CNII-Ch3 Chassis Parameters

	Longitudinal direction	Transverse direction	Vertical direction
Axle-box suspension	K_{ax} = 0 kN/m F_{ax} = 0.25	K_{ay} = 0 kN/m F_{ay} = 0.25	K_{az} = 20000 kN/m V_{az} = 100 kNs/m
Central suspension	K_{cx} = 6000 kN/m F_{cx} = 0.25	K_{cy} = 6000 kN/m F_{cy} = 0.1	K_{cz} = 4000 kN/m F_{cz} = 0.1
Sliders	$K_{šx}$ = 0 kN/m $F_{šx}$ = 0.125	$K_{šy}$ = 0 kN/m $F_{šy}$ = 0.125	$K_{šz}$ = 800 kN/m $V_{šz}$ = 0 kNs/m

7. SELECTION OF MOVEMENT SPEED WHEN OPTIMISING CHASSIS PARAMETERS

In the beginning we must answer the question on selection of speed for calculations when solving the tasks of search of chassis optimal parameters. For that we will perform the search of optimal parameters under different driving speeds, when initial parameters are the same as selected above. We will calculate the optimal parameters when driving speed *v=60 km/h.*

Results of optimal parameters search:

Tab. 3

Principal Dynamic Indices

	K_{dva}	K_{dha}	K_s	K_{avc}	Goal function
Under initial parameter values	0.327	0.218	2.399	0.33	0.27943
Under optimal parameter values	0.287	0.183	3.21	0.286	0.10732
%	-12	-16	34	-13	-62

Optimal parameter values:

Axle-box suspension:

In longitudinal direction: K_{ax} = 0, F_{ax} = 0.25

In transverse direction: K_{ay} = 0, F_{ay} = 0.19

In vertical direction: K_{az} = 15530, V_{az} = 100

Central suspension:

In longitudinal direction: K_{cx} = 5750, F_{cx} = 0.165

In transverse direction: K_{cy} = 10700, F_{cy} = 0.016

In vertical direction: K_{cz} = 2620, F_{cz} = 0.116

Sliders:

In longitudinal direction:	$K_{šx} = 0$,	$F_{šx} = 0.12$
In transverse direction:	$K_{šy} = 0$,	$F_{šy} = 0.105$
In vertical direction:	$K_{šz} = 290$,	$V_{šz} = 0$

Graphic change of K_d and K_s is shown in Fig. 1, 2 and 3.

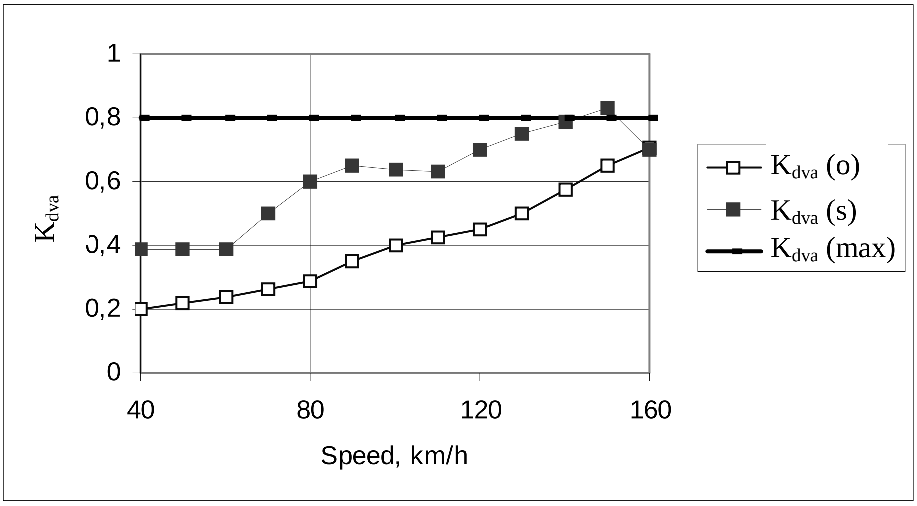

Fig 1. Rigidity in axle-box suspensions K_{dv} for speed *v=60 km/h*
Рис. 1. Жесткость буксового подвешивания K_{dv} для скорости *v=60 км/час*

