POSSIBLE AND REAL POWERFLOWS IN CONNECTED DIFFERENTIAL GEAR DRIVES WITH $\eta_0<i_{pq}<1/\eta_0$ INNER RATIO

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Abstract: *It's well known [1], that the powerflow of two degree of freedom three base element type planetary drives (differentials) can be of two kinds in case of given properties of moving. So two kinematic attributes, for example i_{pq} inner ratio and k_{pr} kinematic ratio determine the two possible powerflows unambiguously.*

From the two degree of freedom three base element type planetary drives we can assemble simple one degree of freedom connected planetary drives by connection and fixation of base elements, in which one of the three base element type planetary drives works as a differential drive. In case of $i_{pq}<\eta_0$ and $i_{pq}>1/\eta_0$ inner ratios the powerflow of the one degree of freedom connected drive is determined by the powerflow of the differential drive (for a given structure). Whereas in case of $\eta_0<i_{pq}<1/\eta_0$ differential inner ratios some connected drives theoretically can work with two different powerflows – when input and output base elements are constant. This paper shows the problem by an example, and looks for the answer, whether which of the two theoretically possible powerflows will be realised in the given planetary gear drive.

Key words*: planetary gear drive, differential drive, connected planetary drive*

The simple one degree of freedom connected planetary drives can be derived from two degree of freedom three base element type planetary drives (differentials) by connection and fixation of base elements. Denoting the number of three base element type differential drives by m, the number of moving base elements in connected drive by n_0, the degree of freedom of the connected system (s):

$$s= n_0-m, \qquad (1)$$

so in case of $m=2$ and $n_0=2$ there must be $n_0=s+m=2+2=4$ moving base elements in the connected drive. Since before connecting the two differential drives had $n_0^{'}=6$ moving base elements, the connected two degree of freedom planetary drive must have 2 joined and 2 nonjoined base elements. Fixing an element we can get the one degree of freedom drive. If we fix a connected element, we get a serial-connected drive, in which both differential works as a one degree of freedom drive (Fig.1.a.).

At the same time by fixing a nonjoined element we get a driving-side- or a driven-side-connected simple one degree of freedom drive (Fig.1.b.-c.), in which one of the three base element planetary drives works as a differential drive (*D*).

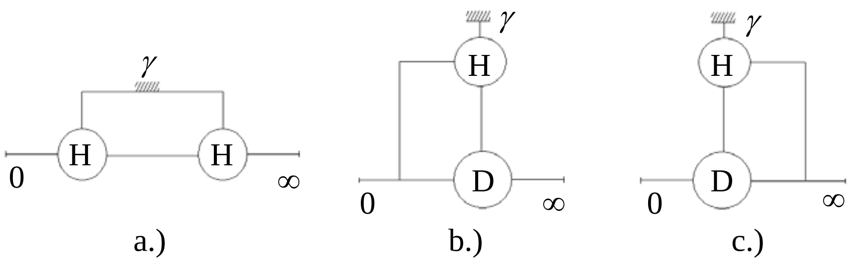


Fig.1.

The other (*H*) can be a one degree of freedom planetary drive, a normal drive, a stepped-, or an infinitely variable drive.

We mention, that there are $3!=6$ different possibilities to arrange the base elements of a differential drive. So the number of the possible kinematic schemes: $3*6^m=3*6^2=108$, from which 36 serial connected, 36 driving-side-connected and 36 driven-side-connected drive.

The *p* and *q* toothed base elements of the *D* differential drive are connected by a gear chain (planet gear or planet gear chain), the *r* base element is the arm (bridge). We use this notations, with the comment, that *p,q* and *r* can be single and also joined base element, but if it is joined, the base element of the one degree of freedom drive (*H*) can differ from the one of the differential drive (for example: the *p* joined base element units the differential's *p* toothed base element and the *H* drive's *r* base element).

