”Research Bulletin the Jan Wyżykowski University. Studies in Technical Sciences”
2018 (7), s. 35–46. ISSN 2543-6740.

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Measurement complex for studying dynamics of high-speed vehicles

Abstract: Equipment set for studying dynamics characteristics of vehicles as automatic control objects is presented. Dynamics characteristics of various mobile objects were studied at test site. Experimental procedure, electronic data processing using a method of adjustable equivalent model is provided. Research data and received mathematical models are provided.

Keywords: a set of measurement, vehicle, dynamics, automatic control.

Zestaw pomiarów do badania dynamiki szybkich pojazdów

Streszczenie: Przedstawiono sprzęt przeznaczony do badania dynamicznych cech pojazdów jako obiektów kontrolowanych automatycznie.

Słowa kluczowe: zestaw pomiarów,dynamika pojazdu, kontrola automatyczna

1 Introduction

The subject-matter of experimental studies of motion dynamics is measuring and observing the object’s reaction or response to a specified input perturbance with reference to a command variable, for example the turning angle of controlled castor wheels, on condition of the moving object’s initial unperturbed state, which corresponds to the rectilinear movement with constant (fixed) speed. Rectilinear movement corresponds to defining a rectilinear reference path, and the object’s reaction – to temporal variation of the linear and angular deviation of the object casing point from the reference path, and speed and acceleration of these changes resulting from the change of rolling plane angle of the controlled wheels. The fact of rectilinear movement is established by the zero value of controlled wheels turning angle (or that of a steering wheel, if the play is absent) and the zero value of the linear lateral deviation of an arbitrary point on the object casing centerline from some unmeasured value, which has been accepted as a zero point, as well as the zero value of the angular deviation of the object casing centerline. Accordingly, all derivatives of these variables also have zero values. Moreover, zero values of angular deviation are indicative of the absence of equidistant movement (parallel to the specified direction). A rectilinear reference path may be set up by an artificially created benchmark, for example by a variable magnetic field, from a long conductor with current

2. Overview

The following is required for it: a guidance cable, an alternating current generator and inductive measuring devices for lateral linear and angular deviation. Such organization of a real experiment is not suitable for high-speed vehicles, however it is acceptable for low-speed ones, such as the factory vehicle robots, and enables to obtain all the source data. Reference path for high-speed vehicles may be set up by using natural fixed benchmarks, for example a fixed coordinate system connected with the Earth's magnetic field, and reconciling the reference direction of movement with the direction of these coordinate axes. To identify the object's deviation from the specified direction one uses a gyroscopic method of measuring angular values, which boasts high precision and wide measuring range. Together with it, there is no more necessity of laying a guidance cable and everything connected with it, but it is impossible to measure lateral linear deviations by a direct method. Lacking information may be obtained by subsequent computer processing of experimental data using, for example, a LabVIEW software package. Modelling by LabVIEW software reminds modelling by an analog computer, but in digital form [L1].

An analog computer uses physical blocks, i.e. operational amplifiers; other operational blocks, such as invertors, adders, integrators, differentiators, squarers, comparators etc., and functional converters for non-linear functions, are built on their basis. All this means that physical blocks are used for studying process dynamics. A digital machine – a computer – in the LabVIEW medium uses the same elements, but represented digitally and depicted by various geometrical figures. LabVIEW contains an expanded library of mathematical models of various technical means intended for mathematical modelling of complicated technical systems. The work in LabVIEW consists in finding the required elements in the library, dragging them with a mouse on a computer screen and joining them with a line (equivalent of a wire) and attaching a geometrical figure of an oscillograph at the exit. Such way of graphic modelling allows to obtain information about the lateral deviations of vehicles. This value is the key one for the subsequent development of automatic control system for such objects.

3. Experimentation

Such organization of a real experiment and the subsequent data processing is reasonable for high-speed and large vehicles of medium and heavy classes. Up to the moment of test signal sending, the test conductor shall provide the driving with reference to the zero value of course setter position of a navigational gyroscope. Correction of the rest non-zero initial deviations at the moment of input signal sending during the test drive is performed by automatic zero setting schemes of measurement channels for the registered values [L2].

