Experimental Research of 4x4 ATV Motion Along the Curved Trajectory at the Test Bench

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Abstract. The article presents the results of experimental evaluation value of the reactive torque on the ATV steering shaft during its motion along circle. The tests were carried out on a test bench. The developed method provides for experiments on trajectories of different curvature. Three races were performed for each radius.

1 Purpose, objects, and conditions of tests. Test bench

The purpose of the test is to determine the value of reactive torque on the steering ATV shaft as a function of the velocity and curvature of the ATV's trajectory.

Vehicles were fully fueled and equipped before the tests. The test objects are ATV with curb weight (mass of the sample prepared for normal operation, filled with fuel and other technical fluids, with tools, without cargo and crew). The vehicle was additionally loaded with ballast. It was corresponded to its full weight. The tests were carried out after 24 hours of test object operation.

Tests are carried out at the testing area for experimental research that is part of the Research and Experimental center of the Mytishchi branch of the Bauman Moscow State Technical University [1-3].

The tests were carried out on a test bench on a flat area in the summer-autumn period. Climatic conditions under which the tests were carried out: ambient temperature +12 °C, average wind speeds 3 m/s, atmospheric pressure 749 mm Hg, relative humidity 55 %.

The test bench for testing wheeled caterpillar movers and support skis is a metal construction that provides to research the autonomously motion of the ATV along a circular trajectory (Figure 1). The test bench is a modular construction that makes easy to assemble and disassemble it, to set links of different lengths to enable motion along trajectories of different curvature.

Test bench consists of base, rotating support, links, adapter plate, three-dimensional construction of the ATV support [4-7].

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Fig. 1. Test bench general view.

2 Measuring equipment and measured quantities

During tests 11 files can be obtained. The control and measuring (sensors) equipment records:

- 1) Crankshaft position. Two parameters are written to the file: time and voltage on the sensor.
- 2) Rear axle angular velocity. Two parameters are written to the file: time and voltage on the sensor. One axle turn corresponds to 33 sensor pulses in the main gear of the rear axle.
- 3) Front left wheel angular velocity. Two parameters are written to the file: time and voltage on the sensor. One turn of the wheel axle corresponds to 4 encoder pulses.
- 4) Front right wheel angular velocity. Two parameters are written to the file: time and voltage on the sensor. One turn of the wheel axle corresponds to 4 encoder pulses.
- 5) Data from bridge-mounted strain gauges located on the steering shaft to determine the torque on it. Two parameters are written to the file: time and voltage on the sensor. Equation for determining instantaneous torque:

$$M = (U_{in} - U_0) \cdot K_c \quad (1)$$

M – torque on the steering shaft, N·m; U_{in} = instantaneous voltage on the sensor, mV; U_0 – voltage on the sensor in an unloaded state, mV; K_c – calibration coefficient, N·m/mV.

- 6) Data from acceleration sensor ZET7152-N in lateral direction, positive direction from left to right. The sensor is installed in the center of mass of the loaded ATV. Two parameters are written to the file: time and instantaneous acceleration in m/s².

- 7) Data from acceleration sensor ZET7152-N in longitudinal direction, positive direction against motion. The sensor is installed in the center of mass of the loaded ATV. Two parameters are written to the file: time and instantaneous acceleration in m/s².

- 8) Data from acceleration sensor ZET7152-N in vertical direction, positive upward direction. The sensor is installed in the center of mass of the loaded ATV. Two parameters are written to the file: time and instantaneous acceleration in m/s².

- 9) Data from the sensor installed on the recording device body to record the beginning of the experiment and its end. Two parameters are written to the file: time and voltage.

- 10) Data from an encoder installed on the steering shaft. Two parameters are written to the file: the time and the angle of the shaft position.

- 11) Data from an encoder installed on the test bench base mechanism. Two parameters are written to the file: the time and the angle of the test bench rod.

3 Test results

During tests file records were obtained from the corresponding sensors. The results were processed using the appropriate calibration coefficients. Thus, the initial data were obtained for further analysis.

The tests were carried out at different velocities and with different lengths of the test bench links ($R_1 = 6,1\text{ m}$ and $R_2 = 9,3\text{ m}$).

