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A new method for description of the pitting process on worm wheels propagation

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ABSTRACT

The purpose of this study concerning the pitting damage on worm wheels is dual. The first aim is to formulate an empirical correlation between the pitted area and the number of load cycles based on the determination of damaged areas from digital images. Second, it aims at revealing damage dynamics by using the very same set of digital images processed and presented in a novel way.

Test results for 6 teeth are used to formulate a new correlation between the pitted area and the number of load cycles, which is then compared to the referent one. Results show that the differences between the pitted areas measured in this study and in the referent one surely exist, which has an impact on the empirical formulation and thus the prediction of the worm wheel life. Also, an interesting finding is how the damaged areas overlap on the teeth, with more than 50% occurring only on one tooth or two. This could be explained through the contact complexity of a real worm pair.

1. Introduction

Because of benefits derived from their geometry and working principle, worm drives are irreplaceable parts in power transmission industry and applications. They are used where achieving high transmission ratios with small assembly dimensions in one reduction stage is needed. They are characterised by silent operation because of the dominant sliding motion between tooth flanks of the worm gear and the worm wheel. On the other hand, their performance is highly dependent on the lubricating film thickness which is, in turn, influenced by many operating parameters such as lubricant, sliding speed, surface roughness, load, paired materials, worm profile, shaft deflection, meshing error, and temperature.

Worm wheel, usually the driven member of worm drive, is prone to severe damage, such as sliding wear, pitting, tooth breakage, and scuffing [1] [ISO-loading]. Fig. 1 (left to right) shows examples of scuffing, the result of completely worn tooth in combination with tooth breakage, and finally pitting on the exit side of a wheel tooth.

While scuffing and tooth breakage usually occur due to irregular operating conditions [2,3], sliding wear and pitting are more usual damage types that could occur even in normal operating conditions [4]. It is known that, unlike steel spur gears where the occurrence of pitting usually announces a near end of service [5], worm gears can operate even if pitting areas on a worm wheel exceed 40% of the total tooth flank area, with or without a significant efficiency loss.

Pitting phenomena and stress distribution on worm wheels are investigated by many authors and by different approaches: by conducting tests [6,7,8] or, more often today, by performing simulations [9,10,11]. This study aims at dealing with experimental approaches, with the method of measuring pitted areas in particular.

1.1. Measuring of pitted areas

Thirty years ago, not many researchers had access to some kind of a highly accurate area measuring device. Measuring of an area was usually performed by means of a planimeter [12]. However, it was shown [13] that planimeters of various kinds produce more or less accurate values depending on the area being measured. The equations from [13] presented in a diagram (Fig. 2) show inversely proportional dependence of errors on measured areas resulting in greater errors for smaller measured areas.

In view of the small size of individual pits, it seems reasonable to conclude that measurement errors can be extremely high. Bearing in mind that these values were used to formulate correlations between the pitted area and the number of load cycles, one could justifiably express his/her doubts on the usability of those correlations [7,8]. For comparison, similar testing is performed on two worm wheels and pitting advance is documented by digital images.

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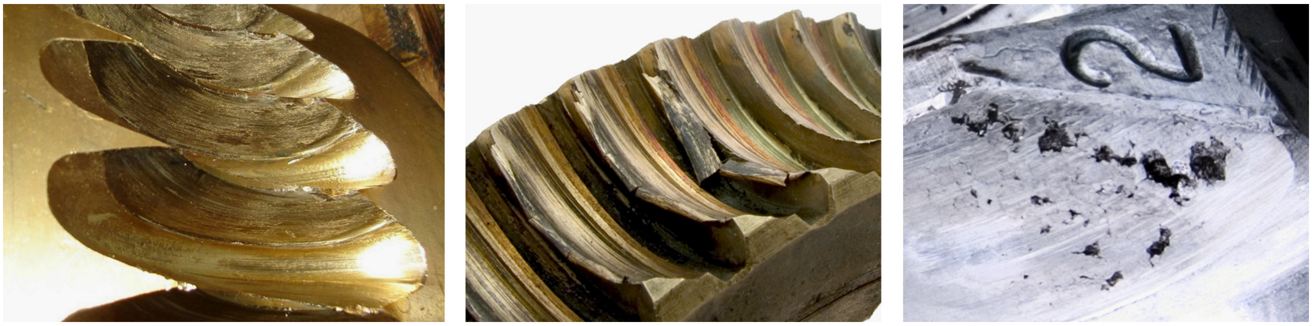

Fig. 1. Most common types of damage on worm wheels.

