Serbian Tribology Society

SERBIATRIB '13

13th International Conference on Tribology

Faculty of Engineering in Kragujevac

Kragujevac, Serbia, 15 – 17 May 2013

CYCLO DRIVE EFFICIENCY

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Abstract: *Cyclo drives have a many good characteristics: high gear ratio, compact design, two-thirds of its reduction components in contact at all times, reliability and long life in the most severe applications, minimal vibration, low noise, low backlash and extended operational life, high power density, wide variety of inputs available,… One of the most important its characteristics is high efficiency.*
Two methods for determining of cyclo drive efficiency are presented in this paper. Their complete analytical models are defined. The influence of various parameters on the cyclo drive efficiency is also analyzed (power, rotational angle of input shaft, gear ratio, ...). The calculation of the cyclo drive efficiency by both methods is done for the real one-stage cyclo speed reducer. Concluding remarks and directions for future work are presented at the end of the paper.

Keywords: *cyclo drive, cycloid, gear, power losses, efficiency*

1. INTRODUCTION

Cycloidal speed reducer belong the group of planetary drives (Figure 1). Because of very wide area of application, production of cyclo drives has growing character and wide area of application: processing equipment, conveyors, presses, mixers, food industry, automotive plants, spinning machines, cranes,…

The most important working characteristics of cyclo drives are: wide range of possible gear ratios, quiet and reliable work, low level of noise and vibrations, exceptionally compact design, high efficiency rate, ... *Lehmann* gave the basic information about cycloidal gearing, [1]. The dynamic behavior of a cyclo drives is presented in Refs. [2,3]. *Kosse* investigated the hysteresis phenomenon in cyclo drives and damping properties derived from dickey curves under torsional impact load, [4]. *Liu* and other generated a new type of double-enveloping cyclo drive and calculated the torsional stiffness, [5]. The influence of friction on contact forces distribution is presented in papers [6,7]. *Sensiger* developed a new method for cycloidal gear profile, efficiency and stress optimization, [8]. *Chmurawa* and *Lokiec* presented the inside meshing and force distributions of cycloid disk with modified profile, [9]. A new concept of a two-stage cyclo drive is presented in paper [10].

Friction and wear have a greatest impact on the cyclo drive efficiency, [11, 12]. The calculation of the cyclo drive efficiency by two method (*Malhotra* and *Gorla*) for the real one-stage cyclo speed reducer is presented in this paper.

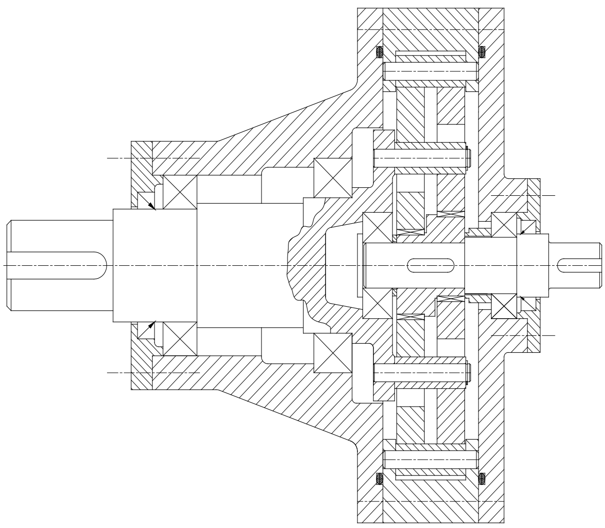

Figure 1. Cyclo drive

2. EFFICIENCY OF CYCLO DRIVE

Efficiency of cyclo drive primarily depends on the resistance due to friction between the elements of cyclo drive. Two methods for determining of cyclo drive efficiency are presented in this paper: *Malhotra* method [11] and *Gorla* method [12].

2.1 Malhotra method for calculating of cyclo drive efficiency, [11]

The various sources of power loss in a cyclo drive are:

- Rolling friction in the mounting of the cycloid disc on the input shaft,
- Rolling friction between output rollers and holes in the cycloid disc,
- Rolling friction between housing rollers and the cycloid disc,
- Sliding friction in the mounting of the output rollers,
- Sliding friction in the mounting of the housing rollers.

Design parameters are presented on Figure 2, and loads on Figure 3.

