Toroidal variator with hydro-gas pressure mechanism for creating a holddown

R N Polyakov¹, A A Revkov¹4, F Shengping², and L I She³

¹Orel State University named after I.S. Turgenev, Komsomolskaya street, 95, Orel, 302026, Russia
²School of Mechanical and Energy Engineering, Jimei University, 185 Yinjiang Rd., Jimei District, Xiamen, 361021, China
³School of Mechanical and Automotive Engineering, Xiamen University of Technology, 600 Ligong Rd, Jimei District, Xiamen, Fujian, 361024, China
E-mail: ⁴artem_revkov@mail.ru

Abstract. The article presents an analysis of the existing constructions of automatic shift gearboxes (automatic transmissions) in modern cars and describes a new construction based on a toroidal variator with a hydraulically variable holddown. There is a rationale that in comparison with the traditional automatic transmissions, a new one has smaller mass-dimensions with the same possibilities of transmitting smoothly variable torque from the engine to the car wheels. The innovation of the construction consists in the mechanism for pressing the intermediate disk of the variator to the friction surfaces due to the controlled hydraulic actuator and a membrane that eliminates bulky pressing linkage in a traditional construction of the toroidal variators.

1. Introduction

The automobile in modern life, first of all, is a means for comfortable movement from one point to another. Nowadays the modern car driver appreciates comfort, convenience and reliability. Automobile manufacturers focus on comfort in the car operation and develop and implement various electronic assistants, various systems for easy driving. One of these assistants is the automatic transmission [1-4]. The widespread use of automatic shift gearboxes in the automotive industry has given an impulse to the development of technological solutions in this direction. In addition to the most popular cars with torque converter automatic transmissions on the market, the cars with robotic automatic transmissions and variators (CVT) are in high demand.

Recently the share of cars with variators has considerably increased. There are many drivers’ negative opinions and many experts’ positive opinions about this type of transmission.

The variator as a development was patented in the XVIII century. It was widely used in the equipment that did not have the same power as a passenger car (with electric generators, in chainsaws, snowmobiles, machine tools, sewing machines) in the 1950s and 1980s.

The first continuously variable transmission was installed on the Dutch DAF cars, which were comparable to motor vehicles in 1958. One of the first models to test the V-belt variator was the DAF 600 car. In the late 70s, Volvo company owned the patent, but years later the concern refused to use the variator in their cars because of its short life time.
In the 80-ies of the XX century, the variator was used on Ford, Fiat, and Subaru cars. And only Subaru improved the construction using a metal push belt instead of an elastic one in the CVT construction.

The V-belt and V-chain types of variator used in modern cars have quite stiff requirements for overloads, and it often leads to its failure. Taking the disadvantage of such variators into consideration, the most promising type of variator is the toroidal one [5,6,7]. The toroidal variators have smaller mass-dimensions than other automatic transmissions, they are able to transmit more torque than V-belt and V-chain ones, but still they have a number of disadvantages. The mechanism of operation of the friction transmission involves the creation of high holddown on solid surfaces of a contact of the variable curvature, which leads to the significant contact stresses and in the transient mode of changing the gear ratio to wear of the working surfaces. On the one hand, in order to increase the load capacity of the variator, it is necessary to create a large holddown, on the other hand, the resulting force of friction leads to the wear of the contacting surfaces of the driving and driven disks, especially in the transient mode, when the gear ratio changes.

2. The text

A possible solution to this problem is to create a new mechanism for creating a pressure force due to hydraulic or pneumatic action on the membrane in contact with the working surfaces of the master and slave disks. Due to the effect of limiting membrane deformations by toroidal surfaces, it is possible to create high specific compressive forces and, consequently, high friction forces and transmit high torques in the main mode, and by controlling the pressure on the membrane, reduce the compressive forces in the transition mode and significantly reduce the wear of working surfaces. The design of such a variator is shown in Figure 1.

