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THE NEW EQUIPEMENT FOR DYNAMICAL MEASUREMENT OF THE KINEMATICS OF RAILROAD VEHICLES

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***Abstract*:** *The paper presents a concept of electronic system for railroad vehicle dynamical measurement of kinematic parameters. The original measurement system is based on the encoders and computer data-processing equipement. Experimental results of angular and roud velocity, acceleration, and braking distances measurements, performed on one real vehicle are presented. The results of working pressure in the braking installation are also presented. The concept of linear and new type of pseudo-random encoders application is explained.*

1.0 INTRODUCTION

Efficiency and functionality of railroad vehicles braking systems is assigned by international standards. Parameters of braking system are checked experimentally in new vehicles development and their prototype examination, both for performed constructive solutions and for admission of vehicles into traffic. Braking distance is a parameter which integrates technical characteristics of a braking system and vehicle development success. On the other side, braking system is generated by kinematical and dynamical behavior of vehicles. Therefore, stop distance measuring is an important parameter for evaluation of vehicle dynamic behavior. The complexity of stop distance establishing is obvious with movable assets, because the exact kinematical result indicators are necessary during measurement. Stop distance measuring can be performed in a very reliable electronic way, and it is reduced to the speed cycle measurement, i.e. angular velocity of wheels and its integration. With computer appliance, measuring sizes are electronically processed and graphically displayed. The concept of measuring pulse incremental encoder in a given time interval is used for digital measuring of angular velocity. This paper shows economical solution which satisfies practical needs of measuring angular velocity and stop distance calculation upon vehicle braking.

2.0 THE METHOD OF MEASURING AND CONSTRUCTION OF DEVICES

Starting from necessity of accuracy in measuring speed and position, the optical impulse indicator – encoder has been chosen as a signal indicator. The obtained digital signal can be implemented into digital computer section. The complexity of the approach and the presence of qualitative measuring computers [3] have implied more frequent application of converters for translation of digital into analogue signal. Although indirect, this method simplifies operation and access into measuring computers. In converters, digital signal of variable frequency is translated into signal of angular rotor frequency, and then into analogue signal of limited level. The level of the output analogue signal depends on A/D converter of a measuring computer. Such an idea is illustrated in fig. 1.

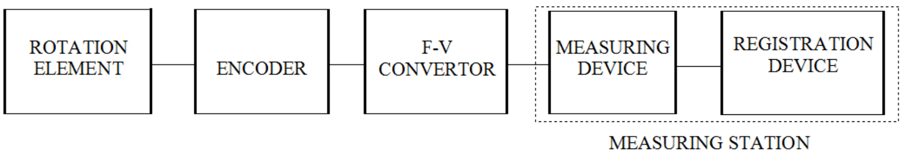

Fig. 1 Ideal concept of equipment schedule at speed measuring

Practical realization of the idea has been performed by using tipical Z-1000 encoder with optical circle division into 1000 parts. The converter, shown in fig. 2, has been developed for signal encoder processing.

