Effect of tire dynamic characteristics on vibration load at the operator's workplace

P A Korchagin, I A Teterina, A B Letopolsky

Siberian Automobile and Highway University, prospect Mira 5, 644080, Omsk, Russia

Abstract. The article addresses a current issue – reducing the vibration load at the operator's workplace in the utility machine with respect to the use of chassis elements as vibroprotection element. The results of studies aimed at determining the effect of tires dynamic characteristics on the vibration load of the operator's workplace are presented. A computational scheme designed to conduct experimental research has been shown. Correlation between tire rigidity and air pressure in the tire, as well as correlation between tire service life and tire pressure have been revealed. Results of studies aimed at determining relations between the dynamics of mean-square values of vibration acceleration of the frame, the floor and the operator's seat, and the rigidity coefficients of utility machine tires. Conclusions have been made as to the relevance of using chassis elements as vibroprotection element at the operator's workplace in the utility machine.

1. Introduction

The level of vibration load at the operator's workplace is one the most important ergonomic characteristics of road building machinery. Nowadays, problems related to providing operator's ergonomic work and compliance with health and safety regulations concerning the magnitude of dynamic impact at the operator's workplace in road building machines haven't been solved yet.

Fundamental research in the field of providing vibroprotection of operators and equipment has been conducted by Kozlovsky M.Z, Bolotin V.V., Ivanov N.I., Frolov K.V. [1]. The greatest progress in designing vibroprotection systems in wheeled and crawler machinery through improvements in cab's suspension system and operator's seat has been made by Gaitzgory M.M., Hodakova A.A., Kochetov O.S., Elisseva S.B. [2].

The works of Afanasiev V.L., Malinovsky E. Yu., Vasiliev V.S. mainly focus on modelling smooth movement of road building machines [3]. The effect of the rigidity coefficient of the wheels on the magnitude of dynamic impacts on the road building machine has been investigated by Chetyrkin Yu.B., Sorokin V.N., Tarasov V.N. [4].

Research into the effect of tire dynamic characteristics on vibration load in wheeled vehicles is being conducted by Harlamov S.L., Gorin S.L., Abdulgazis A.U., Shemiev S.B.

The dynamics of car movement has been studied by Kutkov G.M., Novitsky A.V., Kovalev V.A. The works of Gerger V.P., Kozinov E.A., Sovrasov V.V., Starodubtseva S.A. have been devoted to the optimization of characteristics of vibroprotection systems in mobile machines and structures, as well as in vehicle tires.

However, no research has been presented in the given literature as to the determining vibration load at the operator's workplace (the cab's floor and the seat) in the utility machine. At the same time, the problem of obtaining high ergonomic characteristics of the utility machines, which affect operator's efficiency and physical condition, still remains of great importance in contemporary engineering.

Vibration load at the operator's workplace is determined by particular performance and structural parameters, one of the latter being tire elastic properties, in particular, pressure inside the tires, in addition to rigidity coefficient (C_i) and coefficient of resistance (b_i) of cab's suspension and operator's seat.

2. Problem setting

It is of importance to determine relations between the parameters of tire dynamic characteristics and the magnitude of the vibration load at the operator's workplace in the utility machine.

3. Theory

The smooth movement of the machine can be affected by tire characteristics, such as dynamic rigidity, radial static rate and shock absorption [5]. The only way to change the tire dynamic rigidity without modifying its structural parameters (i.e. material, form, etc.) is to change the pressure inside it [6]. In figure 1 correlation between these parameters is shown.

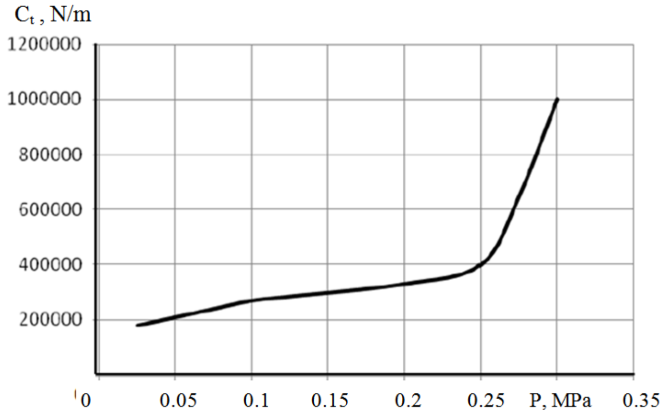

Figure 1. Correlation between tire dynamic rigidity and air pressure inside the tire.

