MINI FRICTION DRIVE

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ABSTRACT

Friction wheels can be manufactured with higher accuracy than gear wheels and are more favourable for mini drives and low noise environment.

SPE gained experience on friction drives in the ESA TRP study 'low noise gears' [1].
For this study SPE and partners built a low noise gear based on a multi roller friction drive. This drive with a ratio of 100 did comply the specifications very well. Thanks to the imperfection of one wheel it was possible to detect any noise, otherwise it was not possible to verify the theoretical model derived.

Funded by NIVR SPE has used this experience for the development of mini drives.
In the study SPE did find the following advantages:

- Low noise, due to high accuracy and proper elasticity in the right direction
- no backlash
- high extend of component and function integration (no coupling and motor bearing is needed, actually it replaces the motor bearing)
- it can always be smaller (an order) then a mini gear solution.
- it opens doors to new flexible and integrated solutions and functions like variable drive ratio, combined axial and rotational displacement and other complex movements.

Although slip can be seen as a disadvantage it has the advantage of a torque limiter, while slip can be compensated if the output displacement is controlled.

SPE has built a functional mini friction drive. The functional model performed very well and it was decided to built a test model to compare it with a mini gear box. The first results were promising, however the test sample did fail due to the not hardened shaft of the mini motor. New tests with improved material are going on, but cannot be presented in this paper.

From the functional model and the preliminary test results and the results of the LNG project the following can be stated:

The mini friction drive is smaller and lower in mass than the gear box compared, for the same torque specification.
The noise of the friction drive is an order smaller, which is also true for the backlash.
The friction drive is very suitable for the first stage of a motor drive.
If seen as an integrated motor bearing it upgrades the performances (torque, power, efficiency,) of that mini motor with the ratio of the friction drive.

The mini friction drive is promising for applications such as mini pumps, mini pointing mechanisms, mini diaphragms, integrated and multi direction displacement mechanisms, mini robots. In the μg environment the use of this type of mechanism is a must.

INTRODUCTION

The study aims at the investigation of the feasibility of a new design for a mini motor gearbox combination, using function integration and experience gained with friction gears used in the low noise gear project [1]. For the low noise gear project a multi roller friction drive (MRFD) with a ratio of 100 was used, see fig.1.

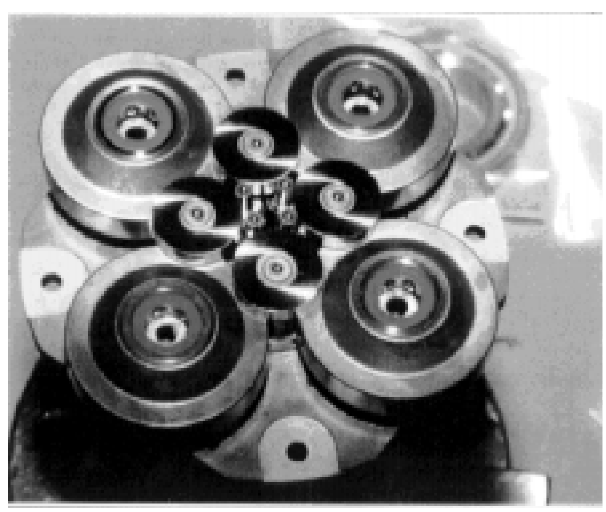

Figure 1 Multi Roller Friction Drive (4-4-4).

From the test performed on the MRFD it was found that the first stage was most sensible for noise, while this stage had also the smallest dimensions and the smallest torque. These conditions are optimal for friction drives.
The larger stages of the MRFD did hardly contribute in the noise and while the torque of these stages is higher for the compactness and the mass it is better to provide these stages with gear wheels.
In the so created hybrid friction and gear wheel combination the advantage of the mini and noise characteristics needed in the first stages and the compactness needed in the higher stages is optimized.
Because a planetary friction drive has the same function as a roller bearing it was decided to replace the motor output bearing by a friction drive. So a new motor is created in which a first stage drive is integrated with the bearing, with nearly the same compactness and mass as the original motor.
The advantage in compactness and mass is even better, because due to modularity most gearheads of mini drives have the same gear wheels for all stages so the first stages are over-dimensioned.
From a functional test [2], part of a first feasibility study, it is decided for further development to concentrate on the critical aspects found. The main critical point is the provision of pre-stress needed for traction without the creation of noise. The pre-stress will be applied by deformation of the outer ring. To avoid torque noise this ring should be machined very accurately, while the suspension of the ring should be soft, without influencing the characteristics of the motor.

GENERATION OF PRE STRESS

The pre-stress will be applied by making the inner diameter of the outer ring smaller than the outer diameter of the planet system.
The pre-stress should be sufficient to perform the maximum friction torque, which is equal to the stall torque of the motor.

