# DETERMINING ROAD VEHICLE STRESSES UNDER VARIOUS OPERATING CONDITIONS

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## 1. Introduction

The commerce makes ever changing engineering demands on the bus industry in respect of both volume and quality. Investigating buses sold in inland or abroad, can it be stated that each bus will be operated under various load conditions, on different roads, under different traffic conditions and driven by drivers different of attitudes. Business considerations may imponent to rate the given vehicle structure component for a longer life or for a greater load capacity than usual. The ever changing market demands can only be satesfied in possession of a design method, able to respond to these changing parameters with the flexibility required.

## 2. Summing up the results of previous investigations

During the previous investigations the most important factors of the static and dynamic loads acting on the structure of road vehicles have been determined [1]. On this basis the static load a random variable in a point $s$ of the structure can be written as:

$$M_{stat}(s) = F_1\{\mathbf{M}(t),\ \mathbf{S}(t, \mathbf{M}),\ \epsilon(t), \alpha\} \tag{1}$$

where $\mathbf{M}(t)$ — matrix composed of the own mass of the vehicle and the working load, which depends on the time "$t$" because of the changing load conditions;

$\mathbf{S}(t, \mathbf{M})$ — stiffness matrix containing the stiffness data of the vehicle and the freight. Since during the normal use of the wear and tear, loosening, corrosion occur, also the stiffness data may vary as a function of time;

$\epsilon(t)$ — kinematic load due to manufacturing inaccuracies (e.g. assembly or welding stresses), present in the structure already at the moment of putting in use of the vehicle and normally independent of time;

$\alpha$ — effect of kinematic loads during stoppage or longer standing of the vehicle due to road surface unevennesses (e.g. torsion of the structure).

The dynamic stress in a point $s$ of the structure is also random variable, such as:

$$M_{din}(s) = F_2\{\mathbf{M}(t), v(\mathbf{M}, k, u, z)\, x(l), \mathbf{S}(t, \mathbf{M}), \mathbf{K}(t, \mathbf{M}), d\} \quad (2)$$

where

$v$ — speed of the vehicle with a given engine which depends on the load condition $\mathbf{M}$ and — intermediating the regulating activity of the driver — on the road quality, its unevennesses, i.e. on the category $k$, the traffic conditions $u$ (traffic saturation etc.), the geometric tracing $z$ (terrain relief, sinuosity etc.)

$x(l)$ — unevenness at a point $l$;

$\mathbf{K}(t, \mathbf{M})$ — damping matrix characteristic of the vehicle, depending both on the load and the time (changing of the damping by the load and in the structure);

$d$ — additional stress originating from the dynamic riding effect (acceleration, braking, turning).

To facilitate the calculation the following symplifying assumptions will be applied [2]:

— In our different types of outes excitation may act on the vehicle reality on its left and right sides and the front and rear suspensions of the vehicle. The rear suspension of the vehicle is supposed, to get exactly the same excitation as the front suspension, with a phase delay arising from the wheelbase and the speed and this excitation is assumed to be identical both at the left and the right side (i.e. the structure can be modelled in plane). Knowing the cross-correlation between the excitations of the left and right wheels, the investigation can be extended to spatial models as well);

— the vehicle is considered as a linear system;

— the continuous spectrum of road conditions will be replaced by a limited number of realisations

$$\left.\begin{array}{l} -\mathbf{S} \neq \mathbf{S}(t) \\ -\mathbf{K} \neq \mathbf{K}(t) \end{array}\right\} \text{ i.e. the system is time invariant}$$

— the dynamic riding effects are disregarded, or rather their influence can be determined by a time dependent analysis to be added to the stress statistics;

— the practically unsteady phenomenon is regarded as the sum of permanent at the same time ergodic processes of adequate duralion;
— the probability of getting on to the $k$-th road type is proportional to the relative length of the $k$-th road type within the given road network;
— $\epsilon \neq \epsilon(t)$. Accordingly the two — parameter distribution function of stresses will be shifted by a constant value on the axis of the static loading by by kinematic stresses due to the manufacturing processes. In case of serial production, the shift of the individual elements is of random character, but easily to calculated knowing the distribution function of $\epsilon$ [3, 4];
— the matrix $\mathbf{M}$ is taken into consideration as the histogram of a finite number of realizations weighted by the travel $k$ length, too (the statistics for this can be determined e.g. from passenger counting on another vehicle of the same capacity, or from bills of loading);
— under the established conditions the dynamic load is considered as of normal distribution with zero expected value;
— the stress in an arbitrary point $s$ of the car frame is supposed to be unambiguously described by a single value (e.g. for buses with integral body, the lattice bars can be described by normal stresses and the door and window columns by bending stresses).

With these simplifying assemptions Eqs. (1) and (2) become:

$$M_{stat}(s) = F_1'(\mathbf{M}) \tag{3}$$

and

$$M_{din}(s) = F_2'\{\mathbf{M}, v(k), \Phi_k, \mathbf{W}(\mathbf{M}, \mathbf{S}, \mathbf{K}, v)\} \tag{4}$$

These are applied to determine the two — parameters distribution function of the stress at a point $s$ of the structure of long-distance buses [2];

$$H(x, y) = \sum_{\substack{j \\ (y_j < y)}} g_j \int_{-\infty}^{x} \sum_{i,k} \frac{P_{ik} \cdot r_k}{\sqrt{2\pi} \cdot D_{ikj}} \exp\left[-\frac{\xi^2}{2 D_{ikj}^2}\right] d\xi \tag{5}$$

where

$g_j$ — relative frequency of the $j$-th stress state

$p_{ik}$ — the conditional probability of the fact, that the vehicle proceeds at a speed of category $i$ on the road of category $k$

