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RESEARCH INTO SPECIAL DESIGN ISSUES FOR SMALL PLASTIC GEARS

Booklet of PhD Theses

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1. INTRODUCTION

1.1. SMALL PLASTIC GEARS

In this dissertation, small plastic gears refer to involute profile, straight-toothed, external gears with a module no greater than 0.5 mm. The base material of these gears is some type of plastic, usually POM or PA [1].

Small plastic gears can be found in almost every field. They are mostly used not for power transmission, but for performing some kind of kinematic operation. The automotive industry, for example, uses them to adjust rearview mirrors or to move the deflector plates of air conditioning systems [2]. They are also used in office equipment such as printers for head movement, in various measuring instruments, in positioning drives, and in applications such as motion-based games in the gaming industry [3] [4].

There is no international standard for the calculations required for the reliable design of plastic gears; instead, regionally accepted national guidelines or guidelines within individual companies are used [5]. This means that essentially every major plastic gear manufacturer has its own calculation method and guidelines. This situation poses a major obstacle for the plastic gear industry, as it hinders the easy exchange of design knowledge and information [6] [7] [8].

In Western European countries, the only generally accepted guideline for plastic gears was the German VDI 2545 guideline, which was withdrawn in 1996 because the calculations and experience relating to heating had become outdated. After almost 20 years, the VDI published a new guideline in 2014, VDI 2736. On the other hand, the Japanese standard JIS B 1759 for calculating the bending load capacity of plastic gears was published in 2013 [6] [9].

1.2. RESEARCH OBJECTIVES

The lack of international standards and the shortcomings of certain guidelines led me to examine this topic in greater depth. The aim of my research was to address the design issues caused by the lack of international standards. I focused on those issues that could pose the greatest problems and that I could realistically solve with the time and resources available to me.

First, I wanted to address the manufacturing and assembly problems that appear on small plastic gears. Although recirculation torque testing is often used to examine gearbox faults, the cause and detectability of the fault itself are not usually addressed. Therefore, I set myself the goal of using the recirculation torque characteristic curve to detect not only the faults on individual gears, but also their type and magnitude. This could result in significant savings in manufacturing processes. For example, when an injection moulding fault is detected, the problematic parts could be immediately removed from production, resulting in fewer defective gears and less energy wasted on assembly and disposal.

To solve the previous problem, I had to find a manufacturing method that would allow me to produce gears with the required accuracy from the resources available to me, in small quantities, without faults, and with faults placed by me on the gear geometry. Small plastic gears are usually produced by injection moulding. However, this is only economical for large production volumes. Therefore, I set myself the goal of investigating 3D printing methods to determine which one would allow me to produce the quality and quantity of gears required for the tests with the technology and parameters available to me.

It is also necessary to detect faults on small plastic gears because they can influence the tooth root stresses and surface Hertzian stresses that arise on the teeth. Excessive increases in these stresses are among the most common causes of failure in plastic gears. Therefore, I wanted to use the finite element method to investigate the effect of individual faults on the stresses arising in the gears.

Finally, my goal was to address the issue of heating in small plastic gears. In the case of small plastic gears, excessive heating not only has a negative effect on strength characteristics, but can also lead to the disappearance of tooth clearance, which can result in tooth breakage. The formulas used to calculate the heating of plastic gears were created for normal-sized gears. Therefore, I wanted to use measurements to examine whether the formulas show any deviation from the measured values in the case of small modules.

2. PRESENTATION OF RESEARCH RESULTS

2.1. THE ACCURACY OF 3D PRINTED SMALL PLASTIC GEARS

To test the recirculation torque, I had to find a manufacturing method that would allow me to produce gears with the required accuracy from the resources available to me, in small quantities, without faults, and with faults placed by me on the gear geometry. Therefore, I examined the accuracy of gears manufactured using the 3D printing technologies available to me. I performed measurements using three different technologies. These were FDM, SLA, and SLS.

I performed the examinations using an optical microscope and designed and manufactured special measuring templates for them using SLA printing. I examined five parameters using the microscope. These were tooth shape, tooth thickness, pitch, tooth height, and addendum. I examined the shape of each tooth individually, while for the other parameters, I took measurements on 40 randomly selected teeth.

I generated the gear geometry with a module of 0.5 mm using KISSSoft software. I chose two different numbers of teeth for the tests: z=30 and z=50. I compared the printed gears with the injection-moulded gears at my disposal, as I wanted to perform the tests with gears whose accuracy was at least equal to that of these injection-moulded gears. The module and number of teeth of the injection-moulded wheels were the same as those of the gears generated for printing.

A comparison of the tooth profile with the initial geometry tooth profile showed that SLA technology closely approximates the expected profile with only a slight deviation. In contrast, FDM technology differed significantly from the standard profile. The profile of the gear manufactured using the SLS process achieved accuracy between the two. In terms of tooth thickness, the maximum deviation was 5.8% for the SLA process, while for FDM and SLS it was over 10%. In terms of pitch, SLA had an accuracy of 1.3%, while the other two processes showed an error of over 4%. In terms of tooth height, the maximum deviation for SLA was 2.6%, while for SLS it was over 10% and for FDM technology it was over 20%. In the case of the addendum, the deviation in μm was similar to that of tooth height.

2.2. MEASURING THE RECIRCULATION TORQUE

The recirculation torque refers to the torque required to turn the drive unit at least one full revolution without load on one of its shafts.

Since the recirculation torque is proportional to the internal friction of the gearbox, its measurement has long been used as a verification method, especially for large bevel gearboxes. The method is also used for small gearboxes because the expected manufacturing costs and manufactured weight of such gearboxes typically do not allow for more thorough quality control procedures. However, typically only the maximum torque of the gearbox is compared with the maximum value for acceptance. If this value is exceeded, the gearbox is rejected without investigating the cause and effect of the fault [10].

My goal was to use the torque curve analysis to determine not only that the gearbox contained faulty gears, but also to draw conclusions about the cause of the fault. Since I only had a static torque meter at my disposal and rotating torque meters are much more expensive than static ones, I designed a dynamic torque meter based on the principle of a differential.

