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POSSIBILITY OF IDENTIFICATION OF PERMANENT WAY AND TRAIN UNDERCARRIAGE AFFECTING RAILWAY TRAFFIC SAFETY

ABSTRACT

This paper will try to present some of the causes which result in vibrations during the train movement. Vibrations originate at the contact point between the undercarriage and the tracks. Theoretical analysis has been done of determining the spectral density of the acceleration process - vibrations of the non-suspended and suspended locomotive mass, and then the vibrations of diesel electric locomotive type HŽ 2061 were measured in different morphological conditions and geometrical state of the track at different speeds. Based on the correlation and spectral analysis of the measured accelerations - vibrations, conclusions can be made about the condition of the track and of the non-suspended mass of the locomotive. It should be stressed that determining the nature of vibrations is in the function of determining the system reliability. If it refers to the train and track in exploitation, the life time can be predicted, i.e. the overhaul can be planned, and if it refers to the development, then we can use the results as the basis to determine modifications and improvements.

The efficiency of applying fuzzy logic in controlling the train ride with various input variables has been presented, where special emphasis is put on the input variable which provides us with the data on vibrations parameter. The analysis of vibrations acting on the system, and the processing of the vibrations parameter and the use of fuzzy logic provide us with the possibility of controlling the train power plant.

KEY WORDS

vibrations analysis, diesel locomotive, spectral analysis, fuzzy logic

1. INTRODUCTION

Vibrations in railway traffic systems can be measured and analysed in two ways.

The first, classical way is to measure vibrations which are caused by unevenness on the permanent way, using the appropriate measurement methods to estimate its current condition, in order to determine what needs to be done so as to provide safety and satisfactory conditions of the track for safe and reliable railway traffic.

The other, new way, which is to be presented in this paper as a more sophisticated, qualitative and safer way of railway transportation, consists in simultaneous measuring of vibrations on the permanent way and on the undercarriage of the mobile capacities. This, in fact means that during the motion of a certain train composition along any railway line, there are two elements which come into contact at certain points, and affect each other in causing vibrations which have their characteristics precisely defined by the cause of their origin. During the motion of a train, namely, we have two subsystems and these are: the permanent way, which is stable, fixed subsystem, along which a mobile subsystem is moving by means of wheels at a certain speed, represented by the train composition, i.e. the locomotive with a certain number of railway cars. The consequence of certain dynamic forces occurring mainly at the contact points of the wheels and the tracks is a whole range of vibrations whose intensity and form depend on the current level of proper service of the permanent way and the undercarriage of the mobile capacities.

Dynamic forces that occur, consist of two components: deterministic and random vibrations.

Random components of vibrations at the contact point between the wheels and the track are caused by unevenness of the permanent way and the undercarriage of the mobile capacities.

These vibrations (disturbances) are transferred from the non-suspended to the suspended masses.

It is interesting to determine and predict the life time of the railway track or the railway vehicle based on the analysis of vibrations in ideal and actual exploitation conditions, after a certain time of using the track or the train, i.e. to determine precisely when to perform their repair or overhaul, thus achieving optimal economy and maximum possible safety and reliability of the railway traffic process.

Therefore, accurate measurements of vibration parameters during the train ride along a railway track and their analysis provide exact information about the possible "problems" and "troubles" which, if not previously eliminated, might have unsurpassable consequences on the safety and reliability of the railway traffic.

It is better if fuzzy logic is applied, which apart from considering vibrations as input parameter, also provides the possibility of controlling the optimal train ride regarding power consumption, safety, reliability, precision and comfort of railway passenger and goods transportation. Thus the engine driver is released from certain routine tasks which reduces the possibility of committing errors and enables better quality of monitoring the traffic process.

2. VIBRATIONS

Vibrations and problems caused by them date from the time when trains started to be constructed. At the beginning it was possible to determine the level of vibrations by touch or by listening on the basis of experience, and one could control whether this condition was getting worse.

Vibrations are mechanical oscillations of the system (construction, engines, vehicles, etc.), whereas oscillations generally present periodical movement of any amplitude. The study of mechanical vibrations is of great significance in all the branches of technology, e.g. in mechanical and civil engineering, naval architecture, construction of aircraft, where periodical movement of bodies or their parts always occurs with small amplitudes. Vibrations occur usually as undesired and damaging. They are harmful to people, and in engines, vehicles and generally in constructions they cause disturbances in operation and fractures and waste of mechanical energy.

Regarding power supply, i.e. the excitation method, vibrations are divided into free, forced, self-induced and parametric.

- Free vibrations occur when the vibration system is disturbed from the balanced condition and is left on its own. Then there is no further secondary energy supply and the system vibrates by its so-called proper frequency, i.e. by proper frequencies if the system has more degrees of freedom.
- Forced vibrations occur by acting of an excited or disturbing force F(t), which is a function of time and permanently supplies the system with energy. The disturbance may be also given by the movement of the base, which is the so-called kinematic excitation. However, this force is not defined only by the movement of the base but also by the features of the system.
- Self-induced vibrations occur and are maintained by constant supply of secondary energy. The character of the force which causes vibrations is not variable and it acts constantly in the same direction.
- Parametric vibrations occur due to the periodic change of one of the basic system parameters: mass, absorbency or constant of elasticity.

According to the form of the differential equation of motion, vibrations can be linear and non-linear. The analysis of non-linear vibrations is mathematically much more complex, and therefore, whenever possible, the calculation includes linearisation, especially if the shift amplitudes are small.