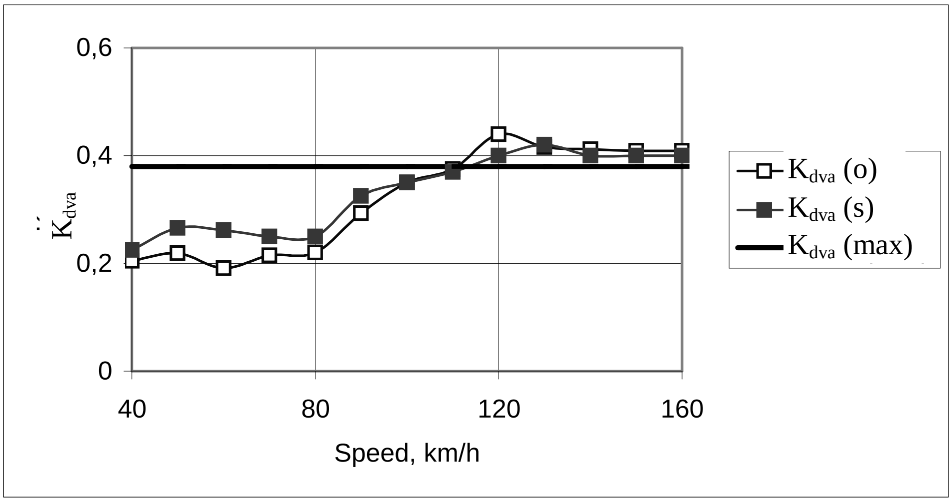

Fig. 2. Rigidity in axle-box suspensions K_{dh} for speed *v=60 km/h*
Рис. 2. Жесткость буксового подвешивания K_{dh} для скорости *v=60 км/час*

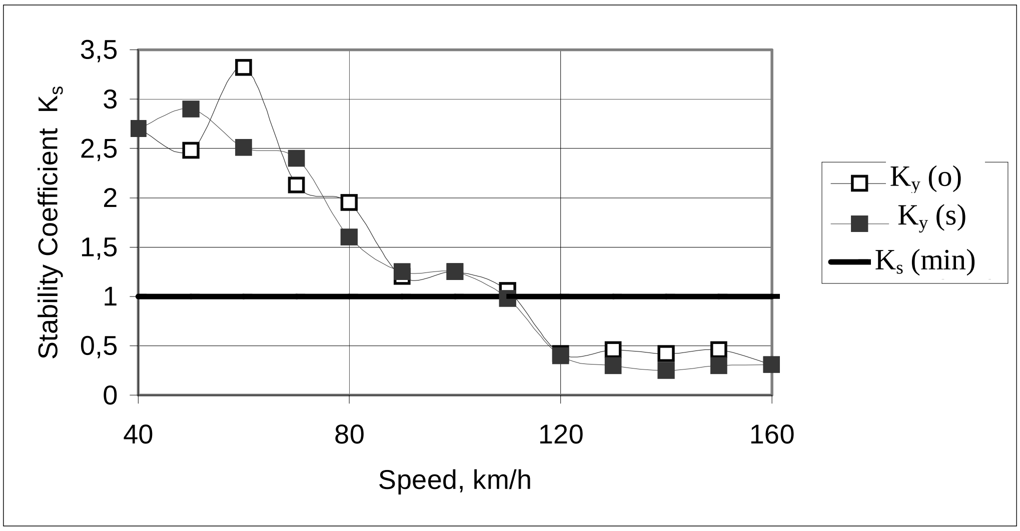

Fig. 3. Stability coefficient K_s for speed *v=60 km/h*
Рис. 3. Коэффициент устойчивости K_s для скорости *v=60 км/час*

From the presented results it is visible that for the selected carriage, both in case of standard and optimised parameters, the limit driving speed is 100 km/h, as limited by coefficient K_s. Let's see calculation results when speed *v=140 km/h*.

Tab. 4

Principal Dynamic Indices

	K_{dva}	K_{dha}	K_s	K_{avc}	Goal function
Under initial parameter values	0.548	0.254	1.213	0.536	0.897
Under optimal parameter values	0.349	0.223	2.289	0.373	0.418
%	-36	-12	89	-30	-53

Optimal parameter values:
Axle-Box Suspension:
Longitudinal direction: Kax = 0, Fax = 0.23
Transverse direction: Kay = 0, Fay = 0.23
Vertical direction: Kaz = 18200, Vaz = 93
Central suspension:
Longitudinal direction: Kcx = 5470, Fcx = 0.23
Transverse direction: Kcy = 5490, Fcy = 0.09
Vertical direction: Kcz = 3490, Fcz = 0.09
Sliders:
Longitudinal direction: Kšx = 0, Fšx = 0.12
Transverse direction: Kšy = 0, Fšy = 0.12
Vertical direction: Kšz = 748, Všz = 0

Graphic change of K_d and K_s is shown in Fig. 4, 5 and 6.

