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EQUIPMENT FOR THE ANALYSIS OF FAULTS OF SMALL PLASTIC GEARS

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ABSTRACT

In the case of small plastic gears, production volumes and manufacturing processes severely limit the number of methods that can be used to detect faults. It is therefore particularly important to understand the phenomena caused by faults that are also present, detectable, and measurable on the gear shafts. Among the rotational characteristics, the measurement of the torque on the input side is a common test method for gear drives, especially for bevel gears. This method is also suitable for detecting certain faults in gearboxes with small gears and for distinguishing the effects of faults and manufacturing characteristics. In this research, we have established the basis and equipment for a series of measurements that can be used to gather more definitive information than previously known, to understand the effects of faults in small plastic gears.

1. INTRODUCTION

Among the rotational characteristics, the measurement of the torque on the input side is a common test method for gear drives, especially for bevel gears. It has been shown previously that this method can also be used to detect certain faults in gearboxes containing small gears, ($m \leq 0.5$ mm with a maximum characteristic size not larger than 30 mm) and to distinguish the effects of faults and manufacturing characteristics.

However, the tools available for us in the past were limited. We could not achieve gear ratios different than 1:1. In addition, we could not create multi-stage drives. There were also problems with the accurate positioning of the equipment. We presented these problems in [1]. We had also limited possibilities with the measured faults, as we could not produce gears with these specific faults. For these reasons, we had to design new equipment and find a way to create small plastic gears with faults.

In this research, this method will be refined to define the ideal design of drive units and to design and integrate gears with specific faults in drive units, taking advantage of the potential of new technologies, for example SLA 3D printing. In this way, the measurement results associated with each fault can be more accurately determined.

2. THE DRIVE UNITS

For testing plastic gears, suitable test benches are used. [2] [3] However, such a bench would be expensive to build for testing small plastic gears. Therefore, we had to develop alternative equipment that would allow testing of the complete system, while keeping the gears in the correct position and ensuring they can be loaded throughout the entire duration of the measurements. For this purpose, we have designed a special drive unit which, when installed in the appropriate equipment, can be used to carry out the measurements with the given settings. This replaces expensive test benches with a more affordable alternative. The drive units are designed so that a static torque meter can be used for the tests. Therefore, we preferred designs where the rotatability of the complete drive unit is possible.

2.1. The requirements

We have taken several aspects into account when designing the drive units. These include [1]:

1. They should hold a pair of gears.
2. They can be used to develop multiple gear ratios.
3. They should be capable of being combined, i.e., multi-stage drives should be possible.
4. They can always be positioned in the same way within the specified accuracy into the clamp.
5. There must be sufficient space for the gears.
6. Have high stiffness in the bearings.
7. They should have two divisions perpendicular to the gear axes, (e.g., a central housing part with two covers for the bearings).
8. To produce as many versions as possible, using the resources and technologies available for us.

2.2. The design and manufacture of the drive units

Two versions of drive units were designed. Each of these drive units are made up of three parts. The central part is a central housing, which remains constant for all tests. A pair of covers are connected to the housing part. These covers contain the bearings. The covers are

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interchangeable, so that parts with different designs and wheelbases can be fitted to the housing, depending on the gear ratio, or bearing arrangement to be tested. In addition, the drive units are accurately positioned by means of positioning holes and pins, so that they can always be fitted in the same way in the housing with the required precision. In addition, it is possible to combine the drive units, so that multi-stage drives can be designed. For the multi-stage design, we have also created intermediate pieces, which are located between the drive units and serve to accommodate the couplings.

2.2.1. The first type

The first type has a classic, rectangular body design. However, it has a major disadvantage; that it can only be produced with sufficient precision using accurate CNC milling machines, which are not currently available for us.

The prototype of these drive units is produced with an Ultimaker FDM 3D printer. This prototype will not be used for tests, as it is not accurate enough.