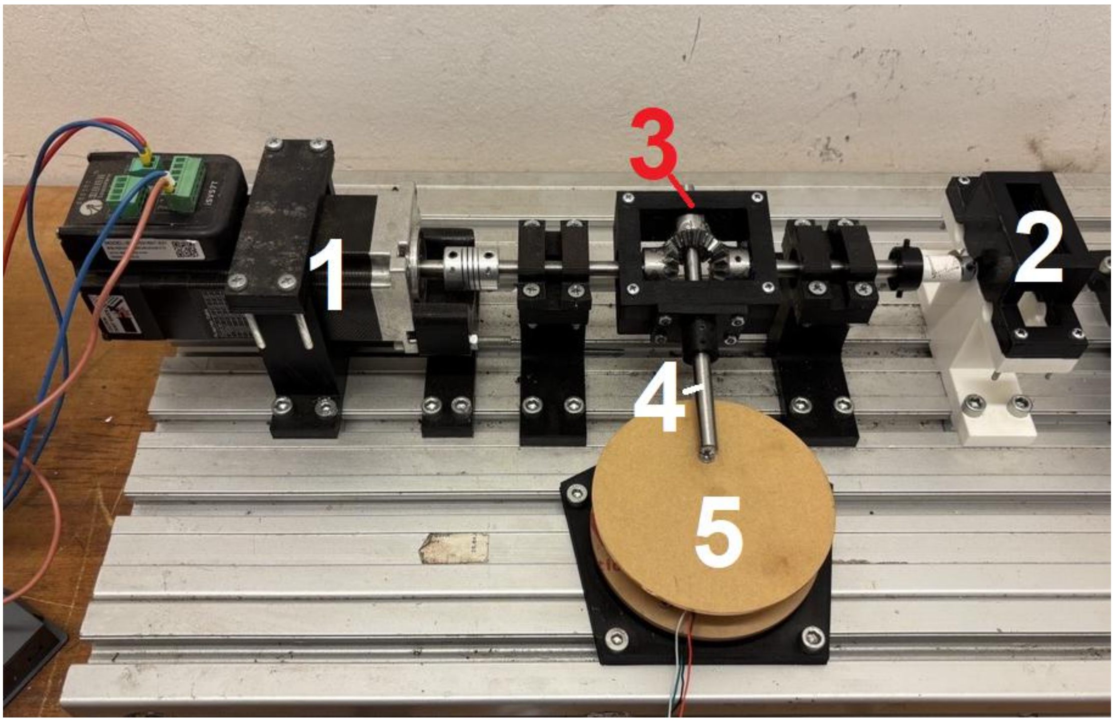

Figure 1.: The dynamic torque measuring device (1: drive motor, 2: drive unit containing the gears to be measured, 3: bevel gear unit, 4: measuring shaft, 5: measuring sensor)

To confirm that SLA is the most suitable 3D printing technology for these tests, I also performed recirculation torque tests on all three printing processes and on the injection-moulded wheels. The results of the recirculation torque and microscopic tests clearly show that stereolithography is by far the most accurate 3D printing technology of the three. Since only SLA printing meets the quality requirements for further testing, I used gears manufactured with this technology for my further tests involving torque measurement.

The first of the faults I dealt with was the tooth thickness faults in small plastic gears. I examined four different cases. In the first case, the modified tooth was 0.2 mm smaller than the standard value, in the second case it was 0.1 mm smaller, in the third case it was 0.1 mm larger, and in the fourth case it was 0.2 mm larger.

In the case of reduced tooth thickness, the cyclically repeating locations where the torque value decreases significantly compared to the reference value are clearly visible. The smaller the thickness of the faulty tooth, the lower the torque value at these locations. It can also be seen that, apart from these locations, all other values correspond to those of gear pairs without faults.

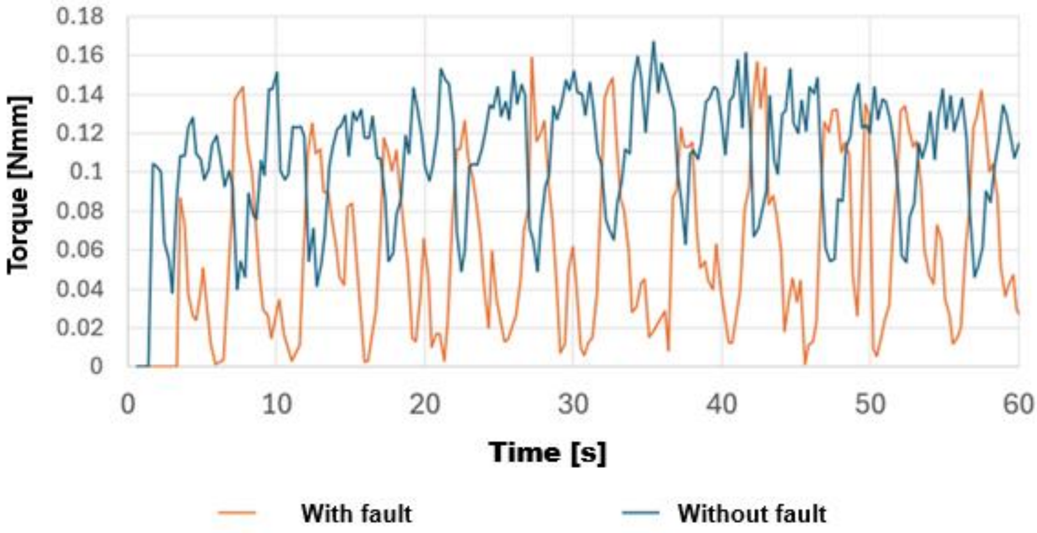

Figure 2.: The recirculation torque curves for z=30, if one tooth of one gear is 0,2 mm smaller than the others

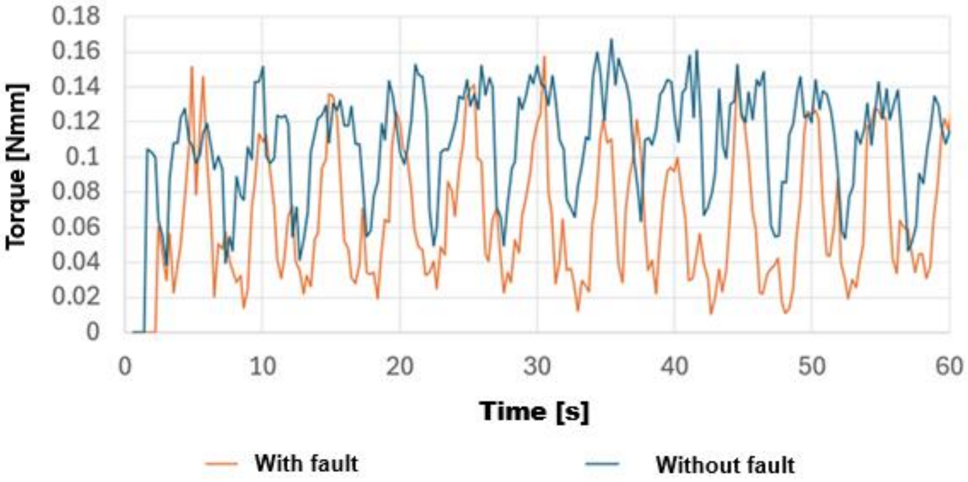

Figure 3.: The recirculation torque curves for z=30, if one tooth of one gear is 0,1 mm smaller than the others

In the case of increased tooth thickness, the diagrams show when the faulty tooth comes into contact, the torque increases significantly, but otherwise the torque value takes on the values of the fault-free case. The greater the thickness of the faulty tooth, the greater the torque value at the cyclically occurring points.