4. Instrumentation

Functional logical diagram of dynamic characteristic recorders we have developed for the auto test track is presented in Fig. 1

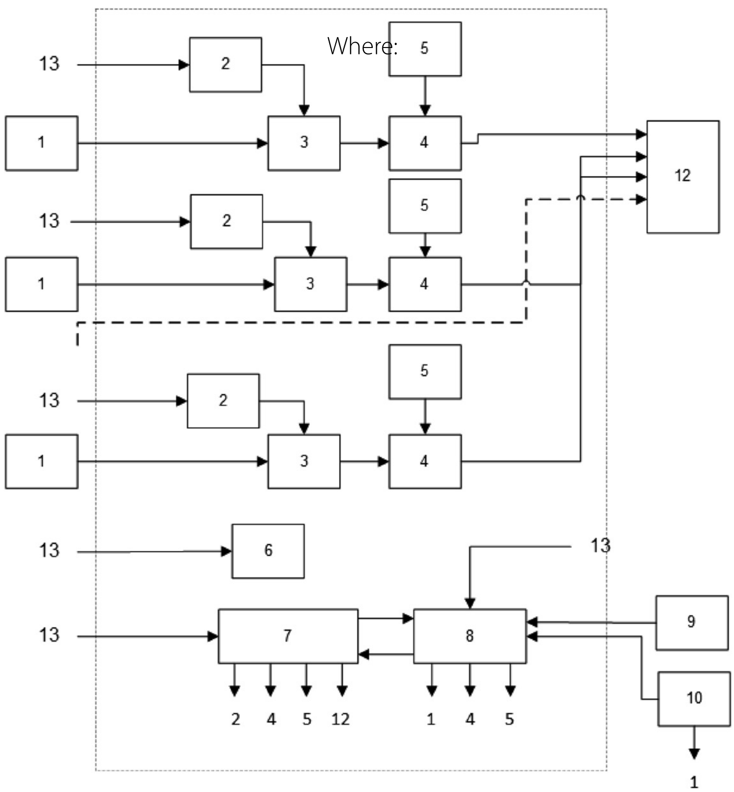

Fig 1

Where:

(1) – sensor, (2) – record range switch, (3) – measuring bridge, (4) – measuring channel with automatic zero setting, (5) – indicator unit of exceeded record level, (6) – measuring channel integrity checking circuit, (7) – relay control unit, (8) – power supply unit, (9) – battery, (10) – converter, (11) – electronic control unit, (12) – oscillograph, (13) – test conducting operator.

Its main component is the electronic control unit (ECU) which fulfills the following functions:

a) to commutate measuring sensors (1) with recording equipment, oscillograph (12), and internal power source – accumulator battery (9) and converter (10) through the relay control module (7) and power supply unit (8) which contains stabilized DC power sources of + 10 V, – 10 V, +5 V, +2 V, +200 V, + – 27 V, -13 V and a three-phase voltage source of 36 V, 400 Hz;
b) to filter useful signals with the help of iterative active low frequency RC-filters with flat characteristics;
c) to perform automatic zero setting of random initial levels of registered values immediately before sending a disturbing test signal;
d) to set the required ranges of recording the measured values with the help of the test conducting operator and range switches (RS), or automatically during the test drive, and to control exceedance of the allowed record level with the help of the exceedance indication unit (EIU) and light indication;
e) to check the integrity of the complex by means of polling measurement channels by the integrity checking circuit (ICS) and integrity light indication;

f) to balance measurement channels with automatic zero setting; g) to stabilize and control the voltage of power supply units; h) to switch between the Polling-Setting and

Adjustment-Measurement working modes, to clear the information about the previous drive on the signal panel, to launch electric clock and speedy gyro-unit recovery for measuring banking angle, and to fulfil other auxiliary functions. Specialized complexes for experimental dynamic studies of controlled vehicle motion are presented in Fig. 2,