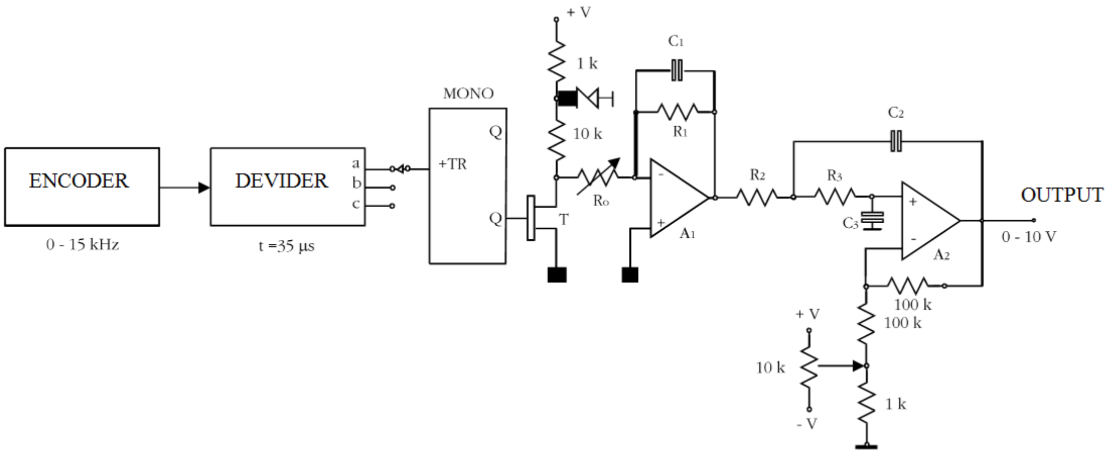

Fig. 2. The electric circuit scheme of F-V converter

F-V converter enables obtaining analogue output stress in proportion to the frequency of the input signal. Although there are finished integrated circuits nowadays for this appliance, the circuit with discrete components has been used in this work for modeling desired characteristics, in accordance to concrete needs of a measuring system. The encoder connected to the vehicle wheel is a generator of impulse variable frequency functioning as angular velocity. Mono-stable circuit is triggered by these impulses and generates precise impulses of constant amplitude and width (about 35 μs for f=0-15 kHz). For obtaining proportional DC, the integrator, i.e. low-frequency filter, has been used (Batterworth-ov filter of the third order). The output stress varies on the scale 0-10 V, and it can be adjusted by Ro resistant when needed, or by impulse width change if frequency extent allows it. Linearity of the converter is 0.1%.

Professional converters are additionally equipped with electric circuits for direction of rotation identification, considering possibility of the encoder and signals that it generates. By choosing quotient of divisor (switch a), the operation in the area of lower or higher speed is enabled, depending on customer needs. For each chosen quotient of converter, operation characteristic of F-V-ω is determined, where F is the encoder frequency, V is the one-way electricity stress in the output, and ω is the angular velocity of the encoder rotor. Determination of operation characteristics has been performed in a laboratory by electronic way. It is realized by signal generating of the chosen frequency and by measuring output analogue voltage from the circuit electronically. Suggested procedure of braking distance calculation – by measuring angle, is simple and it is based on integration of generated encoder impulses upon braking.

3.0 APPLICATION

Such constructed a device has been tested in various examinations: measuring speed of executive members of mechanisms, speed of tool machines, speed of drive electric motors in cranes, etc. In the area of dynamic behavior of railroad vehicles, measuring of braking distance of drezina has been realized [6].

