MEASUREMENT OF THE TEMPERATURE ON TOOTH FLANKS OF GEARS WHILE RUNNING

Peter J. Kral [(1)], Stefan Pausch [(2)]

[(1)] Department of Machine Elements, Vienna University of Technology, Vienna, Austria
Phone (+43-1) 58801/30614 Fax (+43-1) 58801/30699 e-mail: peter.kral@tuwien.ac.at
[(2)] Department of Machine Elements, Vienna University of Technology, Vienna, Austria
Phone (+43-1) 58801/30614 Fax (+43-1) 58801/30699

Abstract – *This paper presents a measurement method for measuring temperature values of test gears on a test bed. For better understanding of the wear behaviour of worm gears and for analysing the contact conditions between the flanks of worm and worm wheel in presence of lubricating oil, it is necessary to know the temperature of the contact area. The oil between the flanks is heated by the hot flanks and therefore the viscosity of the lubricating oil is reduced. For this reason the temperature curve of the contact area and thus the oil temperature between the flanks was measured and afterwards applied to a mathematical simulation for calculating the wear. The measurement of the temperatures on the surface of the tooth flank, of the oil temperature in the contact area and in the oil sump is done with aid of thermocouples and temperature-dependent resistors, type PT 100. The construction of the test bed and the measurement circuit is also presented in detail.*

Keywords - Measurement of temperature, surface temperature, gears, worm gears

1. INTRODUCTION

For testing gears (wear, temperature, efficiency, ...) [1-3] it is often necessary to evaluate the temperature of the lubricating oil, the surface of the gearbox and the surface of the tooth flanks and the lubricating oil between the tooth flanks while the gearbox is running the test cycle.

Within the scope of a doctoral thesis [4] for calculating wear [5-8] of worm gears under various conditions (type of lubricating oil, materials and geometry of the wheels and flanks, load of the gear, ...) the temperature on the surface of the tooth-flanks was measured.

2. TEST BED FOR MEASUREMENT

Fig. 1 shows the test bed which was used for measurement of the temperatures (of gearbox surface, flanks of the teeth, oil sump), efficiency of the gear, wear and noise level of the test gears.

The gearbox (1) is mounted on a stable steel frame. The drive motor (2) is directly flanged to the gearbox to guarantee the same configuration as built-in in the moving staircase used in practice. A chain transmission (3) (in a speed ratio of 3:1) between gear and regulated pendulum generator (4) reduces the output-torque and makes it possible to use this generator as brake generator. The equilibrium of the pendulum generator is achieved by regulation (5) of its excitation current and therefore of its excitation field. The energy produced by the generator is converted into warmth by an electric resistor (6). To adjust the output-torque exactly, the generator is loaded by using weights (7). The effective power of the drive motor is measured with the 2-Wattmeter method (8).

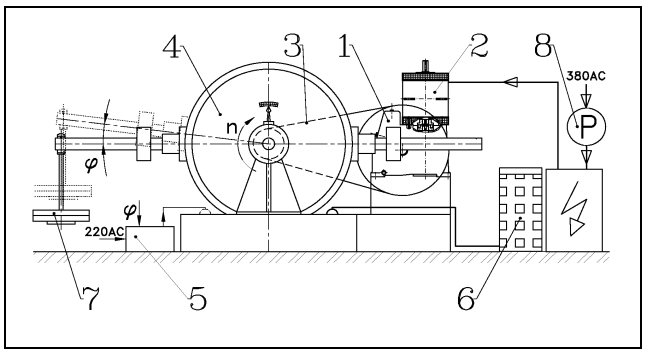

Fig.1 – Test bed for measurement of temperatures (oil, surface of the tooth), wear and gear efficiency.

2.1 Attaching the thermocouples

For measuring the surface temperature of the contact area five thermocouples (see section 4) are glued as closely as possible to the contact area. The exact positions of the thermocouples can be seen in Fig.2. To get the temperature distribution of the whole worm wheel the five thermocouples are fixed at the gear rim and/or tooth flank (number 1, 2, 4, and 5) and on an inner point of the wheel (number 3). Thermocouple number 4 is mounted on an inner point of the tooth flank, nearest to the contact area. It is necessary to glue the sensor as closely as possible to the contact area to get accurate and realistic measurement results. But mounting the thermocouple within the contact area is not possible because the occurring force and friction would damage the sensor quickly.

For gluing the thermocouples to the surface of the worm wheel a liquid metal-adhesive on the basis of epoxy resin is used. This adhesive tolerates maximum temperatures of 160 degrees Celsius and is resistant against synthetic lubricating oils.