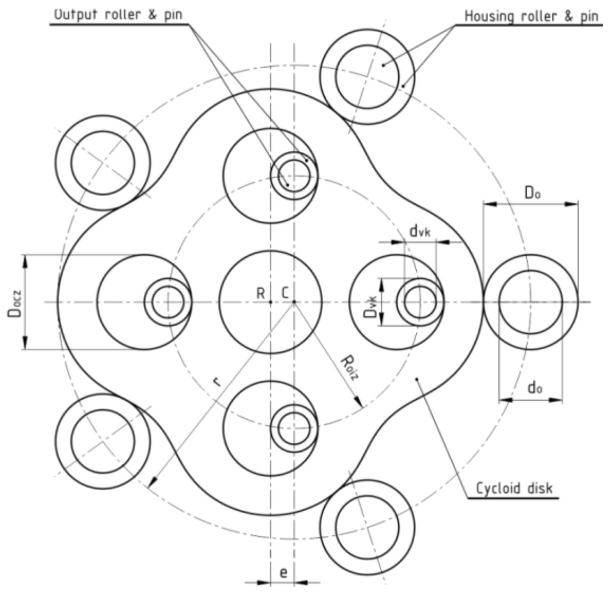

Figure 2. Geometry of cyclo drive

For the elemental rotation $d\theta$ of the cycloid disc, the rotations of the input shaft, output rollers and housing rollers are $n{\cdot}d\theta$, $n{\cdot}d\theta$ and $(n+1){\cdot}d\theta$, respectively. The frictional work per rotation of the input shaft can be determined as:

$$W = \int_0^{2\pi/n} dW = \frac{f_{r1} \cdot D_m \cdot n}{D_r} \int_0^{2\pi/n} F_E(\theta) d\theta + n\left(f_{r2} + \frac{f_{s1} \cdot d_{VK}}{2}\right) \int_0^{2\pi/n} \sum_{j=1}^{q} F_{Kj}(\theta) d\theta + \left(u_{CR} + 1\right)\left(f_{r3} + \frac{f_{s2} \cdot d_O}{2}\right) \int_0^{2\pi/n} \sum_{j=1}^{q} F_{Kj}(\theta) d\theta \quad (1)$$

where: f_{r1}, f_{r2} and f_{r3} are lever arms of rolling friction, f_{s1} and f_{s2} are sliding friction coefficients, D_m is mean diameter of input shaft bearing, D_r is input shaft bearing rollers diameter, F_E is bearing reaction, d_{VK} is diameter of outpit mechanism pins, F_{Kj} is force between output roller j and cycloid disc, q is number of output rollers, u_{CR} is cyclo drive ratio and d_0 is diameter of housing pins.

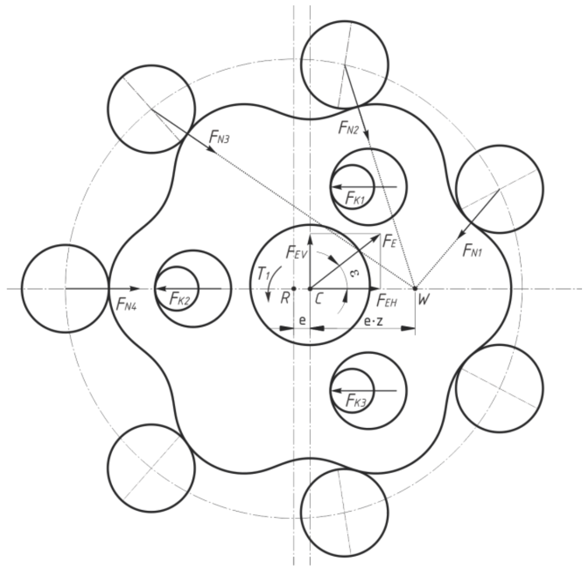

Figure 3. Loads on cycloid disc

The overall efficiency of cyclo drive is then:

$$\eta = \frac{M_a 2\pi - W}{M_a 2\pi} \quad (2)$$

where M_a is input torque.

2.2 Gorla method for calculating of cyclo drive efficiency, [12]

Power loss due to the bearing friction could be computed by means of the following equation:

$$W_{Ma} = M_a \cdot \left(\omega_{inner} - \omega_{outer}\right) \quad (3)$$

where: ω_{inner} is bearing inner race speed and ω_{outer} is bearing outer race speed.

Power loss due to the friction between the pins of the output shaft and the holes of the cycloid disc is:

$$W_K = \sum_{j=1}^{s} f_{Kj} \cdot F_{Kj} \cdot \upsilon_{Kj} \quad (4)$$

where: f_{Kj} is friction coefficient between the pins of the output shaft and the holes of the cycloid disc and υ_{Kj} is sliding speed between the pins of the output shaft and the holes of the cycloid disc.

Power loss due to friction between the cylindrical rollers, the surface of the ring gear and their housing in the planet wheel is:

$$W_N = \sum_{i=1}^{n} \rho \cdot \sin(arctg(f_{Ni})) \cdot \left|F_{Ni}\right| \cdot \left|\omega_{Ni}\right| \quad (5)$$

where: ρ is radius of cylindrical roller, f_{Ni} is friction coefficient between the cylindrical rollers and their houses and ω_{Ni} is relative rotational speed between the cylindrical rollers and the cycloid disc.

Vertical component of force F_{Ni} is calculated based on following expression:

The efficiency of cyclo drive can be calculated as:

$$\eta = \frac{P_{EM} - (W_{Ma} + W_K + W_N)}{P_{EM}} \quad (6)$$

3. CALCULATION OF CYCLO DRIVE EFFICIENCY

The efficiency of cyclo drive by two presented method is has calculated for input parameters in Table 1.