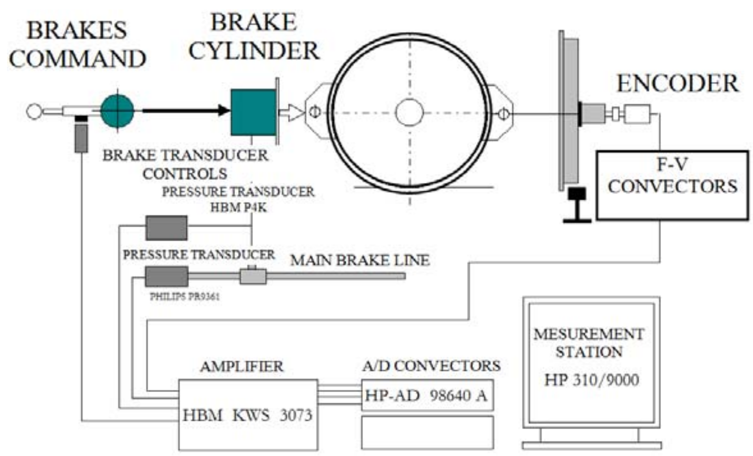

Fig. 3. Measuring equipment schedule for stop distance measuring

Measuring has been realized on drezina DHD 200 of 915-008 series. Braking command signals have been measured on a braking system, as well as pressures in a brake cylinder and the main braking line. Measuring of wheel angular velocity has been performed by direct setting of encoders and connecting a wheel branch. The schedule of measuring equipment is shown in fig. 3. Air pressure in a braking system has been measured by inductive pressure transducers. The activity of a brake is determined by inductive signal transducer (E command – on/off). Speed has been measured by FV converter. Obtained measuring signal is implemented into A/D converter of a measuring computer HP 310/9000, on which measuring results are registered in a best possible way. Formed measuring chain [4,6], illustrated in fig. 3, enables further data processing. The review of experimentally obtained characteristics of dynamic behavior of vehicles and the braking system is shown in fig. 4. Curve B is the angular velocity of a measuring wheel, E is a time curve of a brake activation, C is a curve of pressure in braking cylinder, and D is a curve of pressure in the main line of braking installation. In fig. 5, the axle and wheel bearing (for conection with encoder) are shown.

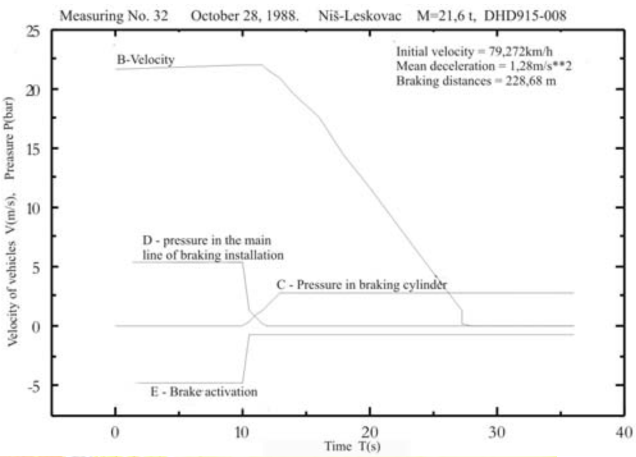

Fig. 4. Measuring no. 32 [6] Braking distance and pressures in braking installation
Fig. 5 Axle bearing on which the encoder is installed.

Recognition of effective braking impact has a basic significance for theoretic studies of dynamic vehicle behavior in non-stationary movement regimes. By introducing experimental characteristics, dynamic systems and their mathematical models can be reliably modeled, without introducing assumptions about starting conditions and lust characteristics. From measured characteristics (Fig. 4), it is possible to determine mechanic power of brakes in the function of speed and pressure in braking cylinder. Fig. 4 shows the process from braking to stopping the vehicle.

Braking distance of vehicles during braking is obtained by numeric integration of speed, by applying trapezoidal rule, and by equations (3.1). Then, the increment of time recording speed is Δt=0.01 (0.04) seconds, and T is the total process time from braking to stopping. Discrete speed values, V(I) (I=1-N), are determined in accordance to calculated number of cycles n(I) , which have the function of output stress from F-V converter into $\mathbf{u}_{(I)}$. So, constants of integration make wheel diameter D and conversion constant F-V of converter k. For easy usage, converter has to have linear characteristics k, which are developed and set for speeds up to 2500 o/min.

$$S=\int_0^T V_{SR}\,dt=\sum_{I=1}^{N}\left[\frac{V_{(I)}+V_{(I+1)}}{2}\cdot\Delta t\right]=\frac{D\cdot\pi}{60}\cdot\sum_{I=1}^{N}\left[\frac{n_{(I)}+n_{(I+1)}}{2}\cdot\Delta t\right]=\frac{D\cdot\pi}{60}\cdot k\cdot\sum_{I=1}^{N}\left[\frac{u_{(I)}+u_{(I+1)}}{2}\cdot\Delta t\right]$$

(3.1)

The mistake, made upon measuring, is the sum of mistakes that are made due to wheel slip during braking, and due to dynamically variable diameter of wheel in contact with rail. Slipping can be reduced by selection of examination regime. The mistake, as a consequence of dynamically variable diameter, can be statistically determined from diameters on the limits of change.

