ской модели $q(t)$ на случайное входное возмущение $\eta(t)$ определялись, как и в [1], по средним значениям абсолютных максимумов.

Алгоритм спектрального анализа при использовании БПФ (быстрое преобразование Фурье) с учетом фильтрации исходной случайной реализации $q(t)$ и сглаживания фильтром Ю. Ханна полученной при этом оценки $G_q(\omega)$ спектральной плотности подробно рассмотрен в [3]. Алгоритм определения коэффициента плавности хода – в [4].

Результаты расчетов в виде графиков зависимостей $C_{1,2}$ (v), $\ddot{z}_{\kappa 1,2\max}$ (v), $K_{дц}(v)$ и $K_{дб}$ (v) приведены на рис. 2–4. Анализ этих графиков показывает, что для пневматического подвешивания значения ПДК до скорости $v_{\max}$ = 100 км/ч меньше тех же показателей пружинного подвешивания: на 9,3–15,6% для коэффициента плавности хода C_1 и на 13,3–14,5% для C_2. На 40,4–37,7% меньше для максимального значения ускорений $\ddot{z}_{\kappa \max 1}$, а для $\ddot{z}_{\kappa \max 2}$ – на 40,5–33,8%. Для коэффициента динамики $K_{дц1}$ меньше на 31,8–34,9% и $K_{дц3}$ – на 32,6–30,5%. Коэффициенты динамики в буксовой ступени рессорного подвешивания $K_{дб}$ для пружинного и пневматического подвешивания в рассматриваемом диапазоне скоростей отличаются незначительно и не превышают допустимого значения $[K_{дб}]$ =0,35.

ВЫВОДЫ

Основываясь на приведенных результатах, можно заключить, что применение пневморессор в центральной ступени рессорного подвешивания модели вагона метрополитена предпочтительнее использования с той же целью пружин и гидравлических гасителей.

ЛИТЕРАТУРА

1. Сердобинцев Е. В., Йе Вин Хан. Вертикальные колебания метровагона с пневмоподвешиванием // Мир транспорта. – 2013. – № 2. – С. 78–84.
2. Поляков А. И. Моделирование на ЦВМ горизонтальных случайных неровностей пути при исследовании нелинейных колебаний рельсовых экипажей // Оборудование и эксплуатация электроподвижного состава. Вып. 738. – М.: МИИТ, 1983. – С. 151–155.
3. Прочность и безотказность подвижного состава железных дорог / А. Н. Савоськин, Г. П. Бурчак, А. П. Матвеевичев и др. – М.: Машиностроение, 1990. – 287 с.
4. Кондрашов В. М. Единые принципы исследования динамики железнодорожных экипажей в теории и эксперименте. – М.: Интекст, 2001. – 190 с. ●

CHOICE OF PARAMETERS FOR A METRO COACH WITH PNEUMATIC SPRINGS

Serdobintsev, Evgeny V. *– D. Sc. (Tech), professor of Moscow State University of Railway Engineering (MIIT), Moscow, Russia.*
Zvantsev, Pavel N. *– Ph.D. (Tech), associate professor of Moscow State University of Railway Engineering (MIIT), Moscow, Russia.*
Ye Win Han *– Ph.D. student of Moscow State University of Railway Engineering (MIIT), Republic of Myanmar.*

ABSTRACT

The government of the Republic of Myanmar cooperates with Russian experts in implementation of the project of metro construction in the biggest city of Yangon. Shaping out of technical specification for manufacturing of rolling stock, well adapted to local conditions, includes the task of selection of design and parameters of springs. At the project phase that task is fulfilled through comparison of dynamic features of metro coach models. The use of pneumatic springs as elastic and dissipative element of body part of spring suspension is one of the variants which are now studied. The article contains results of comparative analysis of dynamic features of pneumatic and classical springs.

ENGLISH SUMMARY

Background. *The previously published article [1] examined possible use of pneumatic springs as an element of central stage of spring suspension of metro coach, designed for use in metro system of the city of Yangon of Republic of Myanmar. Previous study was accomplished with the help of reduced model. It proved advantages of pneumatic spring suspension as compared to classical spring and hydraulic spring systems. It was noted that the definite selection of parameters of spring suspension of metro coach could be done after study based on spatial model simulation, taking into account bouncing and lateral rolling of the body, bogie and wheelsets, as well as rocking of the body and bogies.*

Objectives. *The study, described in the article, was aimed at selection of parameters of spring suspension of a metro coach. Calculated spatial kinematic scheme of the coach is shown in Pic.1.*

Methods. *The study used mechanical and mathematical model of pneumatic spring with one additional tank, the same as in [1]. The researchers used the system of nonlinear differential equations to describe oscillations of mass m, resting on a pneumatic spring. To engineer spatial kinematic model of metro coach the authors adopted a set of assumptions described in the article (e. g. that*

body of the coach, bogie frame, wheelsets are considered to be absolutely solid bodies as their rigidity is considerably higher than the rigidity of joining resilient elements; gravity centers of those solid bodies coincide with their geometric centers, et cetera).

The suggested kinematic scheme gives reason to suppose that oscillations of the model, adopted for the study, can be described by generalized coordinates, which are bouncing, lateral rolling and rocking of the body, bogie frames, wheelsets, mass of tunnel track at right and left wheels of the bogies. Providing for assumptions, the calculated kinematic scheme will have 17 levels of freedom.

