THE INTERNATIONAL CONFERENCE OF THE CARPATHIAN EURO-REGION SPECIALIST IN INDUSTRIAL SYSTEMS
6th edition

FRICTION RESEARCH OF POLYMER GEARS

Gábor Kalácska[1], Róbert Keresztes[1], László Zsidai[1], Patrick DeBaets[2]
[1] Szent István University Gödöllő, Hungary,
[2] University of Gent, Belgium

ABSTRACT
Technical polymers are widespread in the machinery owing to their beneficial properties against metals as operation without lubrication, low friction and wear, light weight, corrosion resistance, low manufacturing costs etc. There are many sorts of technical polymers available of which sliding elements can be produced.[1] To choose proper polymers for a given tribological application is not a simple task owing to many different parameters influencing the performance of a polymer sliding element. We launched a broad research project to clarify the friction and wear phenomena of plastic gears. With this presentation we introduce the newly developed measuring system for studying the friction process between the meshing gears.

1. INTRODUCTION

In many cases investigations on tribometers in laboratory are used to compare the tribological properties of different polymer/metal pairs. In our institutes also many investigations on the tribological properties of technical polymer/steel pairs were performed on different tribometers. The main results were published earlier [2, 3]. Regarding the different ranking of polymer/steel pairs from the point of view of friction and wear obtained by many different tribometers and test-systems, it would be difficult to choose the best polymer/steel pair to make a polymer gear. Based on the survey of the semi-finished engineering polymer distributors and producers we selected the top five engineering polymers used for gears on the European market to investigate their friction and wear properties using test gears.

2. MATERIALS

The properties of the investigated polymers are presented in the Table 1.

Table 1. Properties of investigated polymers [4]

Polymer	Elongation at rupture A (%)	Young modulus E (MPa)	Rockwell M hardness	Tensile strength R_m (MPa)
PA6G-Mg catalytic	40	3000	86	85
Pa6G-Na catalytic	25	3300	88	80
PA66GF-30	7	5200	98	185
POM-C	30	3000	86	70
PETP/PTFE (TX)	8	3200	94	75

The gear mating with polymer gears was made of structural steel S355 with a surface finish (CLA) R_a 2,5 μm.