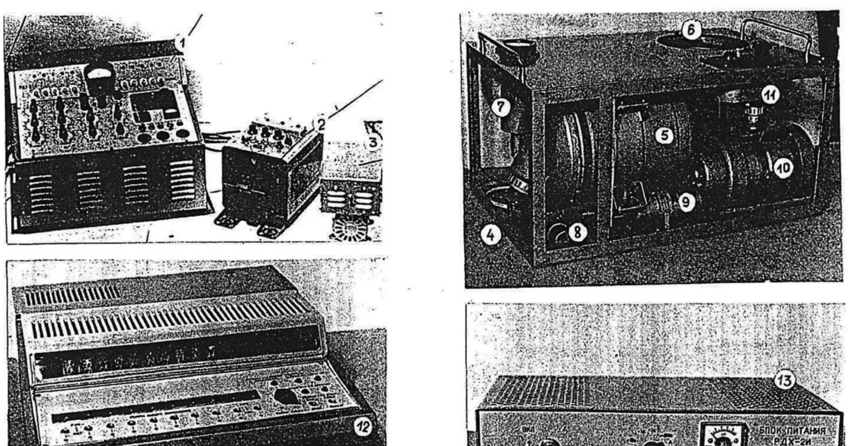

Fig 2

where: (1) – dynamic characteristics recorder RDH OTI-1, (2) – multi-beam oscillograph K12-21, (3) – voltage converter PT-200Ts, (4) – sensor unit, (5) – casing banking angle sensor of the central gyroscopic vertical (CGV)-2, (6) – sensor of the centerline angular deviation from the specified direction of movement of the gyro direction indicator (GDI), (7) – rolling angular velocity sensor AVS, (8) – lateral linear acceleration sensor MP-95, (9) – course angular velocity sensor AVS, (10) – speedy recovery device of the central gyroscopic vertical (CGV), (11) – movement direction (course) setter, (12) – integral dynamic characteristics recorder RDH-2I with the automatic choice of ranges of measured values recording, (13) – power supply unit RDH-2I.

The main reason of error, which decreases the quality of data obtained, are random fluctuations of zero initial levels of measured variables in the rectilinear movement mode, and non-linearity of frequency characteristics of the filters used. These drawbacks were typical of all known hardware solutions for the experimental study of moving wheeled vehicle properties. These drawbacks were eliminated at the developed RDH OTI-1 and RDH-2I complexes by introducing measurement channels with automatic zero-setting and high quality of filtering useful signals. Non-zero initial fluctuation of a useful signal or an initial off-balance signal in the Adjustment mode is compensated and at the same time memorized by a condenser with long self-charge time. In the Measurement mode, initial off-balance signal stored by the memorizing condenser is subtracted from the current useful signal coming to the measurement channel input. Therefore, when the vehicle studied is moving, a test conductor controls the complex by just two buttons –

Adjustment and Measurement, which is very important, and creates the input action by sharply turning the steering wheel at a set angle. Test signal delivery time varies from 0.4 s (unprepared test conducting driver) to 0.1 s (trained test conducting driver). To register dynamic characteristics of the object under study, before sending the input test signal the test conducting driver shall achieve rectilinear motion with constant speed (controlled at the speedometer). The quality of rectilinear driving fully depends of the skills of the test conducting driver.

Of course, there are no absolute zeros of the values which characterize ideal reproduction of rectilinear movement, especially in case of multiple reiteration of experiments. As all parallel reference paths characterize rectilinear movement (we are dealing with the variety of initial unperturbed state forms) compensation of human driving mistakes in the Adjustment mode is similar to the procedure of parallel transferring coordinate axes in the plane and forming measurement zero points, i.e. base levels taken for zero ones. The registered values having been set automatically, the test conducting driver manipulates the Measurement button, EL panel advancing mechanism of the oscillograph switches on simultaneously, the obtained zero levels are registered within a short period of 0.10...0.15 s, and after that the incoming test signal is created by sharply turning the steering wheel. It is possible to switch on the Measurement mode only after the automatic input signal compensation in the Adjustment mode has taken place.