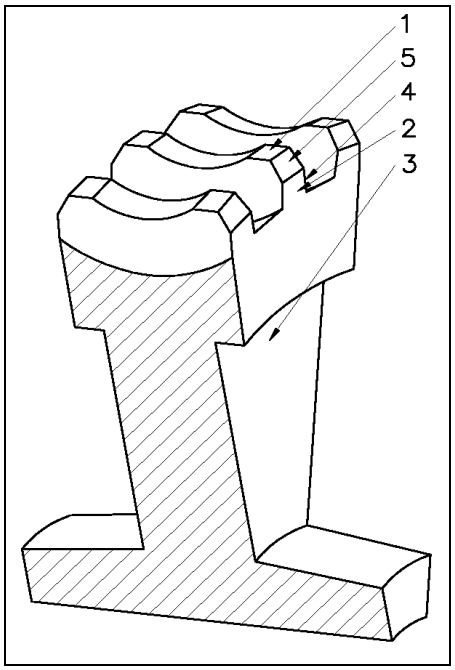

Fig.2 - Positions of the thermocouples.

2.2 Additional preparation of the worm wheel

Fig.3a and 3b show the configuration of the complete measurement set-up (on the worm wheel). The thermocouples (1) are glued to the five positions (see also Fig.2) mentioned in the above section. The electronic evaluation unit (2) is kept in a oil-tight case which is mounted on the rotating worm wheel (3). Thermocouples and electronic evaluation unit are connected through electric cables.

The digitised output signal of the electronic evaluation unit is led out to the computer by a sliding contact (4) and a rotor slip ring (5).

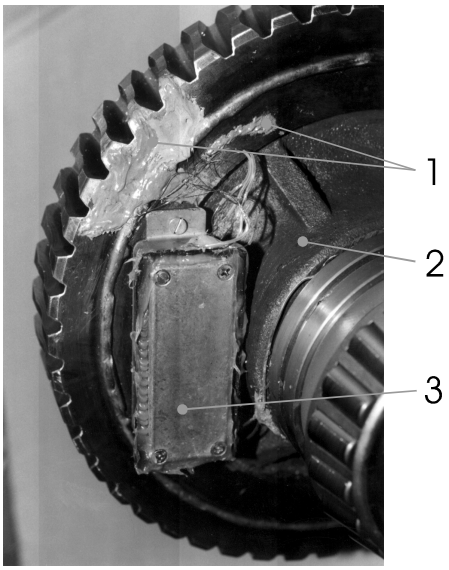

Fig.3a – Thermocouples and electric evaluation unit

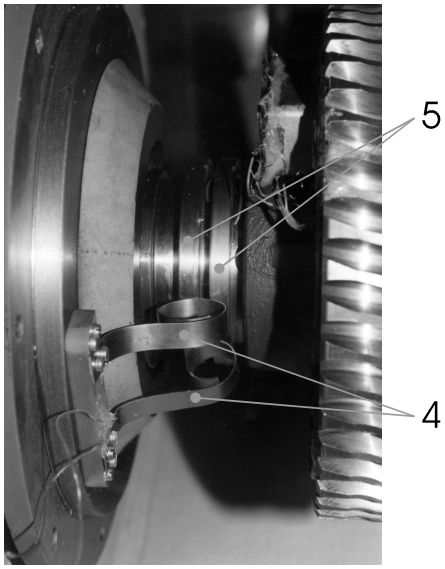

Fig.3b – Sliding contacts and rotor slip ring

2.3 Construction of sliding contacts and rotor slip ring

Fig.4 shows the arrangement of the sliding contact and rotor slip ring in detail. First, simple curved metal strips were used as sliding contacts (Fig.3b). But on account of increasing transmission errors the contact construction was improved.

To ensure the contact between sliding contact and rotor slip ring the slider is pressed against the slip ring by a spring. The signal flow proceeds from the thermocouples to the electronic evaluation unit to the rotor slip ring. By a sliding contact the signal the digitised signal is transmitted out of the gearbox by a cable.