At the same time air pressure inside the tire makes a significant impact on its service life (figure 2). Manufacturers prescribe the range of air pressure magnitudes for any tire class and any load, to provide long service life of tires [4, 7]. Neglecting those requirements leads to reducing the service life of tires.

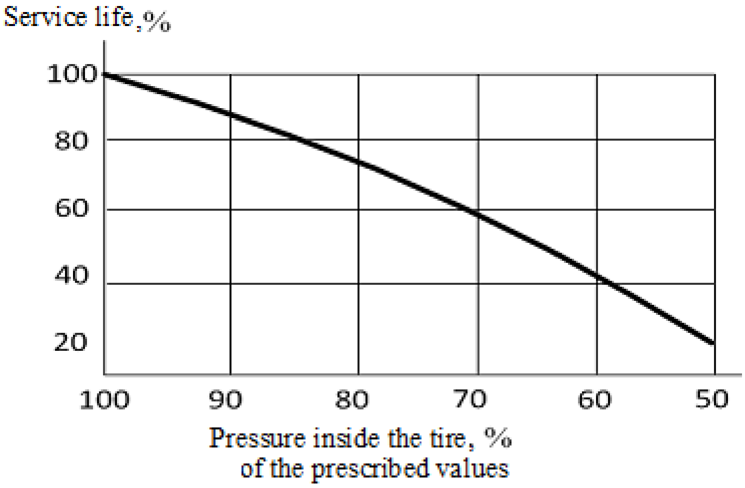

Figure 2. Correlation between tire service life and air pressure inside the tire.

Any deviation from the optimal values results in reducing the service life of tires [8, 9]. In table 1 relations between tire service life reduction and air pressure above and under the prescribed values are presented.

Table 1. Possible reduction of tire service life.

Over the prescribed values		Under the prescribed values	
Air pressure range, %	Service life reduction, %	Air pressure range, %	Service life reduction, %
More than 15	20	More than 15	25
11-15	13	11-15	19
6-10	5	6-10	10
No more than 5	0	No more than 5	0

One of the reasons of the reduced tire service life is referred to its increased deformation. The more significant the deformation is the earlier material fatigue development and temperature increase is observed during the operation [10, 11].

To conduct theoretical research a computational scheme of a complex dynamic system “perturbation influences – machine – operator” was developed (figure 3). The computational scheme is represented by the system of six concentrated masses and reflects most typical features of this system [10, 12].

