Multidiszciplináris Tudományok, 14. kötet, 2. szám (2024) pp. 158–166 **https://doi.org/10.35925/j.multi.2024.2.15**

INVESTIGATION OF TOOTH THICKNESS FAULTS IN SMALL PLASTIC GEARS

Imre Marada
PhD student, University of Miskolc, Institute of Machine and Product Design
3515 Miskolc-Egyetemváros, e-mail: machmi@uni-miskolc.hu

János Bihari
associate professor, University of Miskolc, Institute of Machine and Product Design
3515 Miskolc-Egyetemváros, e-mail: janos.bihari@uni-miskolc.hu

Abstract
In this article we investigated the tooth thickness faults of small plastic gears. Faults in tooth thickness can lead to excessive heating and failure of the gears. It is therefore worth investigating how these can be detected. For the measurements, we used an equipment that is capable of measuring the recirculation torque to investigate the effects of faults on the teeth of small plastic gears. For the analyses, gear geometries were created using 3D CAD software that included a tooth that was different from the standard tooth thickness. The other teeth of the gears were the standard size. The thickness of the faulty tooth was either 0.1 or 0.2 mm less or more than the standard. These gears were analysed by pairing them with gears that did not contain faulty teeth.

Keywords: *gear, fault, torque, tooth thickness*

1. Introduction

Measuring the torque required to rotate the gears of the gearbox on the input side when there is no load on the gearbox is a well-known analysis for gear drives. The torque measured in this case is called the recirculation torque. In our past research, we have repeatedly investigated its suitability for detecting faults in small plastic gears and analysing the effects of faults. Small plastic gears are spur gears with an involute profile. They have a module that is not larger than 0.5 mm. They are made of plastic materials. (VDI, 1981; VDI 2731, 2009; JIS B 1759, 2019; VDI 2736, 2014)

In this study, we investigated whether and how, small plastic gears with tooth thicknesses smaller or larger than the standard can be detected by recirculation torque measurements.

2. The gears

To be able to carry out the tests, we needed gears that had a fault in only one tooth. To do this, the 3D model of the gears generated with KISSSoft software had to be modified with CAD software by reducing or increasing the thickness of one of the teeth. The values of this reduction or increase were 0.1 and 0.2 mm. *Figure 1* and *Figure 2* show the resulting modified teeth. Then we needed to find a manufacturing solution that could produce the gears with sufficient precision, economically in small quantities and accessible to us. We finally decided on a stereolithography (SLA) or resin 3D printer. In our previous research, we already showed that SLA printers can produce the desired tooth thickness with an accuracy of ±30 μm, which is much more accurate for this purpose than fused deposition modelling (FDM) and Selective Laser Sintering (SLS) printers.

SLA (stereolithography) 3D printers use photopolymers, which are light-sensitive materials that change their physical properties when exposed to UV light. Instead of an extrusion nozzle, SLA uses a laser or a display screen to solidify a liquid resin in a process called photopolymerisation. This process generally allows the production of parts with higher resolution, isotropic and waterproof properties. For the production we used a Phrozen Sonic Mini 8k S printer. (Marada et al., 2022)

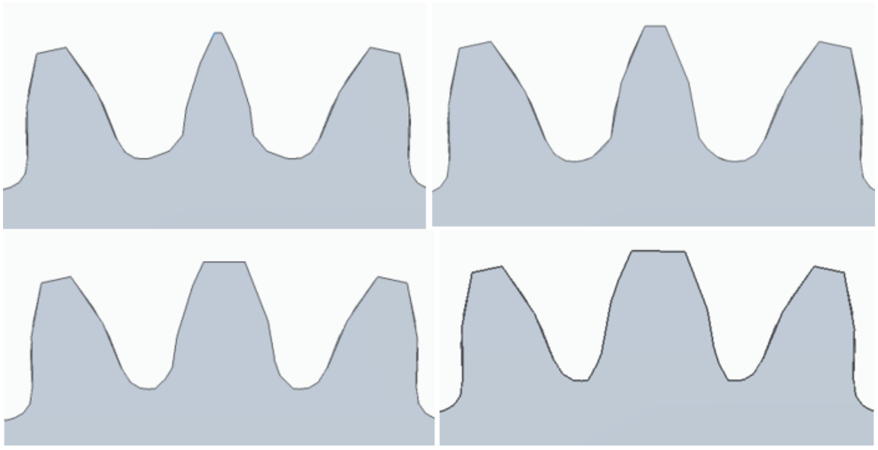

Figure 1. *The modified teeth of z = 30 gears (Top left: tooth reduced by 0.2 mm, top right: tooth reduced by 0.1 mm, bottom left: tooth increased by 0.1 mm, bottom right: tooth increased by 0.2 mm)*