After it let's examine a simple one degree of freedom connected drive built from a differential (*D*) with $i_{pq}<\eta_0$ inner ratio, and a one degree of freedom drive. The differential can work with $p,q\rightarrow r$ and $r\rightarrow p,q$ (e.g. $i_{pq}=-1,\ k_{pr}=0,5$)([1], Fig.1.).

As we mentioned, in case of $i_{pq}<\eta_0$ and $i_{pq}>1/\eta_0$ inner ratios the powerflow of the connected planetary drive is determined exactly by the powerflow of the differential drive. When the powerflow is $p,q\rightarrow r$, the possible connected drive-variations can be seen on Fig.2..

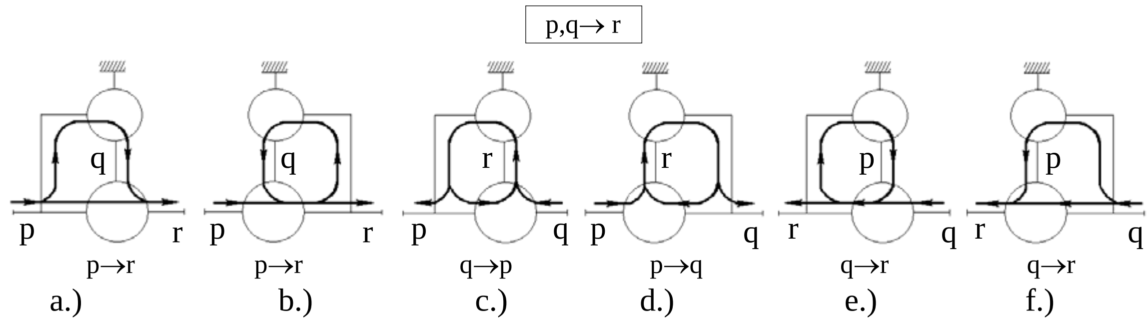


Fig.2.

And for the case when the powerflow of the differential drive is $r \to p,q,$ the connected drives and their powerflows are developed as seen on Fig.3.. From Fig.2.-3. it's obvious, that by same structure and same position of p,q and r base elements (e.g. Fig.2.a. and 3.a. or Fig.2.b. and 3.b.), the driving and the driven base elements are reversed (e.g. the direction of the powerflow on Fig.2.a.is $p \to r,$ while on Fig.3.a. it's $r \to p$).

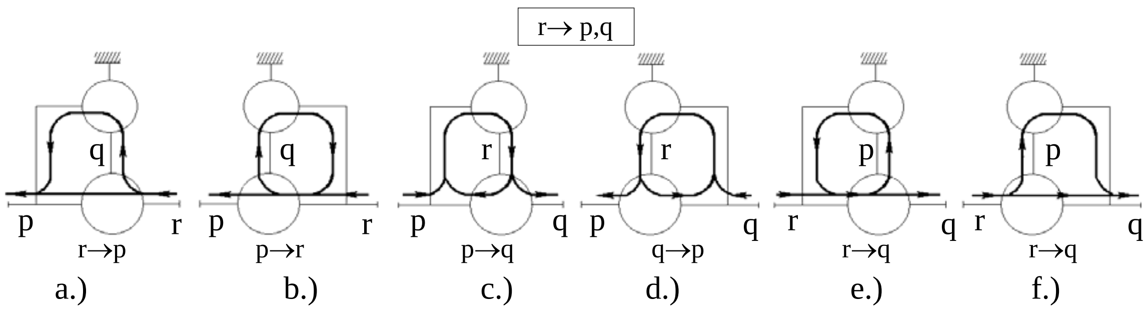
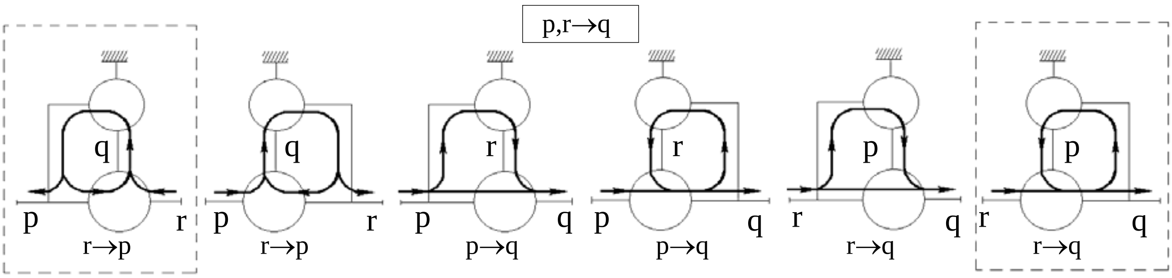