There are two subsystems acting during the train ride, the permanent way and the undercarriage of the mobile capacities. Considered as one system, it is subjected to dynamic forces. Dynamic force consists of two components: the determined and the random vibration. The random component of vibrations at the point of contact between the wheels and the track is caused by the unevenness of the permanent way and the undercarriage. These vibrations are transferred from the non-suspended to the suspended mass. It is interesting to find the parameters of forced and resonant vibrations (acceleration, speed or shift and the related frequencies) in ideal conditions, and their monitoring during exploitation, in order to control the condition of the permanent way, substructure of the locomotive i.e. locomotive as a whole (vibrations of engaging gears - reductor, electric drive, compressor, pumps, etc.). A well designed and a well manufactured - generally overhauled locomotive i.e. tracks will generate a low level of vibrations, but since the moving locomotive elements are subjected to wear, the foundations of tracks settle and the permanent way itself is deformed thus causing changes in dynamic behaviour of the locomotive, reflected in the increase of vibration levels and a possible appearance of resonances.

3.VIBRATIONS PROCESSING

The studied processes which characterise physical occurrences can be divided into two groups: determined and non-determined. Determined processes are those processes in which current values can be determined (described) unambiguously by mathematical formulas. In practice, there are many physical occurrences for which the precise value cannot be predicted at a certain point of time: these are the non-determined processes. These processes are random by nature and they are not described by equations, but by using the mathematical statistics indicators.

The function of time which describes the random occurrence is called the sample function (and if not regarded in a finite time interval - realisation). A set of all the sample functions which is obtained at registering the given random process is called random or stochastic process. Stationary and non-stationary random processes are distinguished. Stationary processes may be ergodic and non-ergodic. For non-stationary processes the non-stationary category needs to be known. Vibrations are stationary ergodic processes, which means that an arbitrary one may be chosen from the set of realisations, that is, the calculated statistical indicator will not depend on time nor on the selected realisation.

For describing the basic properties of random processes, four statistical functions are used: mean square value of the random process, distribution density, correlation function and spectral density. The mean square value gives the elementary notion about the intensity of the process. The distribution density gives the occurrence intervals of the current values for the given probability. Auto-correlation function and spectral density provide the analogous information about the process in time i.e. frequency range.

3.1. The link between the output and input process of the physical system

The theoretical connection needs to be established between the processes on the output and input in the linear system with one or more inputs. For the linear system with constant parameters and one input, if the weight function of the system is $h(\tau)$ and frequency characteristic H(f), the connection of the spectral densities of the output and input process is given by [1]:

$$S_y(f)=|H(f)|^2 S_x(f)$$

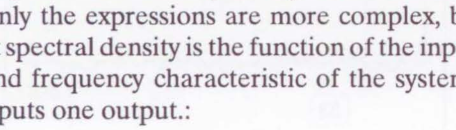

Figure 1 - Linear system with one input process

From the theoretical point of view, the connection between the output and the input of the system with one output and several inputs is presented in a similar way, only the expressions are more complex, but the output spectral density is the function of the input process and frequency characteristic of the system :several inputs one output.:

$$S_y(f)=\sum_{i=1}^{q}|H_i(f)|^2 S_i(f)$$

Dynamic forces caused by vibrations act at the contact point between the tracks and the locomotive wheels. These vibrations are input random process-

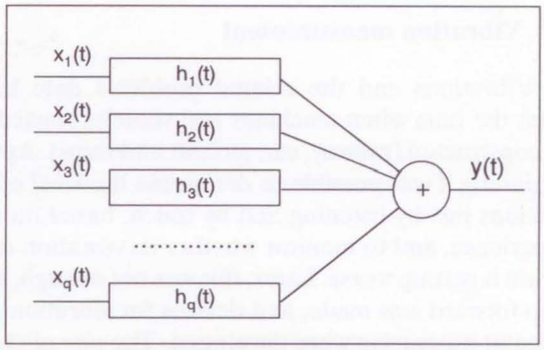

Figure 2 - Linear system with several input processes and one output

vibrations of the non-suspended mass. Vibrations of the suspended mass are output process. Based on the output process the damping of vibrations can be assessed. The same approach can be used to determine the damping efficiency of vibrations that reach the engine driver: seat, platform and control panel.

3.2. Determining the spectral density of the process of the variable dynamic force in the contact point between the wheel and the tracks

Summarised dynamic force in the contact point between the wheels and the tracks caused by unevenness has a structure complex enough and can be divided into the following processes:

- uneven spot per area of tracks
- uneven connections between the axle and the tracks
- uneven areas due to ground settlement and tracks suspension
- uneven areas at the core of the turnout
- uneven areas on the vehicle wheel
- the effect of the composition on the locomotive

The summarised dynamic force is a random stationary ergodic process and in the linear systems can be quantified by spectral density or correlation function.

