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DYNAMIC MEASURMENT OF OVER-ALL EFFICIENCY OF SPIROID GEARS

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Abstract: *The efficiency of spiroid gear was meassured on the experimental stand in dependence on the set of independent input variables, consisting from such items as the time or position function of the driving moment and the type of the loading. Material combinations ranging from the conventional steel-bronze and to more "exotic" pairs of steel-plastics with different lubricants have been used to evaluate the efficiency of spiroid gears as the function of the applied torque.*
Key words: spiroid - gears, mechanical efficiency, experimental testing.

1. INTRODUCTION

In Fig. 1 is shown scheme of the dynamic dynamometer, which allows to measure dynamic properties of the machine aggregates. The testing equipment allows application of active and also passive dynamic loading.

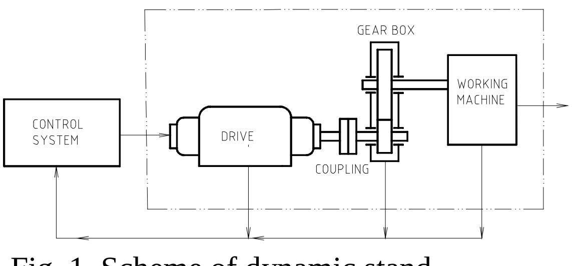

Fig. 1. Scheme of dynamic stand

Experimental equipment for dynamic loading of the machine aggregates makes possible to monitor influence of the aggregate parameters on irregularity of rotation speed ω(t) and driving torque $M(t)$ in respect of time or angular velocity $M(\omega)$, to obtain dynamic properties of the machine aggregates. It makes possible to consider suitability machine with regard to its reliability in operation, accuracy and efficiency for various loading conditions [1].
The gearbox with spiroid gearing (Fig. 2) was tested as a component of the machine aggregates containing a drive and loading machine.

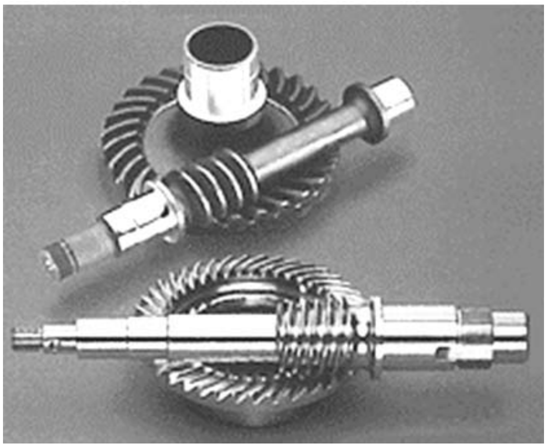
Fig. 2 Spiroid gears

The spiroid gearing is a transition gearing type between hypoid and worm gearing pertaining to gearing group with skew line axes. It consists of spiroid worm with its cylindrical or cone shape and spiroid disc gear with teeth of arc shape.
In comparison with the worm gearings, the spiroid gearings feature by smaller slips of the meshing gear surfaces, further by better conditions for formation of liquid friction and more favourable spreading of contact lines. Fundamental difference between classical and spiroid worms is given by profile asymmetry of the spiroid worm (Fig. 3) [2].

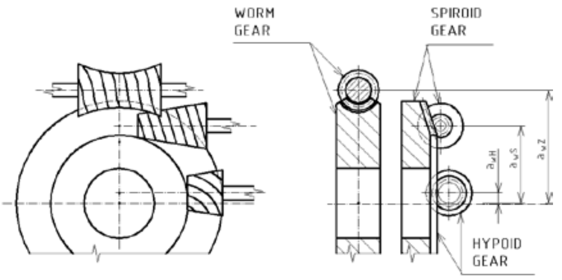

Fig. 3 Type of gears assemblage

The goal of this paper is to present results our experiments with the spiroid gear subjected to the static loading. Influence of torque size on the efficiency within various type of friction was investigated.

2. EXPERIMENTAL MEASUREMENT

The experimental measurements have been carried out using the dynamical stand, which allowed to follow influence of the aggregate parameters on irregularity of angular velocity $\omega(t)$ and driving moment $M(t)$ or to obtain dynamical characteristic of the machine aggregate in its stable and passage state in the form $M(\omega)$. It makes possible to assess machine suitability with regard to its operational reliability, accuracy and its performance within various loading effects [3].
An asynchronous motor (under frequency control) drove the tested gearbox. On the gearbox output side was located DC motor and controlled rectifier working in inverted mode. Current controller controls the rectifier when on the controller input is located generator of optional formed control voltage. Its form corresponds with shape of the transmission mechanism loading torque.
Contemporary discrete programmable control makes possible to improve pre-project documentation by means of the dynamical experimental simulations using mathematic model. By the same way can be also improved testing quality. The dynamical experiments utilising the new generation dynamometers are new testing elements. The dynamical stand makes possible verification of the measured results with the results obtained by CAMS.
In the experiment the gear box with spiroid gearing was tested. (Fig.4). The spiroid gearing was assembled using spiroid worm of cylindrical shape and spiroid wheel with teeth of arc shape.