Fig.3.

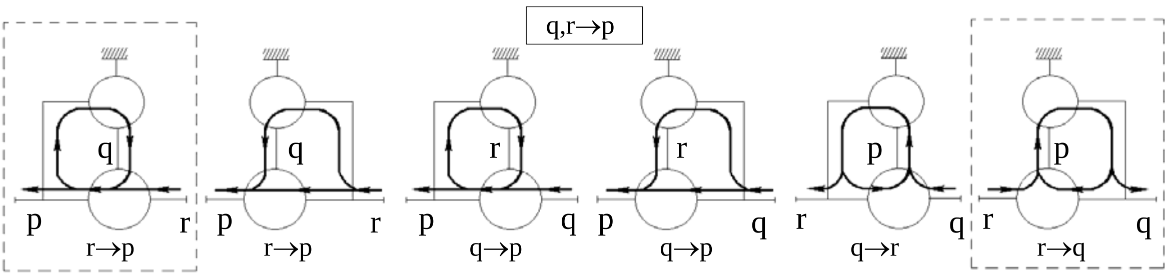
Thus every connected planetary drive has various powerflow, so – for a given structure and given input and output elements – the powerflow can be one kind only. Examinations show, that this establishment is true generally, if we build in differentials with $i_{pq}<\eta_0$ and $i_{pq}>1/\eta_0$ inner ratios. It's necessary to mention, that the H planetary drives are supposed to be non-selflocking in the illustrated directions.

If the built-in differential has $\eta_0<i_{pq}<1/\eta_0$ inner ratio (e.g. $\eta_0=0,98,$ $i_{pq}=1,01,$ $k_{pr}=0,5$)[2], the powerflow can be $p,r \to q$ or $q,r \to p$. The possible connected drives concerned to $p,r \to q$ can be seen on Fig.4.. To $q,r \to p$ powerflows we can assign the connected systems seen on Fig.5..



a.) b.) c.) d.) e.) f.)

Fig.4.



a.) b.) c.) d.) e.) f.)

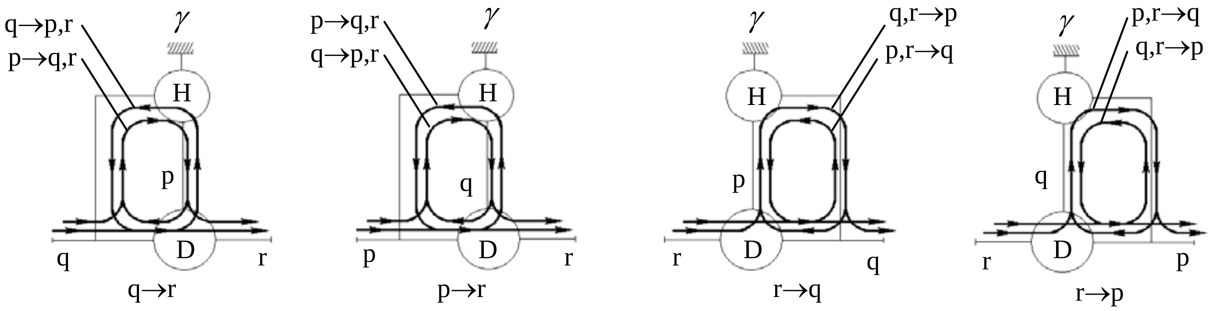
Fig.5.