5. Characteristics of sensors of the complex and peculiarities of their positioning at the studied object

Angular deviations from the reference movement direction Θ is measured by a gyroscopic sensor constructed on the basis of a vibration-resistant gyro direction indicator (GDI). The GDI is placed on the vehicle platform in such a way that the cognominal axes of the device coincide with the cognominal axes of the gyroscope rotor. When the object is turning around its vertical axis, which goes through the transport vehicle center of mass, as a result of turning the controlled wheels, the horizontal gyroscope rotor axis tends to retain its azimuth direction. The gyro-unit casing, tightly connected with the studied object turns around the gyroscope axis at the angle proportional to the angular deviation of a moving vehicle longitudinal axis from the specified reference zero course (direction). In order to measure transient functions with respect to Θ (t) of speedy vehicles, the gyro-unit requires minor circuit changes to obtain alternating signal and commute it to the ECU. The wiper platform of the directional gyroscope has an electric drive. Coarse zero adjustment of the GDI is performed by the test conductor at the not moving vehicle (before the test drive). Fine zero adjustment at the moving vehicle is performed automatically by the zero setting unit through a given measurement channel. As the GDI rotor possesses a substantial kinetic energy reserve, a free gyroscope used as an angle measuring device renders almost no dynamic error. Precision of work is mostly defined by the gyroscope rotor precession. For this reason, the GDI is equipped with the precession corrector. To exclude the error caused by the rotation of Earth at the moment of sending the input test signal, the precession corrector is temporarily switched off. Angular deviation Θ sensor is fixed to the supporting frame on special shock absorbers and is not sensitive towards high frequency fluctuations caused by motor working and concrete road irregularities at the test field. Angular deviations of the spring casing (body) from the vertical plane, or banking Θ, is measured by the central gyroscopic vertical (CGV) which has the form of a two-gyroscope system with force stabilization vertically corrected by a liquid pendulum unit. The CGV provides for the system of quick platform vertical positioning, or a caging device.

The CGV is usually used in aviation automatic pilots. Speedy recovery system is launched automatically upon switching on the complex, the recovery period making 30...120 s. Error of the device after bankings and U-turns not exceeding 10 min, with the angular velocity more than 0.3 grad/s does not exceed 2%.

Movement speed V is measured by an impulse speed sensor. For each turn of a wheel, the sensor emits two impulses which are registered by the oscillograph as rectangular impulses. The number of impulses in real time is proportional to the number of wheel turns. The time T is measured by aviation electric-contact clock which functions synchronically with the oscillograph. The clock is launched automatically at the moment of measurement start and registration of the process under study. In order to enhance precision of oscillogram processing, the time registry range of ΔT = 0.1 s has been chosen. Controlled wheels rotation angle φук is measured by a rotary pulse potentiometric feedback sensor (FS). The sensor shaft is connected with the pitman arm of the steering wheel column by a parallel crank mechanism of telescopic pipes with adjustable length. The main reference point of the sensor is adjusted during its calibration at a non-moving object, and the main reference line is adjusted at a moving object automatically by the zero setting unit. The steering wheel rotation angle is measured by a rotary pulse potentiometric sensor SPO. Change rate of the object angular deviation Θ1 from the specified reference direction and the change rate of banking angle Θ1 are measured by gyroscopic angular velocity sensors constructed on the basis of AVS. When the object turns with respect to its instantaneous center of rotation, the gyroscope turns with respect to its measurement axis. The gyroscope rotor turns around the axis perpendicular to the measurement one until the precessional moment is balanced by the moment created by the gyroscope opposing springs. As the precessional moment is proportional to the angular velocity of gyroscope rotation around the measurement axis and the opposing springs possess a linear characteristic, the rotation angle of the gyroscope rotor around the axis is proportional to the angular velocity of gyroscope rotation around the measurement axis. Transformation of gyroscope turning angular velocity into the angular deviation velocity of the studied object is performed by an induction potentiometer the rotor of which is fixed on the gyroscope precession axis. Lateral and longitudinal linear acceleration Y11 and X11 of a moving object are measured by potentiometric overload sensors MP. The overload sensors are mounted on the platform of the object in such a way that the direction of measured overloads coincides with the axes of sensory elements.