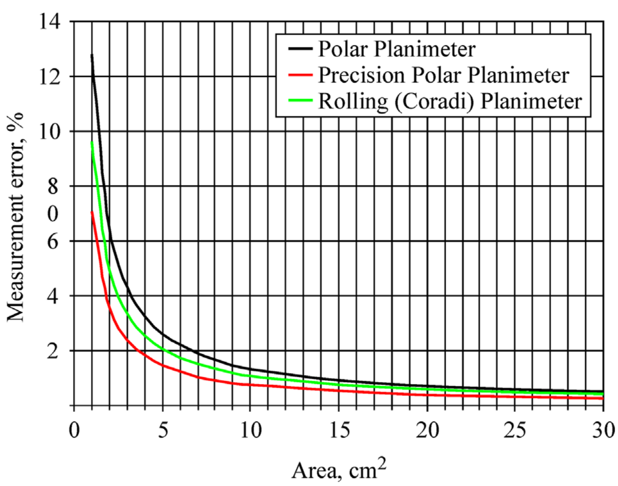

Fig. 2. Dependence between the measured area and the measurement error for single, not repeated, area tracing.

Table 1
Basic data on gearing.

	Number of teeth	Face width (mm)
Worm wheel 1	36	40
Worm wheel 2	36	32
Worm gear	2	

2. Materials and methods

2.1. Gearbox and gearing

The testing is performed on two worm wheels made of (1) AlSn6 and (2) CuSn12 while the worm gear is made of case hardened steel 16MnCr5 (Table 1). The worm gear is positioned below the wheel. Modulus of the ZN type gearing is 4 mm, the centre distance 90 mm, and the pressure angle in the normal plane is 20°. Each sixth tooth on the wheel is marked with a corresponding number, which gives a total of 6 teeth on each wheel.

The gearbox used in this investigation is selected from a regular assortment after being carefully checked for geometrical accuracy in order to eliminate a potential influence of serious manufacturing errors. The casing of the gearbox is adopted and equipped with temperature sensors, a robust camera carrier (Fig. 3, left, parts 10–15) and a precisely built and assembled worm wheel locking mechanism (Fig. 3, left, parts 1–7). Both the carrier and the locking mechanism are firmly attached to the casing. The carrier is positioned so that the axis of the camera objective corresponds with the tooth flank normal at the pitch diameter and half face width. Because of the design of additional gearbox equipment and the nature of investigation, the disassembly of the gearbox is not needed. In this way, all the parts maintain their original positions from the very beginning to the end of testing.

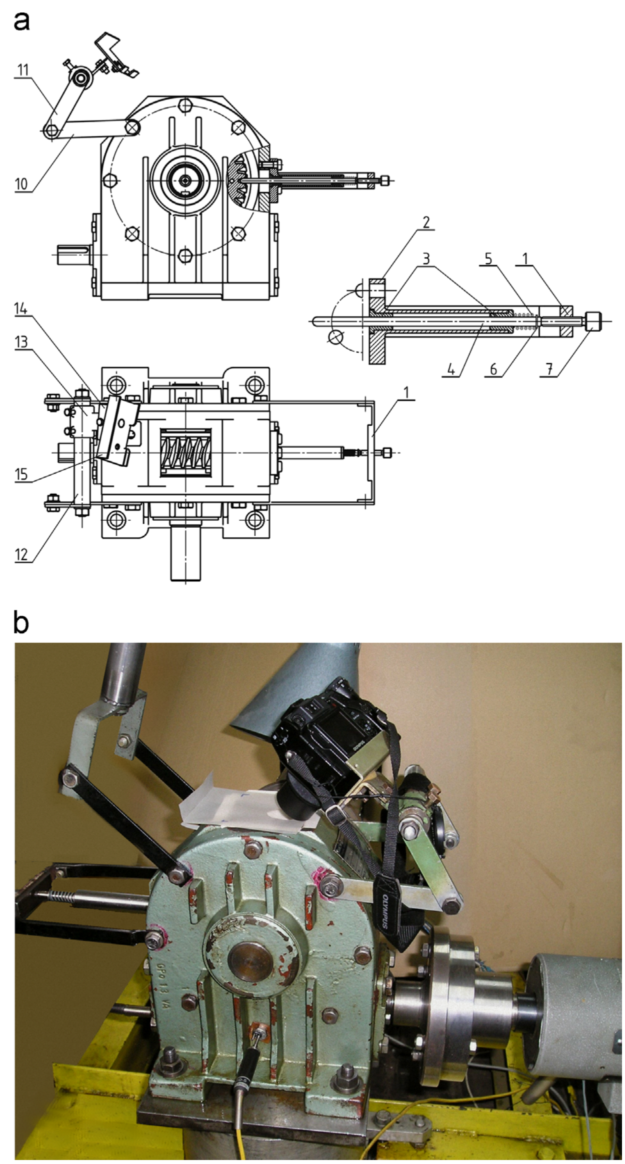

Fig. 3. Assembly drawing (a) and a photograph of the gearbox in use (b).

2.2. Lubricant

Oil used for lubrication of gearing complies with a recommendation for the selection of oils for worm gearboxes based on