An Improved Equipment for Measuring Heating Caused by Reactive Loads

Dr. János Bihari¹, Imre Marada²,

¹Associate Professor, University of Miskolc, Institute of Machine and Product Design, 3515 Miskolc, Miskolc-Egyetemváros, machbj@uni-miskolc.hu

²PhD Student, University of Miskolc, Institute of Machine and Product Design, 3515 Miskolc, Miskolc-Egyetemváros, maradaimre@gmail.com

Abstract. In the case of gears that also perform a support function, taking into account the effect of reactive loads is an essential element of sizing. Pulsating or continuous but variable reactive loads can cause heating similar to or greater than in case of normal operation. This heating can be such that it significantly affects both the operating clearance and the strength characteristics of the gears. The effects of reactive loads were previously measured with the help of special drive units, which proved to be a useful method. However, due to the design of the drive units, these measurements were only able to demonstrate that the effect of the reactive loads is significant for the sizing even if they are not of a magnitude causing immediate failure of the gears. Our new research aims to quantify these effects for as many applications as possible. In this article, we introduce the features of the old method and the solutions, which aim to eliminate their disadvantages.

1. Definitions

Small gear: In our work, "small gear" is a gear with a module not larger than 0,5 mm and a maximum characteristic size under 30 mm.

Plastic gear: In our work, we applied cylindrical gears with involute profile and external straight teeth, made of polyamides or polyoxymethylene.

2. The drive units used previously

Structures that fix the gears in the correct positions and allow for drive and load are required for in-service testing. With these it is possible to test the entire system, e.g., various bearings. For this purpose, we typically use test benches, which are usually very expensive for small plastic gears. For this reason, we have formerly designed a special type of drive unit for the tests of the recirculation torque and the reactive loads. When this was placed into simple devices, we were able to perform tests with it at specific settings, and we could eliminate the difficult adjustment possibilities of the expensive test benches. It was taken into account during the creation of this special equipment, that in several cases during the analysis of small plastic gears, it is usually easier to rotate the entire drive unit, because this makes it possible to install static torque measuring equipment. These drive units, that were used for the previous tests, were created with the consideration of the following basic principles [5]:

1. The drive units need to contain a pair of gears.

2. We need to be capable of the measurement of the recirculation torque and the reactive loads. We also need to be able to combine these tests when it is necessary.
3. We must ensure, that there can be no collision problems with the clamps, thus they need to have rounded outer corners.
4. It is important, that the rigidity must be high in bearings.
5. For the gears we need to create enough space, the various possible layouts and the wheelbase tolerances must be taken into account.
6. A direction perpendicular to the axes of the gears is required for the division of the housings, for mounting purposes. We must also ensure that the positioning of the housing halves is accurate enough.
7. We need to reduce the weight of the housings to be as small as possible. If they are heavier, they can have a negative effect on the recirculation torque tests.
8. We must produce them in as many variations as possible with the tools at our disposal.

The last point of the requirement list in our case meant a Roland Modela CNC milling machine, which can produce the parts for the drive unit with acceptable precision. However, it would have taken 60 hours to manufacture a single housing if we wanted to ensure that point 7 of the requirement list was not ignored. Thus, we manufactured the drive units with FDM 3D printing from ABS material and finishing was made with precision milling. We also had a problem with determining the cutting parameters for the precision milling, so we conducted experiments, as we had no literature or experience at our disposal about the machining of 3D printed parts. These experiments were done on many different materials, we obtained the perfect results with the ABS material, so we chose that. With this method we were able to limit the expensive and slow precision milling to the finishing of the holes of the shafts and bearings. This way we reduced the manufacturing time of the drive units to a mean value of two hours [5].

Essentially, two types of drive units were developed and manufactured in several versions, one for the use of plain bearings (Figure 1) and another for the use of roller bearings (Figure 2). At the time these drive units were created, the tests required four different wheelbases and another design, which simulated the typical faults due to housing distortions, so five versions were made. We designed these different wheelbases in accord with the most important ISO tolerances. The error that was simulated was the skew which is formed when the housing of the drive unit is distorted. For this we inclined the bearing of a shaft by 3° [1] [5].