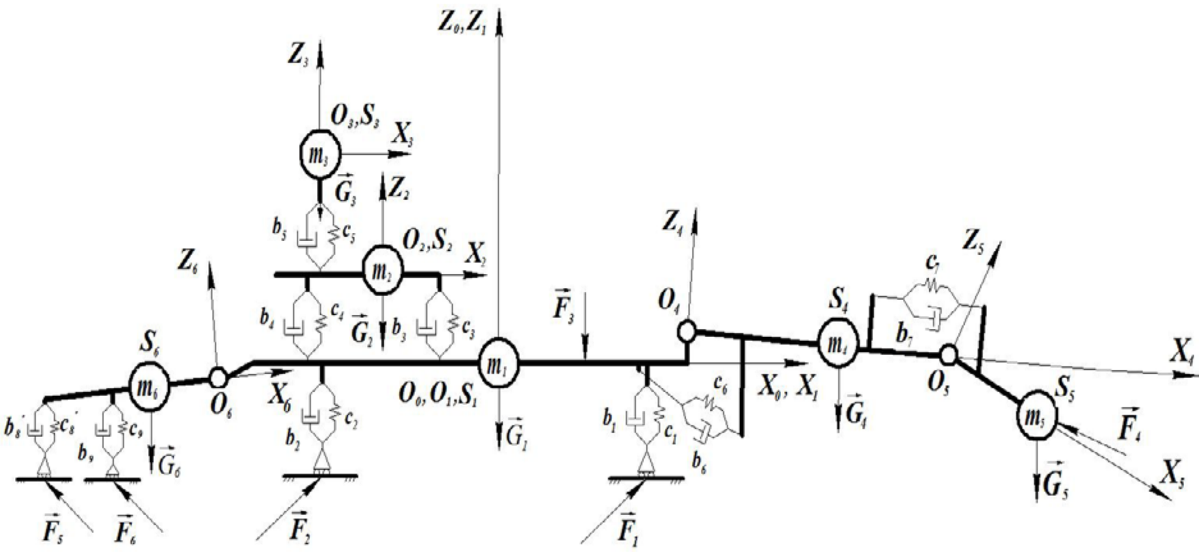

Figure 3. Computational scheme of the dynamic system.

Parameters under investigation related to the chassis dynamic models are given in computational scheme C_1, C_2, b_1 and b_2 [13, 14].

This theoretical research has been aimed at determining relations between the dynamics of mean-square values of vibration acceleration of the frame, the floor and the operator’s seat, and C_i of the utility machine tires [3, 15]. In accordance with the computational scheme of the dynamic system constant parameters were as following:

1. Large values of generalized coordinates, relevant to the operation mode of the machine elements were as shown further: $q_1 = 0$ m; $q_2 = 0$ rad; $q_3 = 0.702$ m; $q_4 = 3.14$ rad; $q_5 = 0.5$ m; $q_6 = 0$ rad; $q_7 = 0$ rad; $q_8 = 0$ rad.

2. C_i and b_i of hydraulic cylinders of working parts, chassis elements, elements of the cab's suspension system and those of the seat suspension were as follows [17]: $C_3 = 625 \cdot 10^3$ N/m; $C_4 = 625 \cdot 10^3$ N/m; $C_5 = 10 \cdot 10^3$ N/m; $C_6 = 20 \cdot 10^3$ N/m; $C_7 = 2.0 \cdot 10^4$ N/m; $C_8 = 1.0 \cdot 10^4$ N/m; $b_1 = 2.57 \cdot 10^4$ N·s/m; $b_2 = 1.99 \cdot 10^4$ N·s/m; $b_3 = 80 \cdot 10^4$ N·s/m; $b_4 = 8.0 \cdot 10^3$ N·s/m; $b_5 = 5.0 \cdot 10^3$ N·s/m; $b_6 = 5.0 \cdot 10^3$ N·s/m; $b_7 = 1.0 \cdot 10^4$ N·s/m; $b_8 = 1.0 \cdot 10^4$ N·s/m.

While studying $C_{i,}$ parameters of the front (C_1) and rear (C_2) wheels varied within $0.5 \cdot 10^5 \ldots 12 \cdot 10^5$ N/m [16].

4. Results

Air pressure inside the tires of MTZ-80 mounted utility machine, which has been recommended by the manufacturer, prescribed by GOST 7463-2003 and operating manuals can be varied within the following values: 0.1 – 0.18 MPa – for the rear wheels, 0.12 – 0.26 MPa – for the front wheels [4, 7, 18]. This pressure corresponds to C_i of the rear wheel equal to $2.7 \cdot 10^5 \ldots$ $3.6 \cdot 10^5$ N/m, and that of the front wheel equal to $29 \cdot 10^5 \ldots 4.6 \cdot 10^5$ N/m [18,19].

As can be seen from the graphs, the magnitude of the dynamic impacts on the cab floor and the cab frame [19, 20] can be decreased due to the change in the air pressure inside the tires of the front and the rear wheels (figure 4) and in the tires of the rear wheels (figure 5) provided that the tire service life is not changed. The dynamic impact change is of no importance yet.

