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APPLICATION OF HARMONIC DRIVE GEARS IN MACHINE TOOLS

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ABSTRACT
New technologies which are mainly based on high speed and precision (robots, manipulators, machine tools, etc.) impose special requirements for gears. Other technologies such as telescopes, radar systems, antenna systems, etc., require high accuracy and speed of positioning. Common for all these facilities and devices are transfer of information, energy and materials from one state to another without bringing their own faults in the system. So, it is important that gears do not have excessive internal backlash.
Harmonic drive gears are one of the newer gears which in there is no internal backlash. Harmonic drive gears have other advantages such as high capacity output bearing, high torque capacity, excellent positioning accuracy and repeatability, compact design, high single stage ratios, high torsional stiffness, high efficiency, simple installation and assembly, etc. In this paper it is described some cases of using Harmonic drive gear in machine tools.
Keywords: harmonic drive, machine tools, gears.

1. INTRODUCTION
The basic components of the flat-type gear system are the Wave Generator and three gearwheels - the Flexspline, Circular Spline and Dynamic Spline. The Wave Generator consists of a sun gear, typically connected to the motor shaft, and two elastically deformable planet gears. The teeth of the planet gears engage with the internal teeth of the Flexspline, which also features external teeth that engage with the Circular and Dynamic Spline. The Flexspline is a thin-walled elastically deformable ring, that adopts the elliptical shape of the Wave Generator. The external teeth of the Flexspline engage with the internal teeth of both the Circular Spline and the Dynamic Spline. The Circular Spline is an internally toothed ring gear and engages with the Flexspline at both ends of the major elliptical axis of the Wave Generator. The Circular Spline possesses two teeth more than the Flexspline. The Dynamic Spline is an internally toothed ring gear with the same number of teeth as the Flexspline. This component rotates in the same direction and with the same speed as the Flexspline and is used as output element when the gear is used as a speed reducer.

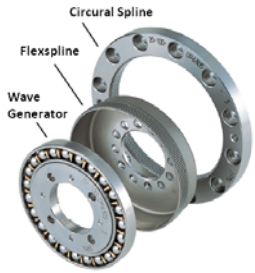

Figure 1. Basic gear components

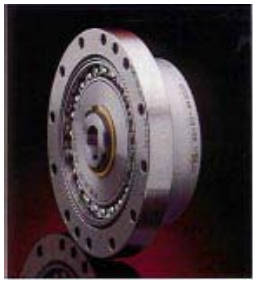
Figure 2. Harmonic drive component

2. PRINCIPLE OF OPERATION

The Micro Harmonic Drive gear is based on a unique principle of operation. When used as a speed reducer, the Wave Generator acts as the input element. By means of the planet gears the Wave Generator deforms the Flexspline elliptically, such that it engages with both internally toothed ring gears, the Circular Spline and the Dynamic Spline. The rotation of the planet gears of the Wave Generator causes the major elliptical axis and thereby the regions of tooth contact to rotate relative to the fixed Circular Spline. Because the Flexspline possesses two teeth less than the Circular Spline, for each 180° clockwise movement of the Wave Generator, the Flexspline moves counterclockwise by one tooth relative to the Circular Spline. Each complete clockwise rotation of the Wave Generator results in the Flexspline moving counterclockwise by two teeth from its previous position relative to the Circular Spline. The Dynamic Spline rotates in the same direction and with the same speed as the Flexspline and is used as the output element.