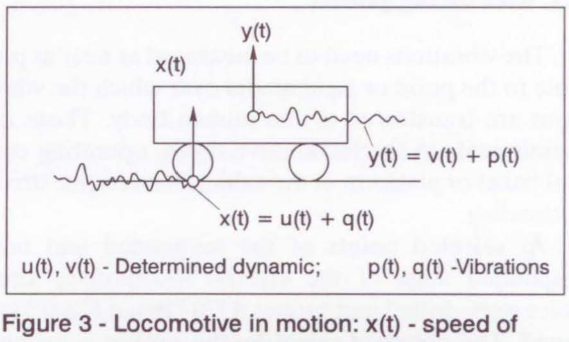

Figure 3 - Locomotive in motion: x(t) - speed of non-suspended mass shift, input process y(t) - speed of suspended mass shift, output process

3.3. Vibration measurement

Vibrations and the related problems date back from the time when machines and vehicles started to be constructed (railway, car, aircraft and ships). At the beginning it was possible to determine the level of vibrations just by listening and by touch, based on the experience, and to monitor whether its vibration condition is getting worse. Later, this was not enough, so a step forward was made, and devices for vibration parameter measuring were developed. The aim of these measurements is multiple. First of all, the vibrations state of the locomotive and the undercarriage need to be determined, i.e. vibration parameters of forced and resonant vibrations (acceleration, speed, shift and the related frequencies) should be measured. Then the source of vibrations need to be analysed. Controlling the condition of the locomotive, railway car and the permanent way by monitoring vibration parameters is a special form of measuring vibrations.

The permanent way and the locomotive undercarriage are involved in train movement. It is subjected to dynamic forces at their contact points. Dynamic force consists of two components: determined and random. Thus, the forced and self-induced oscillations - vibrations present the superposition of the determined and random vibrations. To describe the basic properties of the random processes, four characteristics are applied: mean square value, distribution density, correlation and auto-correlation function, i.e. spectral density. The auto-correlation function and the spectral density are to analogous processes, in time i.e. frequency area, which provide more information on the vibrations than the mean value.

4. EXPERIMENT RESULTS

In assessing the vibration load on the engine driver, the vibrations of the suspended and non-suspended mass were measured, as well as of the seat in the cabin of the electric locomotive HŽ 2061.

4.1. Measuring points

The vibrations need to be measured as near as possible to the point or rigid media over which the vibrations are transferred to the human body. These are mainly seats in the locomotive cabin, operating control panel or platform in the cabin, if the engine driver is standing.

At selected points of the suspended and non-suspended mass of the electric locomotive, screw holes were drilled and probes 4370 "Bruel Kjaer" fastened. The obtained signal by the probes is proportional to the speed i.e. acceleration (depending on the used amplifier) of the measured vibration. The probe signal was connected over the amplifier to the correlator, i.e. spectrum indicator HP 3720/3721. In the concrete case, the behaviour of non-suspended and suspended mass of the electric locomotive was studied as well as of the reducer in unfavourable and geometric conditions.

The obtained probe signals represent the time presentation of the shift or the acceleration of the point at which the vibration is measured. Based on the time presentation in the case of the random process, such as vibrations, one cannot obtain sufficient information about vibrations. Therefore, it is necessary to process the vibration signals. Regardless of the purpose of the vibration analysis, it is very efficient to carry out the correlation analysis, spectral analysis and to determine the distribution function of the current values.

4.2. Results of measurements

Figure 4 presents the spectral density and the correlation function of the vibrations acceleration. The tracks have been laid on the steel sleepers with low ballast bed which causes rough riding. In the diagram presenting spectral density of the vertical accelerations one spectral component has been stressed, at frequency f= 15Hz. The spectral density of the vertical accelerations has a stressed spectral component, and the correlation function is periodic.

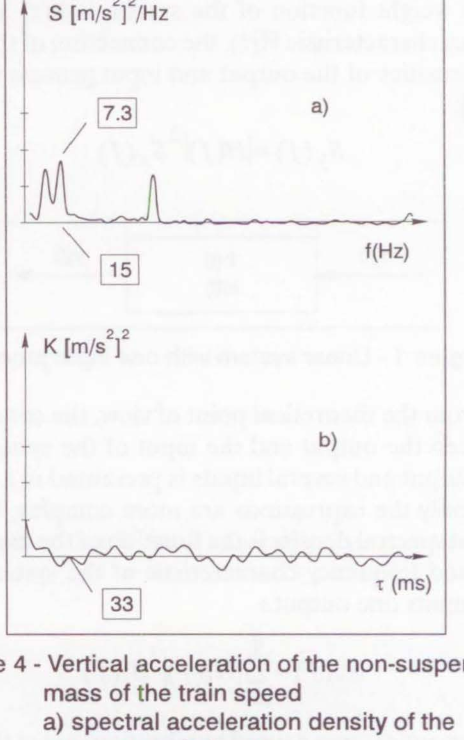

Figure 4 - Vertical acceleration of the non-suspended mass of the train speed
a) spectral acceleration density of the non-suspended mass
b) correlation acceleration function of the non-suspended mass

Figure 5 shows the spectral density of the vertical acceleration of the non-suspended mass if the sleepers are made of wood. The ride is less rough. In the diagram presenting spectral density of the vertical accelerations one spectral component has been stressed, at frequency f= 15Hz, and the spectrum around the stressed frequency, the correlation function is not periodic.

The spectral density of the vertical accelerations in train driving along a line at the speed of 95 km/h, amounts to 5.9 m/s, and the correlation function indicates gradual dampening, Figure 6. However, in curve R=300m the maximum in spectral density is stressed at the frequency of f=7.5Hz and the frequency f=48Hz. It may be assumed here that there are errors present in the width and bends of the tracks, which excite vibrations in the vehicle (40 – 50 Hz).

In passing over a turnout the spectral density has the peak value at f=13Hz, and the correlation function is completely periodic. Obviously, the suspension system affects the amplitude and the frequency of the system reaction, Figure 7.