4.0 TECHNICAL SOLUTION OF PSEUDO-RANDOM ENCODER

Base solution of angular displacement detection, using disc with n concentric code tapes, gives n – the important code word for each discrete angular position. For this purpose, n detectors arranged in transversal direction have been used. Therefore, code tapes reading is performed by series of censors, where each censor is used for reading of a single code tape, providing an output signal which indicates one bit. Then we get n at the end of the censor line – significant output code of the moving system current position.

Main functional components of pseudo-random absolute encoder are systems for code reading [7], where various solutions have been developed, with two or more head-readers, synchronization method of code reading in terms of reliable moment defining for code reading, method of conversion of pseudo-random into natural code, method of error detection in code reading [10]. The example of virtual absolute encoder code disk is illustrated in fig. 6. Rotary code disc consists of two code tapes that are made of translucent and opaque segments.

Internal tape is identical to the tape of incremental encoder and can be used to generate two additional bits in output code. Its main role is to secure synchronization of code reading, and it is often called synchronization tape. This unique example has been chosen to show that space-time width of one incremental cycle equals spatial width of one bit of pseudo-random code tape. However, that relation can be changed. The applied pseudo-random code provides a unique code word, 4 bits length, for each new position of the encoder.

The signal from synchronization code is obtained by using two detectors, AUT and VER, the same as in conventional incremental encoder. Each generated impulse coincides with the moment when synchronization AUT head detects transition between two neighbor sectors. The signals, obtained from these two detectors, help to determine direction of disc encoder rotation. This example shows that pseudo-random coding presents a new way of bit reading in absolute encoders by only one detector application [7,8]. Beside such an advantage, there is one disadvantage, and that is necessity of initial moving after power turning on/off, in order to determine the absolute position.

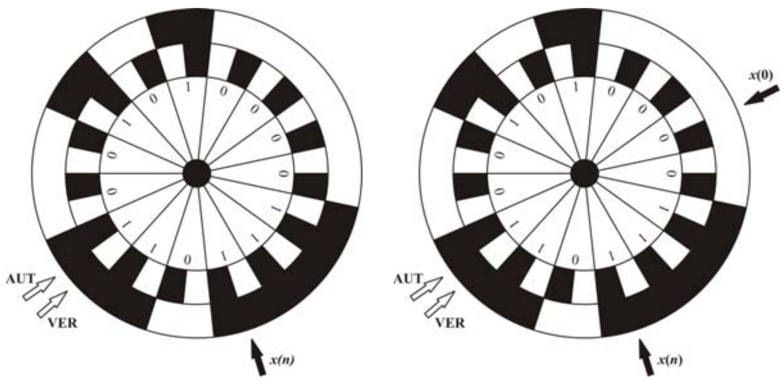

Fig. 6. The example of a virtual absolute encoder code disc
Fig. 7. Serial reading of pseudo-random code with two code head-readers

Serial bit reading of pseudo-random code from code tape is performed by detectors x(n).

However, this method of pseudo-random code reading implicates a problem of losing information about position during change of disc encoder rotation direction, because initial moving is necessary again in order to obtain valid position information. This disadvantage is removed by using additional operations after each direction change which can significantly complicate the system. The additional operations can be done with additional counter and logic circuits, so that the content of shift register always corresponds to the current position [8]. The problem of losing information about position after each direction change in reading method with one head-reader can be simplified by introducing another head-reader at a distance nq, where q is the step of code tape quantization [7,8]. With simple logic that consists of one I and one ILI circuit (multiplexer 2x1), one out of two head-readers is selected for code reading, fig. 7.

Code tape bits, read by head-reader x(n), will be accepted during movable system motion on the left, and bits read by censor head-reader during movable system motion on the right x(0). In this way, code words that are formed after direction change now correspond to the current positions of movable system. Continuity of code words forming upon eventual oscillation of movable system is increased now. Suggested schedule for code head-reader significantly reduces needs for a correction element in the form of parallel totalizer, because systematic errors are eliminated during code reading. While one head-reader forms pseudo-random code word, the other can be used to form control code word.

