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The Differential Hydro-Mechanical Variator

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Abstract

The author has carried out the analysis of dynamic-coupled automatic transmissions and regarded the prospects of their application and development. New design of continuously variable transmission based on differential hydra-mechanical gear train was developed and covered by RF patents No2298125 and No2347966. Principles of work performance for high-torque differential hydra-mechanical gear train based on interoperation equableness of moments opposing one another that are produced at the gear carrier owing to inner forces of differential stages as well as self-actuated pressure variation and hydraulic fluid consumption change when it comes through hydraulic pump and hydraulic actuator.

Keywords: hydra-mechanical gear train, continuously variable transmission, differential hydra-mechanical variator, mechanical diagram, high-torque differential hydra-mechanical variator

1 Introduction

Automatic transmissions are widely spread in the design of modern motor vehicles and dynamic-coupled transmission units are the most advanced of them. The most popular automatic transmission units are hydrokinetic transmissions. They are based on hydrodynamic torque converter coupled with 5-8 staged automated gear boxes the design of which is based on planetary gear trains with links being either blocked or actuated by means of fluid-actuated clutches and free-wheel clutch mechanisms. The significant disadvantage of all fluid-actuated clutches is stepwise variation of the transmission ratio, the value of hydrodynamic converter transformation coefficient limited within 2-2,5 and low efficiency especially within the range of large transmission gear ratios.

Not less popular appear to be the transmission units based on variators that provide stepless torque regulation on output shaft of unit-power plant depending on the load changing within the motion what undoubtedly implements maximal comfort and safety at motor vehicle operation by people with disabilities. But the main advantage of variators lies in the fact that the transmission ratio and, consequently, the value of the torque transmitted between control shaft and output shaft changes gradually what makes possible to optimally match a motor vehicle dynamic motion with engine behavior. These are friction gears that have become the most popular in the function of automobiles' continuously variable transmission units. However, the significant shortcoming inherent to almost all friction gears appears to be: - conveying of tangential (crank) force; - torque transfer by limited plot of surface (by a line but sometimes even a point) what brings to the rise of the surface stress; - the necessity to form great hold-down to prevent the surfaces slipping motion relative to each other what stipulates high pressure on supports, causes significant losses on bearings and reduces the life cycle of the main working components; - the need to take off power for oil pump and steering elements drive [1, 2].

Common disadvantages of all existing automatic transmissions are the following: limited adjustment range, complexity of design stipulated by use of sophisticated and expensive systems of variable fluid drive and automatic steering. It is this circumstance that makes the designers to seek the original solutions.

It is obvious that the elimination of the above shortcomings should be connected with the development of the fundamentally new schemes with the view of their practical realization that could make possible: - self-actuated stepless transformation of torque developed by the engine proportionally to the outer load value; - transformation coefficient of torque developed by the engine and covering the whole range of outer load variation both for light motor vehicles and freighters; - exemption of some steering unit from the vehicle control system.

2 Differential hydro-mechanical variator and principle of operation

A fundamentally new design of continuously variable transmission based on differential hydra-mechanical gear train was developed in fundamental research laboratory at Kamsky State Engineering-Economical Academy and was covered by the patents No2298125 and No2347966 [1, 2].

The inventions were aimed at solving such problems as the enlarging maximal value of transformed torque being conveyed, efficiency upgrading, diminishment of dimensional specifications, providing for self-actuated, with no systems of control, torque regulation on output shaft depending on the load changing and variator adjustment range:

$$i_{\text{var}} = {}^{1}\!/_{i_R} \div 1, \tag{1}$$

where i_{var} – variator transmission ratio; i_R – the given transmission ratio.

The differential hydra-mechanical variator comprises two series-connected differential stages (figure1). The differential stage whose input shaft is coupled with the engine and functions as the variator input shaft appears to be like automatic differential gear train with different values of the transmission ratio.

