



## Development of a Method for Measuring Temperature of Elements of a Multiplier of a Wind Power Installation

---

Boris Morgun, Raul Turmanidze, Julya Morgun, Pavlo Shvahirev  
and Oleksandr Levynskyi

EasyChair preprints are intended for rapid dissemination of research results and are integrated with the rest of EasyChair.

February 20, 2020

# Development of a method for measuring temperature of elements of a multiplier of a wind power installation

Morgun Boris <sup>1[0000-0002-5399-9685]</sup>, Turmanidze Raul <sup>1[0000-0001-9003-6135]</sup>,

Morgun Julya <sup>1[0000-0002-2439-2585]</sup>, Shvahirev Pavlo <sup>1[0000-0003-3913-4412]</sup>,

and Levynskiy Oleksandr <sup>1[0000-001-9643-1494]</sup>

<sup>1</sup>Odessa National Polytechnic University, Shevchenko Ave 1, Odessa, Ukraine, 65044  
Rikokilller.rc@gmail.com

**Abstract.** The possibilities of using a new type of device to evaluate the temperature parameters of the design of the planetary-friction multiplier developed by the authors for a wind power installation are considered. Unlike gear-based animators, planetary-friction gears have compactness, manufacturability, and overload protection, which is especially important for a wind power installation, but they are at risk of high temperatures due to frictional torque transmission. The work presents the design of the multiplier in which, in contrast to the known designs, the contacts between the balls and cages are removed from the bearing interference system, which reduces the risk of heating.

The authors proposed the idea of introducing lubricant into the multiplier, which reduces friction in the contacts between the balls and separators, where the specific pressure is low, and is squeezed out between the balls and bearing rings, where the calculated high pressure is created using a spring, which allows semi-dry friction.

In order to estimate the temperature of multiplier construction elements having small dimensions, the authors developed a contact artificial thermocouple method that allows using its two thermoelectrodes closely located and fixed in the probe to determine its temperature quickly and accurately with contact with the conductive surface of the element. The article provides an analysis of ensuring high measurement accuracy and the result of evaluating the temperature parameters of the multiplier elements during its long-term operation both with and without lubricant. It is established that the design of the multiplier proposed by the authors, when used with lubricant, ensures the heating of bearings not higher than the established standards.

**Keywords:** thermocouple, multiplier, temperature

## 1 Introduction

Known disadvantages of gearboxes and gear-based multipliers are: difficulty in manufacturing, high cost, large dimensions, increased levels of vibration and noise. Therefore, original developments and scientific studies of the designs of ball plane-

tary-friction mechanisms (BPFM) in wind turbines, which act as planetary mechanisms and are distinguished by high manufacturability, compact structures, reduced vibration activity, and drive protection from overloads, are relevant [1, 10, 13, 14].

All the basic requirements for the quality indicators of structures are reduced to ensuring the normal thermal regime of their operation. For planetary-friction mechanisms, where the transmission of torques is carried out by friction, the temperature of structural elements is a fundamental requirement and should be carefully evaluated in the study of experimental samples.

## **2 Literature Review**

In [2], the construction of a planetary-friction mechanism was proposed, which makes it possible to use it as a multiplier for wind power plants. However, the interference mechanisms of the bearings of the proposed design do not provide adjustment of contact forces in the bearings and spurious dry friction between the balls of bearings and cages is not eliminated, which significantly increases the temperature of the planetary-friction mechanism. Temperature measurement by known methods [3] does not allow quickly and with high accuracy to determine the surface temperature, especially in hard-to-reach places of the structure. Measuring the temperature of the elements of the planetary-friction multiplier is a difficult task, since its parts are in close contact with each other and access to them is difficult. The metrological support of the tests largely depends on the accuracy and speed of the used measuring equipment.