At incline I=1.5 % and v=60 km/h, the maximums occur in the range between 52Hz (5.4 m/s^2) and 105Hz (7.13 m/s^2), Figure 9. These periodic occurrences are probably caused by passing of the locomotive through R=300m where the impact occurs due to the action of the leading force or due to the obsoleteness there are some critical spots at approximately same intervals.

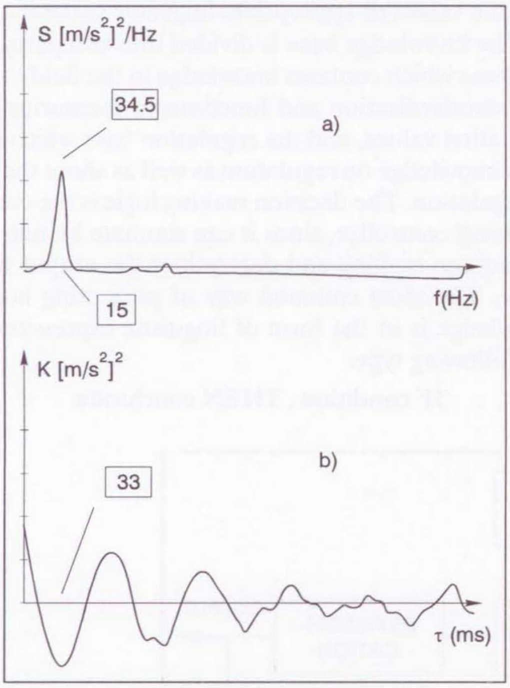

Figure 5 - Vertical acceleration of the non-suspended mass of the train speed
a) spectral acceleration density of the non-suspended mass
b) correlation acceleration function of the non-suspended mass

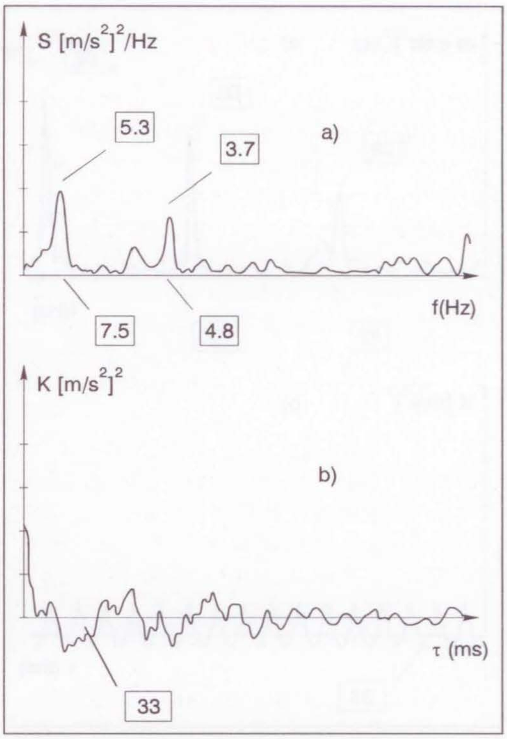

Figure 6 - Vertical acceleration of the suspended mass
a) spectral acceleration density of the non-suspended mass
b) correlation acceleration function of the non-suspended mass

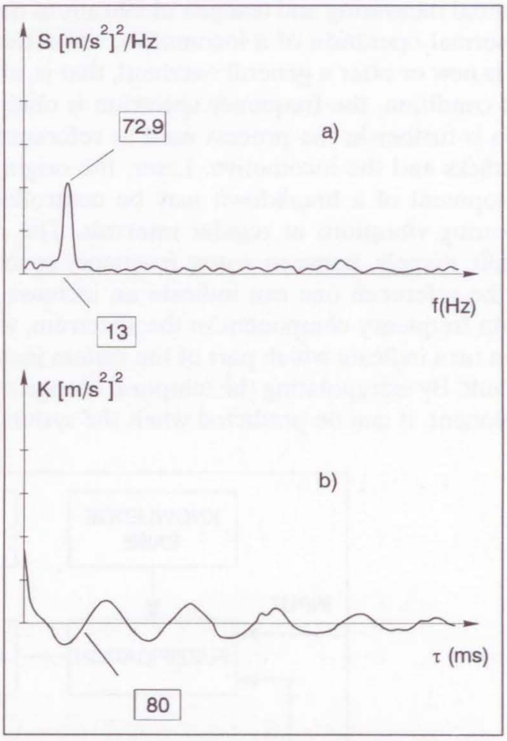

Figure 7 - Vertical acceleration of the suspended mass
a) spectral acceleration density of the non-suspended mass
b) correlation acceleration function of the non-suspended mass

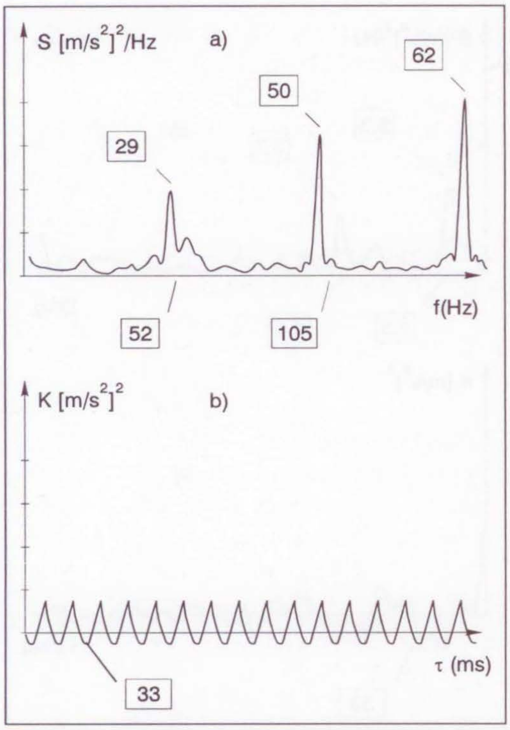

Figure 8 - Vertical acceleration of the suspended mass
a) spectral acceleration density of the suspended mass
b) correlation acceleration density of the suspended mass