Figure 3. Principle of operation

3. APPLICATIONS

3.1. Gantry Milling Machine (Milling Head C-Axis)

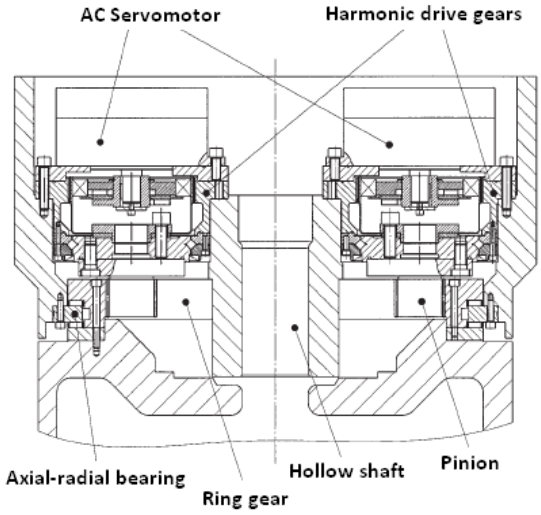

Figure 4. Gantry Milling Machine

This application example concerns a gantry milling machine for the machining of large turbine components. This is a very large machine with very high cutting forces of up to 30 kN and features electrically pre-loaded actuators. This configuration is made possible by a master-slave arrangement supported by many currently available CNC control systems. Importantly the pre-load torque can be varied depending on the operating mode of the machine. For rapid feed moves both actuators work together to provide a very high acceleration torque capacity. As the axis moves into position one actuator begins to act as a brake and increases the pre-load torque to remove the backlash in the pinion-ring gear stage and increase the torsional stiffness of the axis.

The advantages of this master-slave arrangement can be summarized as follows:
- High performance (accuracy, axis dynamics, stiffness)
- Simplification of the machine design
- Cost savings through simplification of machine assembly and commissioning
- Reduction of maintenance and repair effort, particularly in the case of very large machine tools, with long operating lives.

In this design example, showing the C-axis of the milling head, a pinion is attached to the output flange of both the Harmonic drive gear units. These pinions engage with an internally toothed ring gear, which is supported by a very stiff axial-radial needle roller bearing.

3.2. Machining Centre NC Rotary Table

Increasingly Harmonic Drive gears are being used to replace worm or planetary gears in the precise rotary axes of machine tools. High accuracy is usually only possible with worm or planetary gears that are pre-loaded to eliminate backlash. The natural pre-loading of Harmonic Drive gears, combined with their high efficiency means that the temperature rise during operation is much lower, with positive results for the stable positioning accuracy of the machine. Given that assembly and lubrication is carried out according to the manufacturer's recommendations there is no increase in backlash with a Harmonic Drive gear during its operating life. This means there is no need to re-adjust gears to remove backlash, as is common with worm gears or planetary gears. In this design example, the Flexspline of a Harmonic drive gears component set acts as output element. The output flange is supported by a precision output bearing (needle-roller bearing). The Circular Spline, as fixed element, is located in the machine housing. The Wave Generator, as input element, is driven via a toothed belt. To keep the height of the table to a minimum the motor is mounted in parallel to the gear. In this application the cutting forces are not very high, so there is no need for output-side clamping of the table. In the event that very high cutting forces must be held it is advisable to use a curvic coupling to lock the output flange.

