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Torque-compensating adjustment drive for mechanically sensitive devices

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Abstract
A growing number of precision engineering devices are operated under vacuum conditions to shield them against disturbances. Mass comparators, nano-positioning and nano-measuring machines, semiconductor manufacturing equipment, scientific experimental setups, etc. can be mentioned as examples. Adjustment is frequently required to fulfil the intended function. Pre-tensioned screw gears are often used due to their high transmission ratio and self-locking properties. The applied torque needs to be taken by the device. Mechanically sensitive components within the force flow can easily be overloaded, thus causing malfunctions of the device. Within the scope of this work, a drive concept is developed which compensates the introduced torque utilizing a counter torque and suitable coupling. A prototype has been realized according to the demanding requirements of the adjustment of a compliant mechanism. The prototype allows a nominal actuation torque of up to 300 N mm with an angular resolution of 20'. The parasitic reaction torque is reduced down to only 0.25 N mm independent of the nominal torque. The mechanical coupling and decoupling of the adjusting device as well as the actuation of the adjusting gear are achieved by one single motor. The low-reaction torque tightening of screws for the assembly of precision devices was considered as a second possible application.

Keywords: torque compensation, compliant mechanisms, adjustment, mounting

1. Introduction

In the adjustment of precision engineering devices, highly reproducible motions are frequently realized by screw gears, which are manually operated or driven by a motor. The reaction torque from driving these adjustment gears has to be taken by the frame. Mechanically sensitive components in the force loop can easily be overloaded and by that, the function of the device can be disturbed. To avoid this, torque-compensating drives were invented. The applied torque is compensated by a counter torque. Only a minor parasitic torque on the mechanically sensitive device remains.

2. State of the art and requirements

In conventional mechanical engineering, reaction arms are used to create an additional coupling between the mounting tool and the assembly, to return the reaction torque. This concept is used for the manual tightening of screws [1] or the automated mounting of components by robot systems [2]. High ratio planetary gearboxes, which are supported by a form-fit connection to the structure, in addition to the tool, are described as another option for torque compensation [3]. Further possibilities are tools with a dual-rotor motor, in which the stator is pivoted. In this case, the torque is generated by the output shafts and no reaction torque is applied to the frame [4].

Due to the lack of solutions in precision engineering, a drive for torque-compensated adjustment has been developed. High resolution is required, as well as compatibility to vacuum conditions. In addition, limitations of the design space, tool orientation, costs, and electromagnetic compatibility have to be considered. Axial compensation for screw adjustments can remain unconsidered, as only minor translational motions are required. The drive has to be completely decoupled from the device after the adjustment process, without affecting the adjustment results.

3. Prototype of a torque-compensating adjustment drive for precision engineering devices

To find the optimal technical principle for the requirements of the adjustment drive, a systematic design development process was performed. The critical components were dimensioned, and a prototype was designed.

3.1 Concept of operation

The final technical principle of the torque-compensating adjustment drive can be taken from Fig. 1 and a section view is shown in Fig. 2. The main function of the adjustment mechanism is the transmission of an almost torque-free rotary motion from the motor (1) to the adjustment gear (2) of a mechanically sensitive device (3) by the tool (4) and reaction arms (5).

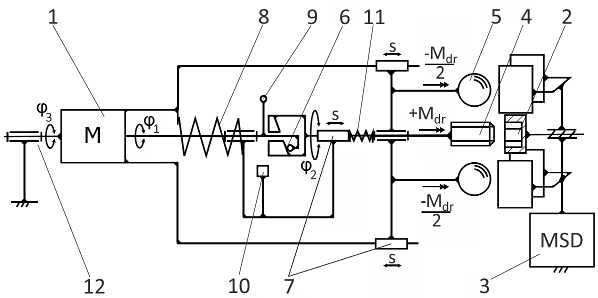

Figure 1. Technical principle of the adjustment drive.

In the initial state, the adjustment drive is decoupled from the mechanically sensitive device. At the start of the adjustment process, the motor initiates a rotary motion (φ_1) to couple (s) the tool and the reaction arms to the mechanically sensitive device by a cam mechanism (6) with guiding elements (7). The frictional torque generated by a spring (8) prevents the transmission of a rotary motion to the tool. After rotating the motor shaft of about 165°, a mechanical stop (9,10) at the cam mechanism is engaged. The frictional torque of the spring is overcome and the rotary motion of the tool is enabled (φ_2). The adjustment mechanism and the device are completely coupled. The angular adjusting motion (φ_2) is carried out by the driver up to the desired value. After the adjustment process, the motor turns in the opposite direction ($-\varphi_1$) to disconnect (-s) the tool and the reaction arms from the mechanically sensitive device. Another spring (11) is used to keep the cam and the follower in contact.