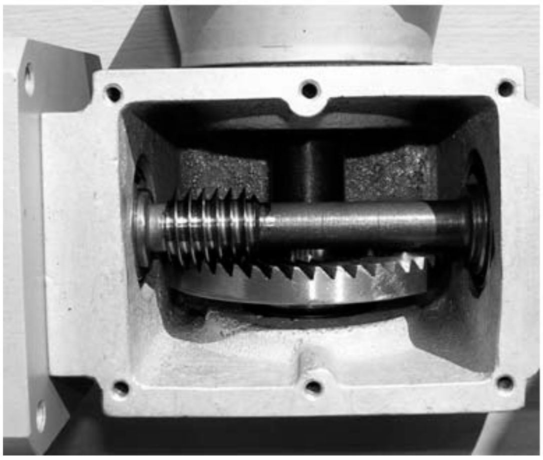

Fig. 4 Spiroid gear box

Parameters of the spiroid gear box:

- gearing modulus m = 1,75mm,
- gear ratio i = 1 : 49,

a) spiroid worm (Fig. 7):

- material - steel 12 060.4 (C 55 E),
- number of teeth: 1

b) spiroid wheel (Fig. 8):

- material - bronze Cu Al8 Fe3 (Fig.5),
  - murlubric (Fig.6).

Fig. 5 Spiroid wheel – bronze

- number of teeth: 49

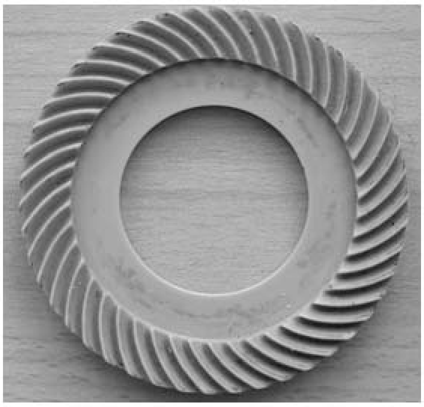

Fig. 6 Spiroid wheel – murlubric

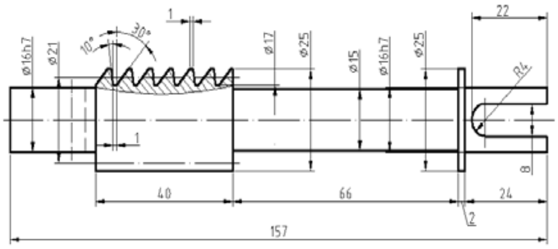

Fig. 7 Dimensions of spiroid worm

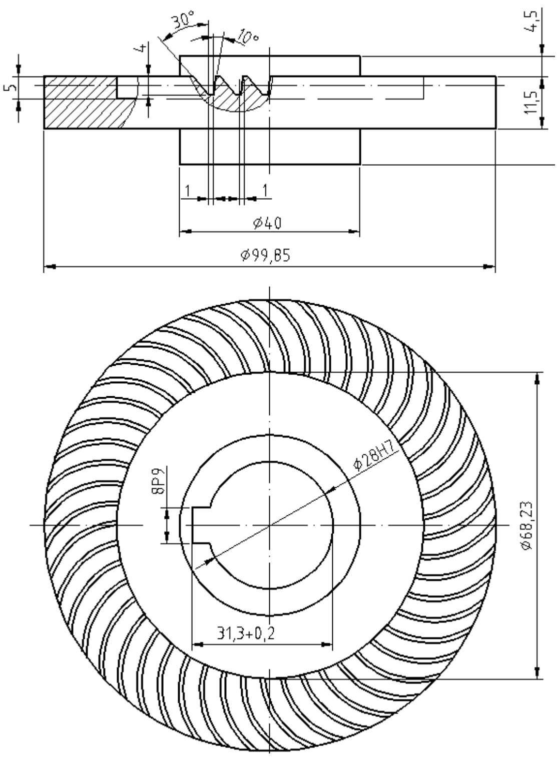

Fig. 8 Dimensions of spiroid wheel

2.1 Spiroid gear pair steel - synthetic material

In the first measurement set was efficiency of spiroid gearing combination steel - murlubric determined. Mean value of loading torque $M_z(\omega)$ for constant cycles n_d = 1 000 rpm, was used in this load state. Parameters of equation (1) used for adjustment of driving moment in the equipment control system are summarized in Table 1.

