# Pronounced Temperature/Time Behaviour

## Plastic/Metal Sliding Pairs under Dry Friction

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In the investigation of the high ratio, high precision Wave Drive gear, interest focussed on the friction moment, friction coefficient and temperature profile. The authors determined these properties experimentally on a belt-drive test rig.



The Wave Drive gear is constructed from different polymers. Apart from its high gear ratio of 1:50 to about 1:5000, its other advantages include lightweight components, good acoustic properties and low costs. However, it also has a number of disadvantages, which result primarily from the use of thermoplastics. They include the low moduli of elasticity, low thermal conductivities and pronounced temperature/time dependencies. These disadvantages directly affect the lifetime of the gear and limit its range of applications. The permissible loads depend on the individual case and on the required lifetime of the gear, since the tribological system behaviour must always be taken into account (Fig.1). The tribological system depends on the sliding process, the friction counterparts involved, the surface topography, the load and the ambient conditions.

At the chair for engineering design of the University of Erlangen-Nuremberg/Germany, a range of experiments were carried out in close cooperation with Oechsler AG as part of a research project called "Development of a novel plastic gear operating according to the Wave Drive principle".

### The Gear under Test Rig

The gear [1] consists of an elliptical wave generator connected to the drive axle, an elastically deformable pulsator wheel, a flexband with external gearing, a housing with ring gear, a housing without ring gear, and an output ring gear with internal toothing. The output ring gear has a diameter of 50 mm. Via the elliptical wave generator, the pulsator wheel generates a "transverse wave". This results in continuous deformation of the cylindrical flexband. A relative movement is produced by the differences in the number of teeth between the flexband and the internally toothed ring gear. The gear ratio is the result of the ratio of the number of teeth 2 ($T_2$) to the difference between the number of teeth 2 and the number of teeth 1 ($T_2$–$T_1$). Since the difference between the two numbers of teeth is generally small (e.g. $T_2 - T_1 = 2$), torques can generally be transmitted with large ratios. The elliptical wave generator has a high speed during operation. This results in considerable sliding friction between the wave generator and pulsator wheel under various operating conditions.

To investigate the tribological properties between the wave generator and pulsator wheel under sliding friction, a belt-drive test rig (Fig. 2) was developed at the chair for engineering design at the University of Erlangen-Nuremberg. The belt-drive test rig consists of a drive motor, a drive pulley, an output pulley, a pneumatic loading device, two toothed belts and a torque transducer. The motor is controlled by means of a PC. The metal wave generator is attached to an axle, connected to a torque measurement shaft. The pulsator wheel is rotated with respect to the wave generator by the friction of two toothed belts. The contact pressure is exerted by a compressed air cylinder mounted on a linear bearing (Fig. 3). The contact pressure can be adjusted between 0 and 500 N to simulate an output torque of between 0 and 65 Nm on the "50 mm size" gear. The speed of the pulsator wheel may be varied up to a maximum of 20 000 rpm by changing the drive pulleys. The test data are recorded by means of Catmann software.

### Frictional Torque on the Wave Generator

Since sliding friction predominates between the wave generator and pulsator wheel, the friction moment, which is determined by the appropriate coefficient of friction, play an important role. The moment of friction between the wave generator and pulsator wheel was measured by means of a torque transducer. The dependencies of the frictional torques on the contact pressure and speed are shown in Fig. 4. It can be seen that the frictional torque of the plastic/metal combination depends both on the contact pressure and on the speed. As the contact pressure and speed both increase, the friction moment also rises. The friction moments measured on the test rig agree satisfactorily with the model developed theoretically.

The friction moment measured on the belt-drive test rig shows a pronounced tribological characteristic of the friction combination. This changes in proportion to the increasing contact pressures. In the illustrated case, the magnitudes of the friction moments also change as the speed is varied. The friction torque can be determined from the corresponding friction coefficient between the wave generator and pulsator wheel.

### Dynamic Friction Coefficient

The dynamic friction coefficient is directly related to the heat generated between the pulsator wheel and wave generator. The dynamic friction coefficient between the wave generator and pulsator wheel can be obtained by evaluating the friction moments. The dynamic coefficient is virtually constant below the softening point of the material. However, if the softening point is exceeded, the friction coefficient

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increases suddenly. This can be attributed to a very large friction power loss between the wave generator and pulsator wheel, which causes melting of the pulsator wheel.