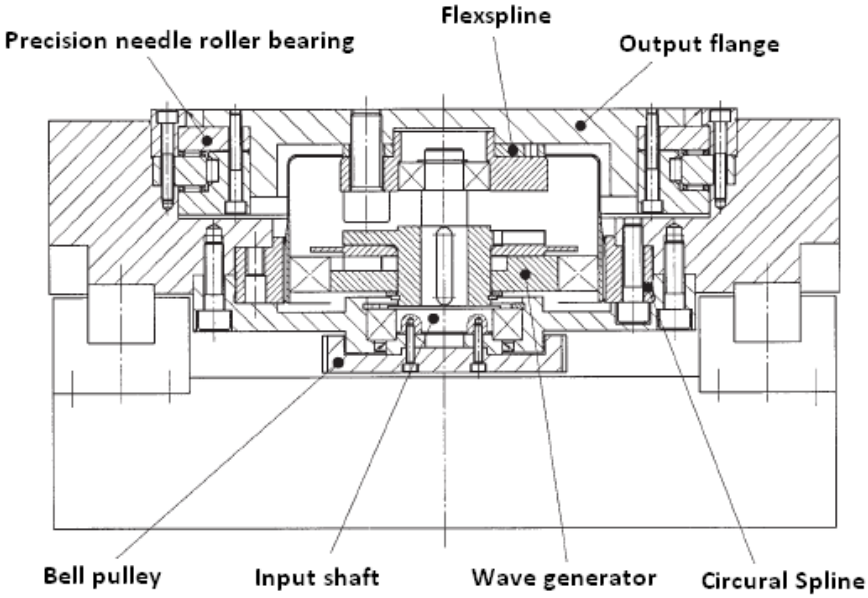

Figure 5. Machining Centre NC Rotary Table

3.3. Water-jet Cutting Machine Fast Linear Axes

The advantages of the Harmonic planetary gears can be exploited in the linear axes of machining centres, e. g. X-Y tables of laser or water-jet cutting machines. Linear axes of cutting machines must work very dynamically and with high precision. Fast positioning moves in rapid feed and precise interpolated contours require low-backlash gears and transmission components. This design example shows the X-Y table of a water-jet cutting machine and demonstrates how standard components can be combined in a cost-effective solution. The difficult environmental conditions, where there is a lot of water and dust, prevent the use of direct measuring systems. In this case the accuracy of the individual moving axes must be achieved by a combination of indirect measurement systems and precise transmission components. The X-axis which has a stroke of 3000 mm and a maximum linear speed of

12 m/min is driven via a rack- and pinion arrangement. The pinion is connected directly to the output flange of the Harmonic planetary gear without the need for additional support bearings. The stiff cross-roller bearing supporting the output flange of the planetary gear can withstand high axial and radial forces. The connection of the planetary gear to the machine base is realised by means of a swivelling plate provided with spring pre loading to minimize backlash between the pinion and the rack. This solution also acts to compensate any wear of the pinion. In combination with the low backlash Harmonic planetary gear this design solution provides constant positioning accuracy during the complete operating life of the machine.

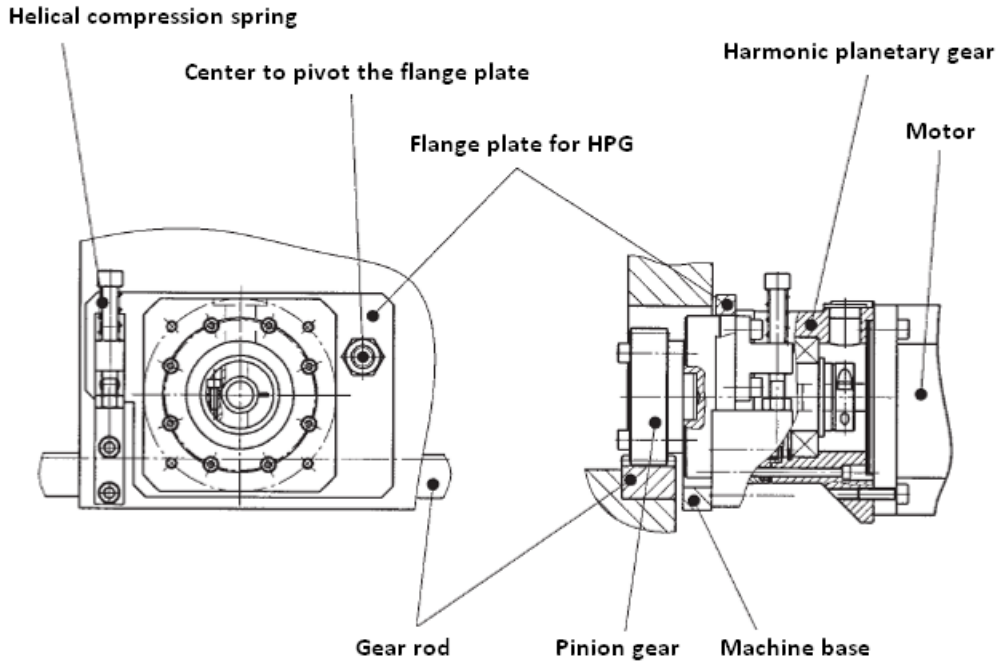

Figure 6. Water-jet Cutting Machine Fast Linear Axes

4. CONCLUSION

Harmonic Drive gears have a long success story in demanding machine tools applications. The range of applications is increasing quickly due to continuous product development, which is leading to greatly improved product performance. One area of particular interest is the development of lightweight gears. The latest research results can reduce weight by more than 50 % without any reduction in torque capacity or accuracy. This research is continuing with gears manufactured from titanium using special surface treatments currently being tested. It is anticipated that this development can lead to even better performance that that already achieved using composite or aluminium components.

5. REFERENCES

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