With this concept, torque compensation is ensured by the simultaneous coupling of the tool and the reaction arms with the mechanically sensitive device. If only one of the two coupling elements would be connected, the motor would be rotated (φ_3) about its bearing (12) and only the friction torque of the preloaded bearing would be transmitted to the device.

3.2 Coupling of adjustment mechanism and device

The couplings of the adjustment mechanism and the mechanically sensitive device, which can be seen in Fig. 2, are designed to avoid overconstraints.

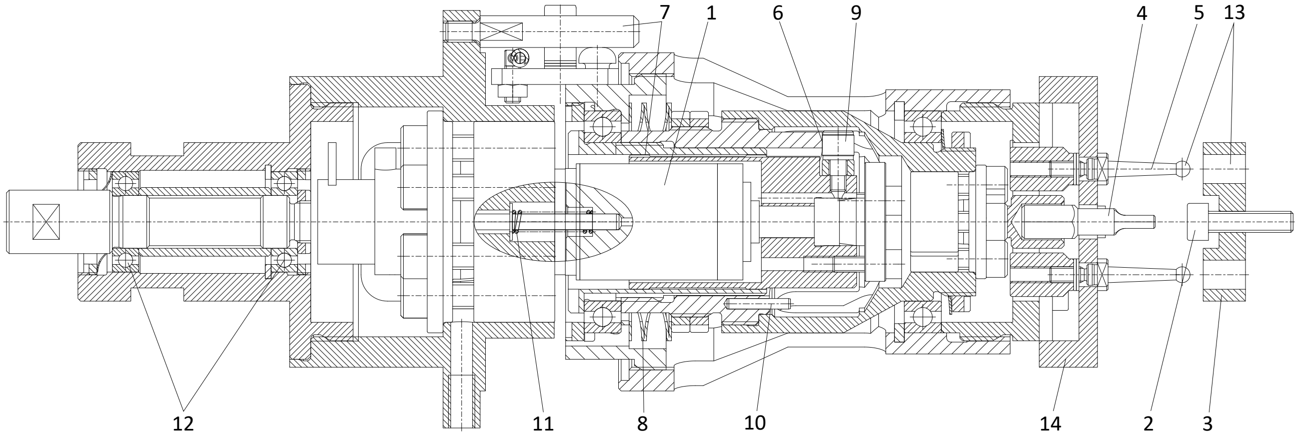

Figure 2. Sectional view of the adjustment drive.

To compensate for lateral and angular misalignment between the adjustment mechanism and the device, sufficient clearance in the form-fit couplings has been provided. To avoid an eccentric torque initiation at the sphere-plane contact pairs (13), an additional elastic element (14), designed as a compliant joint, is attached.

4. Results

The adjustment parameters obtained by the prototype are shown in Tab. 1. Restrictions resulting from the realization of the requirements, the operation concept, and the design of the prototype have been considered. The initiated torque cannot be completely compensated by the adjustment drive. Parasitic torques resulting from the preloaded bearing of the motor are applied to the mechanically sensitive device. To create a torque-compensated coupling between the adjustment mechanism and the device, an additional coupling for torque compensation has to be provided. Due to the form-fit pairings of the coupling, there is clearance, which influences the setting accuracy of the adjustment. Owing to the operating principle of the adjustment mechanism a backlash of 330° exists. The reason for this is the coupling and decoupling of the drive and device. In addition, it is necessary to set a defined position before the start of the adjustment process to enable the form-fitting elements to be coupled. The set position has to be within the range of the tool clearance.

Table 1. Adjustment parameters obtained by the prototype.

Parameter	Value
Parasitic reaction torque	0.25 N mm
Nominal adjustment torque	300 N mm
Resolution adjustment angle	20’
Design space	227x80x80 mm
Vacuum conditions	10^{-6} mbar

5. Conclusion and outlook

A torque-compensating adjustment mechanism for mechanically sensitive devices is presented as the first step of the ongoing development process. With the technical principle shown in Fig. 1, rotary motions can be transmitted to the device, with low remaining reaction torques of about 0.25 N mm. Overconstraints are avoided due to the design of the coupling. The system can be operated in a vacuum and is completely decoupled from the mechanically sensitive device after the adjustment process.

To verify the obtained results, the designed prototype will be manufactured and tested. In an iterative process, the adjustment mechanism will be optimized in terms of remaining initiated torque, design space, the initial position of the form-fitted couplings and operation in a vacuum. In addition, a drive with higher nominal torque will be introduced to test the prototype as a low-impact fastening system for screws in sensitive precision engineering applications.

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