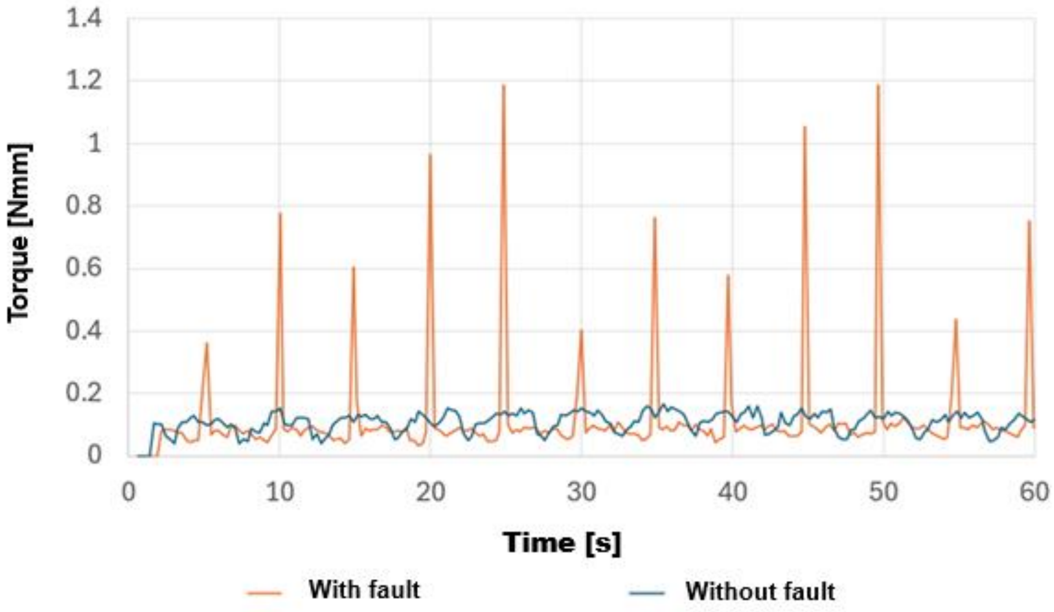

Figure 4.: The recirculation torque curves for z=30, if one tooth of one gear is 0,1 mm larger than the others

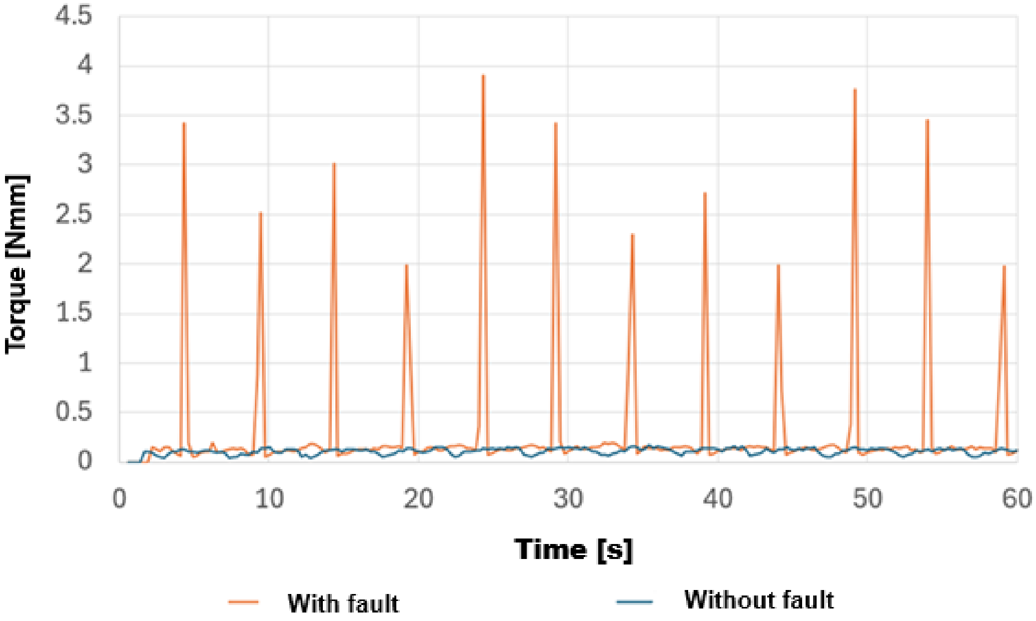

Figure 5.: The recirculation torque curves for z=30, if one tooth of one gear is 0,2 mm larger than the others

The next fault I examined was a fault in the pitch of the small plastic gears. In this case, I created the pitch fault using Solid Edge CAD design software by rotating one of the teeth of the gear around the gear axis. I rotated the faulty tooth so that the pitch changed by 0.05 mm in one case and 0.1 mm in the other case compared to the standard. In the case of pitch faults, I found that when the faulty tooth engages, the torque increases significantly and then suddenly decreases, or vice versa. This can be explained by the fact that the tooth clearance also decreases compared to the standard value at the reduced pitch, while on the other side of the tooth, the tooth clearance exceeds the standard value.