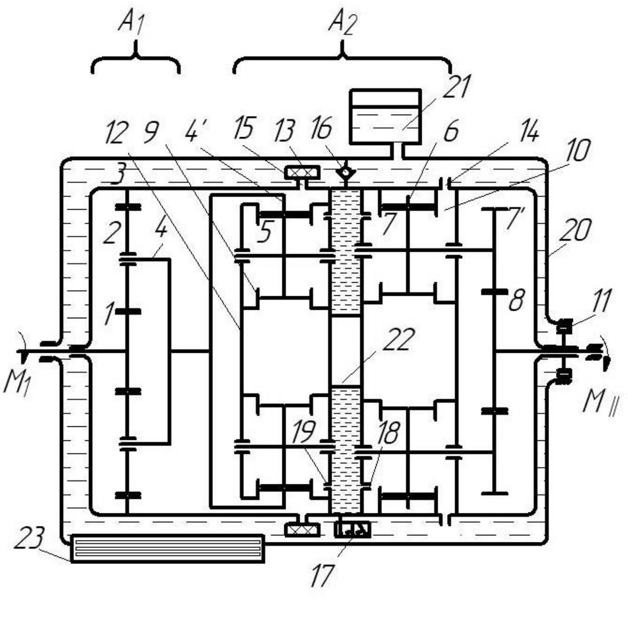

Figure 1: Kinematic scheme hydro-mechanical differential variator:
A1 - mechanical differential mechanism; A2 - hydro-mechanical differential converter; 1 – input element of the differential mechanism, it is also the input shaft of the variator; 2 – satellites; 3 – crown wheel differential mechanism A1; 4 – gear carrier differential mechanism A1, the same input link hydro-mechanical differential converter; 4’ – leading crown wheel hydraulic pump; 5 – satellites of the hydraulic pump; 6 – the crown wheel of the motor; 7-7’ – double-row satellite;

8 – central solar gear shaft; 9 – water pump; 10 – hydraulic motor; 11 – freewheel; 12 – led (chassis) of the variator; 13 – filter; 14 and 19 – respectively, the outlet ports of the hydraulic motor and the hydraulic pump; 15 and 18 – respectively of the inlet window of the motor and the hydraulic pump; 16 – automatic bypass valve; 17 – operated valve; 20 – case; 21 – expansion tank; 22 – annular channel; 23 is a heat exchanger.

The second differential stage presents hydra-mechanical differential converter possessing two planetary sets one of which is formed of multiple-gear hydropump kinematic links consisting of crown wheel to be connected by inside gearing with satellites; and the other - of kinematic links inside multiple-gear hydraulic actuator with double-row satellites whose inside gearing to be connected with the crown wheel and the external gearing - with central sun gear. The crown wheel of the first planetary set serves in the capacity of hydropump input shaft whose hand of rotation coincides with the direction of variator input shaft rotation and central sun gear of the second planetary set acts as the output shaft of the hydraulic actuator. The axles of both satellites at the first differential stage and hydra-mechanical differential converter are installed in the common body. The body is installed on bearings in the variator case and serves as the common gear carrier comprising a freewheel clutch. Apart from mechanical linkage stipulated by the availability of the mutual gear carrier between the planetary sets of the hydra-mechanical differential converter a dynamic hydraulical connection exists and its loop comprises automatic overload relief valve and adjustable valve [3, 4].
Principles of work performance for high-torque differential hydra-mechanical gear train based on interoperation equableness of moments opposing one another that are produced at the gear carrier owing to inner forces of differential stages as well as self-actuated pressure variation p and hydraulic fluid Q consumption change when it comes through hydraulic pump and hydraulic actuator. These variations take place in the consequence of variations in relative speed of differential stages' links at the change of output shaft speed in relation to input shaft permanent speed [5, 6].

Body 12 of high-torque differential hydra-mechanical gear train is rested on bearings installed in case 20 filled with oil. To compensate oil temperature expansion the case has an expansion tank 21. The first differential stage of the variator presents a mechanical differential gear train comprised of input shaft 1, satellites 2, output member 3 and the gear carrier 4. The second differential stage is a fluid-mechanical differential converter having two planetary sets one of which is formed of multiple-gear hydropump 9 kinematic links consisting of crown wheel 4' to be connected by inside gearing with satellites 5; and the other – of kinematic links inside multiple-gear hydraulic actuator 10 with double-row satellites 7-7'whose inside gearing 7 to be connected with the crown wheel 6 and the external gearing 7' - with central sun gear 8. Both hydropump and hydraulic actuator have intake ports: 15 and 17, and exhaust ports: 14 and 18 – their number is equal to the number of hydropump and hydraulic actuator satellites [6].
Self-actuated overload relief valve 16 and controlled valve 17 are installed into

hydraulic annular channel 22. Freewheel clutch 11 is installed between cage (gear carrier) 12 and case 20, filter 13 is fixed on hydropump intake ports and heat exchanger 23 is mounted in the bottom of case 20.

3 Conclusion

Comparing to a prototype, infinitely variable adjustment of kinematic and power parameters is implemented at a total absence of any steering system thus reaching the simplicity of design.

The comparative economic analysis of product profiling of self-actuated gear boxes, beveled chain variators and toroid progressive transmissions produced by the modern automobile industry of different countries shows the high degree of design-engineering consistency of operations in relation to the existing level of geared transmissions and hydraulic machines manufacture, high extent of universalization, considerably less cost of materials and labor effort and, accordingly, lower cost of production.

In automobile industry high-torque differential hydra-mechanical gear trains used in the quality of automatic transmissions for automotive trucks makes the possible to work in the mode of equal powers when the external load varies within the whole range, what brings to optimal power use and, correspondingly, to the considerable diminishment of fuel consumption.

The attainable technical results provide for multifunctional use of the given invention in all fields of machine building.

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