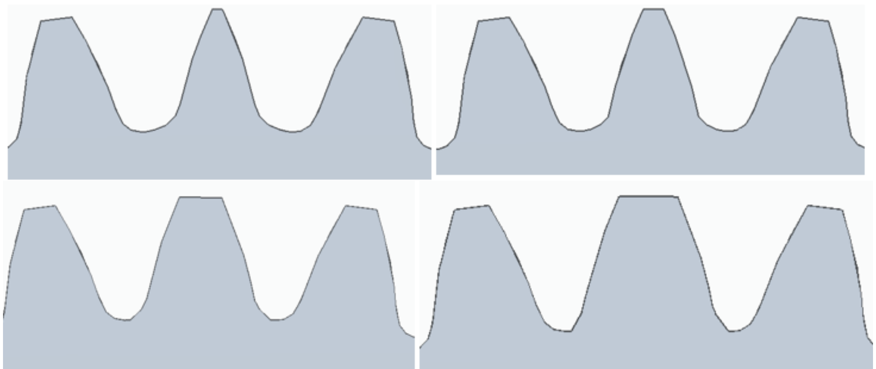

Figure 2. *The modified teeth of z = 50 gears(Top left: tooth reduced by 0.2 mm, top right: tooth reduced by 0.1 mm, bottom left: tooth increased by 0.1 mm, bottom right: tooth increased by 0.2 mm)*

3. The device and the measurement

The equipment used for the tests was a self-designed dynamic torque measuring device, which works on the principle of a differential. *Figure 3* shows the equipment. Its operation and structure will not be discussed in this article, as we have already done it in a previous work. (Marada et al., 2023)

In the measurement, gear pairs with the same number of teeth were tested. In addition, one gear contained a faulty tooth while the other did not.