3. FRICTION EXPERIMENTS WITH REAL GEARS

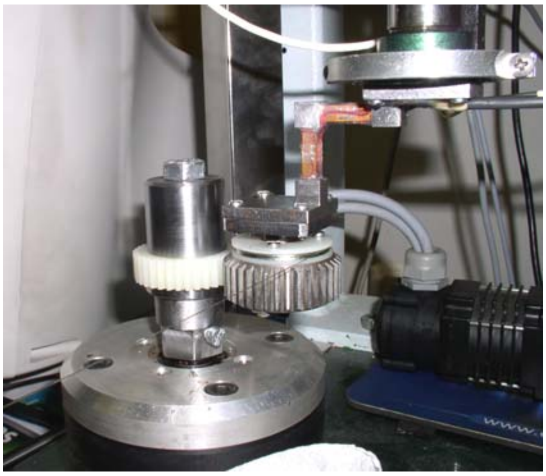


Fig.1: Tested gear pairs

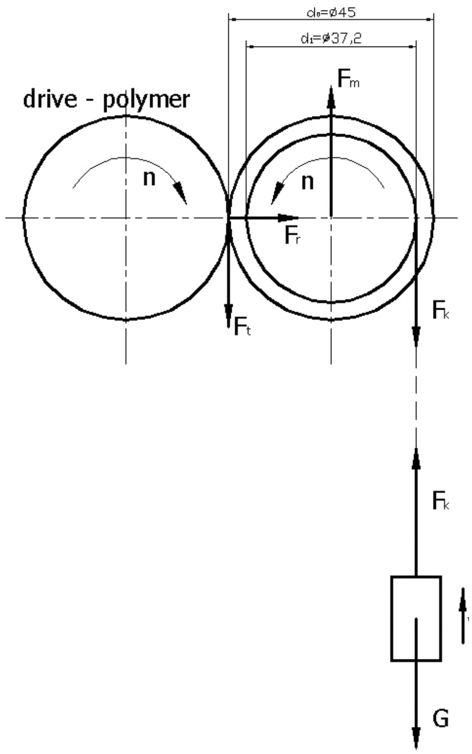


Fig.2: Testing arrangement

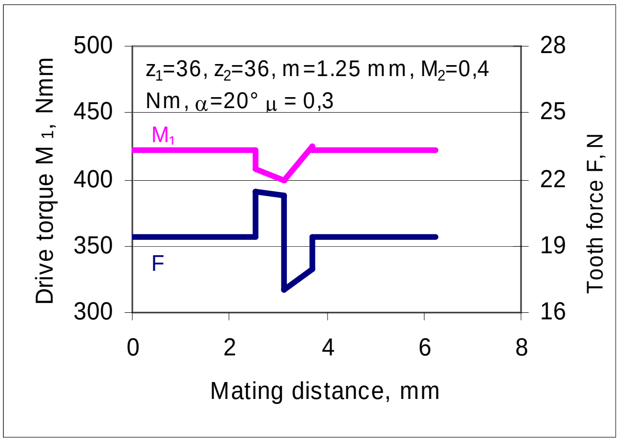


Fig. 3 Calculated values

In the literature we can find different theoretical approach of the gearmesh [5, 6, 7, and 8] but no real information of the polymer/steel friction pairs. We started to approach the phenomena with a real gear tests.

During the experiments a large variety of tangential speed between 0.01 – 0.15 m/s and torque between 0.1 – 0.4 Nm were applied resulting many graphs to evaluate. During the experiments on a polymer/steel spur gear pair loaded with a constant applied torque the radial component (F_r) and the tangential component (F_t) of the tooth force were measured (Fig.2). The variation of the registered radial and tangential force showed the influence of the friction force.

The variation of drive torque and tooth force were calculated taking into consideration the friction coefficient μ and a constant applied driven torque M_2 (Fig. 3). The measured component of forces altered from the calculated owing to the changing the coefficient of friction during the meshing and the misalignment of gears making difficult to evaluate the actual friction coefficient between the teeth of polymer/steel gears.

Regarding the measured forces at our wide testing condition there were no significant differences in efficiency of the different polymer/steel gears. To present the fluctuation of the forces during the contact cycles it is necessary to enlarge the measured graph to show every measured point. This was solved with the following test system.