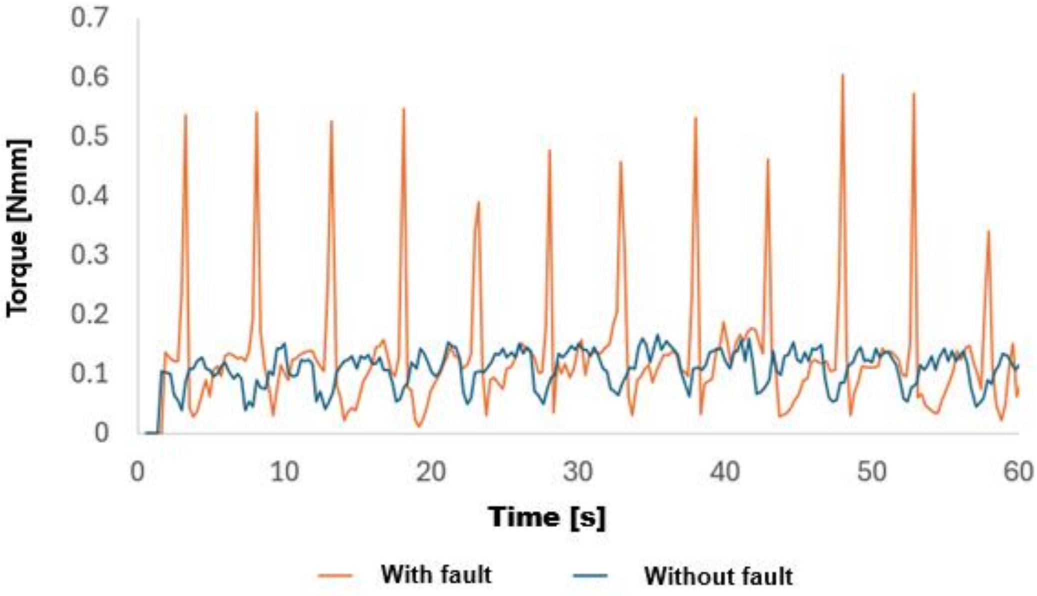

Figure 6.: Torque curve with a pitch fault of 0.05 mm in rotation direction I

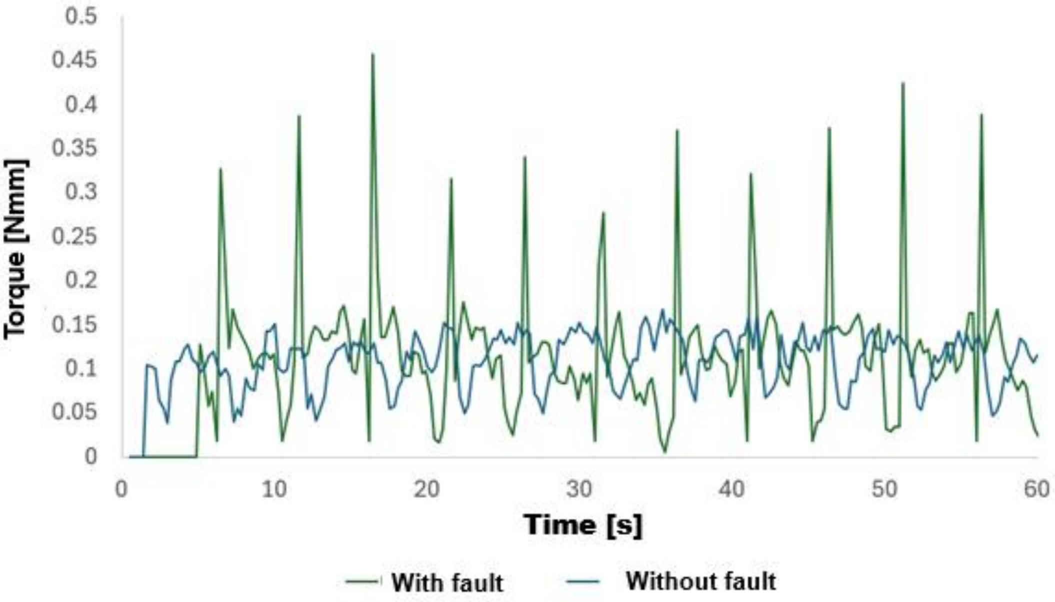

Figure 7.: Torque curve with a pitch fault of 0.05 mm in rotation direction II

Finally, I examined eccentricity faults. To examine eccentricity faults, I made gears whose axes were moved by 0.1 mm and 0.2 mm eccentricity compared to the standard. The diagrams show that the torque increases continuously to a cyclically occurring maximum point and then decreases to a cyclically occurring minimum point. This can be explained by the fact that during the test, the teeth of the two gears continuously approach and move away from each other. When they approach each other, the tooth clearance between the teeth decreases, causing the torque to increase, while when they move apart, the torque decreases due to the increase in tooth clearance. At the points where the gears are connected at the standard distance, the torque value is the same as that measured for gear pairs without faults.