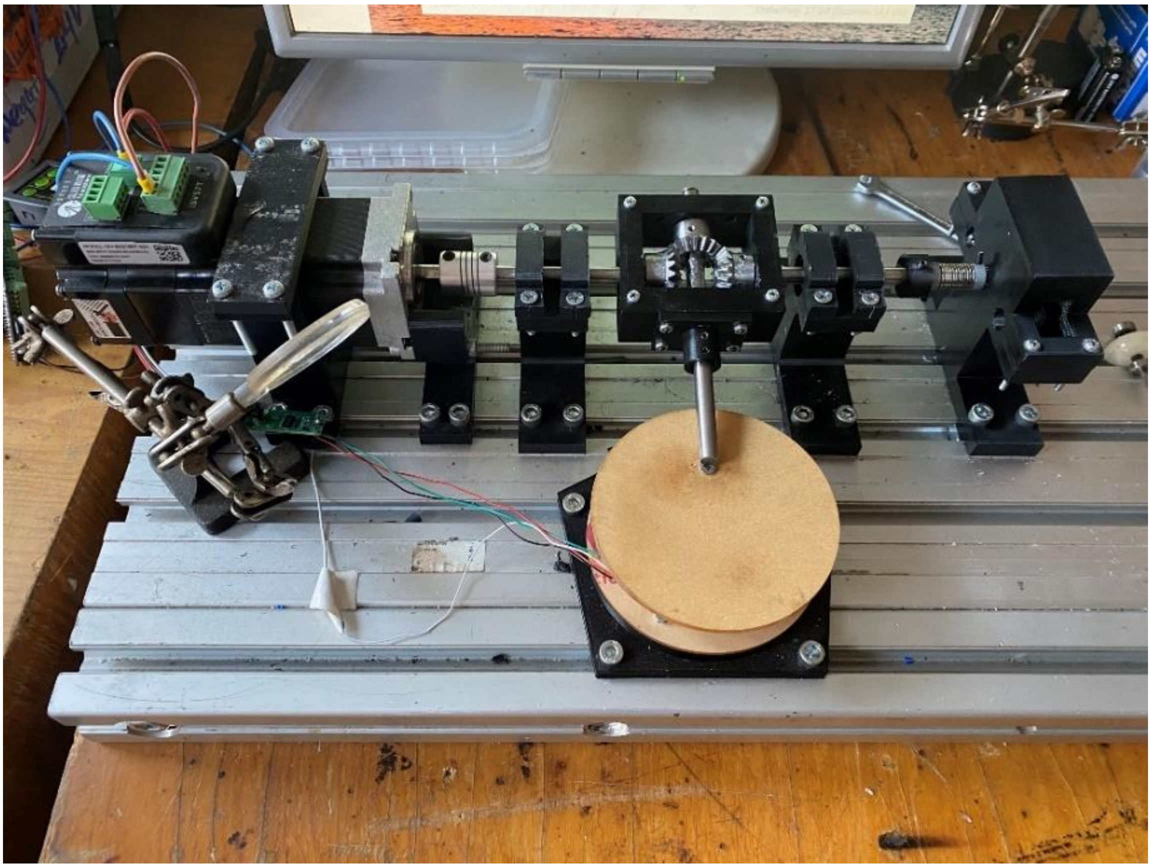

Figure 3. *The torque measuring device*

However, as a reference, tests were required with gears that have no faulty teeth. For each of the two numbers of teeth, three independent tests were performed. The results of these reference measurements are shown in *Tables 1* and *2*. The values in the tables show the values corresponding to the ±30 μm accuracy of SLA technology. The results of the reference measurements are important because deviations from them were sought and investigated in the further measurements.

Table 1. *The recirculation torque for the gear pairs without faults in the case of z = 30*

Measurement	Maximum value [Nmm]	Average value [Nmm]	Minimum value [Nmm]
Measurement 1	0.16701525	0.110430311	0.038259
Measurement 2	0.16701525	0.106189796	0.0485595
Measurement 3	0.16554375	0.098932946	0.03899475
Average	0.16652475	0.105184351	0.04193775

Table 2. *The recirculation torque for the gear pairs without faults in the case of z = 50*

Measurement	Maximum value [Nmm]	Average value [Nmm]	Minimum value [Nmm]
Measurement 1	0.39362625	0.231702011	0.10913625
Measurement 2	0.37155375	0.192418527	0.07970625
Measurement 3	0.387495	0.228799856	0.0981
Average	0.384225	0.217640132	0.0956475

4. The results

In each case, three independent measurements were carried out. The resulting torque curves are shown in *Figures 4* to *11*. Only one measurement result was plotted on each torque curve for easier visibility, but the three independent measurements gave the same result in each case. Each diagram also shows the result of the measurement with the gears without faults for comparison.