No	n_d = 1 000 min^{-1}				
	K_{-1}	K_0	K_1	K_2	ω[s^{-1}]
1	1	1	1	1	16.67
2	1.50	1.50	1.50	1.50	16.67
3	2.00	2.00	2.00	2.00	16.67
4	2.50	2.50	2.50	2.50	16.67
5	2.75	2.75	2.75	2.75	16.67
6	3.00	3.00	3.00	3.00	16.67
7	3.50	3.50	3.50	3.50	16.67
8	4.00	4.00	4.00	4.00	16.67
9	4.50	4.50	4.50	4.50	16.67
10	5.00	5.00	5.00	5.00	16.67

Table 1. Parameters of static loading moment

Value of static loading torque used in control system is calculated by equation [4]:

$$M_z(\omega) = \sum_{x=-1}^{2} K_x\, \omega^x = \quad (1)$$
$$= K_{-1}\omega^{-1} + K_0\omega^0 + K_1\omega^1 + K_2\omega^2$$

where K_{-1}, K_0, K_1 a K_2 are constants to adjust of different typical characteristics of machine aggregate,
ω is angular velocity,
x is given from the list {-1; 0; 1; 2}.

By exponent x in equation (1) is possible to tune up different standard types of loading characteristics:

x = -1, hyperbolically decreasing characteristics as function of angular velocity,

x = 0, loading is independent of the angular velocity,

x = 1 loading moment is linearly dependent on angular velocity - typical for viscous friction,

$x = 2$ nonlinear dependency of loading torque against and angular velocity.

No	DRY FRICTION		
	M_{ka} [Nm]	M_{kj} [Nm]	η [%]
1	1.55	7.45	9.78
2	1.66	10.07	12.35
3	1.87	12.67	13.86
4	1.96	15.40	16.08
5	2.13	18.08	17.36
6	2.50	20.28	16.58
7	2.82	22.38	16.23
8	3.15	24.74	16.02
9	3.51	26.96	15.66
10	3.70	28.43	15.68

Table 2. Efficiency of gearing - dry friction

No	OIL MADIT OT HP 32		
	M_{ka} [Nm]	M_{kj} [Nm]	η [%]
1	1.27	7.47	12.04
2	1.37	10.76	15.98
3	1.48	12.74	17.52
4	1.59	15.37	19.67
5	1.70	18.09	21.77
6	1.80	20.30	23.04
7	1.90	22.42	24.07
8	1.93	24.53	25.93
9	1.91	26.64	28.53
10	1.97	28.96	30.05

Table 3. Efficiency of gearing - Madit OT HP32

Mechanical losses of mechanism in steady-state are characterized by efficiency η. Gear efficiency is defined by ratio of output to input power

$$\eta = \frac{M_{ka}\omega_{ka}}{M_{kj}\omega_{kj}}, \qquad (2)$$

where M_{ka} is output torque, ω_{ka} is output angular velocity, M_{kj} is input torque and ω_{kj} is input angular velocity.

In the Table 2 are presented the values of measured input and output torque and calculated values of efficiency of spiroid gearing with dry friction. The measurements have been carried out also with oil friction using the lubrication means types - MADIT OT-HP 32 (Table 3) and MADIT PP 80 (Table 4).

No	OIL MADIT PP 80		
	M_{ka} [Nm]	M_{kj} [Nm]	η [%]
1	0.42	7.39	35.72
2	0.44	10.21	47.84
3	0.54	12.82	48.76
4	0.59	15.49	53.50
5	0.65	18.17	56.89
6	0.72	20.19	57.46
7	0.82	22.16	55.29
8	0.90	24.46	55.47
9	1.02	26.88	53.78
10	1.15	28.80	50.13

Table 4. Efficiency of gearing - Madit PP 80

The testing equipment has the limited torque value from 30 up to 50 Nm what allows measuring the transmission intended only for small loading torques directly.

Fig. 9 shows dependency between efficiency of spiroid gearing (steel - murlubric) and output torque.