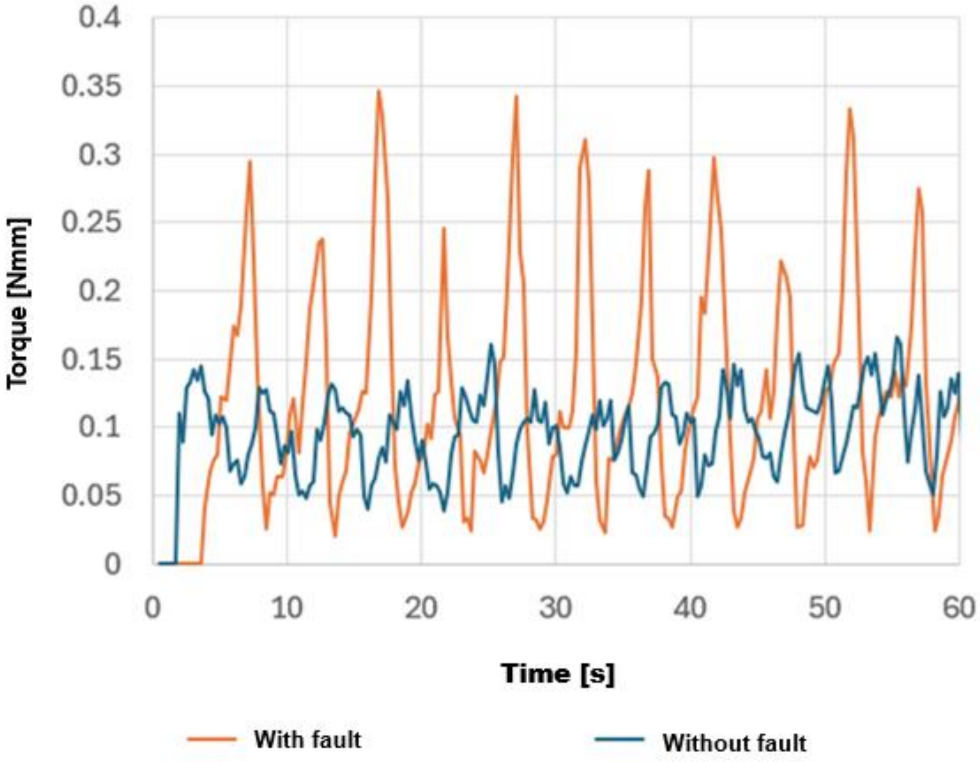

Figure 8.: Effect of a 0.1 mm eccentricity fault in the case of z=30

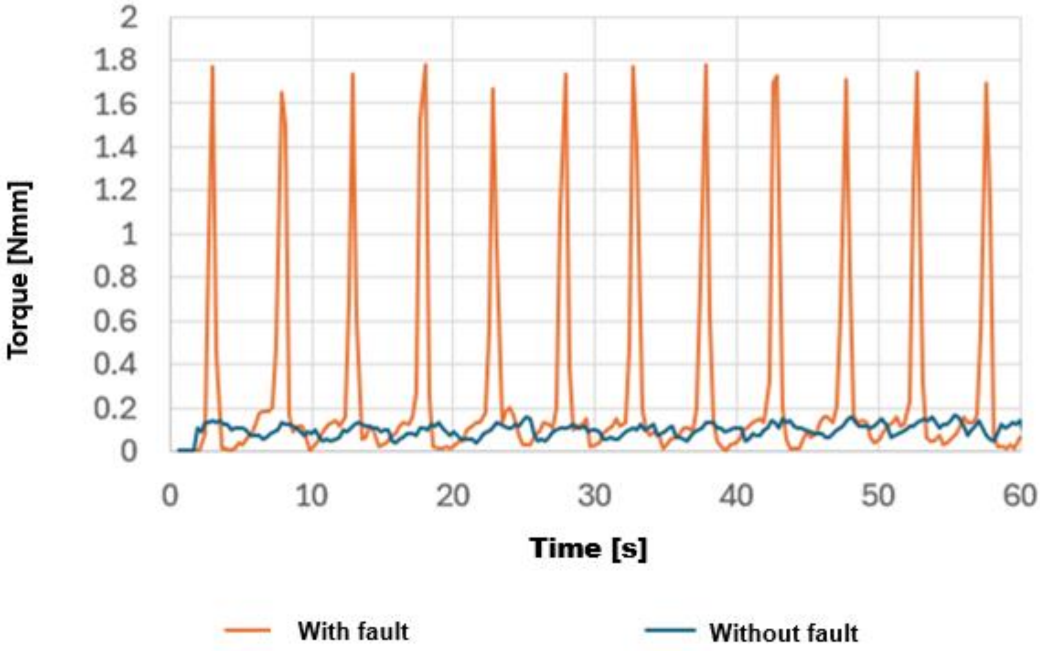

Figure 9.: Effect of a 0.2 mm eccentricity fault in the case of z=30

All in all, it can be said that the effect of the tested faults can be detected using the method of measuring the recirculation torque.

2.3. THE EFFECT OF FAULTS ON THE STRESSES ON THE TEETH

Faults can affect not only the recirculation torque, but also the stresses arising on the teeth during connection. Therefore, I examined the effects on surface and tooth root stresses using the finite element method.

I used Ansys software for the finite element analysis. The model built in the software consisted of two gears. Both gears had a module of 0.5 mm, a tooth width of 2.5 mm, and 30 teeth. One of the most important parts of setting up the model was determining the element size of the finite element mesh. To this end, I also performed simulations for fault-free gear pairs. In order to validate the results obtained from the simulation, I had to compare them with the stress calculation formulas found in the literature. I calculated the stresses based on the VDI 2736 guideline. I started with coarser mesh sizes and refined the size of the elements until I obtained values from the formulas with sufficient accuracy. I only accepted an element size if the deviation was less than 0.1% for all three loads. A mesh size of 4 μm met these conditions.

To illustrate the effect of dimensional deviations, I used tooth thickness faults. To do this, I examined cases where the tooth thickness of one of the two meshing gears was smaller or larger than the standard.

The results showed that the greater the deviation of the tooth thickness from the standard, whether negative or positive, the greater the increase in surface stress compared to the initial value. In the case of tooth root stresses, it can be seen that the smaller the thickness of the defective tooth, the greater the tooth root stress, but the greater the thickness of the tooth, the smaller the tooth root stress on the faulty tooth. In contrast, the larger the tooth of the faulty tooth, the greater the tooth root stress on the faultless gear.