Initial measuring and analysis of vibrations during the normal operation of a locomotive, when the engine is new or after a general overhaul, that is, still in good condition, the frequency spectrum is obtained, which is further in the process used as reference for the tracks and the locomotive. Later, the origin and development of a breakdown may be controlled by measuring vibrations at regular intervals. The comparison, namely, between a new frequency spectrum and the reference one can indicate an increase of a certain frequency component in the spectrum, which can in turn indicate which part of the system includes the fault. By extrapolating the temporal change of the component, it can be predicted when the system will have to be serviced - i.e. what possible damages are to be expected.

5. FUZZY REGULATION PRINCIPLE

Some control systems consist of a series of components which are set in such a way that they control a system by control actions, so that it has the desired characteristics and behaviour. There are two types of control systems depending on whether the control function does or does not depend on the system output. The necessary assumption for the control of a magnitude in a system is the possibility of measuring the magnitudes by a measuring system called a sensor.

The advantages of controlling a complex system such as controlling a railcar by means of fuzzy logic are given by the following features:

- short development time,
- robust regulation,
- improved behaviour of regulation,
- no mathematical model is necessary.

The fuzzy regulation principle can be explained by Figure 9, which shows the basic configuration [8].

The term fuzzification implies measuring of input values, scaling of input variables into related values in the interval [0,1], and converting numerical values into the values of appropriate linguistic variables.

The knowledge base is divided into two parts, the database which contains knowledge in the field of values, standardisation and functions of measuring and regulation values, and the regulation base which contains knowledge on regulation as well as about the aim of regulation. The decision making logic is the core of the fuzzy controller, since it can simulate human way of decision making and determines the output fuzzy value. The most common way of presenting human knowledge is in the form of linguistic expressions of the following type:

IF condition , THEN conclusion.

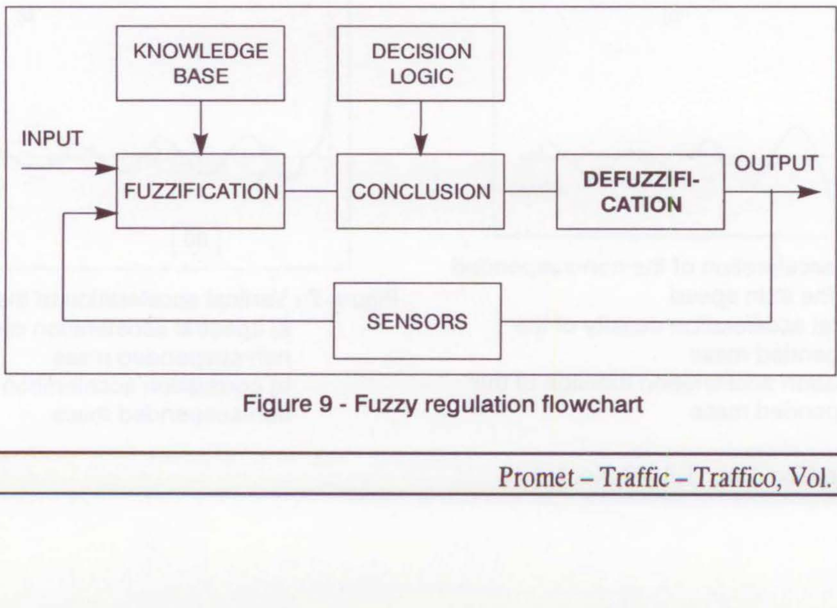

Figure 9 - Fuzzy regulation flowchart

The decision-making rules consist of the condition (IF-part) and the conclusion (THEN-part). IF-part can consist of several conditions linked together by linguistic variables AND and OR. This way of expressing knowledge is suitable because it expresses human empirical and heuristic knowledge in the proper way of linguistic communication. In deduction rules we use linguistic fuzzy variables. Notion of defuzzification is the reverse translation of fuzzy set values into non-fuzzy values of regulation magnitudes at the output.

In order to form an efficient control using fuzzy logic, it is necessary to follow these steps in developing the system itself:

1. Identification of all the variables,
2. Division of variables into fuzzy subsets, assigning to each of them a linguistic symbol,
3. Assigning to every subset a membership function,
4. Assigning fuzzy relations between input and output, forming the decision making logic,
5. Normalising variables in interval [0,1],
6. Fuzzification of input,
7. Making conclusion based on the decision-making rules,
8. Defuzzification, forming discrete output values.

5.1. Regulation of the train motion

In automatic regulation of the train composition motion, fuzzy logic is used to guide the train optimally in time at high riding comfort until the next stopping point, with maximally abiding by the driving regime, i.e. dependence of the planned riding speed on the travelled distance. From the aspect of safe and technological regulation of movement, it is necessary to consider the limit speed which is not to be exceeded, the points of easy driving and points at which the vehicle has to stop, e.g. due to the red signal.