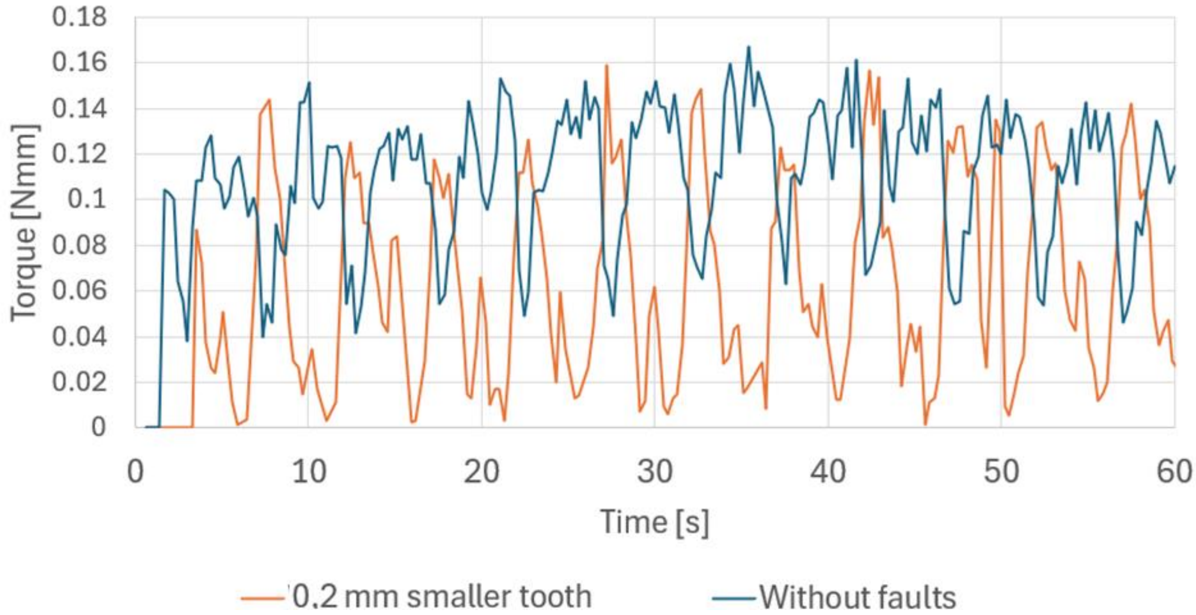

Figure 4. *The torque curve for z = 30, when one tooth is 0.2 mm smaller*

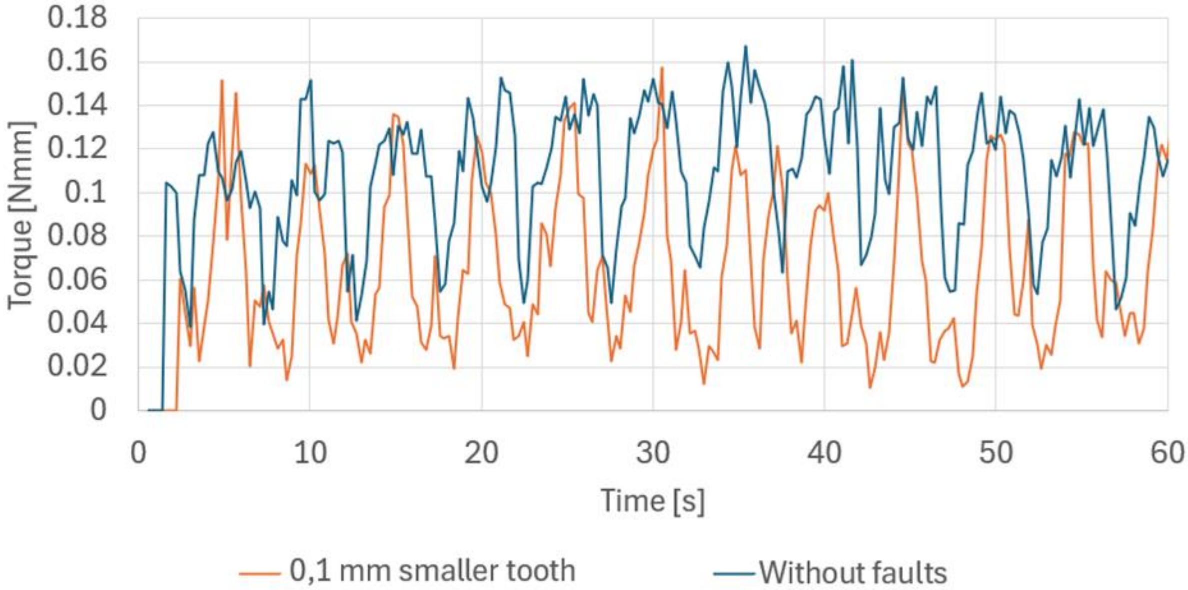

Figure 5. *The torque curve for z = 30, when one tooth is 0.1 mm smaller*

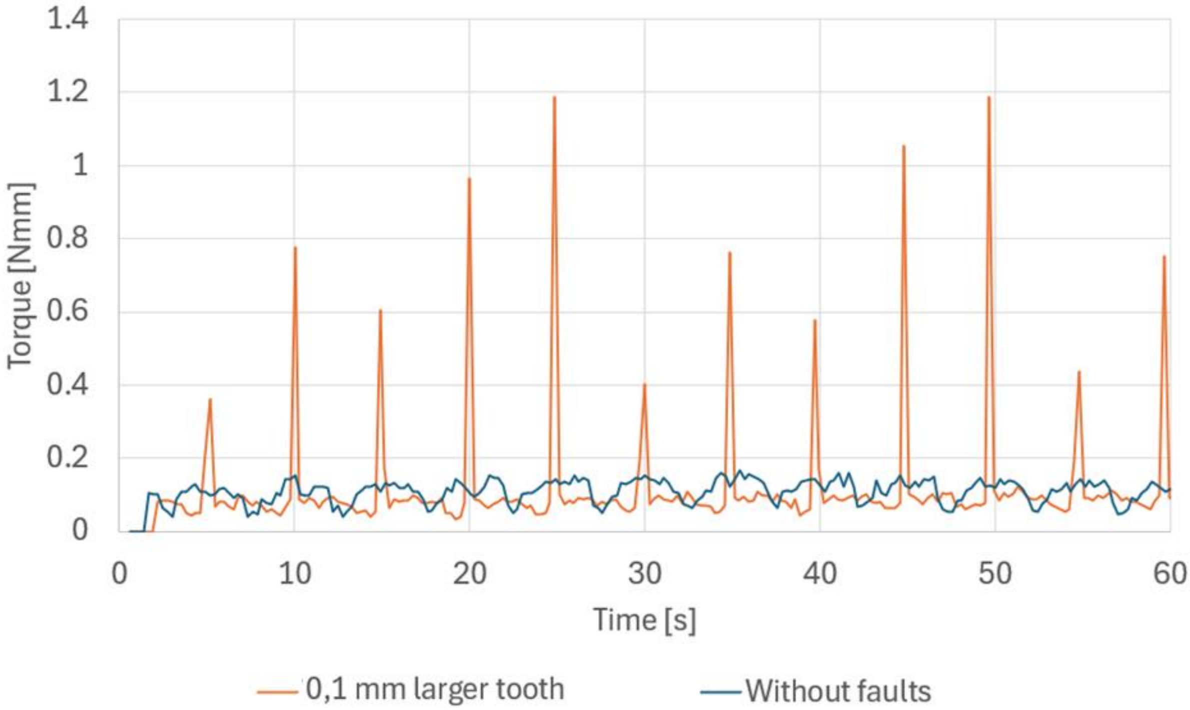

Figure 6. *The torque curve for z = 30, when one tooth is 0.1 mm larger*

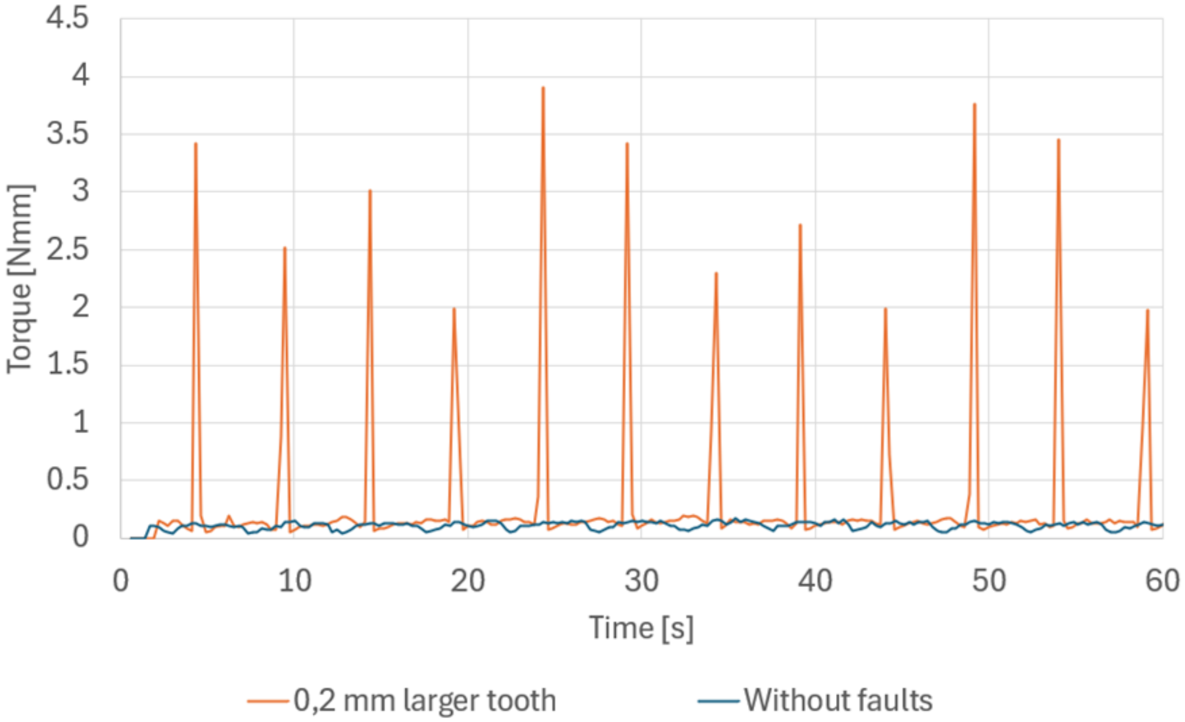

Figure 7. *The torque curve for z = 30, when one tooth is 0.2 mm larger*

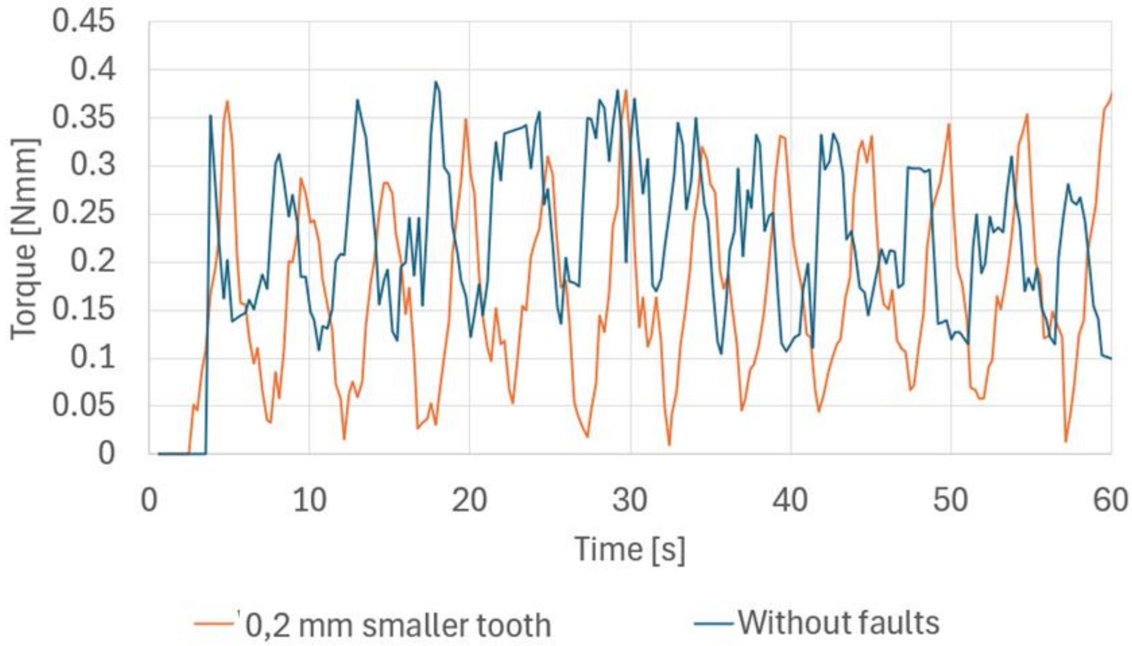

Figure 8. *The torque curve for z = 50, when one tooth is 0.2 mm smaller*

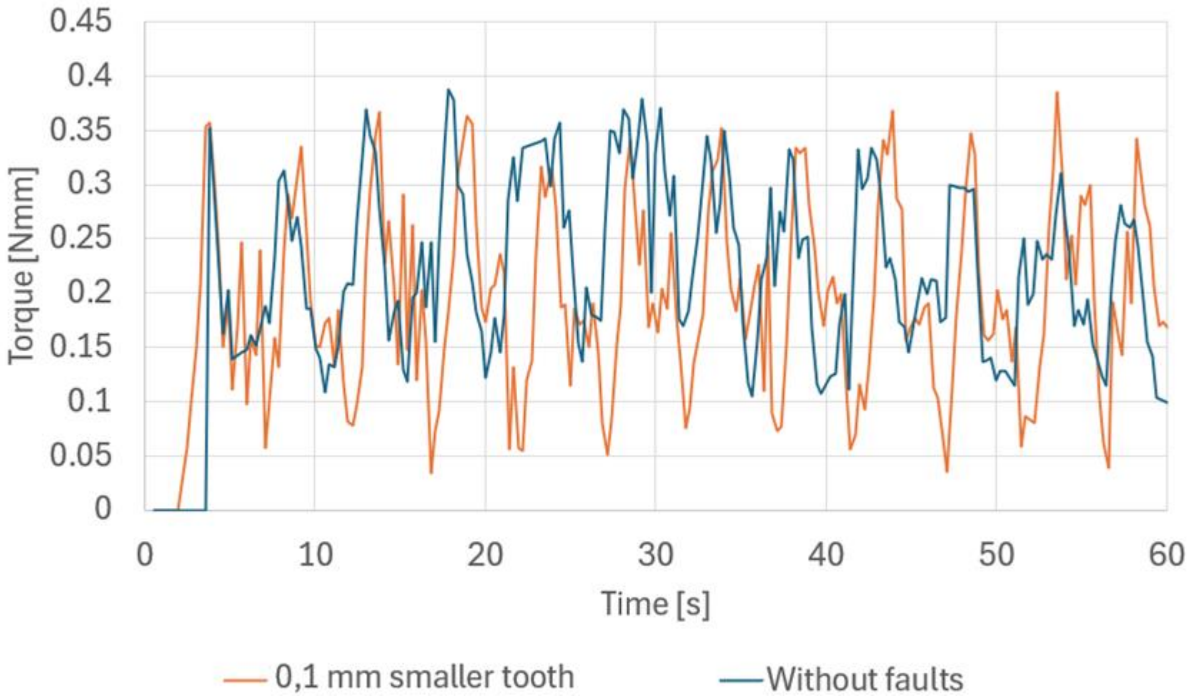

Figure 9. *The torque curve for z = 50, when one tooth is 0.1 mm smaller*

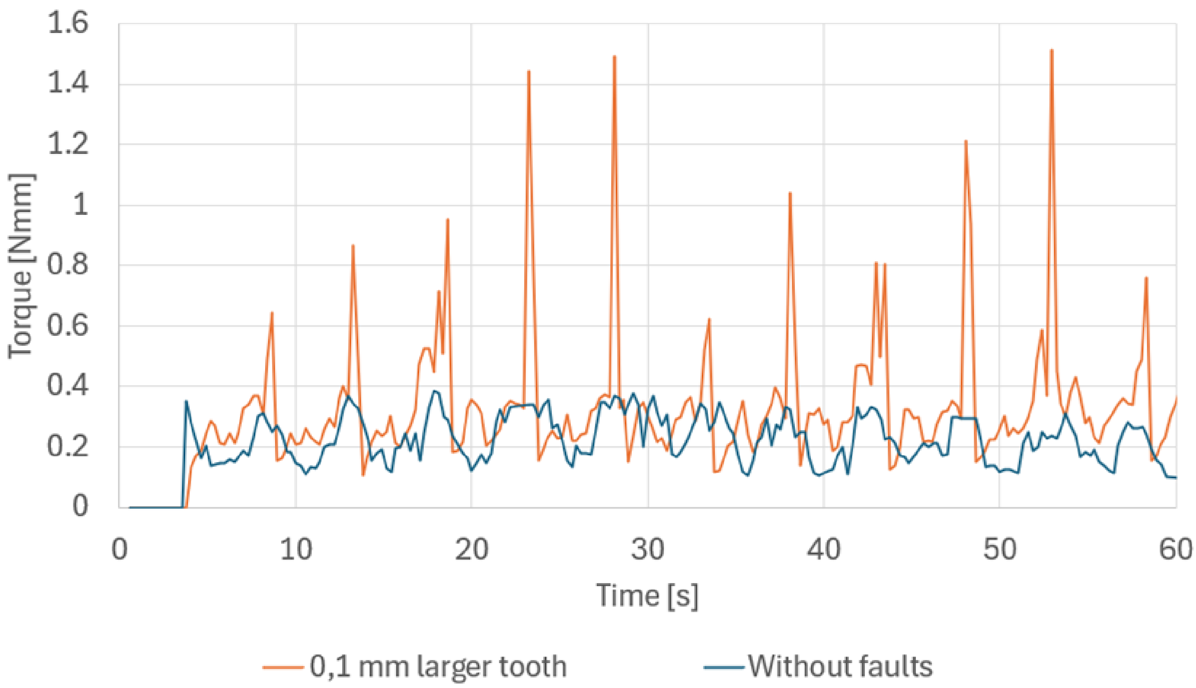

Figure 10. *The torque curve for z = 50, when one tooth is 0.1 mm larger*