Table 1. Cyclo drive parameters

Mark	Value
P_{EM}	4,0 kW
n_{EM}	1420 min^{-1}
u_{CR}	13
f_{r1}, f_{r2}, f_{r3}	f_{r1} = f_{r2} = f_{r3} = 0,003
f_{S1}, f_{S2}	f_{S2} = f_{S2} = 0,03
d_0	8 mm
D_0	14 mm
q	8
d_{vk}	8 mm
D_{vk}	14 mm

Cyclo drive efficiency is calculated in program created in MATLAB. Values of cyclo drive efficiency are:

- η = 94,55% (*Malhotra* method),
- η = 95,03% (*Gorla* method).

Analysis of the influence of input power P_{EM}, input number of revolutions n_{EM} and gear ratio u_{CR} on cyclo drive efficiency by both method is presented in the paper, too (Figure 4, Figure 5 and Figure 6).

Dependence of cyclo drive efficiency on input power is presented on Figure 4. Input power was varied in range from 3 kW to 5 kW. Increasing the input power, cyclo drive efficiency is increasing, too (from 93% to 96%). Values of efficiency calculated by *Malhotra* [11] and *Gorla* [12] method are very similar.

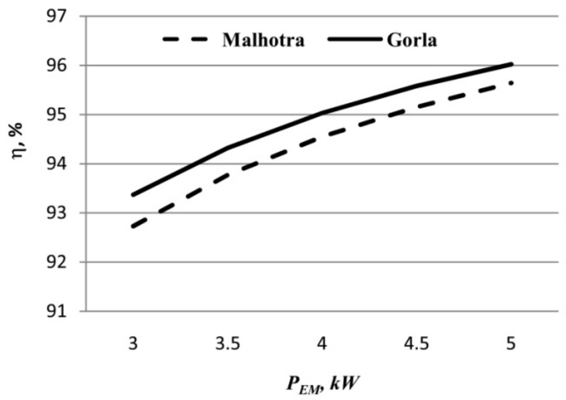

Figure 4. Dependence of cyclo drive efficiency on input power

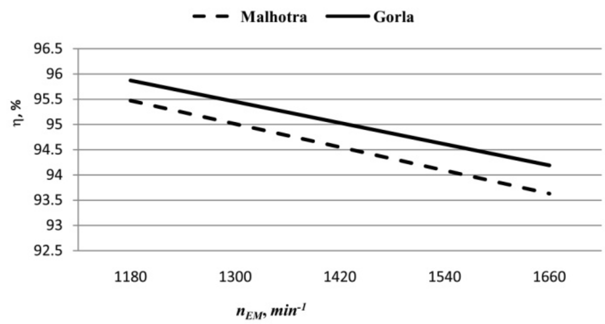

Figure 5. Dependence of cyclo drive efficiency on input number of revolutions

Dependences of cyclo drive efficiency from input number of revolutions is presented on Figure 5. Number of revolutions was varied from 1180 min^{-1} to 1660 min^{-1}. Increasing the input number of revolutions, cyclo drive efficiency decreases (for both method, Figure 5).

Dependence of cyclo drive efficiency on gear ratio is presented on Figure 6. Gear ratio was varied in range from 11 to 16. Increasing the gear ratio (*Malhotra* method), cyclo drive efficiency decreases from 95% to 94%. For *Gorla* method, cyclo drive efficiency increases from 94,8% to 95,3%.

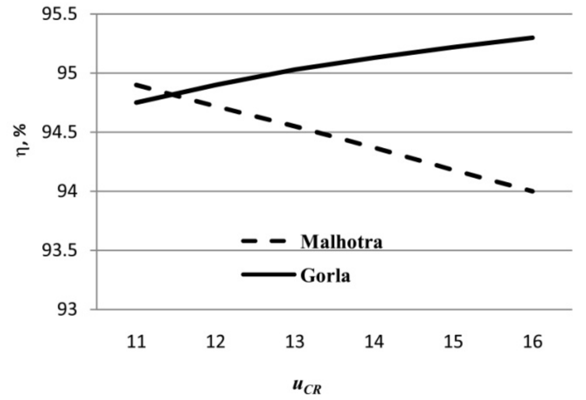

Figure 6. Dependence of cyclo drive efficiency on gear ratio

4. CONCLUSION

Two methods for calculating of cyclo drive efficiency are presented in this paper (*Malhotra* and *Gorla* method). Their complete analytical models are defined. The calculation of the cyclo drive efficiency by both methods is done for the real one-stage cyclo speed reducer.

By analyzing the results, it can be concluded the next:

- One-stage cyclo drive has very high efficiency,
- Both method (*Malhotra* and *Gorla*) have very similar values for efficiency,
- With increasing of input power, cyclo drive efficiency is increasing too,
- With increasing of input number of revolutions, cyclo drive efficiency decreases,
- With increasing of gear ratio, cyclo drive efficiency decreases (*Malhotra* method), or increases, (*Gorla* method).

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