## **3 Research Methodology**

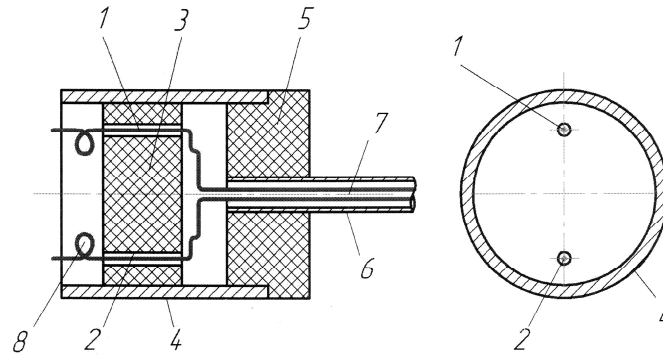
The purpose of the article: the development of a method for measuring the temperature of conductive surfaces with high accuracy and speed and allowing to measure the temperature of small parts located in hard to reach places; measuring the temperature of the elements proposed by the authors of the planetary-friction multiplier [4, 11, 12] at nominal operating conditions in order to assess its performance and durability and confirm its practical expediency; confirmation of the hypothesis about the possible use of lubricant in the friction gears of the multiplier in order to reduce friction between the balls and the separators.

At present, thermocouples, pyrometers, and thermal imagers are widely used to measure the temperature of body surfaces. However, pyrometers and thermal imagers based on the analysis of radiation emanating from the object under study [3] cannot be used to solve the problem. Firstly, the area of the investigated object must be significant. Secondly, at the same body temperature, different amounts of heat are emitted from different metals, that is, there is a different emissivity, which excludes the possibility of accurate temperature measurement.

Known thermocouples having a junction are usually attached to the surface to be measured, which increases the heat sink with the small dimensions of the elements under study and leads to temperature estimation errors.

The authors developed the “Probe for measuring the surface temperature of the body” [6], which has high measurement accuracy, speed and the ability to measure temperature in hard-to-reach places. In the probe there are two thermoelectrodes made in the form of compensation spirals creating a thermocouple and fixed in an insulated core. The working end of the thermocouple has no junction, and the thermoelectrodes freely contact the surface of the body, the temperature of which is measured.

The technical effect achieved by applying the proposed method is that the probe design eliminates the high inertia of heating the thermocouple junction, which reduces the measurement error. In fig. 1 shows a probe that has thermoelectrodes 1 and 2, freely located at the outlet and protruding beyond the plane of the probe end face. The leads of the thermoelectrodes are fixed in an insulated core 3 built into the metal cup 4. A holder 6 with a cable 7 is laid through a ferrule 5 made of plastic, the wires of which are connected to the leads of the thermoelectrodes 1 and 2. Each thermoelectrode has a length compensator made in the form of a spiral 8.



**Fig. 1.** Temperature probe for the proposed measurement method surface temperatures

To measure temperature, the probe is pressed against the test surface. In this case, the thermoelectrodes come into contact with the metal surface and create a thermocouple in which there is an intermediate third electrode, which does not affect the thermo-emf, since the temperature of the contacts is [3, 7].

To achieve high accuracy in determining the temperature using this method, it is obvious that it seeks to bring the thermocouple conductors closer together, as well as to their minimum diameter. In the above studies, chromel-drop thermocouple conductors with a diameter of 0.2 mm were used. Thermo-EMF was recorded by a multi-limit light galvanometer type 167311 from GOERZ.

The error of the contact artificial thermocouple method can be estimated by considering the well-known formula [6]

$$I = \frac{E(t, t_0)}{R_M + R_{II} + R_T}, \quad (1)$$

where  $R_M$  - is the resistance of the millivoltmeter;

$R_{II}$  - resistance of connecting wires;

$R_T$  - thermocouple resistance.

In this case, it depends on several factors, namely: on the transition resistance between the contacting surfaces; the resistance of the contact body and the resistance of the films that may be on the contact surface. As practice has shown, contact resistance can be expressed by the following formula [8]

$$R_r = \frac{d}{P_k^b}, \quad (2)$$

where  $P_k$  - is the contact pressure;

$d$  - constant, depending on the contact material and temperature;

$b$  - constant, depending on the form of contact.