Further experiments proved that the friction coefficient between the metal wave generator and plastic pulsator wheel shows the same phenomenon in continuous operation. In temperature ranges in which the plastic softens, the friction coefficient increases rapidly as the temperature rises. The absolute values at the melting point are almost twice as high as in the lower range of the softening point. In zones adjacent to the softening ranges, constant friction values are to be found between the plastic/metal combinations. In these cases the material properties do not change suddenly.

## Temperature Variation

The temperature of the slide surfaces depends essentially on the ambient temperature, the tribological stress and the heat dissipation conditions. Since the metal wave generator has much higher thermal conductivity than the pulsator wheel, the measured temperature virtually corresponds to the slide surface temperature. The temperature profiles measured on the metal wave generator are shown in Figs. 5 and 6.

This description shows that the pulsator wheel quickly exceeds its softening point at high speeds and high contact pressure, and fails because it melts. Below a contact pressure of 40 N and a drive speed of 1000 rpm under dry friction, the POM SW (polyoxymethylene) pulsator wheel remains functional for a relatively long time. The same applies to the pulsator wheel material POM TF at a contact pressure of 20 N, a drive speed of 1000 rpm and under dry friction. If the frictional combinations are required to transmit a maximum output torque at a particular speed, these plastic/metal combinations can only be used in continuous operations in the temperature range from 80 to 120 °C if certain drive times and cooling down times are observed [2]. At higher temperatures, the wear is significantly increased by melting and the lifetime decreases correspondingly.

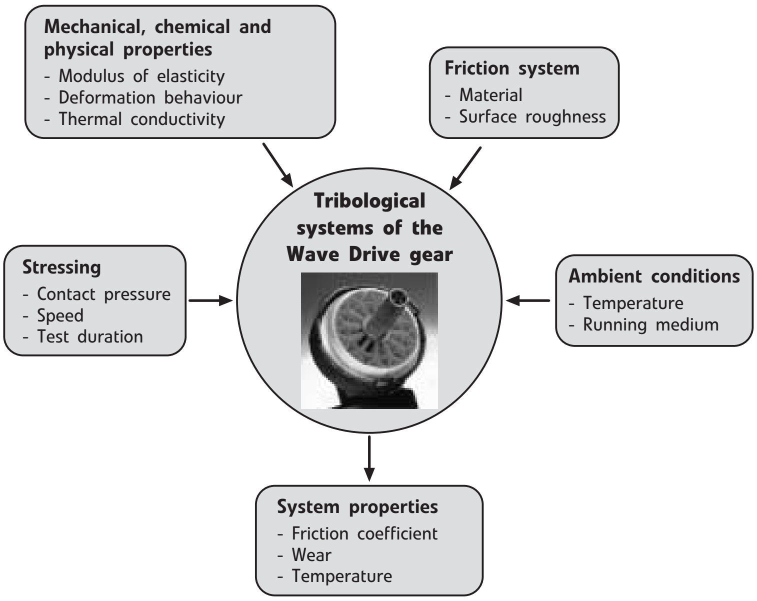


*Fig. 1. The tribological system of the Wave Drive gear is affected by the sliding process, the frictional combinations and their surface topography, and on the loading and ambient conditions*

## Summary

For configurations in which POM SW and POM TF are combined with a metal wave generator, the experiments demonstrated a virtually uniform scattering range of softening points and melting points. The plastics' thermal limit is determined by its heat resistance. Under dry friction, the contact pressures that can be transmitted between the wave generator and pulsator wheel are between 20 and 40 N. It is notable that the aforementioned combinations only allow brief operation once the limiting speed has been exceeded.

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*Fig. 2. The belt-drive test rig at the chair of design engineering at the University of Erlangen-Nuremberg consists of a drive motor, drive pulley, output pulley, pneumatic stressing device, two toothed belts and a torque transducer*

*Fig. 3. The toothed belts here produce the contact force on the elliptical wave generator*

*Fig. 4. The frictional torque of the plastic/metal combination depends on both the contact pressure and speed. As the contact pressure and speed are increased, the friction moment also rises*
*Reibdrehmoment = Friction torque; Presskraft = Contact pressure; 1/min = rpm*

*Fig. 5. Temperature profile of the POM SW/metal generator*
*Gleitflächentemperatur = Temperature of the slide surface; Zeit = Time; Schmelztemperatur = Melting point; Erweichungstemperature = Softening point*

*Fig. 6. Temperature profile of the POM TF/metal generator*
*Gleitflächentemperatur = Temperature of the slide surface; Zeit = Time; Schmelztemperatur = Melting point; Erweichungstemperature = Softening point*