Analysis of ATV transmission operation according to the results of tests on a dynamometer test bench

M Lyashenko¹, P Potapov¹, A Dolotov¹, A Diakov², K Evseev²,³ and A Zverev²

¹Volgograd State Technical University, Volgograd, Russian Federation
²Bauman Moscow State Technical University
³Email: kb_evseev@bmstu.ru

Abstract. The article describes the features and methods of testing the ATV on a hub dynamometer test bench. The graphs of the test results are presented, and the graphs analyzes, aimed at researching the operation of its engine-transmission bench, is carried out. The change of the gear ratio at different throttle positions is specific. This specific operation characteristic of the V-belt variator used in ATV transmission as a gearboxes found.

Introduction

All-terrain vehicles are quite interesting, however, a specific type of transport. Their range of application is quite wide, but at the same time, it is limited by off-road use. Their operating conditions determine the features of their design, in general, transmissions and powertrain systems [1-6].

There are several common schemes and layouts of such vehicles today. The most common is a scheme with a low-volume two-cylinder four-stroke gasoline engine and continuously variable transmission, which includes a transfer case with a reduction gear. V-belt variator is used as a gearbox. In addition, the transmission is all-wheel drive, usually without interaxial differential (sometimes without interwheel). This choice is due to a number of objective reasons [1-4]:

- the engine has sufficient power in its compact size, but the maximum power develops at high revolutions and the torque value is relatively low, especially in the low revolutions [1-6];
- the use of a stepless transmission makes it possible to simplify the overall management of the vehicle, as it is an automatic transmission, which makes it easy to control the traction on off-road conditions, especially in the light of these engine features.
- V-belt variator with rubber belt and mechanical control (centrifugal regulator) allows simplifying the design and providing ease of maintenance with acceptable reliability. At the same time, such a gearbox has a high mechanical efficiency [1-6];
- the use of a transfer case with a reduction gear is conditioned by the above mentioned features of the engine, namely low torque, which is a significant disadvantage in off-road conditions. In addition, vehicles can still tow trailers, which means that the trailer's thrust-to-weight ratio should be high enough [1-6];
- all-wheel drive without axle differential (with rigid front axle connection) does not show any characteristic drawbacks (decrease of machine stability, deterioration of turning ability, increased tire wear, additional loading of transmission with circulating power) on soft soils and in mud, but, on the contrary, increases traction possibilities [1-6];
The design of most of the elements of ATV transmission is already well known and therefore their work does not cause much interest. However, the V-belt variator in this transmission is interesting, because the nature of its work significantly affects the work of the entire powertrain system, and the principle of its operation makes it difficult to analyze - it is necessary to know the law of the centrifugal regulator, which is possible only after individual tests of the unit, or having the manufacturer's data. Accordingly, carrying out tests, which will allow studying the work of the transmission with a wedge-belt variator and applying the obtained characteristics to improve the design of the variator, or to synthesize the control program, is an urgent task.

**Test equipment**

ATV is used as a prototype Can-Am Outlander 570 [7,8], which fully corresponds to the abovementioned design features.

For a long time, we have been using dynamometer test benches for testing complete vehicles, which allow us to investigate the operation of powertrain systems of vehicles as a whole and do not require dismantling the units [9-14]. These stands can be of different types - drum (roller) or hub stands. This paper describes the tests carried out with the help of a step dynamometer stand Dynapack Daqplus 43 located in the laboratory of the Department of Transport Machines and Engines of Volgograd State Technical University. This test bench allows to test vehicles with power up to 2000 hp and torque up to 7000 Nm (all-wheel drive) [15].

The use of a wheelbase eliminates the influence of tyre contact with drum tyres, which is a relevant issue in the case of the vehicle in question, as it is equipped with advanced off-road tread and high profile wheels. In addition, the stand provides a high repeatability and accuracy of results.

The vehicle hubs are connected to the stand loaders by means of special adapters for testing (Figure 1).

![ATV mounted on the stand](image)

**Fig. 1.** ATV mounted on the stand: 1 - loader of the stand, 2 - adapter

**Test methods**

The usual test procedure involves entering the value of the transmission ratio into the test bench control program, where the tests will be conducted. As a result, precise measurement of torque and
power on wheels can be made in different loading modes (e.g. external engine speed response or simulation of road conditions). However, the tests described were intended to evaluate the reactions of a motor transmission system to loading under conditions of constant change in the gear ratio by a variable speed gearbox. In this regard, the program was introduced some "starting" value of the gear ratio, which, in fact, did not correspond to the reality. In order to calculate the current gear ratio, it was necessary to have a wheel speed signal (the default data are recorded by the bench) and the motor speed. The last signal could be received in two ways: by sending a signal to the input of the bench using the OBD protocol, or by sending a signal to the special input of the stand RPM Pickup from any sensor of the ATV. It turned out that the used ATV does not have a standard OBD connector and the corresponding protocol, an attempt to use the CAN-bus on the corresponding connector pins was impossible. The RPM Pickup input requires a 0-5V, 0-20V rectangular pulse signal. The only available source of this signal was the fuel injector control wire, which had to be used with a special converter. This allowed for synchronous recording of the engine speed during the tests. In addition, an adapter was used to feed the standard throttle position sensor signal to the test bench.