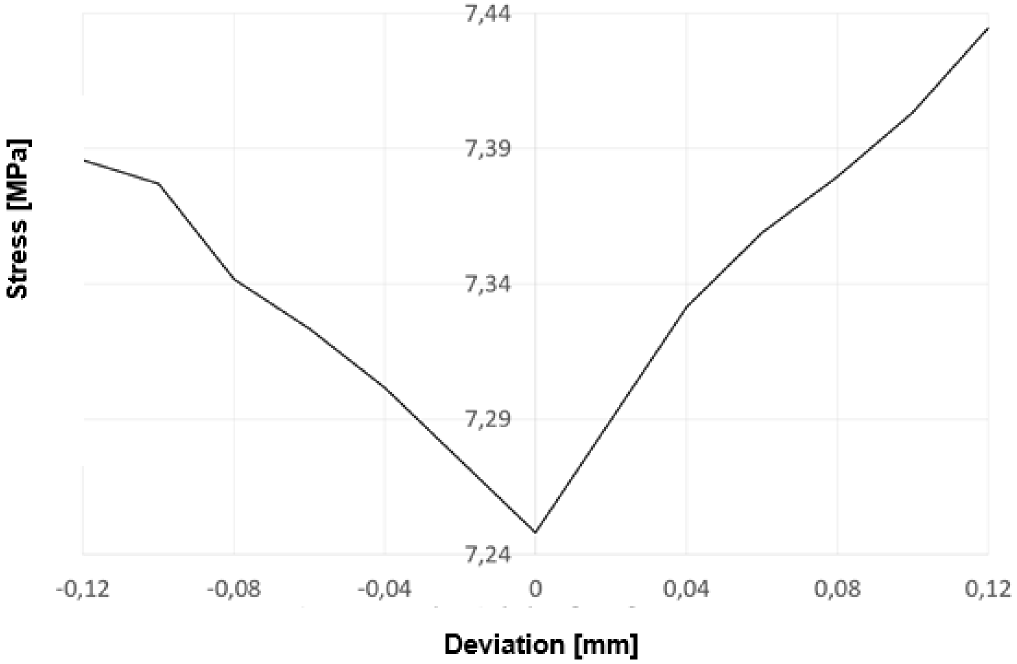

Figure 10.: The effect of tooth thickness faults on the surface stresses

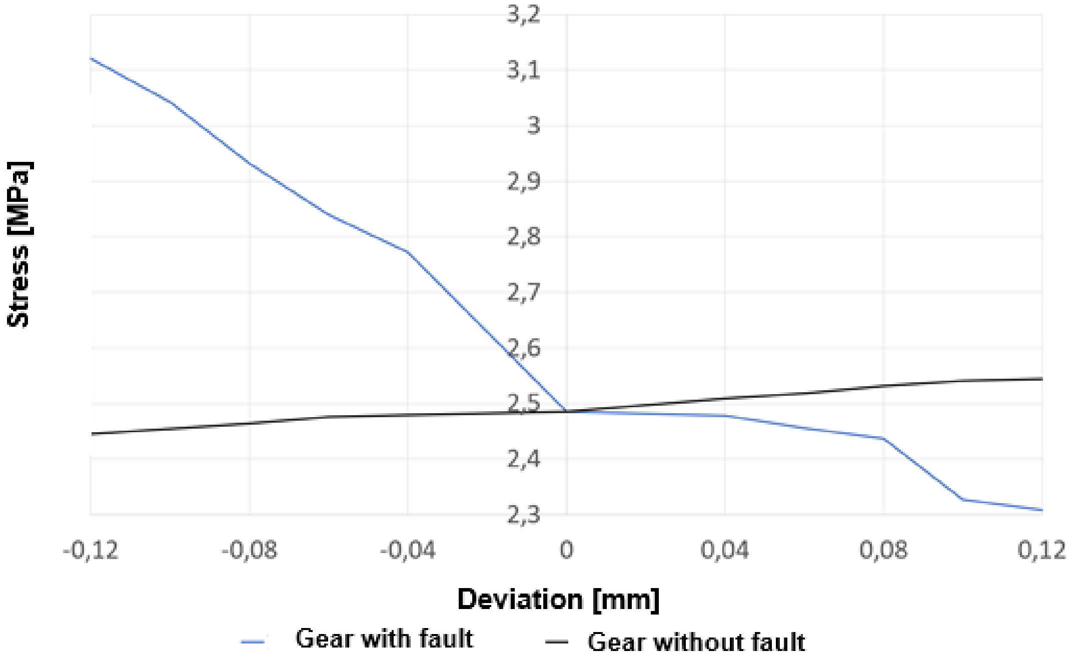

Figure 11.: The effect of tooth thickness faults on the root stresses

In the case of shape deviations, I examined gears manufactured using FDM technology. Therefore, I recreated the teeth of the PLA gear using CAD software. I examined two cases with these. In the first case, I only recreated the profile, not the cavities appearing on the teeth. In the second case, I created the cavities in addition to the profile. In both cases, both contacting gears contained the same faults. The results showed that even in the case without cavities, the stress increased significantly compared to the case without faults. However, in the second case, when the cavities were also placed on the geometry, the stress values increased slightly further.

Among the positional deviations, I chose the deviation in the centre distance of the gears. In these tests, I changed the centre distance between the gears so that the two gears were closer or farther apart than the standard centre distance. I did not change the geometry of the gears for these tests. The results showed that as the centre distance decreases, the surface stress increases, and as the centre distance increases, the stress on the contact surface decreases. The opposite process occurs with tooth root stress as with surface stress. As the centre distance increases, the distance between the tangential force acting on the tooth root and the root increases, and thus the root stress also increases. And as the centre distance decreases, the root stress also decreases.