From formula 2 it follows that the contact temperature is affected by the contact temperature and its shape, as well as the magnitude of the applied force. At high temperatures, oxide films with a thickness of 10 ... 20 Å always appear on the surface of metals with a high ohmic resistance of the order of 140 ... 170 Ohm [9], while the contact resistance of these materials at normal temperature is in the range of 1 ... 5 Ohm. It follows from the foregoing that the internal resistance of a contact artificial thermocouple varies widely and reaches large values that significantly exceed the resistance of commonly used millivoltmeters and galvanometers, which is in the range of 20 ... 60 Ohms. The use of such equipment with low internal resistance in this case will not provide the necessary accuracy. High accuracy can be achieved by using, for example, a highly sensitive multi-limit galvanometer with a GOERZ type indicator 167311, which has an internal resistance on a scale of 100 mV to 200,000 Ohms.

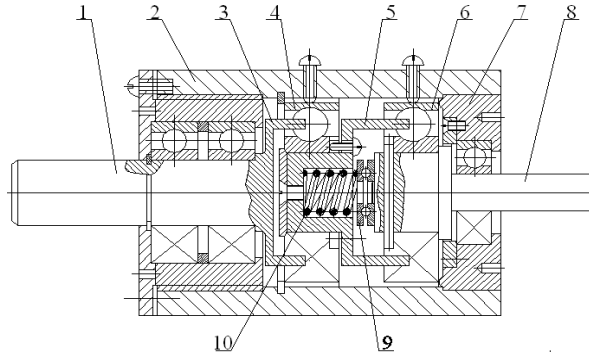
If we assume that the contact resistance varies from 1 to 200 Ohms, then for two contacts of an artificial contact thermocouple, the relative error can be determined from the ratio

$$\begin{aligned} \Delta &= 2 \frac{R^{\max} - R^{\min}}{R^{\min}} 100\% = \\ &= 2 \frac{(R_M + R_k^{\max}) - (R_M + R_k^{\min})}{R_M + R_k^{\min}} 100\% = \quad , \quad (3) \\ &= 2 \frac{(200000 + 400) - (200000 + 2)}{200000 + 2} 100\% = \\ &= 0,004 \cdot 100\% = 0,4\% \end{aligned}$$

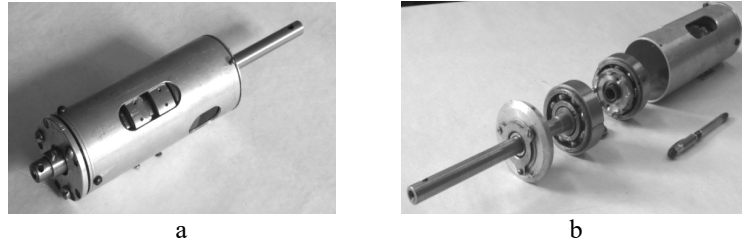
The test developed by the method for assessing the temperature regime was subjected to the design of a two-stage SHFM for wind power plants [4, 12], which consists of an output shaft 1, housing 2, in which bearings 4 and 6 are installed, leads 3 and 5, which engage with bearing cages 3 and 5, a cover 7, which compresses the outer ring of the bearing 6, the output shaft 8, on which the inner ring of the bearing 6 sits rigidly, and a thrust bearing 9, which abuts the spring 10 (Fig. 2 and 3). The outer rings of bearings 4 and 6 are secured against rotation by screws. When turning the cover 7, the outer ring of the bearing 6 moves along the axis of the multiplier and compresses the spring 10 through the balls and the inner ring together with the output shaft 8.

Since the outer ring of the bearing is fixed, the spring 10 unclenches the inner rings of the bearings 4 and 6 with a certain force, creating the necessary adjustable tension

in them, which makes it possible to transmit torque due to the friction of the balls on the ring.



**Fig. 2.** Scheme of the experimental design of BPFM



**Fig. 3.** An experimental sample of BPFM in the assembled state (a) and disassembled (b)

When the input shaft 1 rotates, the leash 3 rotates the separator with the balls of the bearing 4. The rotation is transmitted to the inner ring of the bearing 4 with the leash 5, from it to the bearing cage 6 and its inner ring, mounted on the output shaft. Bearings 4 and 6 in this design act as planetary mechanisms, with a gear ratio  $i_M = i_1 i_2$ , where  $i_1, i_2$  are determined by the formula:

$$i_{kc_n} = \left( \frac{D_B + D_H}{D_B} \right)^{n-1}, \quad (4)$$

where  $D_g$  and  $D_H$  are the diameters of the raceways, respectively, of the inner and outer rings of the bearing.