The ATV angular velocity relatively to the vertical axis of the test bench can be obtained as time differentiation of the angle of test bench rod. The average value of the angular velocity during the "steady" ATV motion is $0,21\text{ rad/s}$, that corresponds to average ATV velocity $V = 4,3\text{ kph}$ (Figure 2). Before the start of the tests, the ATV steering shaft was set in the position $\theta_{steer0} = 20^\circ$ at $R_1 = 6,1\text{ m}$. This position of the steering wheel corresponds to the minimum average value of the torque that occurs on it when driving along the corresponding radius of the test bench at the minimum stable ATV velocity. The ATV steering shaft angle is fixed in this position using a specially designed mechanism. During tests the position of the ATV steering shaft can change due to the elasticity of the steering mechanism and steering shaft lock bracket. The tests were carried out at different velocities (4,3 kph, 9,3 kph, and 15,6 kph) for the test bench at $R_1 = 6,1\text{ m}$ and at speeds (5,2 kph, 10,2 kph and 22,4 kph) for the test bench at $R_2 = 9,3\text{ m}$. After processing the initial data obtained during the first race at radius $R_1 = 6,1\text{ m}$, the following results were obtained.

Fig. 2. Results obtained during the first race at $R_1 = 6,1$ m.
a) – angle of test bench rotation; b) – acceleration of ATV center of mass along three coordinate axes x, y and z; c) – angular velocities of the front wheels and rear axle of the ATV; d) – ATV steering shaft angle; e) – torque on ATV steering shaft

Similarly, the results were obtained and processed for the two remaining races at $R_1 = 6,1$ m and three races at $R_2 = 9,3$ m (Figure 3 and Figure 4).

Fig. 3. Results obtained during the second and third races at $R_1 = 6,1$ m. a) – angle of test bench rotation; b) – acceleration of ATV center of mass along three coordinate axes x, y and z; c) – angular velocities of the front wheels and rear axle of the ATV; d) – ATV steering shaft angle; e) – torque on ATV steering shaft

Fig. 4. Results Results obtained during the three races at $R_2 = 9,3\text{ m}$
a) – angle of test bench rotation; b) – acceleration of ATV center of mass along three coordinate axes x, y and z; c) – angular velocities of the front wheels and rear axle of the ATV; d) – ATV steering shaft angle; e) – torque on ATV steering shaft

For the results obtained, the average values were determined at the "steady" ATV motion. The results of all races are given in Table 1.

Table 1. Average values of the researched parameters of the ATV motion.

Parameter	Test bench links' length					
	R ₁ = 6,1 m			R ₂ = 9,3 m		
	1st race	2nd race	3d race	1st race	2nd race	3d race
ω_z , rad/s	0,21	0,45	0,76	0,17	0,33	0,73
V , km/h	4,3	9,3	15,6	5,2	10,2	22,4
θ_{steer} , degree	21,7	21,3	20	11,2	11,1	9,7
$a_x, \frac{m}{s^2}$	0,25	1,8	4,7	0,2	1,1	5,8
$a_y, \frac{m}{s^2}$	0,7	0,7	0,6	0,7	0,7	0,8
$a_z, \frac{m}{s^2}$	9,8	9,8	9,8	9,8	9,8	9,8
M_{steer} , N · m	-17	-2,5	5,2	-2,5	-0,2	5
ω_l , rad/s	5,2	11,2	18,2	5,6	11,2	25,2
ω_r , rad/s	4,5	9,7	15,9	5,1	10,2	23,1
ω_{rear} , rad/s	4,7	9,8	16,2	5,4	10,6	24

During tests it was established that, while ATV velocity increases for $R_1 = 6,1$ m, the torque on the steering shaft at first decreases from $-17 \text{ N}\cdot\text{m}$ to $-2,5 \text{ N}\cdot\text{m}$, and then increases to $+5,2 \text{ N}\cdot\text{m}$. While ATV velocity increases the effect of the stabilizing torque on the wheels increases also. Stabilizing torque is a result of ATV wheel angle setting. For the links' length $R_2 = 9,3$ m the results will be similar.

In addition, while the ATV velocity increases the steering shaft tends to return to its initial ($\theta_{steer0} = 20^\circ$) position. Due to the elasticity of the mechanism of the handlebar fixation and steering mechanism, the ATV steering shaft turn $1,7^\circ$ for $R_1 = 6,1$ m and $1,5^\circ$ for $R_2 = 9,3$ m.

Centripetal acceleration of ATV center of mass provides lateral force value determination. This lateral force (in the absence of the test bench links) will be applied to the wheels at the contact patch with the support surface [8, 9, 10].

4 Conclusion

After the tests carried out to evaluate value of the reactive torque on the ATV steering shaft, it is possible to determine the wheel slip angles, their values and directions, wheel slip velocities, slip coefficients, longitudinal and lateral components of the contact force, drag coefficients lateral deflection [11, 12]. Using a test bench allows to determine the most energy-efficient motion mode on various support surfaces. It was established that the test bench provides evaluation of the energy losses resulting from the interaction of an elastic mover with a deformable or solid support surface.

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