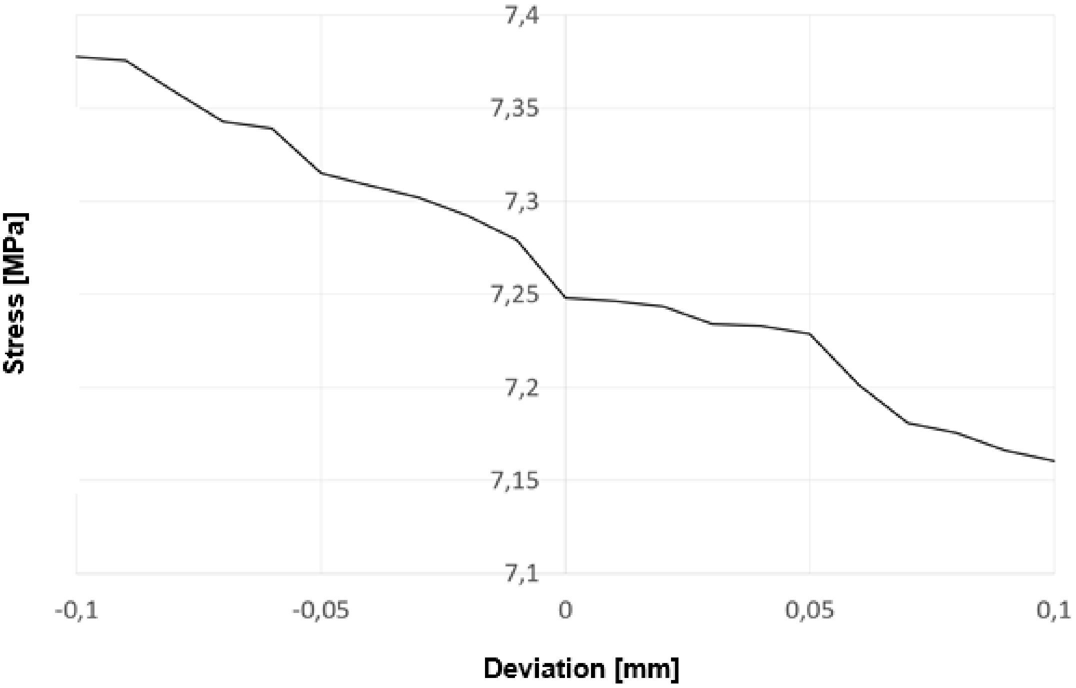

Figure 12.: The effect of centre distance faults on the surface stresses

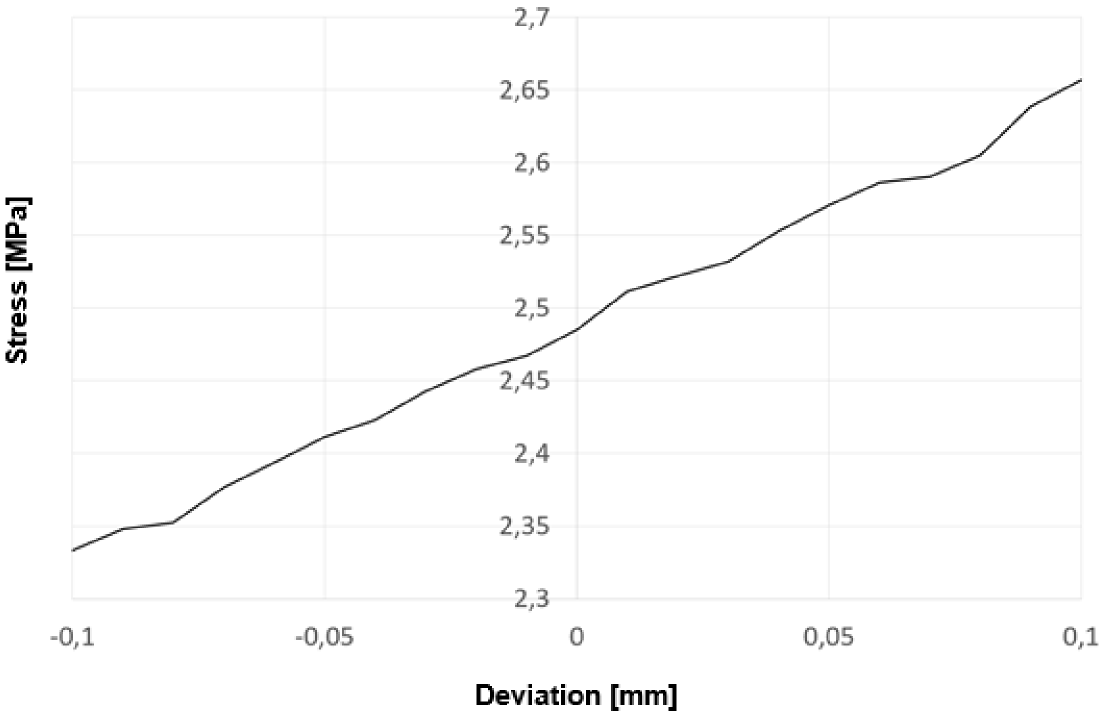

Figure 13.: The effect of centre distance faults on the root stresses

2.4. INVESTIGATION OF THE HEATING OF SMALL PLASTIC GEARS

To measure the heating, I performed five independent measurements and compared them with the results obtained using formulas for calculating the heating of normal-sized plastic gears. For the measurements, I used the same equipment that I used to measure the rotational torque. The difference was that I also applied a load to the gears under test using a loading unit I designed, which consisted of a wheel immersed in liquid. I used a Testo 872 thermal camera to measure the heating of the gears, as measurements were also taken with a thermal camera to determine the VDI 2736 formula. For each measurement, I measured two gears with a module of m=0.5 mm. The driven gear had 30 teeth and the other had 50. The teeth width of the gears was 3 mm and they were made of POM.

The measurements showed that the maximum values measured significantly exceeded the quantities calculated from the formulas in all measurements. The aim is to approximate the maximum values of the formulas as closely as possible, since temperature has a greater effect on the strength and deformation characteristics of plastics than on metals. In addition, at such small sizes, thermal expansion caused by heating can lead to the disappearance of the tooth clearance and thus to tooth breakage. Therefore, it is important to know the maximum temperature to which the gears heat up during operation. For this reason, it would be advisable to define a new formula. Unfortunately, I do not currently have the appropriate tools at my disposal.

However, for the range in which I performed the measurements, I modified the equation according to VDI 2736, which is shown in equation (1). With this equation, the maximum heating can be determined with a correlation of 0.8619 in the range of ϑ_k=21.3…25.1 °C, n_1=273.73…600 1/min and F_t=0.0413…0.2615 N, and m=0.5 mm, z_1=30, z_2=50 and b=3 mm.

$$\vartheta_{1,2} = \vartheta_k + \left[H_v \cdot P \cdot \mu \cdot \left(\frac{k_\vartheta}{b \cdot z \cdot (v \cdot m)^{\frac{3}{4}}} + \frac{R_{\lambda,G}}{A_G}\right) \cdot ED^{0,64}\right] \cdot \left[\left(\frac{\vartheta_k}{21}\right)^3 \cdot (105{,}89 \cdot P^2 - 53{,}754 \cdot P + 6{,}8883)\right] \quad (1)$$

3. THE SUMMARY OF THE RESULTS

To test the recirculation torque of small plastic gears, I needed gears in which I could deliberately place faults and then manufacture in small quantities with sufficient accuracy using the tools and resources at my disposal. To do this, I compared the available, fault-free injection-moulded gears with gears printed using the 3D printing technologies and parameters available to me. A comparison of the tooth profile with the tooth profile of the initial geometry showed that SLA technology closely resembles the expected profile, with only a small deviation. In contrast, FDM technology differed significantly from the standard profile. The profile of the gear manufactured using the SLS process achieved a level of accuracy between the two. In terms of tooth thickness, the maximum deviation was 5.8% for the SLA process, while for FDM and SLS it was well over 10%. In terms of pitch, SLA had an accuracy of 1.3%, while the other two processes showed deviations of over 4%. In terms of tooth height, the maximum deviation for SLA was 2.6%, while for SLS it was over 10% and for FDM technology it was over 20%. In the case of the addendum, the deviation in μm was similar to that of tooth height.

I used the characteristic curve of the recirculation torque to investigate the detectability of defects in small plastic gears. I designed a torque measuring device. I used the equipment to investigate tooth thickness errors as dimensional deviations. I have shown that this method can detect both the presence and magnitude of tooth thickness faults. Among the positional deviations that occur during production, I used the equipment to investigate the faults in the pitch. It has been shown that the method can also detect this type of faults. As positional deviations occurring during assembly, I investigated the effect of centre distance faults. I have shown that the method can be used to detect these types of faults. I have also shown that the faults listed so far are not only detectable on the characteristic diagrams, but can also be separated from each other. In addition, I compared the characteristic curves of the recirculation torque of each 3D printed gear, which can be considered as a form deviation. The characteristic curves also showed the same order of accuracy as the microscopic tests. Based on the results, I have formulated two theses.

I investigated the effects of individual faults on the values of the root stresses and surface stresses on the gear using finite element analyses. I selected one of each of the three possible types of deviations. I used tooth thickness faults to investigate the effect of dimensional deviations. I showed that the greater the deviation of tooth thickness in either direction from the standard, the greater the surface stress. The value of the root stress on the defective tooth is greater the smaller the thickness of that tooth is. In contrast, the greater the thickness of the tooth in contact with the non-faulty tooth, the greater the root stress on the non-faulty tooth. To investigate tooth deviations, I used gears printed using FDM technology. The results showed that both the root stress and the surface stress increase significantly when defective teeth are in contact. To investigate the positional deviations, I used the centre distance faults.

The results showed that the closer the gears are to each other compared to the standard, the higher the Hertz stress at the contact point will be. In contrast, the root stress is higher the further away the gears are from each other.

I developed a measuring device suitable for measuring the temperature and load of small plastic gears operating under load by further developing my system suitable for measuring rotational torque. I compared the results of known temperature calculation formulas with my measurement results, from which I concluded that the formulas give lower temperatures than the measurement results. It is necessary to create a new calculation formula or to refine the knowledge. I defined a new formula for the measurement range.

4. NEW SCIENTIFIC RESULTS - THESES

T1. **To test the recirculation torque of small plastic gears, of the 3D printing processes, using stereolithography (SLA) with the Phrozen Mini 8k S printer, a layer thickness of 0.05 mm and an exposure time of 4 s, and Phrozen Rock Black Stiff material, small plastic gears with sufficient accuracy for testing can be produced.**

Related publications: S1, S2, S3, S4

T2. **By examining the characteristic curve of the recirculation torque, it is possible in many cases to detect the presence, type, and magnitude of dimensional, form, and positional faults in small plastic gears.**

Related publications: S5, S6, S7

T3. **Faults in small plastic gears affect the recirculation torque characteristic curve. In the case of tooth thickness defects, if a tooth larger than the standard size is in contact, the torque value cyclically increases above the value corresponding to the standard size; if a tooth smaller than the standard size is in contact, the torque value cyclically decreases below the standard value. In the case of pitch faults, depending on the direction of rotation, the torque cyclically increases above and then falls below the values corresponding to the standard pitch, or vice versa. In the case of eccentricity faults, the closer the teeth are to each other, the greater the torque, and the further apart they are, the smaller the torque.**