Next, the rotation is transmitted to the bearing cage 6 and transmitted through its inner ring to the output shaft. Since the inner rings of the bearings 4 and 6 rotate at different speeds, a thrust bearing 9 is installed between the output shaft and the spring 10, which creates the tension.

The developed BPFM design allows to exclude the transmission of sliding force through the separators, reduces the corresponding friction between the separators and balls in the axial direction and, as a result, provides a significant increase in the efficiency of the mechanism.

For a preliminary assessment of the operability of the proposed original design of BPFM, a prototype based on bearings 306 with a gear ratio  $i_M = 6,8$  was manufactured and tested.

Research is carried out twice: without the use of grease in the bearings and using grease.

The first study was carried out using grease-free bearings in the BPFM. The input shaft BPFM was fixed in the cartridge of the machine 1K62. The machine spindle revolutions were:  $n_1 = 160 \text{ min}^{-1}$ . The output shaft of the BPFM was fixed using a rotating cone located in the tailstock and received a value of revolutions  $n_2 = 1088 \text{ min}^{-1}$ .

The study lasted 80 minutes with fixing temperature indicators every 10 minutes. According to the results, a graph of the temperature fluctuations of bearings without lubrication is obtained, shown in Fig. 4.

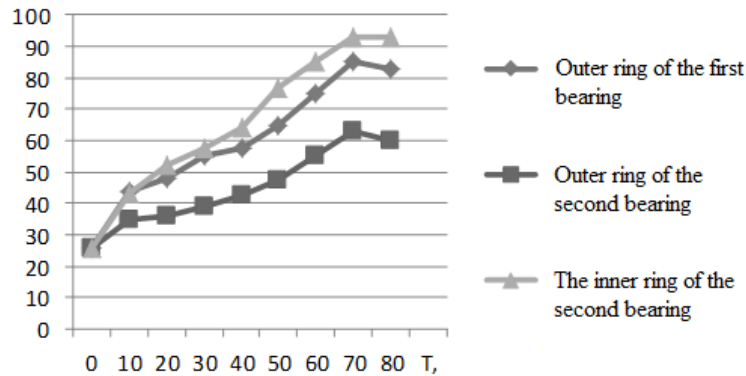


Fig. 4. Graph of fluctuations in temperature of bearings without lubrication

According to the data obtained, a significant increase in the temperature of the BPFM bearing rings without lubrication becomes apparent even at relatively low rotational speeds.

The second study was carried out using grease-lubricated bearings in BPFM. The input shaft BPFM was fixed in the cartridge of the machine 1K62. The machine spindle received revolutions  $n_1 = 630 \text{ min}^{-1}$ . The BPFM output shaft was fixed in a 550 W generator used as a loading device and received revolutions  $n_2 = 4284 \text{ min}^{-1}$ .

The temperature of the multiplier elements was determined using a contact artificial thermocouple and was also recorded by a highly sensitive multi-target galvanometer with a light pointer type 167311 from GOERZ.

The study lasted 35 minutes with fixing temperature indicators every 10 minutes. Based on the results, we obtained a graph of the temperature fluctuations of bearings with lubrication, shown in Fig. 5.

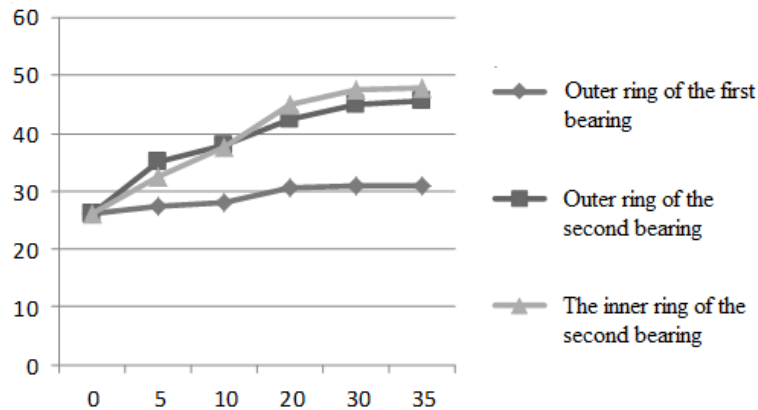


Fig. 5. Graph of fluctuations in temperature of bearings with lubricant

According to the obtained graph, the temperature of the lubricated bearing rings does not increase by more than 20 °C even at input shaft  $n_1 = 630 \text{ min}^{-1}$  speeds and loads for 35 minutes.

