A passively adaptive screwdriver: a novel concept for controlling off-diagonal stiffness

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Abstract: A concept for an automated screw driving mechanism is presented. The proposed mechanism has a self-adjusting axial stiffness that depends on the torsional resistance against screwing. It delivers a greater axial thrust when the torsional resistance is greater, for example, towards the final stage of a screwing operation.

Keywords: adaptive screwdriver, off-diagonal stiffness

1 INTRODUCTION

The increasing need to minimize both production time and labour in a competitive manufacturing industry justifies research for new automated fastening techniques. The literature on automated screwing techniques includes ideas that make use of electronic sensors [**1**] and fuzzy logic control [**2**]. Furthermore, in a related article on achieving passive compliance by changing structural stiffness, which was the inspiration for the work of Ang and Andeen [**3**], the need to couple the axial and torsional stiffness coefficients of a robot arm for automated screwing applications is described.

When manually using a screwdriver to tighten a constant pitch woodscrew, the axial thrust exerted needs to be increased as the screw is driven in and the torque needed to turn becomes higher. Under typical screwdriving conditions, starting with a smaller-than-necessary thrust based on judgement, one would normally increase the thrust as the need is felt by the hand. Therefore, to automate the process of screwdriving, the appropriate level of axial compressive force needs to be continuously adjusted. For a prescribed displacement, the force induced is proportional to the stiffness. Thus, for an automated screwing device that needs to be both position controlled (initially) and torque controlled (in the final stages), it is considered desirable to have a structural member whose axial stiffness could be made to increase with the torsional resistance against driving [**1**]. The purpose of this note is to present a concept for a mechanism that may satisfy these requirements.

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2 CONCEPT

The proposed mechanism is shown in Fig. 1. This comprises a compound shaft consisting of a slender stem (A) that carries a screwdriver head (B) and a stiffer tube (C). The screwdriver base is connected to a control rod (D) that transmits a torque and an axial force. The torque T from a drive shaft (E) is applied to the rod through a gear (F). The control rod has a threaded top that can move inside a positioning head (G). The pitch of the thread on the rod must be same as the pitch of the screw being driven and in the same direction so that the screwing operation does not alter the axial force in the stem. However, at the end of a screwing operation, the axial force in the stem may need to be increased [**1**]. This may be achieved by changing the effective length of the slender stem (A) as follows.

Short lengths of stops (H_1–H_n) are located in the parts of the stem and inside the tube in such a way that when the stem turns in a certain direction in relation to the tube, it may engage the stiff tube at one or more of the stops. Figure 2 shows the transverse section of the mechanism through a typical