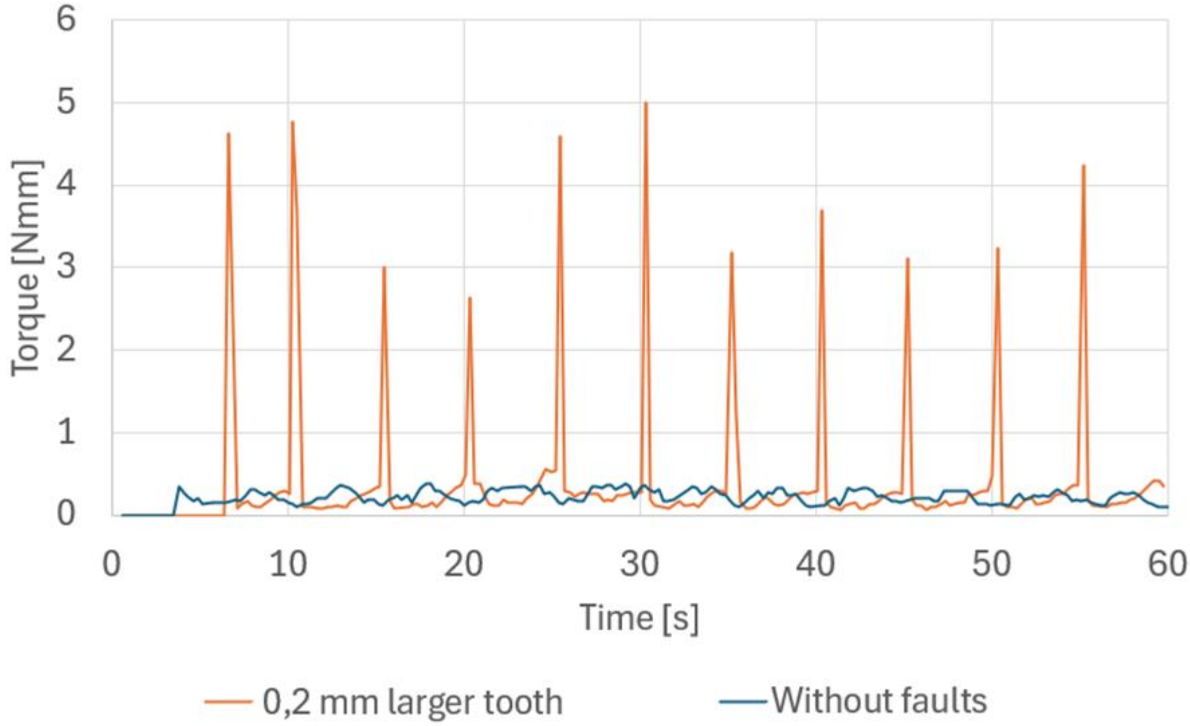

Figure 11. *The torque curve for z = 50, when one tooth is 0.2 mm larger*

During the tests, the gears were rotated at 12 rpm. This is important to point out because each measurement curve shows a repeating deviating value that corresponds to the rotational speed. This is a recess for gears with smaller tooth thicknesses, while for gears with larger tooth thicknesses the torque increases at these points. These positive and negative "peak" values were also examined separately. *Tables 3* and *4* summarise this.

Table 3. *The values of the positive and negative peaks on the torque curves at z = 30*

Name of the value	0.2 mm smaller tooth	0.1 mm smaller tooth	0.1 mm larger tooth	0.2 mm larger tooth
