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THE POSSIBILITIES OF THE TWO-SPEED PLANETARY GEAR TRAINS APPLICATION IN THE TRANSPORT SYSTEMS

Jelena STEFANOVIĆ-MARINOVIĆ [1]
Sanjin TROHA [2]
Miloš MILOVANČEVIĆ [1]

[1)] *Faculty of Mechanical Engineering, University of Niš, Serbia*
[2)] *Faculty of Engineering, University of Rijeka, Croatia*

Abstract

Multi-stage planetary gear trains are obtained from single stage gear trains by linking one or two planetary units shafts. Adequate design of PGT could be used as multiple speed gearboxes. Two-speed two-carrier planetary gears which consist of two coupled and four external shafts and have brakes on single shafts could be use in the systems which request speed change under load.
This paper provides structures of compound two-carrier planetary gears with four external shafts. Also, there is example of these transmissions usage At the end, the application of the multicriteria optimization to these gear trains is appointed.

Key words*: planetary gear trains, multiple speed gearboxes, speed change under load*

1 INTRODUCTION

Planetary gear trains (PGT) are a type of gear trains with many advantages. Since that their application is increasing in mechanical engineering and conveyor systems as single - stage and multi-stage. Multi-stage planetary gear trains are obtained from single stage gear trains by linking one or two planetary units shafts.

Adequate design of PGT could be used as multiple speed gearboxes. Gearboxes which consist of two-carrier planetary gear trains and four external shafts have significant application [1]. There is a significant number of possible schemes of these transmissions. Some transmissions structures could be used as two-speed transmissions by applying convenient brakes layout [1].

This paper provides reviews the possible cases of coupled two-carrier planetary gears with four external shafts. Particularly, application of these transmissions in the transport system is pointed.
At the end, the importance of application of the multicriteria optimization to these gear trains to choose the best solution determined by design parameters is pointed.

2 STRUCTURES OF COMPOUND TWO-CARRIER PGT

It is appropriate to show a simple planetary gear train with the Wolf-Arnaudov's symbol.
By using this symbol the train shafts are shown with different width lines and a circle. Sun gear shaft 1 is shown by a thin line, ring gear shaft 3 by a thick line and the carrier shaft h by two parallel lines since the carrier shaft is summary element regarding by carrier stopping negative transmission ratio is obtained.

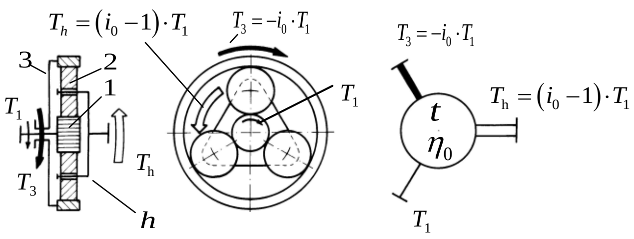


Fig. 1 *Wolf-Arnandov's symbol and torque ratios of the basic type of PGT*

This type of a PGT is often used as single stage transmission, as a building block for higher compound planetary gear trains.

Its advantage over other PGT types lies, first of all, in its efficiency. The efficiency value varies negligibly in the whole range of the internal gear ratio, i.e. ideal torque ratio, $t = |z_3| / z_1$.

Also, this type has small overall dimensions and mass, and its production costs are relatively low because of the relatively simplified production.

Because of its characteristics, it is applicable in transport and stationary machines without limitation in power and velocity, for example in the vital parts of the helicopter, caterpillar, mining, agricultural and other machines and so on.

Planetary gear train shafts are loaded with torques whose ratio is also shown in Fig. 1. Torques on the ring gear shaft T_3 and on the carrier shaft T_h are given as a function of the ideal torque ratio *t* and the torque on the sun gear shaft T_1.