Related publications: S8, S9

T4. **The dimensional, shape, and positional faults of small plastic gears significantly influence the root stress and/or surface stress on the teeth, so it is important to recognize and avoid these faults.**

Related publications: S10

T5. **The formulas most commonly used to calculate the heating of plastic gears give results that differ from reality in the case of small plastic gears, and in the range of ϑ_k=21.3…25.1 °C, n_1=273.73…600 1/min and F_t=0.0413…0.2615 N, with parameters m=0.5 mm, z1=30, z2=50 and b=3 mm, the operating temperature can be determined with a correlation of 0.8619 using the following formula:**

$$\vartheta_{1,2} = \vartheta_k + \left[H_v \cdot P \cdot \mu \cdot \left(\frac{k_\vartheta}{b \cdot z \cdot (v \cdot m)^{\frac{3}{4}}} + \frac{R_{\lambda,G}}{A_G}\right) \cdot ED^{0,64}\right] \cdot \left[\left(\frac{\vartheta_k}{21}\right)^3 \cdot (105{,}89 \cdot P^2 - 53{,}754 \cdot P + 6{,}8883)\right]$$

Related publications: S11, S12, S13, S14

5. LIST OF PUBLICATIONS RELATED TO THE TOPIC OF THE RESEARCH FIELD

S1 Marada I., Csörgő Zs., Kovács S.: FDM nyomtatott PLA és kenderszál erősített PLA fogaskerekek pontosságának vizsgálata, In: Barabás, István OGÉT 2024 - XXXII. Nemzetközi Gépészeti Konferencia: 32nd International Conference on Mechanical Engineering, Erdélyi Magyar Műszaki Tudományos Társaság (EMT) (2024) pp. 236-241., 6 p.

S2 Marada I., Bihari J.: Measuring the effects of faults for the rotational characteristics of small plastic gears, Journal Of Physics-Conference Series 2848: 1 Paper: 012010 (2024)

S3 Marada I., Bihari J.: Analysis of small plastic gears manufactured by SLS printing, Multidiszciplináris Tudományok: A Miskolci Egyetem Közleménye 14: 2 pp. 47-54., 8 p. (2024)

S4 Marada I., Bihari J.: Comparing the Accuracy of 3D Printing Methods for Small Plastic Gears, Journal Of Physics-Conference Series 3142 Paper: 012015, 8 p. (2025)

S5 Marada I. Bihari J.: Designing a new type of drive unit for the analysis of small plastic gears, Multidiszciplináris Tudományok: A Miskolci Egyetem Közleménye 11: 5 pp. 245-250., 6 p. (2021)

S6 Bihari J., Marada I.: An Improved Equipment for Measuring Heating Caused by Reactive Loads, IOP CONFERENCE SERIES: MATERIALS SCIENCE AND ENGINEERING 1237: 1 Paper: 012006, 8 p. (2022)

S7 Marada I., Bihari J.: A kisméretű műanyag fogaskerékpárok átforgatási nyomatékának vizsgálatára szolgáló berendezések összehasonlítása, GÉP 74: 4 pp. 106-109., 4 p. (2023)

S8 Marada I., Bihari J.: Investigation of tooth thickness faults in small plastic gears, Multidiszciplináris Tudományok: A Miskolci Egyetem Közleménye 14: 2 pp. 158-166., 9 p. (2024)

S9 Marada I., Bihari J.: Kisméretű műanyag fogaskerekek osztáshibáinak vizsgálata, GÉP 75: 3-4 pp. 65-68., 4 p. (2024)

S10 Marada I., Bihari J.: The Analysis of Stresses on Small Plastic Gears with Finite Element Simulation, Journal Of Physics-Conference Series 3142 Paper: 012009, 8 p. (2025)

S11 Marada I., Bihari J.: Calculation Methods and Measurement of the Heating of Small Plastic Gears, Lecture Notes In Mechanical Engineering Vehicle and Automotive Engineering 4 pp. 223-236. Paper: Chapter 20, 14 p. (2022)

S12 Marada I., Bihari J.: Comparison of Methods for Calculating the Heating of Plastic Gears, IOP Conference Series: Materials Science Anc Engineering 1237: 1 Paper: 012007, 10 p. (2022)

S13 Marada I.: A kisméretű műanyag fogaskerekek melegedésének számítására szolgáló módszerek összehasonlítása, In: Molnár, Dániel; Molnár, Dóra; Nagy, Adrián Szilárd (szerk.) Tavaszi Szél 2022 / Spring Wind 2022 Tanulmánykötet II., Budapest, Magyarország: Doktoranduszok Országos Szövetsége (DOSZ) 584 p. pp. 297-302., 6 p., (2022)

S14 Bihari J., Marada I.: A kisméretű műanyag fogaskerekek melegedésének mérése, GÉP 76: 3-4 pp. 23-26., 4 p. (2025)

6. LITERATURE CITED IN THE THESES BOOKLET

[1] Bihari, J.: Kisméretű műanyag fogaskerekekkel szerelt hajtóművek tűrésezési problémái, GÉP 2016/5-6., pp: 14 – 17, 2016.

[2] Sarka, F., Bihari, J., Takács, Á., Tóbis, Zs.: Test Method for Investigation of Reactive Loads on Gear Drives with Supporting Function, Lecture Notes In Mechanical Engineering 22 pp. 265-272., 8 p. (2021)

[3] Bihari J., Kisméretű műanyag fogaskerekek tervezési és fejlesztési kérdései, PhD értekezés, Miskolci Egyetem, 2017.

[4] Bihari J., Kisméretű műanyag fogaskerekekre ható külső hatások vizsgálata, GÉP, vol. 68, no. 3, pp. 15–18, 2017.

[5] Bihari, J. – Kamondi, L.: Kis méretű műanyag fogaskerekek vizsgálata, GÉP 62:(7-8), pp: 21 – 24, 2011.

[6] Bae, I. & Kissling, U.: Comparison of strength ratings of plastic gears by VDI 2736 and JIS B 1759 – In vision of building a new international standard, 2019, 10.51202/9783181023556-1267

[7] LICHARZ GMBH: Designing with engineering plastics. Licharz GmbH, Buchholz, Németország, 2016.

[8] DuPont: General Design Principles – Module I., Du Pont de Nemours International SA, Genf, Svác, 2003.

[9] Erhard, G., Strickle, E: Maschinenelemente aus thermoplastischen Kunststoffen, VDI Verlag, Düsseldorf, 1974.

[10] Bihari, J.: Kisméretű műanyag fogaskerekes hajtások hibái, GÉP 65:(2), pp: 19 – 22, 2014.