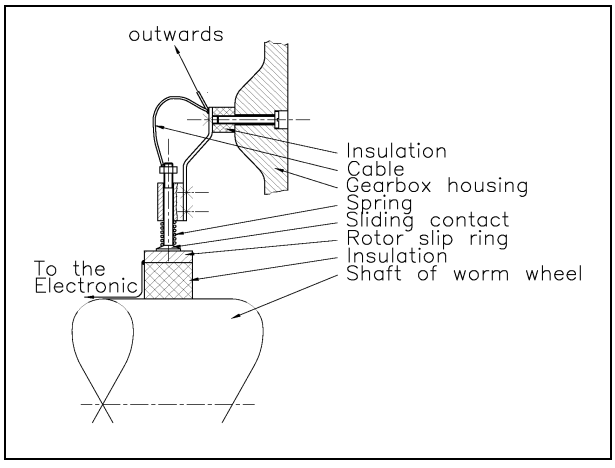

Fig.4 – Improved arrangement of sliding contacts and rotor slip ring for signal transmission

3. MEASUREMENT OF THE TEMPERATURES

3.1. Measurement of the oil-temperature

The temperature in the oil sump of the gearbox is measured by means of temperature depended resistors, type PT 100. This is done to control the functioning of the test bed and the gearing.

3.2. Measurement of the temperature on the tooth surface

To clarify how much the temperature of the oil sump differs from the temperature of the surface of the tooth-flank, and to determine the temperature of the lubricating oil within the contact area between the gear flanks, thermocouples are glued at five positions to the tooth. See Fig.2. To evaluate the temperature curves for both running directions the measurement is done for each direction.

3.3 Sample results of the surface temperature measurements

Fig.5 shows an example of measured temperature curves at a load of 1946 Nm output torque, worm gear with hollow flanks, in clockwise direction. The graph presents the temperatures which were observed for all five thermocouples during the complete test cycle (Start, increase of oil temperature, reaching steady state, cooling down phase) See also Fig.6 and Table 1.

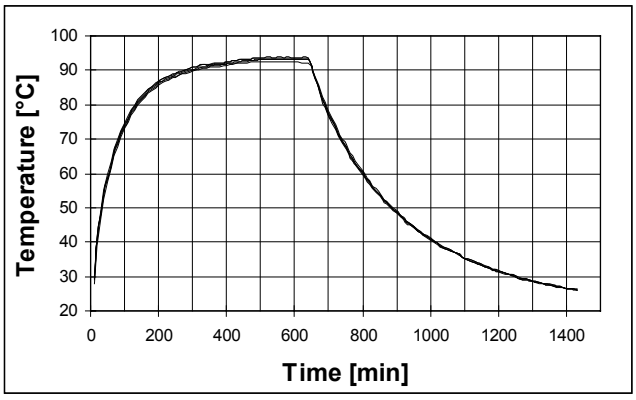

Fig.5 – Example of measured temperature curves, on the tooth surface

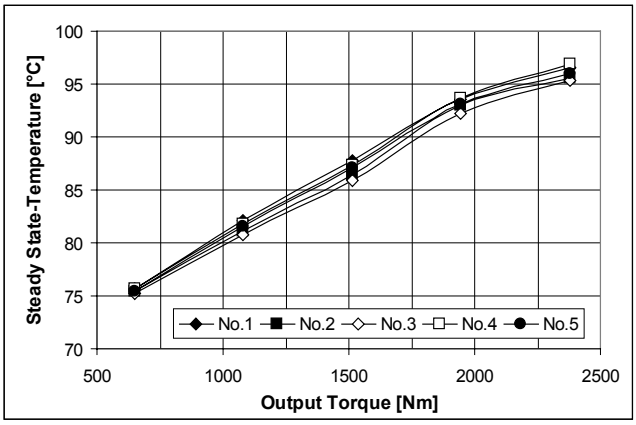

Fig.6 – Steady state temperatures in dependence of output torque, at different measurement positions (No.1-No5)

Table 1 – Steady state temperatures at different measurement positions (No.1-No5, see Fig.2)

Output Torque	Steady State-Temperature [°C], Clockwise				
[Nm]	No.1	No.2	No.3	No.4	No.5
648,0	75,7	75,4	75,2	75,7	75,5
1081,0	82,1	81,1	80,8	81,8	81,6
1513,0	87,8	86,4	85,9	87,3	87,1
1946,0	93,6	93,0	92,2	93,7	93,1
2379,0	96,6	95,6	95,3	96,9	96,0

Fig.6 and Table 1 show the measurement results of the steady state temperatures on five measurement positions of the thermocouples. This is presented for five load steps with increasing output torque.