The regulation of the railcar movement implies the regulation of the travelling speed and the target braking point. General requirements include reaching the speed within optimal period of time, and without exceeding the limits. In overspeeding, it is necessary to give an appropriate alarm signal, whereas below the necessary speed, the instruction is issued for the speed to be increased accurately and within optimal time. In train regulation, the requirement for speeding with the maximum allowed jerk is set, in order to provide maximum riding comfort. In braking up to a target point it is necessary to use the driving regime as much as possible and to achieve the minimum braking distance. The slowing down needs to be kept within the allowed range and increased with the maximum allowed jerk.

One of the most important factors in controlling a train as a mobile object is the knowledge about its precise current position. For this purpose, isolated tracks sections, magnetic contacts, axle counters or geographic positioning system (GPS) can be applied [7].

Regulation system flowchart using fuzzy logic is presented in Figure 10.

5.2. Input values

Suburban traffic by railcars includes many stops, i.e. the driving sections are relatively short. In order to achieve efficient traffic development and minimum energy consumption, as well as precision in timetable, it is necessary to abide by the planned travelling speed. Therefore, the driving regime is defined, i.e. the dependence of the planned riding speed on the travelled distance. The input variable, assigned the name of speed according to Figure 10, in the control system is taken as the difference between the planned and the actual speed of the railcar. The precision in braking and stopping depends significantly on the behaviour of the vehicle and the precision of the locating system.

Slippage also needs to be foreseen as an input variable in the control system, which depends on the condition of the contact surfaces (dry, wet, greasy, worn-out, etc.) and the loading of the driving shafts. Slippage is usually determined by comparing the rotating speed of single shafts. The linguistic term for this variable is slippage, as shown in Figure 10.

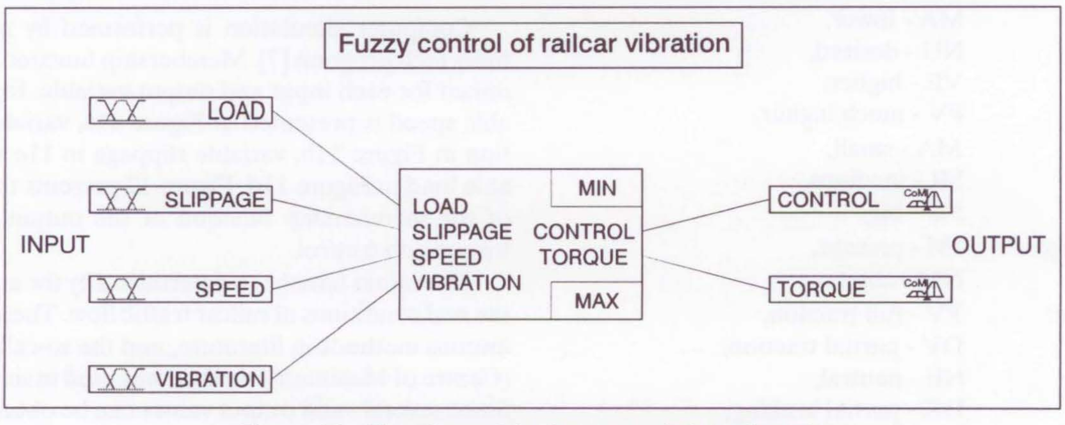

Figure 10 - Flowchart of the fuzzy regulation of a train

Since the total mass of the train can vary with the load, i.e. with the variable number of transported passengers, by as much as 30%, and since this affects the acceleration value and the needed torque of the traction motors, the load also has to be taken into consideration as an input variable. Measurements can be carried out by installing sensors into the vehicle suspension, i.e. by measuring the suspension deflection. The linguistic term for this variable is load.

Among the mentioned input data related to safety of railway transport, the simulation example takes only the data on vibrations as input.

5.3. Output values

Output value in the regulation of railcar control is the torque of the traction electric motor. Traction motors can operate both in the traction regime and in the braking regime. The regulation of traction and braking force can be realised in various ways, depending on the type of the applied traction motors, type of current which supplies them and the applied technical solutions of regulation. Braking by motors is achieved by its switching into the generator operating mode. The linguistic term for this is torque, as shown in Figure 10.

If during the ride certain deviations from the desired characteristics occur - unwanted condition, this data is recorded and therefore the output variable of control is defined.

5.4. Decision-making rules

The regulation strategy set in the decision-making logic is formulated by designing the fuzzy regulator of train control. This requires the knowledge of actual conditions of driving, i.e. behaviour of an average driver. One of the possible forms of decision-making for the mentioned input and output variables in controlling a railcar is given in Table 1.

Each of the variables is divided into fuzzy subsets with the following symbols:

- speed: PM - much lower,
  MA - lower,
  NU - desired,
  VE - higher,
  PV - much higher,
- load: MA - small,
  SR - medium,
  PU - big,
- slippage: IM - present,
  NM - absent,
- torque: PV - full traction,
  DV - partial traction,
  NE - neutral,
  DK - partial braking,
  PK - full braking.
- vibrations: NP - absent,
  PO - present
- control: ZA- record