Figure 1. The housing created for plain bearings [5]
3. Usance of the former drive units and the accomplished results

3.1. Usance of the equipment in the reactive load tests
Difficult-to-diagnose problems can be generated by the effects of reactive loads in drive units fitted with small plastic gears especially when they have a support function too [4]. Since this function is a commonly used additional utilization, principally for drive units with more than one stages, the thorough research of the effects of reactive loads is highly needed. To analyse these effects, we fixed one of the gears and used a repetitive load on the shaft of the other gear. At the time, we fixed the gear with a screw through a hole, and we applied the load through a steel weight. Figure 3 shows the layout of the reactive load test. We attached a lever (3) straight to the output shaft. The drive unit (1) and the drive motor (5) were mounted on a base (2). An eccentric disc (4) was situated on the shaft of the drive motor. The eccentric disk was under the lever, so when the motor was operating, the eccentric disk raised the lever, and the lever loaded the gears. We created this load with the help of a weight (6), which was suspended by a joint (7) at the end of the lever. When we adjusted the location of the drive motor, the angular rotation of the lever was also adjusted. This way, the number of loads corresponds to one per the rotation of the motor, so the speed of the motor determines the number of loads per time duration [5].

3.2. Results of the reactive load tests
We made several tests with the previously used drive units. These tests showed, among other things, that considerable and dangerous local temperature rises can be generated by the effects of reactive loads in the connected teeth [5].

4. The reasons that lead to the development of new drive units
With the drive units used so far, the effects of the reactive loads can be demonstrated, but they are no longer suitable for determining the exact values of the effects. A major problem is that measurements can only be made on a single stage, which is disadvantageous in several respects.
In gearboxes that also have a support function, the drive motor's usually small moment of inertia is very high, and typically acts on the supported element through a ratio of between 1:400 and 1:1600. However, this means a large number of associated components, as well as backlash at each connection. Therefore, testing with one stage and one of the gears locked is not accurate because only the number of teeth corresponding to the contact ratio is connected, whereas in real cases there is always a displacement due to backlash in the system. This displacement can be beneficial for heating, especially if the held element flexibly returns to its original position, such as air dampers with hollow seals, because more teeth are engaged than in the fixed case. However, in the fixed case, there is typically no wear, which is also not true here, because many of these drive units have been shown to experience wear on the tooth surfaces due to small but high repetition rate displacements.

Another characteristic of such plastic drive units is that, due to the large number of stages, the speed and torque differences between the input and output of the gearbox are also very large. To minimise the volume, it is therefore common to vary the modules, number of teeth and tooth widths for the same gear ratio, even per stage. For this reason, the effect of reactive loads does not necessarily only occur on the last stage.

In addition, the fixed solution does not allow the positions to be changed during the test. Damage from repetitive reaction loads occurs when the drive unit starts to operate after a prolonged period of inactivity.

The experiments so far have been carried out at ambient temperatures between 20 and 25 °C. However, the effects of reactive loads are always more dangerous at higher ambient temperatures, so measurements at ambient temperatures of at least 60 °C are also necessary. A further disadvantage of old drive units is that their housing is plastic. This is a common solution in real applications, but due to the thermal expansion of the housings, the wheelbases and thus the operating clearances change (by up to an order of magnitude) more with ambient temperature than with steel housings. Thus, the tests have to deal with both the change in the wheelbases and the change in the gears' own dimensions. As we are currently mainly interested in the behaviour of the gears, this complicates the evaluation of the results considerably.

Typically, drive units that also have a supporting function must be designed so that if the reactive load exceeds the designed supporting force, e.g., in the case of mirror drive units in cars, when the mirror plate is pressed, the drive unit can rotate backwards without damage. In such cases, the drive unit may be subjected to several times the designed working load. Such a test cannot be carried out with fixed gears.

5. Requirements of the new drive unit
With the formerly used drive units we could not create different gear ratios, i.e., we were able to install only gears with equal number of teeth. With the enhanced new drive unit, we must solve this problem. The solution can be done with eccentrics or replaceable covers [5].

The surfaces of the old drive unit used for fastening did not make it possible to return the equipment to the clamp between tests in a changeless way within 0.05 mm in the x and y directions, which created an altering impact during rotation. We need to make possible the accurate repetition with the new equipment [5].