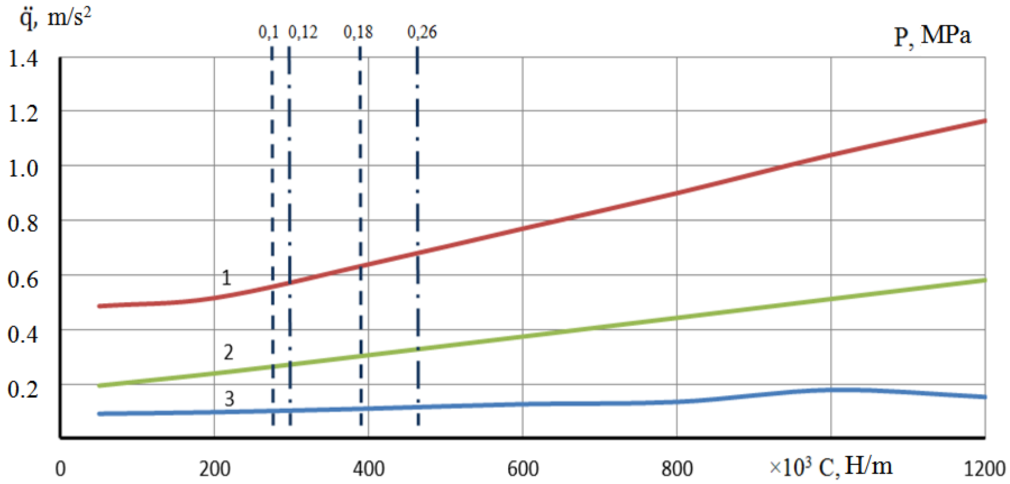

Figure 4. Relations between the dynamics of mean-square values of vibration acceleration on C_i of tires: 1 – the frame, 2 – the floor, 3 – the seat; ------ – permitted values of C_i for the rear wheels, -.-.-.-. – permitted values of C_i for the front wheels.

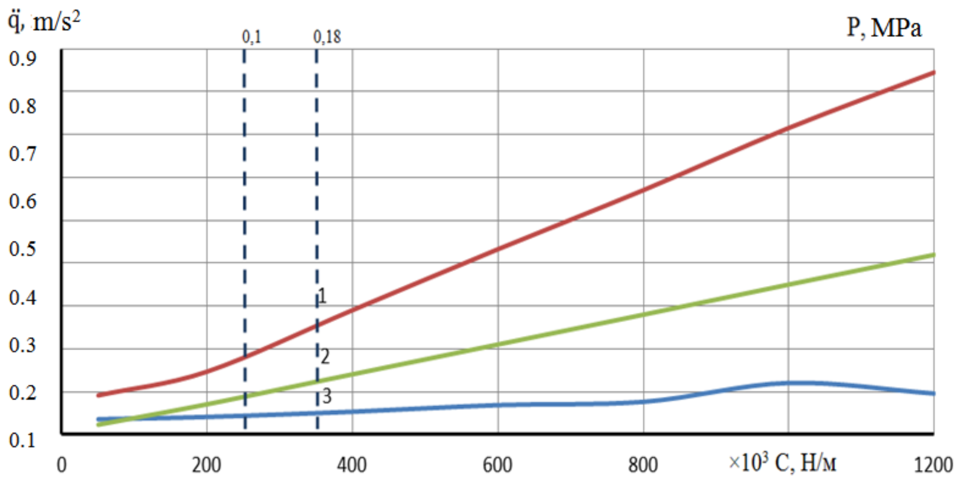

Figure 5. Relations between the dynamics of mean-square values of vibration acceleration on C_i of rear wheels tires: 1– the frame, 2 – the floor, 3 – the seat.

5. Conclusion

As a result of the investigation the following conclusion was made:
1. Changes in the air pressure inside the tires within the values considered do not affect the magnitude of the vibration load at the operator's seat.
2. When tire pressure is at minimal permitted values, the vibration load of the frame and the cab floor is at the average 35% lower.
3. Sustainable parameters of C_i providing the lowest vibration load of the frame and the cab floor were determined as follows: $C_1 = 2.9 \cdot 10^5$ N/m, $C_2 = 2.7 \cdot 10^5$ N/m, which is relevant to the tire pressure of 0.12 MPa for the front wheels and of 0.10 MPa for the rear wheels according to the manufacturer's restrictions.

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