4. FRICTION EXPERIMENTS WITH MODEL TEETH

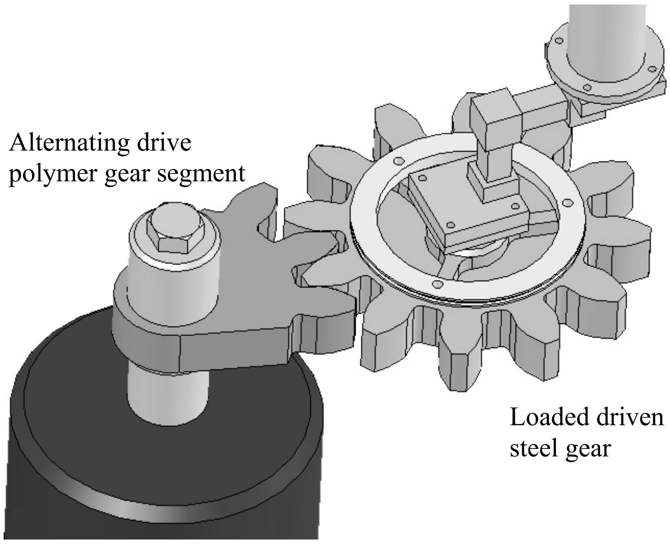


Fig.4. Teeth connection test model

The real-time measurements with real gears give tribological data for general conclusions regarding the friction losses, heat generation etc. There is no information about the friction change or not change along the connection line during the gear mesh. There is no information about the effects of the surface deformation, load distribution – one or two teeth pair connection – during the meshing.
Concluding from the previously mentioned continuously running real gear tests we can state that the investigation of the friction between gear teeth can be achieved with a specially developed test systems, where the main feature of the test systems is the repeatable data collection along the connection line.
That's why we have developed a test method shown in fig. 4. where we can measure the different forces during the gear mesh. In this developed method there are no rotational movements, just an alternating one. We study one connection point along the connection line of teeth pairs.
Knowing the basics of gear studies that means two-pair connection at the beginning and at the end of the connection line and one-pair connection in the neighbourhood of t he pitch point („C").
Regarding the alternating movements we do not need whole gear just a three-teethed segment. From the technical view of the mating steel gear it must be prepared for full size due to balancing reasons.
When we select a given teeth pair in the system, we can calculate the angular position of the start and end of the connection point.
During the tests we have to measure the radial and tangential forces between the extreme points according to the fig. 5. layout of the measurements.
In the system the steel gear is mounted by means of roller bearing on the shaft equipped with strain gauge. In this case we can measure the forces during the gear mesh and we can monitor a single point of connection along the connection line. The angular values can be determined by the angle-data transmitter mounted on the polymer gear segment. The layout can be seen in fig.5.

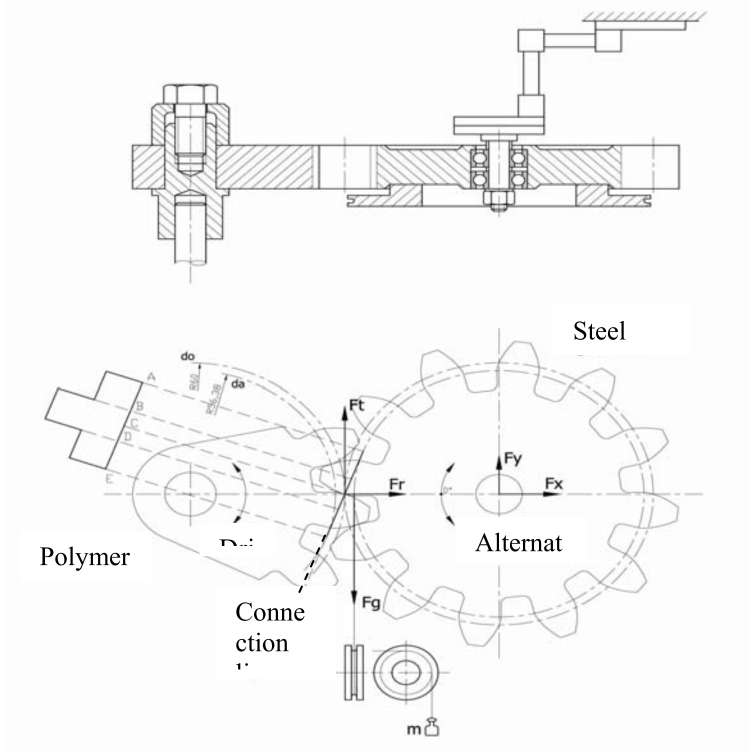
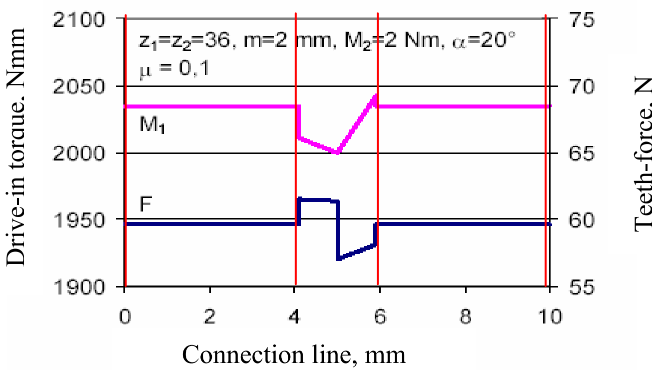