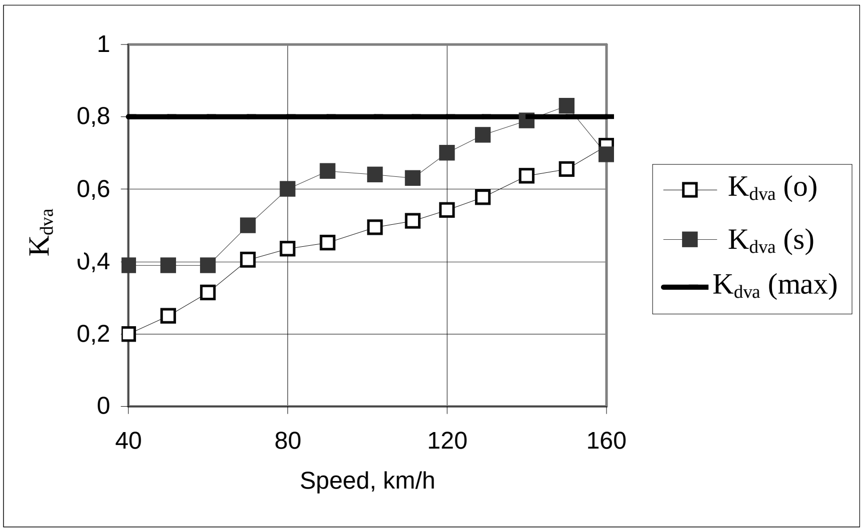

Fig 4. Rigidity in axle-box suspensions K_{dva} for speed *v=140 km/h*
Рис. 4. Жесткость буксового подвешивания K_{dva} для скорости *v=140 км/час*

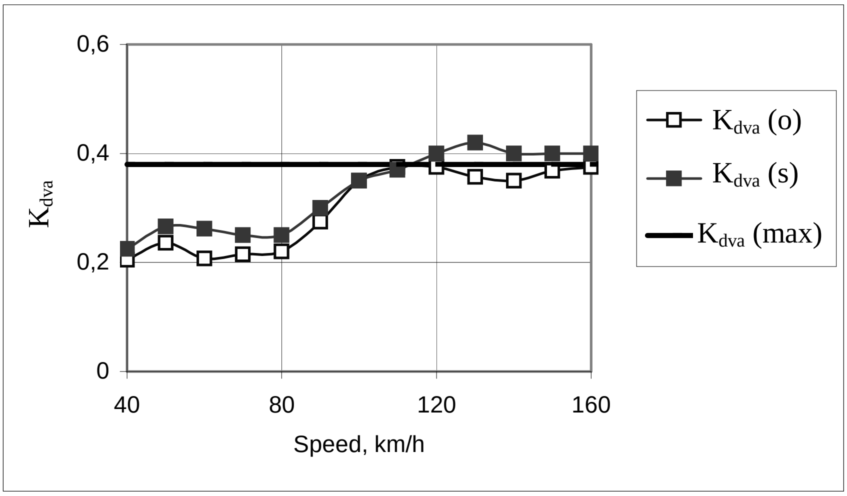

Fig. 5. Rigidity in axle-box suspensions K_{dha} for speed *v=140 km/h*
Рис. 5. Жесткость буксового подвешивания $\boldsymbol{K_{dha}}$ для скорости *v=140 км/час*

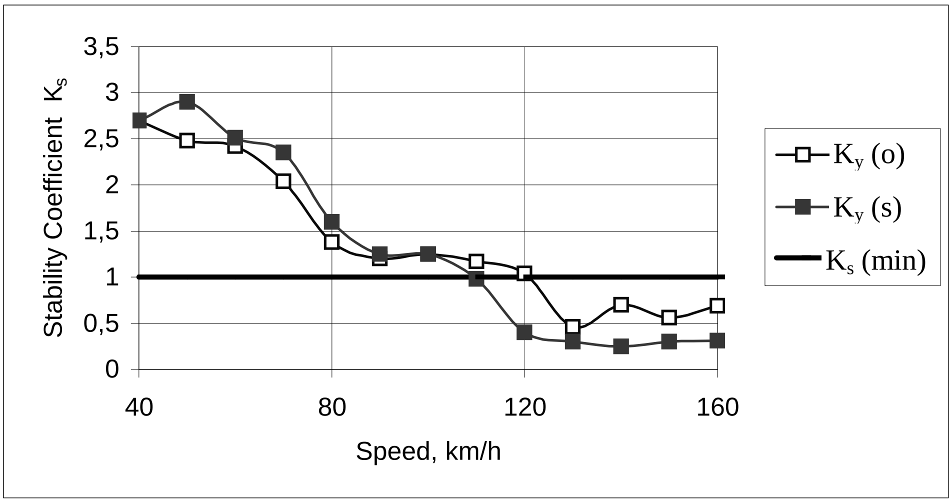

Fig. 6. Stability Coefficient K_s for speed *v=140 km/h*
Рис. 6. Коэффициент устойчивости K_s для скорости *v=140 км/час*

Under this speed, the allowable values of K_{dha} and K_s could not be reached. Such calculations were made for speeds of 60, 80, 110, 120 and 140 km/h.

8. CONCLUSION

Analysis of the results of performed calculations has shown that when determining optimal parameters for chassis suspensions, stability coefficient must be taken as the main index in goal function, since this parameter is the first to limit the driving speed. The calculations should be made with the lowest speed, under which the values of dynamic indices exceed the allowable limits. Further one should search for solutions with other values of initial parameters and each time determine the minimum speed, under which the values of dynamic indices exceed allowable limits. This methodology is very important for calculation of chassis due to constant growth of train speeds.

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