Ideal torque ratio:

$$t = \frac{T_3}{T_1} = \left|\frac{z_3}{z_1}\right| = -i_0 > +1 \tag{1}$$

Torques:

$$T_1 : T_3 : T_h = +1 : (-i_0) : (i_0 - 1) \qquad (2)$$

It is assumed:

$$\eta_0 = \eta_{13(h)} = \eta_{31(h)} = 1 \qquad (3)$$

By joining two shafts of one component planetary gear train with two shafts of the other component planetary gear train a mechanism with four external shafts is obtained (Fig. 2). Two external shafts are coupled external shafts and two are single external shafts. The component planetary gear train will be referred to as the component train and the obtained mechanism with four external shafts will be referred to as the compound train.

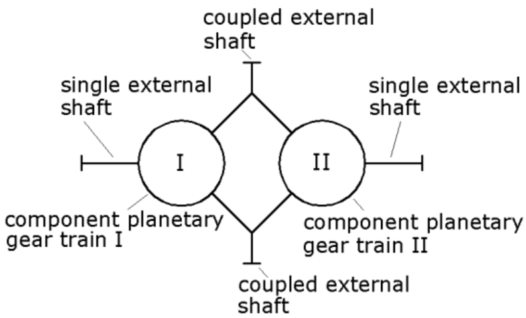


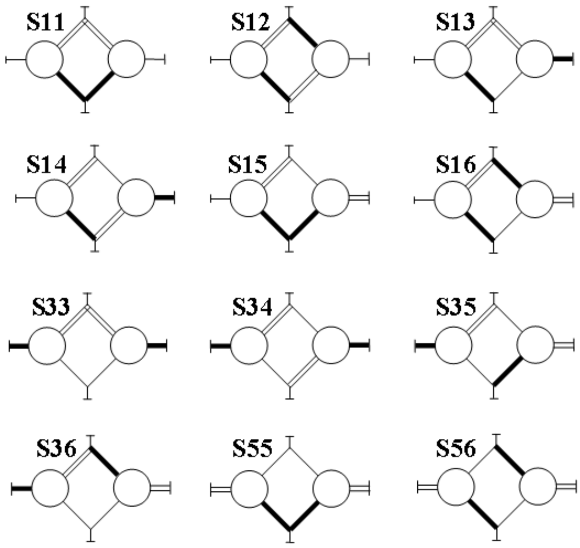
***Fig. 2** Planetary gear train with four external shafts (compound train)*

By placing the brakes on two shafts, a braking system is obtained in which the alternating activation of the brakes shifts the power flow through the planetary gear train, which causes a change in the transmission ratio.

Some planetary gear trains of this type are described in [1, 2, 3, 4]. Possible power flows for planetary gear trains of the considered type are analysed, and functions of the transmission ratio at both gears for some trains of this type are deduced in [1]. In [5], 15 kinematic schemes of the considered type are presented and achievable values of transmission ratios and efficiencies of both gears are given. Shifting capabilities charts for all possible two-speed planetary gear trains are given in [1].

Two component trains can be joined in a whole in 12 different ways, called the planetary gear train with four external shafts. To each of 12 structural schemes an alphanumerical label (S11…S56) is attached, which indicates the ways of connecting the shafts of the main elements of both component trains (Fig. 3). In every presented scheme it is possible to put brakes as well as the driving and the operating machine on external shafts in 12 different ways (V1…V12), which will be here called layout variants (Fig. 4).

The analysis of 12 structural schemes and 12 layout variants shows that there are some different layout variants within the frame of the same scheme, which result in the identical compound train. It has been established that there are [1]:



A – input shaft ; B – output shaft

***Fig. 3** Systematization of all schemes of two-carrier planetary gear train with four external shafts*

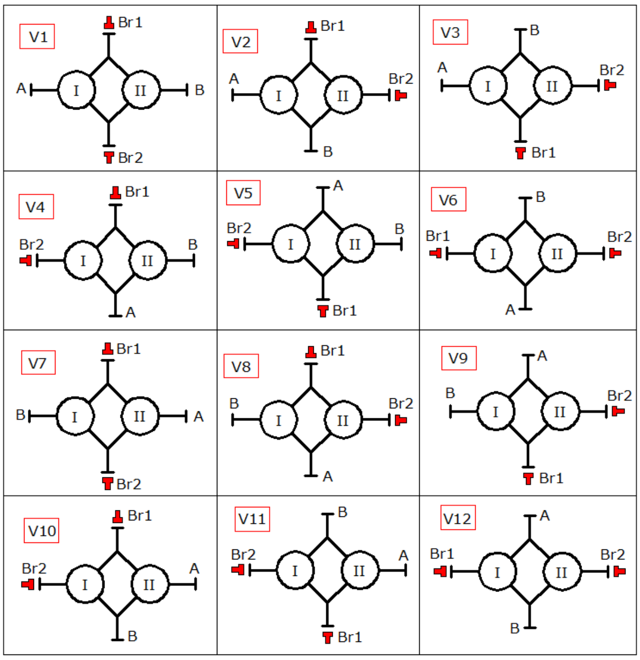


***Fig. 4** Systematization of all layout variants of two-carrier planetary gear train with four external shafts*

- 12 different compound trains with brakes on the single shafts of which each of them has a power input and a power output determined by label V6 or V12 (24 variants)
- 12 different compound trains with brakes on the coupled shafts of which each of them has a power input and a power output determined by label V1 or V7 (24 variants)
- 36 different compound trains with brakes on the coupled and the single shaft (72 variants)

Each of 120 variants of two-speed gearboxes has specific shifting capabilities.

TWO-SPEED PLANETARY GEAR TRAINS

Speed change under load is advantage, and in some occasions request of mechanical system (e.g. machine tools, cranes etc.). Two-speed two-carrier planetary gears which consist of two coupled and four external shafts and have brakes on single shafts could be use in these systems. A special type of mechanism is obtained by settings the brakes on two external shafts that allow energy flow managing throw the transmission and transmission ratio changing. The layout of brakes at these compound gear transmissions has many possibilities [3,4].

Application of these transmissions is necessity in the systems where transmission ratio change under load is request. Such systems are machine tools, conveyer systems, ships.

The application example of two-speed planetary gear trains will be shown at the fishing boat.

The driving machine is four stroke diesel engine. The input number of revolution is 1800÷2100 min^{-1}. The driving machine works in the heavy duty regime with unlimited working hour during year. Transmission ratio in the regime when transmission works like reducer is in the range i=2.5÷6.

For chosen fishing boat [6] two-speed planetary gear train is applicable as a drive of fishing boats propellers. In that case the transmission works with transmission ratio i=4 in one way and with transmission ratio i=-4 in the other way. The transmission is situated on the propeller shaft between engine and propeller.

These requirements are achieved by transmission shown in Fig. 5 as symbolic review of transmission composition, and in Fig. 6 as the kinematic scheme.

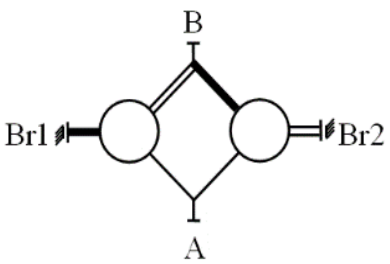


Fig. 5 *Symbolic review of transmission composition*

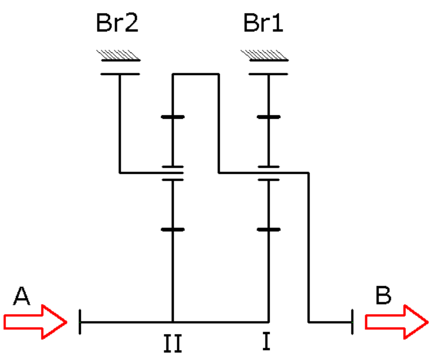


Fig. 6 *Kinematic scheme of two-speed PGT*

Different transmission ratios are achieved by activating brakes.

When the brake Br1 is activated and the brake Br2 inactivated the ring gear in first stage is immovable. The input of the system is A, and sun gear of the first stage and sun gear of the second stage have the same number of revolution. Since the ring gear in the first stage is reactive, the power is transmitted to the carrier of the first stage and than to the output B. Power flow throws the transmission when the brake Br1 is activated is shown in the Fig. 7.