However, while the old drive units were required to be minimal weight so that their mass did not affect the analysis of the recirculation torque, this is no longer a relevant consideration for the new ones. If the drive unit fits exactly into the required devices, the effect of the higher mass can be determined by simple calibration. This allows the drive unit housings to be made of steel, which is important for analysing the effect of reactive loads.

In our previous tests we were not able to combine the old drive units, so we could not test multi-stage drives. At the time the combination of drive units was not necessary, because the gear ratio was always 1:1. However, in our future research we would like to study the interaction between the faults of the gears, so it has a bigger importance to be able to create several stages in our upgraded equipment [5].
When we created the old equipment, the bearing bush of the housing with the plain bearings was manufactured of the plastic material, which was used for the housing. Manufacturers already know and utilize injection moulding techniques, which make it possible to combine different polymers. Thus, we must create housings and covers, where the material of the plain bearings and the material of the housing are not the same [5].

Additionally, we still have to take into account many points of the requirements list, mentioned in section 2, these points are the following [5]:

1. We still need to be able to measure the recirculation torque and the reactive loads. We also need to be able to combine these tests when it is necessary.
2. It is still very important, that the rigidity must be high in bearings.
3. For the gears we need still to create enough space. The possible layouts and the wheelbase tolerances must be taken into account.
4. A direction perpendicular to the axes of the gears is still required for the division of the housings, for mounting purposes. But it is recommended, to have multiple divisions, for example a centre part with covers.
5. We still must produce them in as many variations as possible with the tools at our disposal.

6. New drive units for new tests
The housing of the new drive units consists of three parts, a centre housing part and two covers. The precise positioning of the covers is ensured by two positioning pins. The covers are fixed with through bolts.

![Figure 4. The model of the drive unit](image)

![Figure 5. The centre housing part](image)
The centre housing is constant, the same for all ratios and wheelbases. The covers are interchangeable and can be produced in several variations, allowing the design of drives with different wheelbases and ratios. Different wheelbases are associated with different pairs of covers of different designs, of which the appropriate one for the test must be fixed to the housing. Thus, these drive units can contain not only gear pairs with the same number of teeth, but also different ones. These elements are made of steel by electrical discharge machining.

**Figure 6.** Design of the cover for plain bearings

For the time being, the covers will be made for plain and roller bearings, but other designs are also possible, such as one where plain bearings other than the housing material are used.

**Figure 7.** Design of the cover for roller bearings

The exact positioning of the drive unit in relation to the clamp is achieved by means of the positioning holes in the centre housing. This means that they always engage the same way in the clamp within the required accuracy, thus allowing accurate repeatability, i.e., a drive unit can be repositioned in the clamp within 0.02 mm in the x and y directions. This is currently sufficient accuracy for all planned tests. In addition, the pin mounting allows for accurate calibration, so that inertia due to the higher mass of the gearboxes is not a problem for other tests.
It is also possible to combine the new drive units, so we can even create multi-stage drives. This is an important aspect for them, as the gear ratio is no longer 1:1, but can be any desired, depending on the holes in the covers. This makes it possible to investigate the reactive loads and the interaction of faults by designing multiple stages.
The red elements in Figure 11. are intermediate pieces that provide space for the couplings.

Summary
The new type of drive units allows tests to be carried out in closer-to-reality situations, for example at high ambient temperatures. The steel housings simplify the positioning of the sensors, as they can be provided with holes, so that measurements can be made separately for each step, speeding up data collection. The modular design and the calibratability of the plain bearings also allow to model bearing arrangements with different fits per step, which is common for this type of drive units.

Literature
[1] VDI 2731 Mikrogetriebe, Grundlagen. BeuthVerlag, Berlin, 2009.
[2] Bihari, J.: Kisméretű műanyag fogaskerekes hajtások hibái, GÉP 65:(2), pp; 19 – 22, 2014.
[3] Bihari, J. – Kamondi, L.: Kis méretű műanyag fogaskerekek vizsgálata, GÉP 62:(7-8), pp: 21 – 24, 2011.
[4] 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) VDI 2736 Thermoplastische Zahnräder, Blatt 2, BeuthVerlag, Berlin, 2014.
[5] 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)