Table 1 - Decision-making logic

IF				THEN		THEN	
Load	Slippage	Speed	Vibration	Dos	Control	Dos	Torque
MA	IM	PM	NP			1.00	DV
MA	NM	PM	NP			1.00	PV
SR	IM	PM	NP			1.00	DV
SR	NM	PM	NP			1.00	PV
PU	NM	PM	NP			1.00	PV
MA	IM	MA	NP			1.00	DV
MA	NM	MA	NP			1.00	PV
SR	IM	MA	NP			1.00	DV
SR	NM	MA	NP			1.00	PV
PU	NM	MA	NP			1.00	PV
MA	NM	NU	NP			1.00	NR
SR	NM	NU	NP			1.00	NR
PU	NM	NU	NP			1.00	NR
MA	NM	VE	NP			1.00	OK
SR	NM	VE	NP			1.00	OK
PU	NM	VE	NP			1.00	OK
MA	NM	PV	NP			1.00	OK
SR	NM	PV	NP			1.00	PK
PU	NM	PV	NP			1.00	PK
MA	IM	PM	PO	1.00	ZA	1.00	OK
MA	NM	PM	PO	1.00	ZA	1.00	OK
SR	IM	PM	PO	1.00	ZA	1.00	OK

5.5. Computer simulation

Computer simulation is performed by means of fuzzy tech program [7]. Membership function is determined for each input and output variable. Input variable speed is presented in Figure 11a, variable vibration in Figure 11b, variable slippage in 11c and variable load in Figure 11d. Figure 12 presents the values of the membership function of the output variable torque and control.

The values have been determined by the analysis of the real conditions of railcar traffic flow. There are numerous methods in literature, and the so-called CoM (Centre of Maximum) method was used in simulation. Since several valid output values can be obtained, the defuzzification method has to find a compromise be-

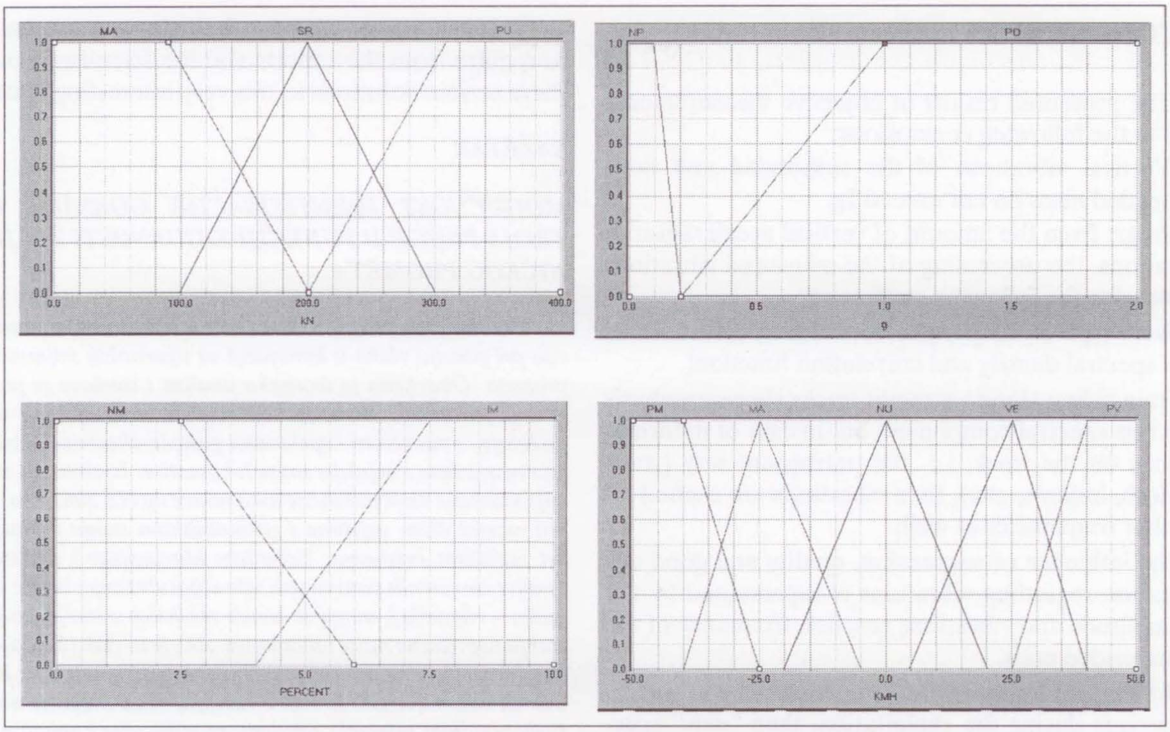

Figure 11 - Membership function of the input variables

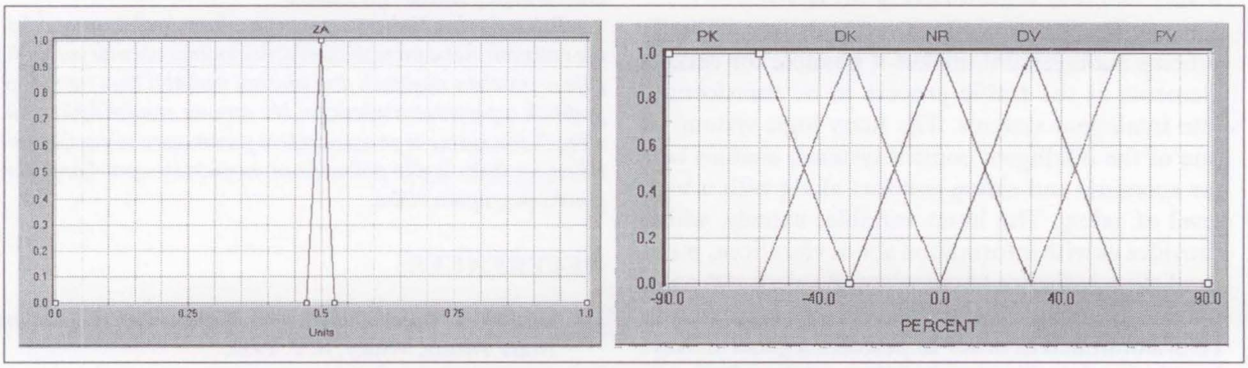

Figure 12 - Membership function of the output variable

tween different values. CoM method calculates the output non-fuzzy value based on the maximum obtained value according to the mentioned decision-making rules.