Fig.5. Teeth connection model

5. EVALUATION

The very detailed evaluation has been running in frame of a PhD program. Now we show the basic information content of the measurements.
We calculated the angular position the start and end point of the connection, and the one-tooth pair regime on the connection line.
During the measurements the number of teeth both polymer and steel gear were the same, so the transmitted ratio was 1. For the reference point of the angle-data transmitter the pitch point was set. In this case the diagrams of the connection forces are symmetrical, easy to plot and understand.
One-teeth-pair connection can be identified between -7.5° and 7.5°.
The start of the connection can be found at -21.3° and the end at 21.3°.
In the research program we use two different thicknesses of the polymer gear segment – 5 and 10 mm - to improve the loading possibilities of the gear surfaces.
The applied module was 10 mm, involutes teeth profile and Z=12.
Kozma [9] earlier studied the friction phenomena between the gears and found that the forces and torque during the connection changed due to the friction. He distinguished two cases: the change of the teeth-force and torque in case of constant drive torque, and the change of teeth-force and torque in case of constant driven torque. The latter can be seen in fig. 6. In his theoretical studies he took constant friction between the surfaces, however we know from our previous research projects and from the literature that the friction between a polymer and steel surfaces was nearly



never constant.
In the fig.7. we can see a measured diagram of a gear mesh along the connection line. On the horizontal line we can found the angular movement. Vertical lines split the curves in the function of the characteristic regimes: two-teeth- pair, one-teeth-pair and again two-teeth-pair connections, according to the calculation based on the geometries.
Two driven loads were applied:1.12 Nm and 2.25 Nm for testing resulting two curves in the diagrams.
The upper diagram of fig.7. shows the change of F_x shaft forces (fig.5.) in case of two load levels. It is very easy to identify the certain connection regimes even comparing to the theoretical graphs of Kozma and the approaching results of NASA [10] published earlier. The tendencies of the theory and practice are similar – even the neighbourhood of the pitch point, 0° in the diagram - but not the same.
There are many influencing factors during a practical measurement, but the slightly differing slops on the curves and transition points can be identified.
We found that one of the main influencing factors in our well-controlled test system is the changing friction effect between the teeth surfaces. That correlates with our broad static and dynamic pin-on-disc polymer/steel tribotest results.