4. ELECTRONIC CIRCUIT

The electronic circuit diagram can be seen in Fig.7. The measurement signal of the thermocouples is processed by a multiplexer (MUX), an amplifier and an analogue-digital converter (ADC) and is sent to the microprocessor (µP), where it is encoded. The encoding is necessary for a sufficient signal transmission. Thus the digital signal can be easily forwarded by an insulated collector ring (mounted on the shaft of the worm wheel) and a sliding contact (insulated and mounted on inner side of the gear box). This signal is converted and read in the Personal Computer by means of a RS-232-interface and is analysed by a computer program. The electronic circuit gets the power supply also through the collector ring (see Fig.7) and a resistor (Type KTY 10) delivers the required reference-temperature.

5. DISCUSSION OF MEASUREMENT ACCURACY

For this case of measurements the determination of the exact measurement errors was not the main target but the applicability of the measurement method in practice. Anyway an accuracy analysis of the temperature measurement should include the following aspects.

The measurement of the exact temperature of the contact area is not possible because the glued thermocouples would not resist the occurring friction and gearing forces. Therefore the only measured temperature is the one of the nearest possible point to the contact area and thus a temperature difference/error will result.

Moreover the used adhesive may influence the heat transfer between thermocouple and the surface of the tooth and therefore causes slightly inaccurate measurements.

Additionally the copper-constantan thermocouples show an measurement error in dependence of the temperature range. In this measurement range (30-100 degrees Celsius) the measurement error for this type of thermocouples is about ± 1 °C. Finally in the electronic circuit (ADC, contact points, wires, etc.) measurement errors could occur.

In conclusion, the measurement error can be estimated in a range of ± 2-3 °C. For this case the evaluated measurement accuracy is high enough to enable sufficient temperature results which can be used as input data for the numerical simulation of wear in worm gears.

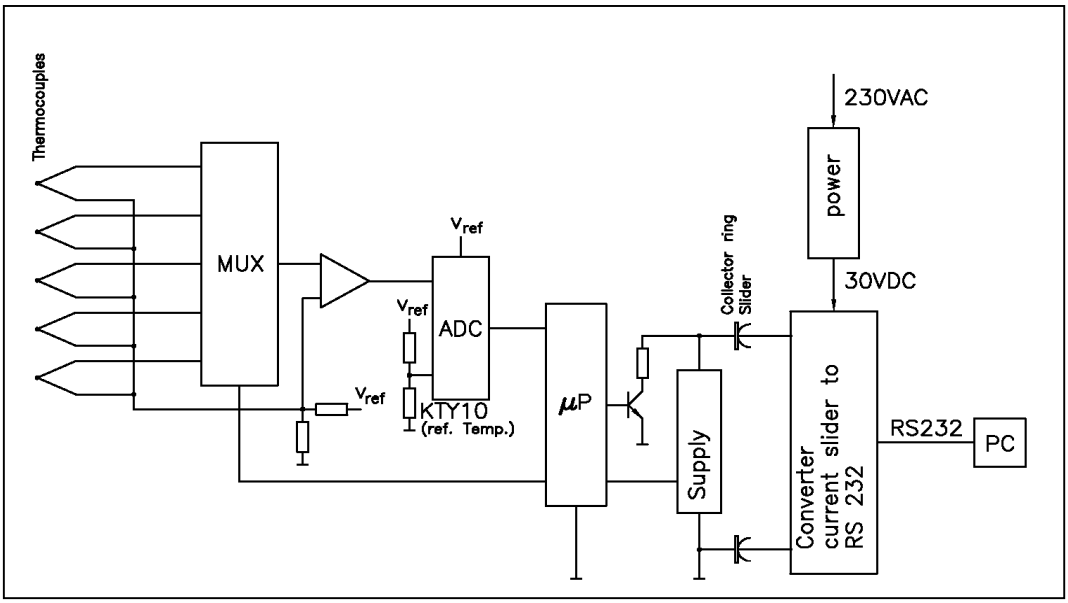

Figure 7: Circuit diagram, Measurement of the surface-temperatures by five thermocouples, mounted on a rotating worm wheel

6. SUMMARY

Measurements of the temperature on the surface of the tooth flanks can be done by application of the presented measurement method.

Thermocouples are glued as colsely as possible to the interesting contact area and are connected to an electronic evaluation unit. This unit delivers digitised signals and transmits these measurement variables to the personal computer for later analyses.

By means of this method accurate results for temperature curves (lubricating oil in gearboxes and/or surface temperatures, etc.) can be easily determined and used for further calculations (e.g. numerical calculations of wear, viscosity of the oil in particular test state).

7. REFERENCES

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