$r_k$ — the relative frequency of the distribution of the so-called standard road qualities along the length of road

$D_{ikj}$ — the standard deviation of the dynamic stress obtained in the case of linear systems, according to Mitschke [5];

$$D_{ikj} = \frac{1}{\sqrt{2\pi}} \left[\int_0^{\infty} W_i^2(\omega) \cdot \Phi_k(\omega)\, d\omega\right]^{\frac{1}{2}} \tag{6}$$

$W_i(\omega)$-speed dependent transfer characteristic for the given structural component;

$\Phi_k(\omega)$-performance density spectrum for the given road category. The investigation can also be extended to nonlinear systems (nonlinear spring and damping characteristic, wheel — bouncy, dry friction etc.). In this case the performance density spectrum $\Phi_k$ has to be replaced by investigation as time of suitable length (hence of $x(l)$) representative of the given road category $k$. Also this latter permits do determine the standard deviation of the dynamic stress, decisive from the point of view of our investigation. Since the majority of our buses are operating in other than long distance lines, the two-parameters distribution function has to be determined under other operational conditions, as well.

## 3. Determination of stresses in urban-traffic buses

In urban traffic the road quality can be approximately considered as homogeneous. The driver is compelled by the rhythm of the traffic to keep the speed prescribed or below independent of the road quality. The speed selection becomes independent of the subjectiv sense of the driver, because of the limit speeds in towns hardly disturb the vibrational comfort of the vehicle. At the same time the traffic conditions (traffic lights, pedestrian crossing etc.) render the traffic process unsteady. The speed of the vehicle can be stated to be independent of the road quality, the load condition and the geometric tracing of the road but to largely depend on the traffic circumstances.

Accordingly (4) and (5) can be written as:

$$M_{din}(s) = F_2''\{\mathbf{M}, v(u), \Phi_k, \mathbf{W}(\mathbf{M}, \mathbf{S}, \mathbf{K}, v)\} \tag{7}$$

$$H(x, y) = \sum_{\substack{j \\ (y_j<y)}} g_j \int_{-\infty}^{x} \sum_{i,k} \frac{p_i \cdot r_k}{\sqrt{2\pi}\, D_{ikj}} \exp\left[-\frac{\xi^2}{2D_{ikj}^2}\right] d\xi \tag{8}$$

where

$p_i$ — the probability of riding at a speed in category $i$ under the given traffic conditions.

## 4. Determination of stresses in buses operated terrain

In hilly-terrain (e.g. mountain routes) the driver is compelled by consecutive rises, slopes and turns to choose a speed below that corresponding to the road quality of the vibrational comfort of the vehicle also the engine performance under given load conditions may set a limit. Supposing that the suitable engine performance is available, then the speed depends in first approximation only on the geometric tracing of the road. Considering this, realisations (4) and (5) can be written as:

$$M_{din}(s) = F_2'''\{\mathbf{M}, v(z), \Phi_k, \mathbf{W}(\mathbf{M}, \mathbf{S}, \mathbf{K}, v)\} \tag{9}$$

$$H(x, y) = \sum_{\substack{j \\ (y_j < y)}} g_j \int_{-\infty}^{x} \sum_{i,k} \frac{p_i \cdot r_k}{\sqrt{2\pi}\, D_{ikj}} \exp\left[-\frac{\xi^2}{2D_{ikj}^2}\right] d\xi \tag{9'}$$

or in the load dependent case:

$$M_{din}(s) = F_2''''\{\mathbf{M}, v(\mathbf{M}, z), \Phi_k, \mathbf{W}(\mathbf{M}, \mathbf{S}, \mathbf{K}, v)\} \tag{10}$$

$$H(x, y) = \sum_{\substack{j \\ (y_j < y)}} g_j \int_{-\infty}^{x} \sum_{i,k} \frac{p_{ij} \cdot r_k}{\sqrt{2\pi} \cdot D_{ikj}} \exp\left[-\frac{\xi^2}{2D_{ikj}^2}\right] d\xi \tag{10'}$$

where

$p_i'$ — probability of riding at a speed of category $i$ for the given road geometry;

$p_{ij}$ — the conditional probability of riding at a speed of category $i$ in the $j$-th load state.

## 5. Determination of the joint stress distribution function for buses of various purposes

Knowing the probability of the occurrence of each typical operating condition for the vehicle working under miscellaneous operating conditions — where $m_l$ ($l = 1,2,3$ $m_1$ = long-distance; $m_2$ = urban; $m_3$ = hilly-country) — then it is possible to determine the stress distribution function for a vehicle structure, which can be used in all working conditions.

Denote the quoted conditional probabilities by:

$$P_{il} = \begin{Bmatrix} P_{i,1}(k) & l = 1 \\ P_{i,2}(u) & l = 2 \\ P_{i,3}(z) & l = 3 \end{Bmatrix} \tag{11}$$

In this case the two parameter stress distribution function in a point $s$ of the structure can be determined in the following form:

$$H(x, y) = \sum_{\substack{j \\ (y_j < y)}} g_j \int_{-\infty}^{x} \sum_{i,k,l} \frac{m_l \cdot P_{il} \cdot r_k}{\sqrt{2\pi} \cdot D_{ikj}} \exp\left[-\frac{\xi^2}{2\, D_{ikj}}\right] d\xi \tag{12}$$

## Summary

The stress distribution function have been determined earlier. The fact that the buses are driven both in urban traffic and in hilly terrain imposes to elaborate a joint two-parameter distribution function, taking every operating condition into consideration. Knowledge of the stress distribution function and application of a proper damage theory permits to preassess useful life at the probability wanted, or the endurance of a given construction under various operating conditions.

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