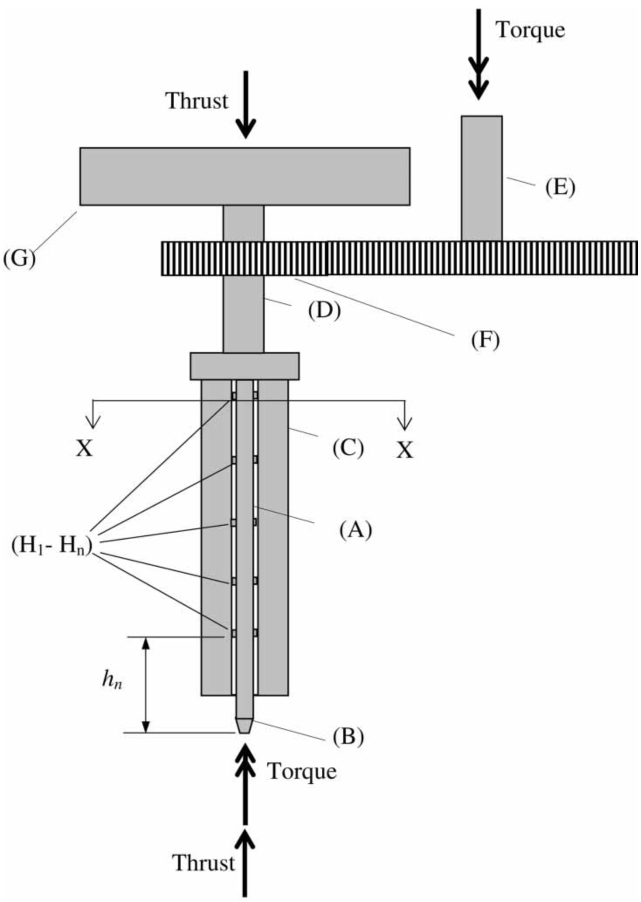

Fig. 1 Screw mechanism

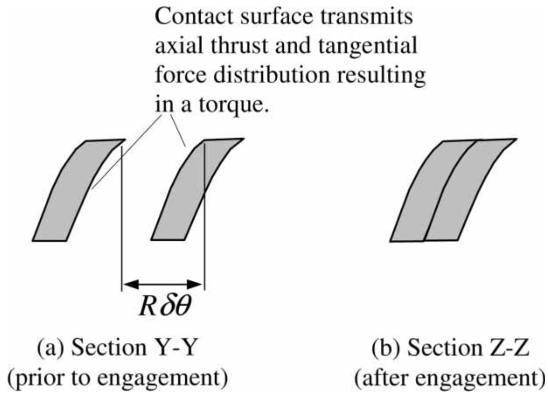

Fig. 3 Radial view of circumferential sections of the engaging stops

stop before and after the engagement of the stop. The contact surfaces must be at an angle, forming a helical surface, so that they can transfer both an axial force and a torque, as shown in Fig. 3. The pitch between the contact surfaces is defined by the angle $\delta\theta$. The relationship between the torque T_i in the stem and the angle of twist at the time of engagement of the ith stop is given by $\delta\theta = T_i h_i/(GJ)$, where G is the shear modulus, J the polar second moment of area of the cross-section of the stem, and h_i the length of the stem undergoing relative twisting at the ith stop.

It can be seen if the pitch angle $\delta\theta$ is kept constant as the torque induced reaches a magnitude of $GJ\delta\theta/h_i$, the ith stop will be engaged. Each time an engagement takes place, the axial stiffness of the stem will increase as the effective length of the stem decreases.

Thus, it is clear that this engaging of the components takes place gradually from the top, with increasing resistance against screwing. When the screwdriver is used to turn a screw, the initial resistance against turning is small. As the resistance increases, the stem (A) undergoes a twisting rotation in relation to the tube (C), causing engagement of the stops at the top (H_1). As soon as the two components are engaged at H_1, the effective length of the stem decreases, thus increasing its axial stiffness. If further turning results in a continued increase in torsional resistance, the relative twisting between the tube

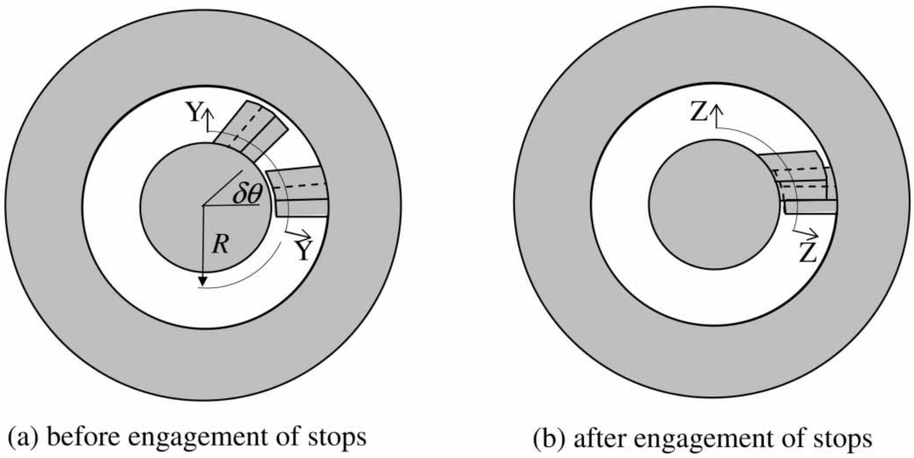

Fig. 2 Section X–X

and the remaining part of the stem below the H_1 causes further engagement at H_2. This increases the axial stiffness. In this way, the axial stiffness of the stem may be made to increase, adapting to the torsional resistance of the screw.

The object of the design is to ensure that as the screw is turned the stem and the tube are made to engage, reducing the effective length of the slender stem, this being the distance between the driving head at the bottom and the lowest point where the stem is locked to the tube.

3 DESIGN CONSIDERATIONS

In order to complete a prototype for testing, the following design and build considerations should be kept in mind. The stem must provide the necessary stiffness and strength for specified screwing applications. These may have to be determined through preliminary tests during which the applied torque, the angle of twist, and the axial and torsional strain are measured. Once the torque and axial force requirements are known, the relative twist between the stem and tube should be calculated for the torque for which the axial force needs to be changed. This information is used to locate the stops. At the unstressed state, there will be a gap between the engaging stops. These gaps should be designed to close one by one as the relative angle of the twist between the remaining part of the stem and the tube increases to predetermined values. The best geometric configuration may need to be determined experimentally by trial and error. Instead of a number of discrete stops, continuous helical ridge on the stem and inside the tube may be used, providing a continuous variation of stiffness.

4 CONCLUDING REMARKS

A concept for a compound shaft that changes its stiffness according to the torsional resistance is presented. This may prove to be useful in designing an automated screwdriver. Further work towards the development of a prototype is in progress.

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