Combined Torque Converter for Mining Machines

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Abstract. Transmissions of many technological and transport machines for mining enterprises are equipped with hydro-mechanical transmissions (HMT) with torque converters. HMTs have a number of positive properties. But a significant drawback of traditional automotive single-stage (single-turbine) torque converters is their relatively narrow torque ratio, which most often makes 2 or 3. Multi-stage torque converters in which two or three turbines are simultaneously connected to the output shaft demonstrate higher converting properties. The torque ratio of multi-stage hydraulic torque converters makes 4-6 or more. The drop in the efficiency in the range of large ratios and the lack of hydraulic coupling mode is one of the disadvantages of multistage torque converters. In order to overcome these shortcomings, the design of a combined torque converter is proposed. It combines modes of operation with one and two active turbines, as well as modes of hydraulic coupling and blocking. The main turbine of a combined torque converter is of the centrifugal type. The combination of single-stage and two-stage operation modes is achieved through the use of a composite pump wheel, one part of which can be used as a second centrifugal turbine. Two clutches are provided to control the torque converter.

1. Introduction

Bulldozers, graders, scrapers, bucket loaders, and handling machines, dump trucks, and other wheeled and tracked self-propelled machines form the core transport and technological machines fleet in the mining industry [1, 2]. The transmissions of such self-propelled machines are widely equipped with hydromechanical transmission (HMT), which contains a hydrodynamic torque transformer, a mechanical stepped gearbox, and a hydraulic control system [3, 4]. Useful properties of torque converters are well manifested in self-propelled machines operating in poor road conditions and off-road. Torque converters can execute continuous automatic torque change and at the same time carry out shock absorption and vibration.

However, the insufficient range of automatic changes in the engine torque is a significant drawback of the most common automotive single-stage torque converters, having one centrifugal pump wheel and one turbine centripetal type. The maximum values of torque ratio for such devices are usually between 1.8 and 3. Another significant drawback of single-stage torque converters is in their relatively low efficiency in the field of small speed ratios (0-0.6) [5, 6].

Multistage torque converters, in which the maximum value of the torque ratio is 4-6 or more demonstrate higher transforming properties in the small torque ratios. In multistage torque converters two or three turbines of different types are simultaneously connected to the output shaft [7]. The high maximum values of the torque conversion factor in multistage torque converters reduce the number of
stages in the gearbox and thereby simplify the kinematic scheme of the transmission and transmission control system.

Multistage torque converters of various types, such as Lysholm-Smith [8], Twin Disc [9], Brockhouse [10], Packard [11], SRM (Svenska Rotor Maskiner) [12], Volvo [13] are used in transport, mining and construction engineering. Such torque converters are used in transmissions of heavy vehicles, buses, tractors, tanks, railway locomotives, etc.

However, in high speed ratios of more than 0.6, the parameters of multistage torque converters sharply deteriorate due to increased hydraulic losses. There are complex variants of two-stage torque converters, which are capable of switching to the hydraulic coupling mode with a speed ratio of more than 0.8. In order to eliminate the braking effect of the first turbine wheel at a speed ratio of more than 0.5 and on the hydraulic coupling mode, it is advisable to connect this wheel to the output shaft of the torque converter by means of a free-running clutch [14]. However, in the hydraulic coupling mode two-stage torque converters demonstrate lower efficiency, compared to single-stage torque converters due to the relatively large number of rotating impellers [15]. The last drawback can be overcome by blocking the two-stage torque converter with a lock-up clutch when the fluid coupling mode is on.

Hydrostatic transmission (HST), which also have very significant advantages compete with hydromechanical transmissions with torque converters [16]. However, HSTs have some serious shortcomings, which prevent from their widespread introduction on self-propelled machines. These disadvantages are: high complexity and cost of hydraulic equipment; high requirements for the quality of the working fluid; high requirements for the qualification of staff and service culture of hydrostatic machines; special solutions necessary to initiate the start up of hydraulic equipment to work at low temperatures; a significant dissipation during intensive operation of the hydrostatic machines requires specific solutions for effective removal of heat, especially in conditions of high ambient temperatures; high noise level [17].