6. Result

Fig. 3 shows some results of studying vehicle dynamics following the results of experimental drives using RDH-2I complexes. Dynamic characteristics of studied heavy class objects and their influence on the step disturbance φук = 40 at different movement speed from 2.78 to 19.46 m/s: Θ) experimental reactions of ZIL-130 with respect to angle Θ; b) experimental reactions of MAZ -500 with respect to angleΘ; c) reaction of MAZ-500 with respect to linear deviation Y, obtained on the computer by method of adjustable digital model (– – – without load, ---- with nominal load). Experimental data were processed in the computer by the method of adjustable model when input effect U(t) was simultaneously exerted on the input of the studied object (experimental dynamic characteristics) and on the adjusted model. Then both reactions (that of the object and that of the model) were compared, uncoincidence error was calculated according to the criterion chosen, and new parameters of the adjusted model were calculated on this basis. Based on the vehicle kinematic diagram its equivalent and adjustable mathematical model can be found in the following ways:

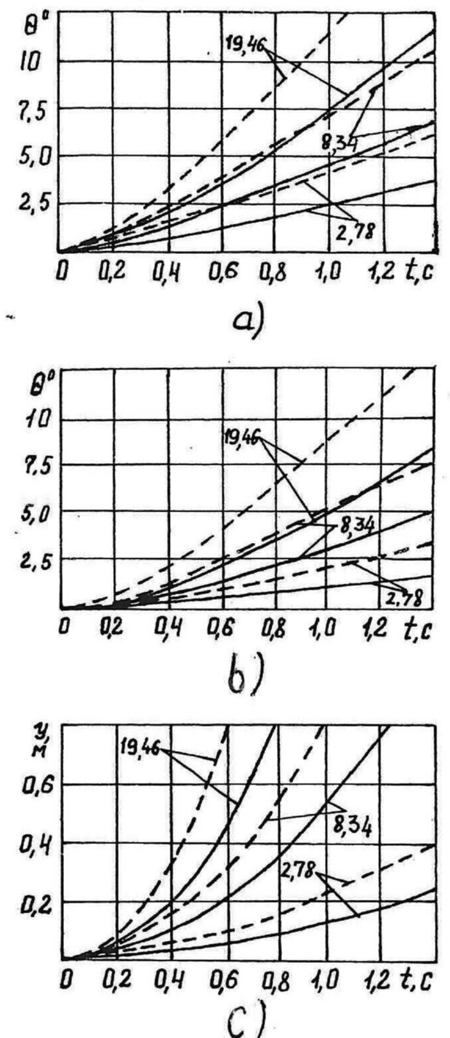

Fig 3

According to the course deviation θ:

$W\theta^* = K\theta\,(T_1\,p+1)(T_2\,p+1)/\,p\,(T_1\,p+1)(T_2\,p+1)$;

According to the linear deviation Y:

$Wy^* = Ky^*\,(T_1\,p+1)(T_2\,p+1)\,/\,p^2\,(T_1\,p+1)(T_2\,p+1)$,

where $Ky^* = K\theta\,V$, and V is the movement speed.

Search procedure for coefficients of the adjustable mathematical model was repeated until the integral error criterion has been minimized, i.e. until the closest coincidence of real object and model reactions has been reached. Fig. 4 shows the dependences of the adjusted model coefficients on the movement speed, obtained according to experimental dynamic characteristics of heavy class objects under study: θ) MAZ-500; b) ZIL-130 (– – – without load, ---- with nominal load).