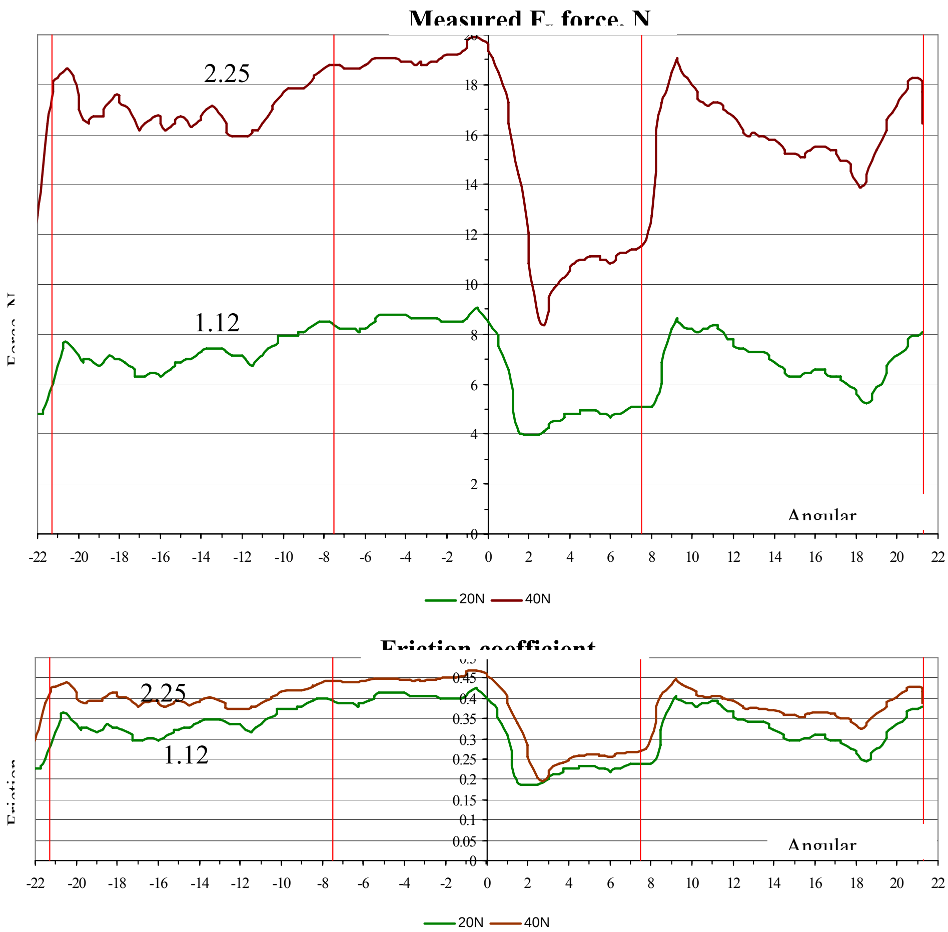


Fig.7. The measured forces and friction along the connection line

The lower diagram of fig.7. shows the change of the friction coefficient along the connection line. In our case the definition of the friction coefficient is ratio between the normal and tangential forces of each point during the gear mesh.

The measured friction values change between 0.2 and 0.45 in case of cast polyamide 6 drive gear segment in the running in stage.

6. Conclusions

- The newly developed test method and testrig can be used for more detailed friction investigation between different teeth pairs.
- We can monitor the change of friction along the connection line; we can clarify the role of friction in case of different mashing materials.
- During the connection we can distinguish by measurements and calculation the tree main regimes: two-teeth-pair, one-teeth-pair and two-teeth-pair connections.
- The former theoretical and practical results are in accordance, but the theoretical results can be enhanced.
- The developed method is suitable to investigate the teeth-forces and torque, the friction along the connection line in case of different load and speed, too.
- During longer operation period the change of the mentioned factors can be monitored in the function of time: the change of friction results not constant efficiency of the drive.
- To establish this new technical information of the polymer/steel gear pairs further measurements are needed.

ACKNOWLEDGEMENT

The project were supported by OTKA T42511, OTKA T37244 and TéT B-1/04 research funds.

REFERENCES

[1] Antal – Fledrich – Kalácska – Kozma: Műszaki műanyagok gépészeti alapjai, Műszaki műanyagok gépészeti alapjai, Minerva-Sop Bt. Sopron, 1997

[2] L. Zsidai, P. De Baets, P. Samyn, G. Kalacska, A.P. Van Peteghem, F. Van Parys: 2002, The tribological behaviour of engineering plastics during sliding friction investigated with small-scale specimens. WEAR 253 p. 673-688. Elsevier.

[3] P. Debaets, F. Van Parys, G. Kalacska: 2002, The friction and wear of different polymers under high load conditions. = Synthetic lubrication, Vol 18, 2002, p. 109-118. Elsevier.

[4] www.quattroplast.hu

[5] Duda M.: Der geometrische Verlustbeiwert und die Verlustansymmertrie bei geradverzahnten Stirnradgetrieben. Forschung im Ingenieurwesen 37, 1971.

[6] Radzimovsky, E.I., Mirarefi, A., Broom, W.E., Instantaneous Efficiency and Coefficient of Friction of an Involute Gear Drive, ASME Journal of Engineering for Industry, Nov. 1973, p. 1131–1138

[7] Niemann G., Winter H.: Maschinenelemente II. Sringer Verlag Berlin, 1989.

[8] Ishibashi A. Et al.: Effect of Type of Lubricant an Shape of Tooth Profile upon Efficiency of Gear Drives. Lubrication Science Vol. 11. No. 2. 1999. p. 135-163.

[9] Kozma Mihály: A fogaskerekek súrlódási vesztesége. Gép. okt. – nov., 2004

[10] Brian Rebbechi, Fred B Oswald, Dennis P. Townsend: Measurement of Gear Tooth Dynamic Friction. NASA Technical memorandum 107279, Army Research Laboratory, 1996