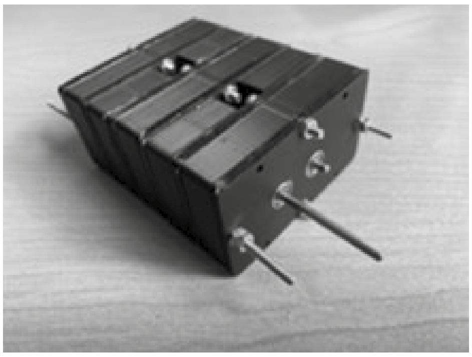

Figure 2. The prototype of the drive unit

2.2.2. The second type

This type of drive unit has a cylindrical design. This is necessary to make it as easy as possible to machine them with a lathe. This is also advantageous because it is easier to calibrate for testing. Another big advantage is that the cover is designed so that the tested shaft is coaxial with the drive unit. This makes it easier to coaxially align the drive unit with the motor and the torque measuring shaft.

Prototypes of these drive units were also made. The prototype was made by machining polycarbonate. It can be used for measurements, however in the future, these drive units will be made of aluminum or steel.

Figure 3. The prototype of the drive unit

3. THE MANUFACTURE OF GEARS FOR THE MEASUREMENTS

The gears used for the measurements are produced with a Phrozen Sonic Mini 4k SLA 3D printer. The software KISSsoft was used to generate the geometry for the production. The advantage of this software compared to other similar software is that it generates an involute profile.

The tooth profile was created according to DIN 3967 and VDI 2731. [4] [5]

The material of the gears is a resin called "Rock-Black Stiff", produced by Phrozen.

The gears are created with different modules and numbers of teeth, in order to make measurements for as many different cases as possible. All gears are produced without faults and also with the faults. This is necessary to compare the running characteristics of gears with and without faults during the measurements. These faults are the faults that are typical of injection molded gears. [6] [7] The faults include non-involute profile, waviness of the tooth, material gaps on the tooth flank, and an increase or decrease in the size of the teeth compared to the standard dimensions. The faults were created by modifying the tooth profile in the CAD software.

This manufacturing method is a huge improvement over those available in the past, as we previously were unable to produce gears with such faults in prior tests.

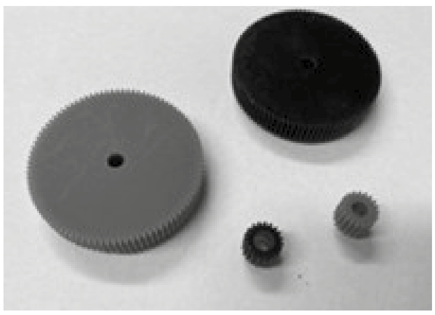

Figure 4. The manufactured gears

4. THE PRINCIPLE OF MEASUREMENT

The entire drive unit is rotated when the torque is measured. One shaft of the drive unit is connected to the torque meter, which is stationary during the process. This is advantageous because it allows the use of a static torque measuring shaft. It requires less effort and less preparation for the accuracy required for this measurement, than non-static torque meters.

For the measurement, first we must determine the optimal number of steps for the drive units, which will give the clearest measurement results. Next, we will assemble drive units that contain gears with faults and, for comparison, gears without faults. Tests shall be carried out to determine the torques that will be applied on the drive units. Finally, the running characteristics of drive units containing gears with faults must be compared with those of drive units without faults.

5. THE EQUIPMENT FOR THE MEASUREMENT

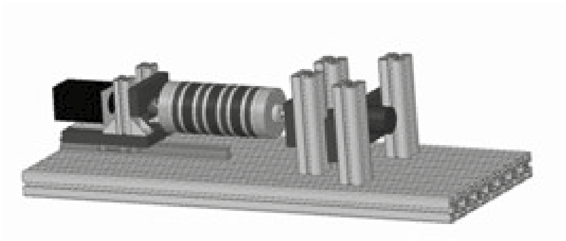

Figure 5. The 3D model of the equipment with the cylindrical drive unit

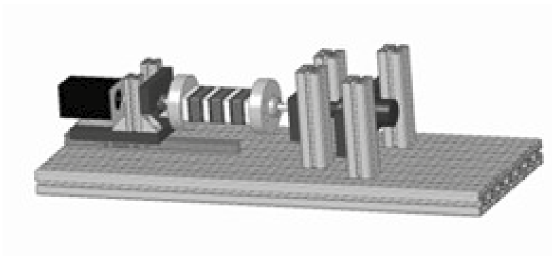

Figure 6. The 3D model of the equipment with the rectangular drive unit

The rotation is performed by an electric motor. On each side of the drive unit, we have fitted custom-designed connecting elements. These are connected to the shafts by KL locking devices, which's shafts are supported by bearings. The double bearing arrangement ensures that the drive unit does not stress the bearings during measurement, thus guaranteeing the required accuracy. One of these shafts is connected to the motor, the other shaft is hollow. This is necessary to connect the measured shaft of the drive unit to the torque meter.