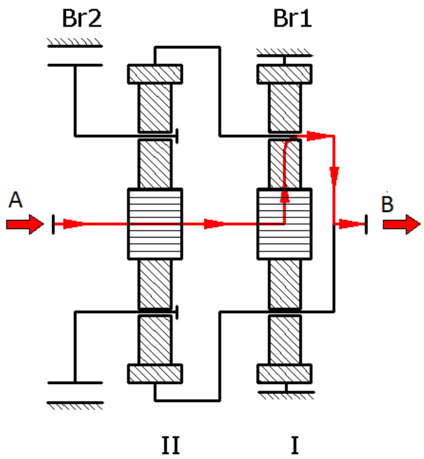


Fig. 7 *Power flow throws the transmission when the brake Br1 is activated*

In this case transmission ratio is i=4.0, and basic transmission ratio is i_0=-3.0. The input data is n_{in}=1800 min^{-1} and P=588 kW. The input element is sun gear of the first stage.

When the brake Br2 is activated and the brake Br1 inactivated, sun gear of the first stage and sun gear of the second stage rotate, but the carrier of the second stage is reactive and power transmitted through the sun gear of second stage and ring gear of second stage to the output B. Power flow throws the transmission when the brake Br2 is activated is shown in the Fig. 8.

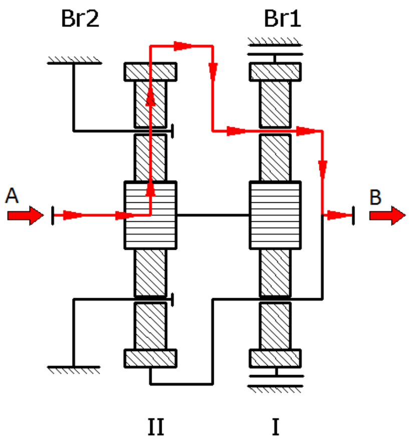


Fig. 8 *Power flow throws the transmission when the brake Br2 is activated*

If the carrier is immovable, the required transmission ratio is equal to the basic transmission ratio (ideal torque ratio). i=i_0=-4.0. The input element is sun gear of the second stage and the input data is the same as in the previous regime: n_{in}=1800 min^{-1} and P=588 kW.

The different regimes of two-speed two-carrier PGTs cause the difference in the design parameters of the first stage and the second stage.

In order to choose “the best” solution determined by adopted design parameters it is suitable to applicate mathematical optimization. Since in most optimization problems several functions need to be optimized, and they cannot all have optimal values at the same time, such problems are called non-trivial *multiple criteria* (or *multiple objective*, *multicriteria*) optimization problems [7].

Multicriteria optimization problems are very common in many scientific and technical solutions. The optimization of gear trains as concrete technical systems supposes a very complex mathematical model which has to describe the operation of a real system in real circumstances.

A model of planetary gear multicriteria optimization adjusted to the basic type of planetary gear trains based on an original algorithm is created [7, 8]. The mathematical model consists of objective functions, variables and functional constraints.

The optimization of the planetary gear transmission is conducted by using four criteria, including the economic criterion, which makes this optimization task a sort of techno-economical optimization.

In order to make a different approach than the models in which an optimal solution is adopted by analyzing the solutions from the set of Pareto solutions [7,8], the application of multicriteria optimization methods for choosing an optimal solution from Pareto solutions is included in this model.

Developed mathematical model and developed software is applicable to the two-speed two-carrier planetary gear trains optimization, too. In that case it is need to considered each stage separately regarding the dependences between two stages and input elements [6].

3 CONCLUSION

In this paper two-speed two carrier planetary gear trains (PGTs) are introduced. First of all, the structure of compound two-carrier PGTs with four external shafts is pointed. These compound gear trains consists of two basic type of PGTs and have considerable application at the systems which need transmission ratio changes under load. Then an example of these transmissions usage is shown.

At the end, the application of the multicriteria optimization to these gear trains is pointed. Multicriteria optimization can be applied to choice design parameters for defined input data.

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Contact address:
Jelena Stefanović-Marinović,
Mašinski fakultet u Nišu
18000 NIŠ
A. Medvedeva 14
E-mail: jelenas@masfak.ni.ac.rs