In view of the availability of these sensor signals, it was decided to use the following test methods:
- acceleration of the ATV to maximum speed at a given constant throttle position;
- increasing the load on the wheels with the help of the stand until the minimum steady speed of the ATV engine is reached (the load was increased with some experimentally selected step with holding it for a few seconds at each step to achieve the established mode if necessary, at a sufficiently small step it was not necessary) [16-18];

**Test results**

During each test, engine speed, axle wheel speed, throttle position, axle wheel torque (two axles in all-wheel drive mode), wheel power were recorded. Then the received data have been transferred in the tabular editor and processed.

Examples of the dependencies obtained are given below. The curve designations on the graphs are as follows:
- Tacho–engine speed by sensor, rpm;
- HubRpm - wheel spins on the stand, rpm
- AxleTrq – wheel torque (total), Nm;
- AxleTrqM - torque on the rear wheels (total for the axle), Nm;
- AxleTrqS -torque on front wheels (total for axle), Nm;
- AxlePow - wheel power, hp.;
- V1:TPS - throttle opening degree by sensor, %;
- Ratio - current gear ratio.
- time - test time, sec.

Figures 2-4 show the graphs of the above mentioned values recorded by the time of measurement.

All diagrams have the following characteristic features that are the peculiarity of the loading process: the time scale starts from the moment of reaching the specified position of the throttle valve; it was not possible to reach the minimum revolutions (they would have to correspond to the moment of opening of the centrifugal regulator - about 1700 rpm), but due to the discrepancy of the ratio of transmission of the stand control program it was wrong to think that the engine had reached the minimum stable revolutions (about 600 rpm) and discharged the load. Therefore, the minimum speed zone was left out of the test.

The graphs (Figures 2-4) show the graphical dependencies for opening the throttle valve 60, 80, 100%.
**Fig. 2.** Test results at 60% throttle opening

**Fig. 3.** Test results at 80% throttle opening
All the graphs show a generally similar pattern of change in the performance of the powertrain system: it is clear that the overall ratio changes almost linearly throughout most of the test, with the values of the ratio close to the different degrees of opening the throttle, the nature of the reduction in engine speed is almost identical. The maximum gear ratio is about 80, the minimum is about 10.

**Fig. 4.** Test results at 100% throttle opening

**Fig. 5.** Dependence of transmission ratio and total torque on engine speed
Figure 5 shows that the nature of the change in the total gear ratio of the transmission is the same for all the throttle positions - the main section corresponds to a linear increase (in fact, almost constant value) and short growth areas. Moreover, the areas of rapid growth of the ratio at different degrees of opening of the throttle valve correspond to different engine revolutions. So, for TPS 60, 80, 100 the growth area at low revolutions practically coincides, and at high revolutions the shift on 250 revolutions is observed. Thus for TPS 40% both growth areas differ - the beginning of a growth area at high revolutions is shifted already on 500 revolutions/min from TPS100%, and at low revolutions - on 250 revolutions/min. However, the linear section coincides in size with other cases. Similar character is observed at other degrees of opening of the throttle valve - the smaller the opening, the earlier the switching begins on revolutions and the greater the minimum gear ratio.

The change in torque also corresponds to the change in the gear ratio, but the graphs show that the maximum torque at TPS 60,80,100 is the same at 4250-5000 rpm. With a TPS of 60%, the maximum torque is less and is achieved at lower speeds. The torque increase in the gear ratio corresponds to the moment when the engine starts to reduce the speed and passes the maximum torque zone.

This pattern of change suggests that the V-belt variable speed gear ratio is adjusted not only in terms of drive sheave speed (motor speed), but also in terms of motor torque (torque response) and is likely to depend on the cam profile of the driven pulley.

**Conclusion**

The conducted researches have shown the possibility of testing the ATV on a stepped dynamometer stand according to the given method, but have revealed several features that should be paid attention to during further researches: for example, achievement of the minimum engine revolutions at a high transmission ratio and peculiarities of operation of the program of stand control, which does not allow to introduce too high value of the transmission ratio; transient processes in changing the gear ratio, which require the selection of the incremental load step and the stabilization of the load at each step.

The specific character of the change in the transmission ratio of stepless transmission, which depends not only on the speed of rotation, but also on the load factor, is revealed. The assumed characteristic of the centrifugal regulator of the V-belt variable speed gearbox should be a curve that characterizes the change in the position of the weights depending on the input shaft revolutions. This curve should be common for all modes of motor operation [19]. However, from the graph analysis, the actual characteristic of the change in gear ratio (which depends on the characteristic of the regulator) by engine speed is a group of curves that have the same nature of change, but different values depending on the position of the throttle valve.

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