Parameters of the model of metro coach, of pneumatic spring with rubber-cord casing (model H-6), of rail track of the tunnel, which are necessary to solve the problem, are listed in table 1. As the authors suppose to use nonlinear model of pneumatic spring, the study is accomplished in temporary realm on the basis of solution of a system of differential equations by Runge-Kutta method of order 4.

Results. *The authors describe the system of equations for the case when pneumatic spring is used in the central stage of spring suspension.*

Using [1,2] where the algorithm of generation of random process of disturbance is described, the authors produced generation of $\eta_{пр}$ and $\eta_{л}$ – which are equivalent geometric irregularities of left and right rails of tunnel metro track in conformity with supposed spectral density. Dispersions $\eta_{пр}$ and $\eta_{л}$ are assumed to be the same and equal to 13,01 мм^2. So the impact of lateral rolling on the oscillation results are not considerable and deformation of right and left elements of spring suspension are similar (it is shown in the Pic. 2–4).

The rates of dynamic features during comparison of the use in central stage of spring suspension of springs with hydraulic dampers and pneumatic springs were accepted as:

– rates of dynamics in the elements of central and box-axle stages of spring suspension $K_{дц1}$, $K_{дц2}$, $K_{дц3}$, $K_{дц4}$, $K_{дб1}$, $K_{дб2}$, $K_{дб3}$, $K_{дб4}$, $K_{дб5}$, $K_{дб6}$, $K_{дб7}$, $K_{дб8}$;

Are maximum values of vertical accelerations on the floor of the body over first and second pivot points $\ddot{z}_{к1,\,2\max}$;

– rate of smoothness of motion on the floor of the body over first and second pivot points $C_{1,2}$.

The rates of dynamics in that case reflected the ratio of maximum value of dynamic effort $F_{дин}^{\max}$ in above mentioned stages of spring suspension to its static value $F_{стат}$. Maximum values of realization of random processes of reaction of dynamic model q (t) to random entry disturbance η (t) were defined (as in [1]) by average values of absolute maximums.

Algorithm of spectral analysis during application of fast Fourier transform (with consideration for filtering of exit random realization q (t)) and process of smoothing with Hann filter of evaluation $G_q(\omega)$ of spectral density are described in details in [3]. Algorithm of determining of smoothness of motion is described in [4].

The results of calculations in the form of flow-charts of dependencies $C_{1,2}$ (v), $\ddot{z}_{к1,2\max}$ (v), $K_{дц}$ (v) и $K_{дб}$ (v) are shown in the Pic. 2–4. Analysis of those charts proves that for pneumatic springs, as compared with classical spring suspension: values of dynamic features at velocity less than 100 km/h are less by 9,3–15,6% for smoothness of motion C_1 and by 13,3–14,5% for C_2.; by 40,4–37,7% for maximum values of acceleration $\ddot{z}_{к\max 1}$; by 40,5–33,8% for $\ddot{z}_{к\max 2}$; by 31,8–34,9% for dynamics rate $K_{дц1}$ and by 32,6–30,5% for $K_{дц3}$. Rates of dynamics in axle-box stage of spring suspension $K_{дб}$ for both spring and pneumatic suspension in considered spectrum of velocity don't have considerable differences and don't exceed allowable value [$K_{дб}$] =0,35.

Conclusions.

Use of pneumatic springs in studied conditions in central stage of spring suspension of metro coach is more advantageous than use of springs and hydraulic dampers.

Key words: *metro, Myanmar, Yangon, rolling stock, spring suspension, pneumatic spring, quality indices, mathematical model, comparative analysis.*

REFERENCES

1. Serdobintsev E. V., Ye Win Han. Vertical Oscillations of the Metro Wagon with Pneumatic Suspension [*Vertikal'nye kolebaniya metrovagona s pnevmopodveshivaniem*]. *Mir Transporta [*World of Transport and Transportation*] Journal*, 2013, Vol. 46, Iss.2, pp. 78–84.

2. Polyakov A. I. Simulation of horizontal random irregularities of the track during the study of nonlinear oscillations of rail vehicles with the help of digital computers [*Modelirovanie na TsVM gorizontal'nyh sluchaynyh nerovnostey puti pri issledovanii nelineynyh kolebaniy rel'sovyh ekipazhey*]. Equipment and operation of electric rolling stock [*Oborudovanie i ekspluatatsiya elektropodvizhnogo sostava*], Vyp. 738, Moscow, MIIT, 1983, pp.151–155.

3. Savoskin, A.N., Burchak, G.P., Matveevichev, A.P. et al. Reliability and infallibility of rail rolling stock [*Prochnost' i bezotkaznost' podvizhnogo sostava zheleznyh dorog*]. Moscow, Mashinostroenie publ., 1990, 287 p.

4. Kondrashov V. M. Unified guidelines for studies of dynamics of rail vehicles in theory and experiment [*Edinye printsipy issledovaniya dinamiki zheleznodorozhnyh ekipazhey v teorii i eksperimente*]. Moscow, Intekst publ., 2001, 190 p.

Координаты авторов (contact information): Сердобинцев Е. В. (Serdobintsev E. V.) – + 7 (499) 978–71–52, Званцев П. Н. (Zvantsev P. N.) – zpn3@yandex.ru, Йе Вин Хан (Ye Win Han) – Yewinhan9@gmail.com.

Статья поступила в редакцию / article received 07.10.2013
Принята к публикации / article accepted 14.11.2013