Maximum peak value	0.01839375	0.0309015	1.1875005	3.94141275
Average peak value	0.008353079	0.017457498	0.681010979	2.66233841
Minimum peak value	0.00073575	0.00809325	0.28767825	1.26033975
Difference between maximum and minimum	0.017658	0.02280825	0.89982225	2.681073

Table 4. *The values of the positive and negative peaks on the torque curves at z = 50*

Name of the value	.,2 mm smaller tooth	0.1 mm smaller tooth	0.1 mm larger tooth	0.2 mm larger tooth
Maximum peak value	0.06744375	0.0858375	1.71307125	5.84553375
Average peak value	0.028092273	0.057577734	1.131593382	3.790858826
Minimum peak value	0.0073575	0.03310875	0.6204825	1.603935
Difference between maximum and minimum	0.06008625	0.05272875	1.09258875	4.24159875

The results in the table show that the peak values are within given limits. For measurements with smaller teeth, this value is in the order of hundredths of Nmm, which can be caused by inaccuracies in the printing technology or inaccuracies in the device. In contrast, for measurements with a larger tooth, this variation is of the order of Nmm. It may be worth investigating in the future what causes such a large deviation.

5. Summary

In this article, we have investigated whether it is possible to detect tooth thickness faults in small plastic gears by measuring the recirculation torque of the gear pairs. To achieve this, SLA technology was used to print gears that contained one tooth 0.1 or 0.2 mm larger or smaller than the others. These gears were paired with gears that did not contain any faults and then measured using a torque measuring device we designed. The results showed that this method is suitable for this research.

References

[1] Marada I., Bihari J. (2022). A kisméretű műanyag fogaskerekek FDM és SLA elven történő 3D nyomtatása során szerzett tapasztalatok. *GÉP*, 73 (3–4), 60–65.

[2] Marada I., Bihari J. (2023). A kisméretű műanyag fogaskerékpárok átforgatási nyomatékának vizsgálatára szolgáló berendezések összehasonlítása. *GÉP*, 74 (4), 106–109.

[3] VDI 2736 (2014). *Thermoplastische Zahnräder*. BeuthVerlag, Berlin.

[4] JIS B 1759 (2019). (JGMA/JSA) *Estimation of tooth bending strength of cylindrical plastic gears*. Japanese Standards Association, Tokyo, 2020.

[5] VDI 2731 (2009). *Mikrogetriebe, Grundlagen*. BeuthVerlag, Berlin.

[6] VDI (1981). *Zahnräder aus thermoplastischen Kunststoffe*. VDI Verlag, Düsseldorf.