The needed pre-stress is determined by the elastic deformation of the ring, which is a function of the material, thickness and the width of the ring.
The noise of the drive depends on the imperfection of the wheels and the ring and the elasticity of the ring. High perfection and high elasticity performs the lowest noise. At the other hand the ring should be stiff enough to provide sufficient suspension of the motor shaft and strength of the ring, because an elastic ring requests a small thickness and causes high fatigue bending stresses. To comply to all these conditions the optimal ring dimensions are derived for two types of mini motors from which the bearing was exchanged by a friction drive; a MAXON motor and a MINIMOTOR motor.

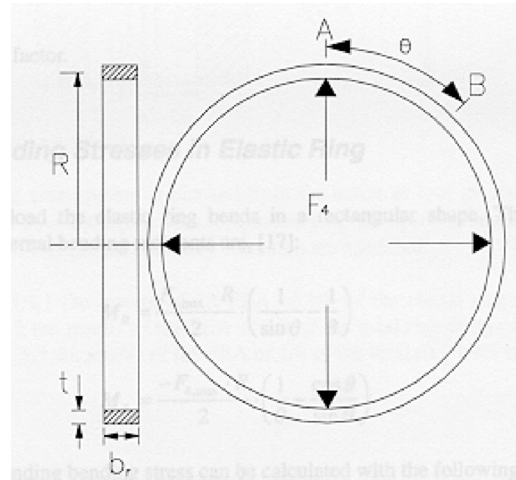

Figure 2 Outer Ring pre-stressed with 4 planets.

For the MAXON 8mm motor the graph of fig.3 satisfies the needed pre-stress.

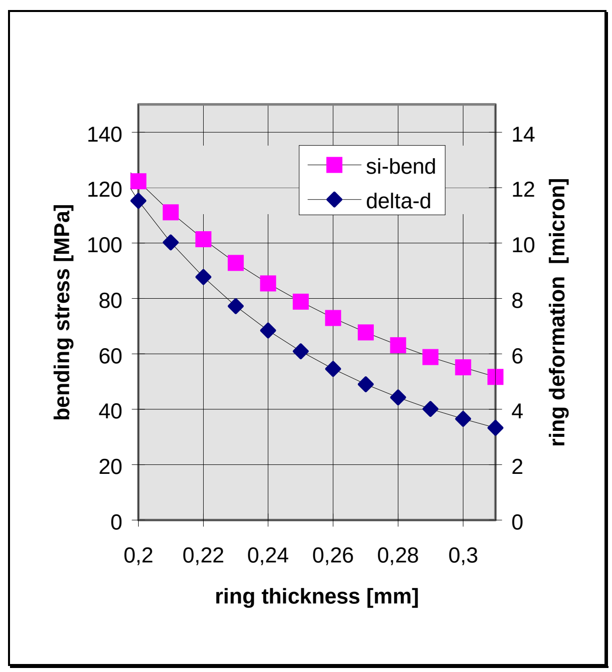

Figure 3: Pre-stress parameters of the outer ring for the MAXON motor.

For fabrication two aspects are important:

- a large deformation needs less accuracy and produces less noise.
- a large deformation will give high stresses in the ring and needs a thin ring

Between these aspects the best option should be taken: a deformation of 10 µm is suitable, so a thickness of 0,21 mm is required.

The required rings for the smallest MINIMOTOR motor can be found in fig. 4.

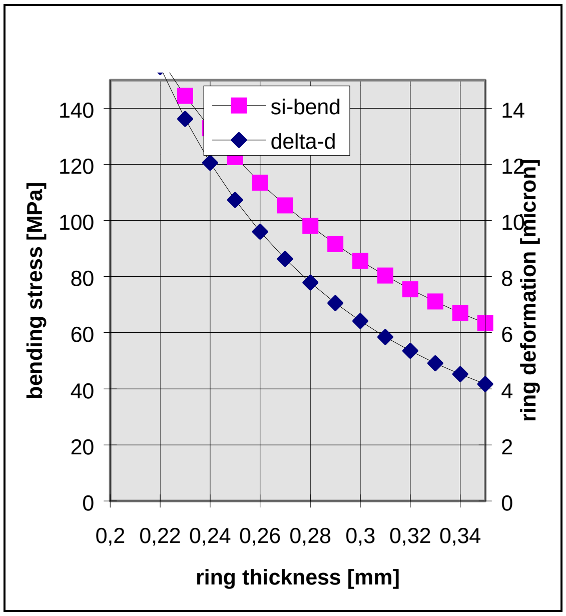

Figure 4: Pre-stress parameters of the outer ring for the MINIMOTOR motor.

For the MINIMOTOR motor a ring thickness of 0,26 mm is required for a deformation of 10 µm.

RING SUSPENSION

Due to the integration concept the ring has to suspend the motor shaft and should be stiff in transversal direction . At the other hand to apply pre-stress on the planet wheels it should be elastic in local radial direction.
In comparison with the pre-stress the transversal force of the motor is small so no problems with the ring elasticity are expected. However the ring itself should be suspended, while the suspension should have a minor influence on the pre-stress at the planet wheels. If the ring is suspended with a rubber ring in a larger concentric ring the global stiffness will be sufficient, while the local stiffness to meet the pre-stress requirement will be elastic enough.