#### 4 Results

This experiment confirms the hypothesis put forward on the possibility of using grease in planetary-friction mechanisms in order to significantly reduce friction losses and reduce the heating of the structure. The graph shown in fig. 5 confirms the presence of slight heating of structural elements even with prolonged use.

#### 5 Conclusions

The method developed by the authors for measuring the surface temperature of conductive bodies by two contact thermoelectrodes has a high measurement accuracy, eliminates the inertia of heating the thermocouple junction and ensures speed.

The proposed method for measuring the surface temperature of conductive materials can be used in systems with such features as inaccessibility, movement of system elements, small surface area for measurements, and the inability to use standard temperature sensors.

The use of lubricant in the planetary-friction multiplier with a simultaneous increase in the interference of the bearings causes crushing of the oil film in the spots of contact of the balls with the rings and leads to the appearance of semi-dry friction, which provides torque transmission. At the same time, the friction between the balls and the separator in contact on a large surface is carried out under lubrication conditions and does not cause significant friction losses.

Tests made it possible to establish the operability of the proposed design of the planetary-friction multiplier and its operation at permissible temperatures in the case of bearings with grease.



## References

1. New and non-traditional technologies in the energy sector / G. Oborsky, A. Bundyuk, B. Morgun, I. Prokopovich et al. - Odessa: Phoenix, 2016. – 127 p.
2. Patent of Ukraine for invention No. 87778 Planetary-friction gearbox / S. Guturya, B. Morgun, Y. Morgun // Bul. № 15, 2009
3. Measurement of physical quantities / G. Oborsky, P. Slobodianyuk, V. Kostenko, S. Antoshuk. - Odessa: Astroprint. 2012. - 329 p.
4. Patent of Ukraine for Invention No. 112370 Planetary-frictional multiplier / G. Oborsky, B. Morgun, S. Guturya, Yu. Morgun // Bul. № 16, 2016.
5. DSTU ISO 81400 - 4. Wind installations. Part 4. Design and specifications of the gearbox.
6. Patent of Ukraine for utility model No. 104319. Probe for measuring the surface temperature of bodies / G. Oborsky, B. Morgun, Yu. Morgun, I. Prokopovich // Bul. № 2, 2016.
7. Preobrazhensky, V. Thermotechnical measurements and devices / V. Transfiguration. - M.: Energy, 1954. - 426 p.
8. Reference on elements of automation and telemechanics. - M: Gosenergoizdat, 1967. - 423 p.
9. Slutskaya V. Thin films using microwave technology / V. Slutskaya. - K.: Tekhnika, 1967. - 288 p.
10. G. Oborsky Planetary mechanisms of wind power plants / G. Oborsky, B. Morgun, Yu. Morgun // Information technology in education, science and production. Coll. of sciences. BC - Iss. 3 (8), 2015 - pp. 102-109
11. Kinematics of planetary-friction gearboxes / S. Guturya, B. Morgun, Yu. Morgun et al. // Problems of computer engineering and structural strength. - 2009. - Vip. 13. P. 43-49.
12. Ball planetary-friction animator for wind turbines / S. Guturya, Yu. Morgun, A. Lyashevsky, A. Belozarov // Mater. int. scientific-practical conf. "New and non-traditional technologies in resource and energy conservation. 2014. - S. 44-47.
13. Guturya S. Patent of Ukraine: UA 87778 "Planetary-friction box of tweezers" / S Guturya, B. Morgun, Yu. Morgun. - Publ. 08/10/2009. - Bull. № 15, 2009. - 3 p.
14. Guturya, S. Increase of power efficiency of the ball friction-planetary mechanisms / S. Guturya, B. Morgun, Yu. Morgun // Les problèmes contemporains du technosphere et de formations des cadres d'ingénieurs. Recueil d'ouvrages du IV Conférence internationale scientifique et méthodique a Hammamet. – 2010. – P. 65-74.