A new solution of pseudo-random encoder improved technical value of speed measuring [4,7]. Characteristics: High resolution measuring device (12 bits). It has three code tapes: external incremental tape for reading synchronization of pseudo-random code and two internal pseudo-random tapes mutually displaced for (n-1) bits. Resolution increase does not require increasing the number of code tapes. Introducing two pseudo-random code tapes does not require any modifications of detector distance during resolution measurement change. Pseudo-random solution of code disc in the encoder enables continuity of code words forming during multiplex direction changes by using very simple electronic bloc of encoders. New type of absolute encoders emerged as the result of tendency to reduce large number of code tapes and censors of high resolution measurement in absolute encoders. Disc dimensions and circle diameters that limit code tapes are adjusted to the optic part of the encoder, i.e. to the position and dimensions of source and detectors of light. For encoder to be 12 bits resolution, incremental tape must contain 2048 (2n+1 bits) fields whose width is twice smaller than the width of a bit from pseudo-random tapes (fig.8.a).

So, as the resolution of pseudo-random tapes is 10 bits, each tape contains 1024 fields (bits, i.e. the sequence of “zeros” and “ones”), and they are mutually displaced for n-1=9 bits. Two additional bits in total 12 bits resolution come from incremental tape. Material that can be used for disc creation is glass, but it is not recommended in case of strong impact shocks. Even though they have small masses, Mylar and metal code discs withstand impact shocks without any deformation.

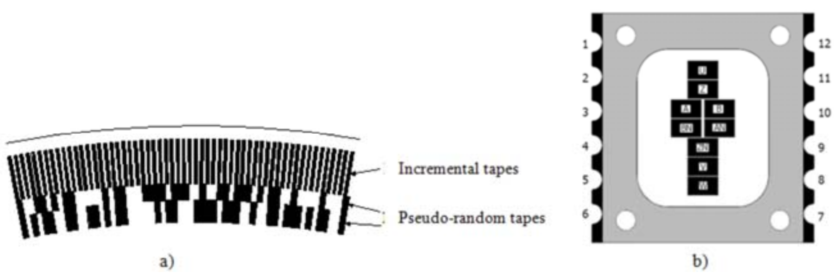

Fig. 8. Enlarged detail of a code disc (a), -PMD09 optical sensor for encoder (b)

Optical glass BK7 is used in the visible part of the spectrum. It has high linear optical permeability in visible spectrum up to 350 nm. If the censor in fig. 8b was used for code reading, then photo-diodes A, B, AN and BN would read incremental tape, and photo-diodes ZN and W two pseudo-random code tapes.

5.0 CONCLUSION

The presented experience in creation and exploitation shows that it is possible to form a device for current angular velocity measuring with scarce resources. The basic concept or electric circuit can be further improved by unit processing for direction recognition of a shaft rotation. Accuracy can be increased whether by choosing encoder of higher resolution or electronic circuit converter adaptation. In doing so, attention should be paid to the speed of response to excitation and operating frequency circuits.

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НОВА ТЕХНИКА ЗА ДИНАМИЧНО ИЗМЕРВАНЕ НА КИНЕМАТИЧНИТЕ ПАРАМЕТРИ НА РЕЛСОВИ ПРЕВОЗНИ СРЕДСТВА

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РЕПУБЛИКА СЪРБИЯ

Ключови думи: *Релсово превозно средство, измерване на скоростта, спирачен път, оптично кодиращо устройство, псевдослучаен*

Резюме: *Статията представя концепция за изграждане на електронна система за динамично измерване на кинематичните параметри на релсови превозни средства. Новата система за измерване е базирана на кодиращи устройства и оборудване за компютърно обработване на данните. Представени са експерименталните резултати за ъглова скорост, ускорение и измервания на спирачния път от изследвания, извършени върху реално превозно средство. Също така са представени резултатите за работното налягане в спирачната уредба. Обяснена е концепцията за приложението на линейни и нов тип псевдослучайни кодиращи устройства.*