For determination of the rubber the following characteristics are assumed:

The transversal stiffness should be larger than 10^5 N/m, while the local radial stiffness should be smaller than 0,5 10^5 (10 times smaller than the pre-stress).

If the rubber has a low shear modulus the thickness can be smaller due to the shear deformation of the rubber.

REALISATION

The test model is manufactured by fitting standard off-the-shelve components , except for the structural, housing parts.
This method results in a breadboard model which has a high quality (wrt accuracy) to cost ratio and is for one test model very effective to proof the principle to test.

During assembly no specific problems occurred, except that all tailor made structural components should be made very accurate : the principle relies on it.

A photo of the test model is given in fig. 5.

Figure 5: Photo of the test model.

Test

The bread board model developed for the test is consisting of :

- a mini motor
- drive electronics
- a torque load generator
- a torque sensor
- an input and an output speed sensor

The torque load is generated by an eddy current brake, made from a transformer.

The torque produced is derived from the motor current and analyzed with an FFT analyzer.

A photo of the test equipment is given in fig. 6.

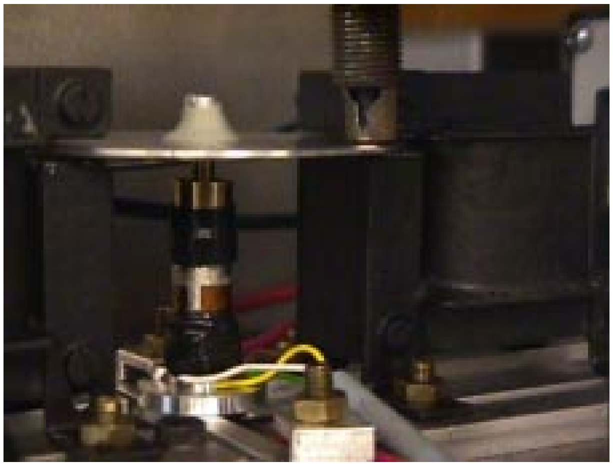

Figure 6: Test equipment.

PRELIMENARY TEST RESULTS

In a first test the Mini Friction Drive is compared with the original gearbox.
Both the mini gearbox and the Mini Friction Drive did produce noise, not suitable for low noise applications. Although the Mini Friction Drive produces less noise it was expected from the Low Noise Gear Project that the noise of the Mini Friction Drive should be less.
The backlash of the gear box was large, while the Mini Friction Drive had no backlash.

In the noise of the Mini Friction Drive a large 3_P(per revolution) contribution was found, which means that the planets do roll over an irregularity on the ring or an eccentricity between the motor bearing and the planet system was present (for simplicity and prevention of motor damage the original motor bearing was not removed) .
Also the motor shaft had a damaged surface, which was due to the not hardened material of the shaft. During manufacturing of the rubber ring it was found that an accurate ring was hard to make, which could cause irregularities.

RECOMMENDATIONS

From the preliminary tests it is recommended to use a hardened shaft or a shaft provided with a hardened clamped or glued ring. The rubber should be manufactured by filling the slit between the outer ring and the housing with a rubber compound that will harden between the slit. Also the motor bearing will be removed.
With this configuration new tests will be performed.

CONCLUSIONS

The noise of the gearhead of the standard mini motor was not suitable for low noise applications. Although the noise of the Mini Friction Drive was also too high it could be determined easy from the test results, so a large improvement comparable with the results of the Low Noise Gear project are still expected.
We expect to show better results during the presentation in September 1999.

The backlash of the Mini Friction Drive was zero, while the backlash of the standard gearheads was large.

For both the stall-torque (at zero speed) was low, although at the point the imperfection or the statically undetermination between the original bearing and the Mini Friction Drive was present the zero torque was much higher.

The efficiency was not measured but will be good due to the rolling friction, comparable with a roller bearing.

If the motor with a Mini Friction Drive bearing is seen as a black box and compared with the original motor then the efficiency and the mass of the box is improved considerably.
Because when the output speed and torque is kept the same, the Ohmic losses and the electromagnetic material of the motor are approximately reduced by the ratio of the Mini Friction Drive , supposing the motor for this unit is designed for the higher rotor speed and lower torque.
SPE has gained experience in developing mini actuators, and started recently for using the same friction principles for the micro and nano technology; these sectors are proposed to be defined by :

- mini $1 < \text{volume} < 10^4\ mm^3$
- micro $10^3 < \text{volume} < 10^9\ \mu m^3$
- nano $\text{volume} < 10^3\ \mu m^3$

REFERENCES

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[3] K.J. van Brink, F. Hagg, Concept Definition, SPE Mini Friction Drive TN 001 (1/0), 2 November 1997