2. Basic statement

One of the ways to overcome the shortcomings of HMT with single-stage automotive torque converters is in the combination of different transmission modes depending on the movement conditions of the self-propelled machine [18, 19]. For example, when driving a self-propelled machine in good road conditions, the combined torque converter operates with one active turbine, and if necessary, the self-propelled machine under high resistance to movement, the torque converter switches to the mode with two active turbines [20].

Figure 1 shows the principal kinematic scheme of the combined torque converter in a complex version with a single-wheeled reactor. This combined torque converter provides for operating in single-stage and two-stage modes as well as in fluid coupling and blocking modes [21].

All the elements of the combined torque converter are installed in the housing 1. The torque converter contains a centrifugal type pump consisting of two impellers 2 and 3, the main turbine 4 of the centripetal type, the reactor 5 mounted on a free-running clutch 6. On the other hand, the free-running clutch 6 is connected by the housing 1. Impeller 2 is connected to the input shaft 7 and turbine 4 by means of another free-running clutch 8 to the output shaft 9. The combined torque converter is also equipped with two controlled clutches 10 and 11. Clutch 10 is designed to link wheel 3 to the input shaft 7, and clutch 11 to link the wheel 3 to the output shaft 9. This clutches can be designed as a frictional multi-plate with hydraulic control.

The combined torque converter works as follows.

In the first mode, the torque converter operates in the two-stage mode. In this case, clutch 10 is off, clutch 11 is enabled and connects wheel 3 to the output shaft 9. Impeller 3 is disconnected from impeller 2, and the flow and pressure of the working fluid in the torque converter is created only by impeller 2. Impeller 3 at the same time operates as a centrifugal type turbine, which has a higher efficiency and torque ratio compared to the turbine of the centripetal type in small speed ratios of the torque converter (from 0 to 0.4).
Since the centrifugal pump wheel and the centrifugal turbine are characterized by a relatively small curvature of their blades, it is therefore much easier to provide for the characteristics of a combined torque converter with joint or separate operation of wheels 2 and 3. In general, impellers 2 and 3 can have the same number of plain radial or tangential blades.

![Figure 1. Kinematic scheme of the combined torque converter.](image)

In the second mode, the torque converter operates as a single-stage one. In this case, clutch 11 is switched off, the active clutch 10 connecting wheel 3 to input shaft 7 is switched on. Impellers 2 and 3 work together in this mode, forming a single centrifugal pump wheel located symmetrically to turbine 4. This ensures the high efficiency of the torque converter in large gear ratios (of more than 0.4) and in the mode of hydraulic coupling. The torque on the output shaft 9 consists of moments from two turbines: centrifugal turbine 3 and centripetal turbine 4. In some cases, the working fluid coming out of wheel 3 can produce for the negative torque on turbine 4, reducing the total torque on the output shaft 9. To prevent this negative phenomenon, the turbine is connected to the output shaft with a freewheel clutch 8, which disconnects turbine 4 from output shaft 9. As the ratio of the torque converter increases, the freewheel clutch 8 activates turbine 4.

The transition of the combined torque converter to the hydraulic coupling mode in the range of high speed ratios (of more than 0.8) is carried out by a freewheel clutch 6 breaking the connection of reactor 5 with housing 1.

The third operation mode of the combined torque converter is the blocking, carried out by simultaneously switching on couplings 10 and 11. All the working wheels 2, 3 and 4 are connected to each other; input shaft 7 is directly connected to output shaft 9. The speed and torque ratios of the combined torque converter on the lock mode makes 1. This mode can also be used for braking a self-propelled machine with an engine.

3. Conclusion
The considered combined torque converter joins the positive properties of a complex single-stage torque converter (i.e. high efficiency at high speed ratios and in the mode of hydraulic coupling) and that of a multi-stage torque converter (i.e. increasing the maximum value of the torque ratio and
efficiency at low speed ratios). Thus, this combined torque converter in its range of control is
equivalent to a hydromechanical transmission consisting of a single-stage lockable integrated torque
converter and a two-stage gearbox. This reduces the number of gears in the gearbox shared with the
torque converter. Unlike multiturbine torque converters, the multistage torque converter has no
summing gear. These positive properties of the combined torque converter provide for fuel economy
by increasing the average efficiency of the transmission in a self-propelled machine.

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