The computer simulation results are presented in Figures 13 and 14. Figure 13 shows the dependence of the torque on the input variables of speed and vibrations, and Figure 14 the dependence of the control variable on the speed and vibrations. The next step should be the controller itself and the comparison with the actual values on a certain driving regime. The obtained results of the previous simulation can serve as the theoretical basis in developing the model itself.

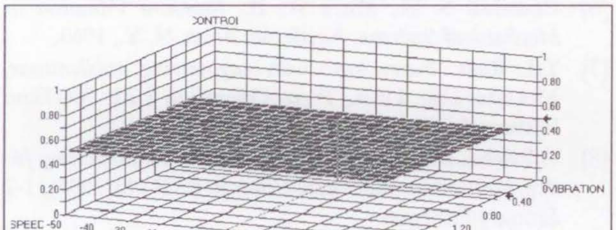

Figure 14 - Dependence of control on input parameters of speed and vibrations

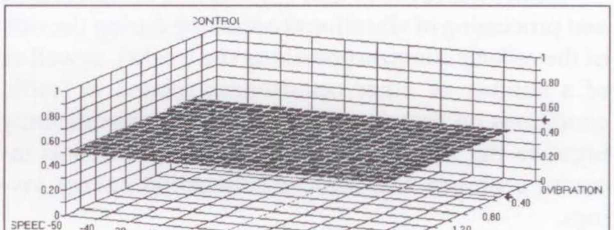

Figure 14 - Dependence of control on input parameters of speed and vibrations

6. CONCLUSION

The presented results of objective measurements lead to the following conclusions:

Vertical vibrations of the suspended and non-suspended mass do not exceed 2g.

Apart from the amount of vertical acceleration of vibrations, the processing of the measured vibrations allows also the following statements:

- Every type of sleeper provides characteristic forms of spectral density and correlation function;
- Train riding along a straight tracks shows emphasis in one spectral component, but in case of deformations on the track, i.e. the permanent way (track width, indents, etc.), then vibrations are excited on other frequencies as well.
- The influence of suspension, quality and good operation regarding vibrations is represented by the amplitude and vibrations reaction frequency of the suspended mass.
- If there are faults on the permanent way or undercarriage during the exploitation, then "new" spectral components occur that had not been present before and they indicate the faulty spots.
- The application of modern methods in automatic process management, makes it possible for certain elements of the traffic process to be transformed into intelligent systems. The fuzzy logic system, as one of the intelligent control systems, enables better economy and riding comfort along with a high level of safety. The input variable, namely, which provides us with information about vibrations, is the prediction indicator about when the worn out parts need to be replaced, and when the operation has to be discontinued in order to perform a general overhaul both of the fixed and of the mobile railway capacities.

Finally, the practical use of processing vertical accelerations has been presented, but the research still needs to be done in order to provide better quality conclusions on the condition of certain vital parts of the permanent way or undercarriage, whether at all or to what extent the "disturbances" and "breakdowns" can be tolerated.

It can be concluded that appropriate measurement and processing of vibrations (occurring during the ride of the railway composition along the tracks), as well as of a number of other occurrences related to traffic conditions on certain railway tracks, can significantly improve the safety and riding comfort, as well as increase economy and achieve substantial energy savings.

This is a serious task for the railway management to require from the experts and the scientists around them serious solutions to this very interesting issue.

SAŽETAK

MOGUĆNOST IDENTIFIKACIJE GORNJEG USTROJA PRUGE U FUNKCIJI SIGURNOSTI ŽELJEZNIČKOG PROMETA

U ovom radu pokazati ćemo neke uzroke nastajanja vibracija pri gibanju vlaka u konotaciji sa sigurnošću željezničkog prometa. Obavljena je teoretska analiza i izvršeno je procesiranje parametre vibracije koje nastaju u kontaktnoj točci podvozja, s tračnicom - spektralna gustoća akceleracija vibracija neovješene i ovješene mase lokomotive. Izvršena su mjerenja vibracija dizel električne lokomotive tip HŽ 2061 u različitim morfološkim uvjetima i geometrijskom stanju kolosijeka pri različitim brzinama. Temeljem korelacijske i spektralne analize izmjerenih parametara vibracija (ubrzanja, brzine i pomaka - vibracija), mogu se izvući zaključci o stanju pruge, i stanju neovješene mase lokomotive. Ako je to vlak i kolosijek u eksploataciji možemo predvidjeti vijek trajanja, odnosno kada obaviti remont, a ako se radi o razvoju, onda možemo na osnovu rezultata mjerenja usmjeriti modifikacije i poboljšanja. Treba istaknuti da je određivanje prirode vibracija u funkciji određivanja pouzdanosti sustava.

Pokazana je učinkovitost primjene fuzzy logike za upravljanje vožnjom vlaka pri različitim djelovanjima ulaznih varijabli, gdje je poseban naglasak dan ulaznoj varijabli koja nam daje podatak o parametru vibracija. Na osnovu analize djelovanja vibracijana sustav te procesiranjem parametara vibracija i korištenjem fuzzy logike pokazuje se mogućnost upravljanja pogonskom grupom vlaka.

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