This variator works as follows: the torus disk 1 transmits the movement to the intermediate disk 2, which in turn rotates the disk 5. If you want to change the transmission ratio of rotation should relieve pressure on the membrane 4. For this, the motor 2 moves the piston 3 in such a way that the pressure in the channels is reduced, thereby reducing the pressure of the membrane 4 on the surface of the lead 1 and the slave disk 5 (Figure 2a). The intermediate disk is rotated to the desired position. The electric motor 2 moves the piston 3 in such a way that the pressure in the channels increases, thereby increasing the pressure of the membrane 4 on the surface of the drive 1 and the driven 5 disks – the friction forces increase and the main work cycle is carried out (Figure 2b).

Figure 1. Construction of a toroidal variator with a hydraulically variable handdown.
Figure 2. Position of the intermediate disk membrane during the transient mode (a) and during the main operation mode (b).

The principle of operation of this design is based on the postulate that the movement of the membrane with increasing pressure in the hydraulic channels can not be greater than the initial gap $h$, but at the same time, creating an arbitrarily large pressure, you can achieve significant clamping forces and, accordingly, friction forces, the value of which determines the maximum torque transmitted by the variator. Of course, in this case, the load on the bearings of the drive and driven shafts increases significantly, but using, for example, high-precision angular contact tapered bearings, you can achieve acceptable friction characteristics in the bearings and, thus, significantly win in the mass dimensions of the transmission as a whole.

Figure 3. Strain-stress state of the intermediate disk membrane: a- map of movements, b-stresses.
Figure 4. Calculation diagram (a) and map of total linear movements (b).

The paper [8] presents the results of numerical experiments confirming the stated principles of operation and positive qualities of the new type of variator.

To transmit a torque of 140 N·m, it is necessary to provide a pressure in the hydraulic channels of
the order of 0.8 MPa. Technical rubber with a thickness of 20 mm was chosen as the membrane material. Pinning conditions: on the upper and lower faces. Figure 3 shows calculations of the strain-stress state.

Based on the calculation, it can be concluded that the membrane stress is an order of magnitude less than the limit, and even in this case, the necessary clamping force and sufficient friction forces are provided to transmit the required torque.

Additionally, this principle was tested on an object with a modified geometry. In a commercial variator, the closing loop that restricts the movement of the membrane is the toroidal surface of the master and slave disks. That is, we are dealing with the contact of a convex surface over a concave one on a limited area of the surface. A number of additional numerical experiments were performed for the contact of a convex and concave surface on the full circumference of the circle. The calculation scheme and calculation results are shown in Figure 4.

The finite element calculation assumes a rigid fixation of the shell along the boundaries of the connection with the hub, which leads to the expected result: the displacement is less than 60 microns, and the voltage is less than 5 MPa at the point of attachment. Physically, it may be a welded joint, but it has a certain malleability, which should be in further research. If rubber is used as a membrane material, the technological question of joining the main disk also remains open. It also plays a role that the movement of the membrane is limited by the gap between the inner and outer cylindrical surface.

The main drawback of the claimed approach is that with a limited geometry of the closing circuits of the hydraulic system, it is difficult to ensure complete tightness. The solution to this problem can be the use of a gas circuit with the use of air as the working medium. this will greatly simplify the design and reduce the requirements for sealing technologies of the intermediate disk.

3. Conclusion

As a result, the principle of operation of force closure of surfaces of different curvature is estimated to create the necessary normal pressures and friction forces in contact, that can be used, in particular, in promising transmissions based on the toroidal variators. The creation of such devices requires the development of methods for calculating the main parts and components and conducting experimental research. In addition, one of the challenges for creating a new type of transmission requires the use of units of precision mechanics, electronics and control to ensure the co-operation of the rotation mechanism of the intermediate disc of the variator and the hydraulic drive to create the pressure on the membrane, which will require the use of mechatronics technologies in cars [9,10].

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