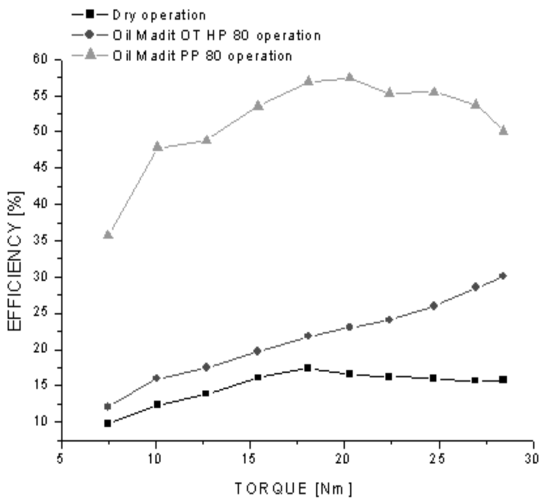

Fig. 9 The influence of constant loading on the efficiency of spiroid gear steel - murlubric

2.2 Spiroid gears by steel - bronze

In the second measurement set was efficiency of spiroid gearing combination steel - bronze determined. Mean value of loading torque $M_z(\omega)$ for constant cycles $n_d = 1\ 000$ rpm, was used in this load state. Parameters of equation (1) used for adjustment of driving moment in the equipment control system are summarized in Table 1.
In the Table 5 can be found the measured and calculated values connected with spiroid gearing with oil friction using the lubrication MADIT OT-HP 32.

No	**Madit OT HP 32**		
	M_{ka} [Nm]	M_{kj} [Nm]	η [%]
1	0.58026	5.45673	19.19
2	0.87955	10.59583	24.59
3	1.16632	15.87251	27.77
4	1.58343	24.46201	31.53
5	1.73654	27.84561	32.72

Table 5. Efficiency of gearing - Madit OT HP32

The next measurements have been carried out with oil friction using the lubrication means type - MADIT PP 80 (Table 6)

No	**OIL MADIT PP 80**		
	M_{ka} [Nm]	M_{kj} [Nm]	η [%]
1	0.81250	5.47462	13.75
2	1.11875	9.65986	17.62
3	1.41056	16.11797	23.32
4	1.82400	24.75865	27.70
5	2.03980	28.53256	28.55

Table 6. Efficiency of gearing - Madit PP 80

The next measurements have been carried out with oil friction using the lubrication means type - MADIT HYPOL (Table 7).

No	**Madit HYPOL**		
	M_{ka} [Nm]	M_{kj} [Nm]	η [%]
1	0.71279	5.60280	16.042
2	0.97641	10.91269	22.81
3	1.21591	16.10327	27.03
4	1.61548	24.76020	31.28
5	1.97382	34.93250	36.05

Table 7. Efficiency of gearing - Madit HYPOL

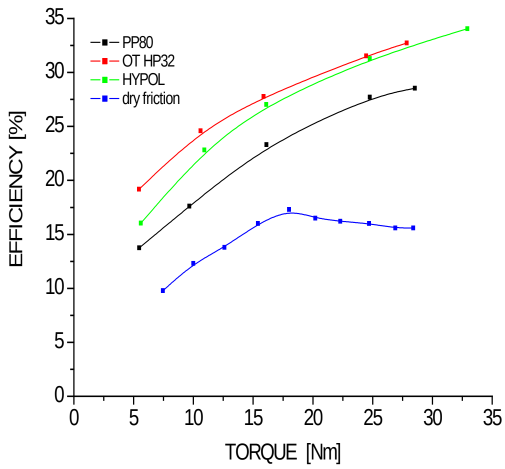

Fig. 10 The influence of constant loading on the efficiency of spiroid gear steel - bronze

Fig. 10 shows dependency between efficiency of spiroid gearing (steel - bronze) and output torque.

3. CONCLUSION

The equipment for dynamical loading of the machine aggregates and mechanisms can be used for simulation of dynamic loading with defined static and dynamic parameters within a considered technological process. The dynamic dynamometer can be used in laboratory, production, input tests and for service life tests of any subsystem of a mechatronical systems under given dynamic loads.

The main aim of this paper is to present the problematic of static load influence on the spiroid gears and influence of torque value on gear efficiency by consideration of various type of friction. The tested spiroid gearbox has the gear ratio $i = 49$ with gearing modulus m = 1,75 mm. Material of spiroid worm was steel and gear wheel was made from bronze and/or murlubric. The measured and calculated results show that the lowest efficiency is within dry friction run. After reached maximum efficiency, the efficiency is decreasing while the further loading still increases – Fig. 10. Rise of loading (torque) for spiroid gearing with the lubrication leads to the increase of gear efficiency. The highest efficiency 57% was reached with gear wheel made from murlubric and with the lubrication using MADIT PP80. Gear wheel made from bronze achieve efficiency 36% with the lubrication using MADIT HYPOL.

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