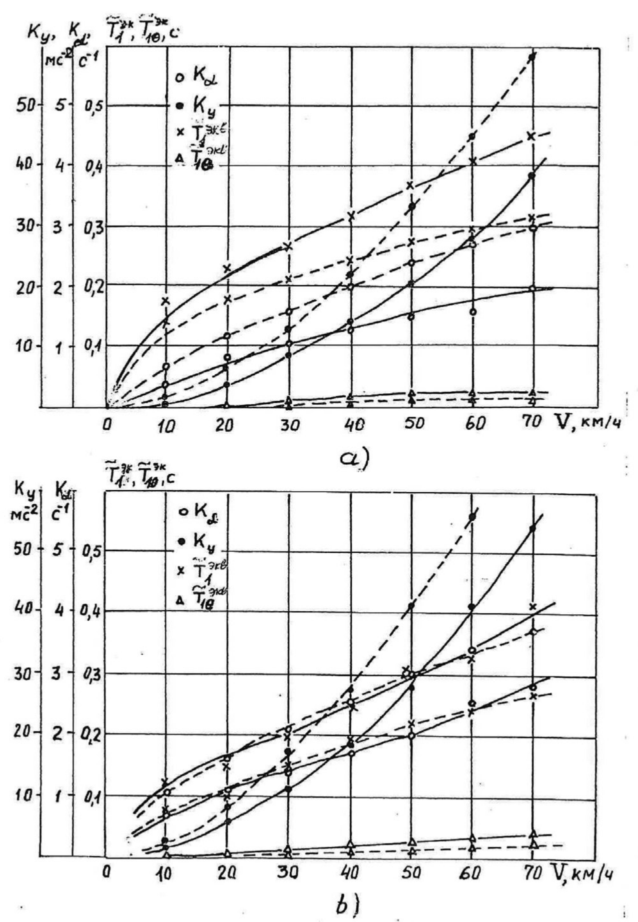

Fig 4

Results of mathematical models with variable coefficients are presented in tables 1, 2 ; Table 1 – Measuring dynamic properties of the studied object MAZ-500 without load with respect to movement speed V;

Tab 1

V , мс$^{-I}$	W_{Θ}^{*}	K_y^{*}, мс$^{-2}$
I,39	$\frac{0,35(I,425p+I)(0,005p+I)}{p(0,00952p+I)(0,00478p+I)}$	0,487
2,78	$\frac{0,696(0,705p+I)(0,0085p+I)}{p(0,0I87p+I)(0,00966p+I)}$	I,946
5,56	$\frac{I,37(0,339p+I)(0,0I7p+I)}{p(0,036Ip+I)(0,0I97p+I)}$	7,6I7
8,34	$\frac{I,99(0,2Ip+I)(0,0285p+I)}{p(0,05IIp+I)(0,0304p+I)}$	I6,656
II,I2	$\frac{2,55(0,I34p+I)(0,0437p+I)}{p(0,059Ip+I)(0,045p+I)}$	28,356
I3,9	$\frac{3,027(0,00587p^2+0,I42p+I)}{p(0,00393p^2+0,I24p+I)}$	42,II7
I6,68	$\frac{3,43(0,00587p^2+0,II9p+I)}{p(0,00534p^2+0,I4p+I)}$	57,2I2
I9,46	$\frac{3,75(0,0059p^2+0,I02p+I)}{p(0,00682p^2+0,I53p+I)}$	72,975

Tab 2

V , мс$^{-I}$	W_{θ}^{*}	K_y^{*}, мс$^{-2}$
I,39	$\frac{0,365(I,293\,p+I)(0,003\,p+I)}{p\,(0,0I24\,p+I)\,(0,00555\,p+I)}$	0,507
2,78	$\frac{0,726(0,64\,p+I)(0,0095\,p+I)}{p(0,0245\,p+I)(0,0II2\,p+I)}$	2,0I83
5,56	$\frac{I,42(0,303\,p+I)(0,02\,p+I)}{p\,(0,0468\,p+I)(0,0228\,p+I)}$	7,9
8,34	$\frac{2,0I77(0,I84\,p+I)(0,0325\,p+I)}{p(0,063I\,p+I)(0,036I\,p+I)}$	I6,83
II,I2	$\frac{2,54(0,I03\,p+I)(0,0576\,p+I)}{p\,(0,0725\,p+I)(0,0525\,p+I)}$	28,24
I3,9	$\frac{2,95(0,00594\,p^2+0,I29\,p+I)}{p(0,00553\,p^2+0,I45\,p+I)}$	4I,005
I6,68	$\frac{3,26(0,00594\,p^2+0,I08\,p+I)}{p(0,00734\,p^2+0,I6\,p+I)}$	54,38
I9,46	$\frac{3,48(0,00596\,p^2+0,0924\,p+I)}{p(0,009I4\,p^2+0,I7I\,p+I)}$	67,72

Table 2 – Measuring dynamic properties of the studied object ZIL-130 without load with respect to movement speed V; Table 3 – Measuring dynamic properties of MAZ-500 with nominal load with respect to standard parameter V.

7. Conclusion

Test conducted on the testing area confirmed volatility of these objects. Special equipment complex was developed. This complex can be used for study of the dynamic characteristics of various mobile objects with the purpose of their automatic movement control. The proposed experimental procedure permits to determine the characteristics peculiarities of the mobile objects, their mathematical model, structure and dynamic parameters. This procedure can be used for study of wide variety of mobile objects.

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