It can be seen, that in Fig.4.a.- 5.a. and Fig.4.f.- 5.f. the drives have same structures and the input and output base elements are also identical, "only" the closed powerflows are inverted.

The general examination of the connected planetary drives shows, that the theoretical possibility of two different powerflows' development exists only when the inner ratio of the differential is $\eta_0<i_{pq}<1/\eta_0$ and when the two powerflows are $p\to q,r$; $q\to p,r$ or $p,r\to q$; $q,r\to p$. These conditions are satisfied by connected planetary drives seen on Fig.6..

Their common properties are that *r* arm can't be a joined base element, and the ***power-adding*** or power-distributing base element of the differential always must be central toothed element (*p* or *q*). The connected systems on Fig.6.a.-b. have always $k_{pr}>1$ kinematic ratio and the output element is *r*. In case of drives seen on Fig.6.c.-d. the kinematic ratio is $k_{pr}<1$ and *r* is the input base element.

It also can be seen from Fig.6., that these connected drives have closed powerflow always.



a.) b.) c.) d.)

Fig.6.

Example

The power rates of a differential gear drive with $i_{pq}=1,01$ inner ratio, $k_{pr}=0,5$ kinematic ratio and $\eta_0=0,98$ efficiency (η_0 –efficiency when the differential works as a simple gear drive) have been determined in paper [2] (Table 1.). For the sake of simplicity let's suppose, that the H drive is without loss ($\eta_H=1$) and P_r input power of the connected system is a unit ($P_r=\varphi_{rr}=1$). By such assumptions the powerloss of tooth-friction of the connected drive seen on Fig.4.a. is $P_{V(p,r\to q)}\equiv\varphi_V=-0,3333$ and the efficiency of the differential drive is $\eta_{p,r\to q}=0,9807$. Considering only the friction losses, the efficiency of the connected system in case of $p,r\to q$ differential powerflow is:

$$\eta_{r\to p}^{(p,r\to q)}=\frac{P_r+P_{v(p,r\to q)}}{P_r}=\frac{1-0,3333}{1}=0,6666\ .$$

If the powerflow is $q,r\to p$, the powerloss in the differential is $P_{V(q,r\to p)}\equiv\varphi_V=-0,9804$, so the connected drive's efficiency is (Fig.5.a.):

$$\eta_{r\to p}^{(q,r\to p)}=\frac{P_r+P_{v(q,r\to p)}}{P_r}=\frac{1-0,9804}{1}=0,0196\ .$$

The question occurs, whether which powerflow will be realised in the planetary drive, so how high the efficiency will be.

Based on the rules and experiences in the processes of nature and other fields, it can be told with high likelihood, that in this case also the „theory of least resistance" will predominates. So the powerflow with the lower loss will exist, and the connected drive will work with the higher efficiency.

It can be laid down generally, that the alternative working possibilities of connected planetary drives can occur only in cases of $\eta_0 < i_{pq} < 1/\eta_0$ differential inner ratio, and when arm is loaded by external moment. So e.g. in Wolfrom planetary drives' case this type of alternative working is not possible.

References:

[1] APRÓ, F.: **Egyszerű egy- és kétszabadságfokú bolygóművek tervezése. Kinematikai- és nyomatékviszonyok, teljesítményfolyam és hatásfok.** Sajtó alatt.

[2] APRÓ, F. : **Egyszerű egy- és kétszabadságfokú bolygóművek tervezése. Teljesítmény-arányok veszteségmentes és veszteséges bolygóműben.** Sajtó alatt.

[3] MÜLLER, H.W.: **Die Umlanfgetriebe.** Springer-Verlag Berlin Heidelberg New York. Zweite neubearbeitete und erweiterbe Auflage: 1998.p. 260.