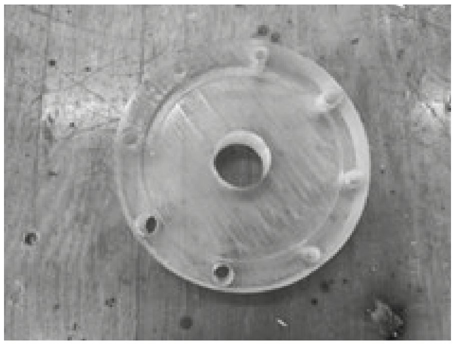

Figure 7. The connecting element

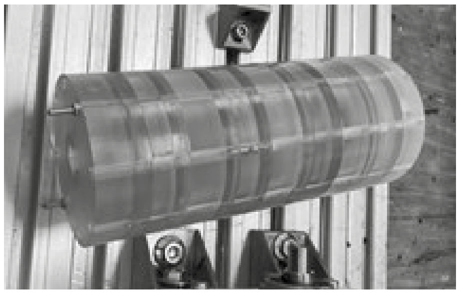

Figure 8. The connecting elements combined with a four-stage drive unit

To simplify installation and to ensure measurement with different steps, a linear guide is used. This means that the block of the linear guide is attached to the motor and the motor-side bearing assembly so that they can be moved to the correct position.

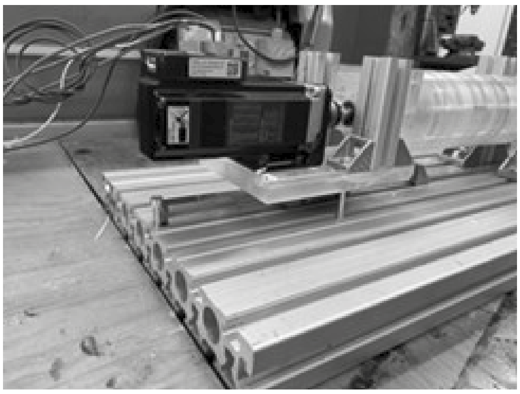

Figure 9. The linear guide and the motor

For the measurement of torque, we use a PCE TM-80 torque measuring shaft. It has a resolution of 0,1 Ncm with a measurement range from 0 to 147 Ncm.

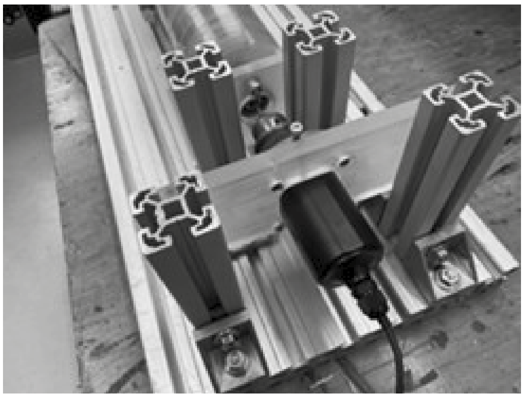

Figure 10. The torque measuring shaft

With the installation of the cylindrical drive unit, we made a prototype for the measuring equipment.

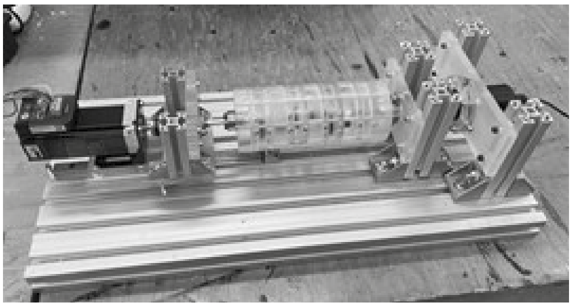

Figure 11. Prototype of the equipment

6. SUMMARY

In this research, we have established the basis and equipment for a series of measurements that can be used to gather more definitive information than previously known to analyze the faults in small plastic gears. We designed the special drive units and the equipment for the tests. We also generated and created small plastic gears with the help of 3D printers. A prototype of this equipment was manufactured. Our next step will be the further improvement of the equipment and the measurement of the torque. We will carry out many measurements for different faults, modules, and gear ratios.

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