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THE MECHANICS, CONCEPTUALIZATION AND DESIGN OF AN ERGONOMIC CLOCKWISE DIRECTIONAL SCREWDRIVER

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ABSTRACT

Studies concluded that clockwise torque directions secure and improve grip force compared to counter-clockwise torque directions. However, it appears that there is no study on the design and development of an ergonomic screwdriver to address the difficulty of manually unfastening screws. In this study, a screwdriver concept was developed with clockwise directional input and ergonomic features. Previous studies found that the ergonomic design recommendations involved in designing the handles of hand tools were diameter, shape and material. The planetary gear system was proposed in the design concept as a solution to change the screwdriver input direction inwards for unfastening tasks. Ergonomics design factors such as handle diameter, shape and surface material were also taken into consideration for a more secure grip. With lower force requirements and ergonomic features, this screwdriver can potentially benefit manual workers towards decreasing risks of sustaining CTDs and accidents, and eventually improve efficiency in precision tasks.

Keywords: clockwise direction, grip force, engineering design, ergonomics features, conceptual design.

INTRODUCTION

A screwdriver is a common hand tool to perform activities of assembling or disassembling objects with screws. However, the user of a screwdriver can potentially sustain hand injuries and Cumulative Trauma Disorders (CTDs). A poor handle design results in an awkward gripping posture, which reduces the grip strength and increases stress on the wrist and fingers (Kong and Lowe, 2005b; Kuijt-Evers *et al.,* 2004; Mastalerz et al., 2009; Meagher, 1987; Ng *et al.*, 2014; Ng *et al.,* 2015b). Since discomfort can decrease work productivity (Kuijt-Evers *et al.*, 2004), an ergonomics consideration for the hand tool design would increase users' efficiency (Kuijt-Evers *et al.*, 2007; Ng *et al.*, 2016b; Ng *et al.*, 2016c) and decrease injury risks.

Features that help to relieve stress concentration on the hand (Kong and Lowe, 2005a; Kong and Lowe, 2005b; Kong et al., 2008) or reduce force exertion (Dempsey *et al.,* 2004) are considered as an application of ergonomic knowledge which improves users' comfort and reduces injuries (Kong and Lowe, 2005a). In designing an ergonomic handle, its shape, size, weight, and material (Kong et al., 2002; Ng and Jee, 2016; Ng *et al.,* 2016d) are considered, so as to improvise hand grip (Kong and Lowe, 2005b) and user confidence in performing a task. Hence, a hand tool with lower force requirements, good grip, and ergonomic features is recommended to decrease the risk of having CTDs and accidents, and also to improve the efficiency and performance of a task. The aim of this study is to conceptualise and design a new screwdriver with the clockwise torque direction as the input direction and ergonomics features to decrease the user's risk of sustaining CTDs.

LITERATURE REVIEW

Design recommendation for handle diameter

The geometry of the handle is important because it affects the torque generation (Kong and Lowe, 2005a; Seo *et al.,* 2007; Shih and Wang, 1996; Wyoming, 2011) and the grip force requirement (Edgren *et al.,* 2004; Kong and Lowe, 2005b; Mastalerz *et al.*, 2009; Seo and Armstrong, 2008). According to various studies, the recommended diameter or diameter range for an optimal grip of a cylindrical handle are 38.1 mm (Mastalerz *et al.*, 2009), 31.5-40.3 mm (Kong and Lowe, 2005b), 37.3-47.8 mm (Kong and Lowe, 2005a), 40 mm (Seo and Armstrong, 2008) and 30 mm (Mastalerz *et al.*, 2009), as these are the ranges where higher maximum grip forces can be applied. Pheasant and O'Neill (1975), Seo *et al.* (2007) and Seo and Armstrong (2008) explained that as the thumb pads and fingertips are in place when gripping an object, a greater reaction force is observed at the palm, which increases the total normal force as well.

Design recommendation for handle cross-sectional shape

The total normal force can also be increased by modifying the handle into a cross-sectional shape to better fit the hand. In fact, several studies show that certain handle shapes actually affect torque capacity, grip strength and contact area (Kong *et al.*, 2008; Ng *et al.*, 2016a; Seo and Armstrong, 2011; Shih and Wang, 1996; Wyoming, 2011). From studies by Kong et al. (2008) and Shih and Wang (1996), the overall maximum torque capacity and total normal force of a triangular cross-sectional shape handle were the greatest among circular, square and hexagonal shapes. One of the reasons is because the moment arm of the cross-section for the triangular shape is larger than other shapes (Kong *et al.*, 2008; Shih and Wang, 1996) allowing greater torque to be produced.

However, Kong *et al*. (2008) found that the cross-sectional triangular shape is the least comfortable shape to grip as compared to the circular and hexagonal shapes. Researchers such as Seo and Armstrong (2011), Gregor and Bojan (2013) and Gregor and Bojan (2014) also studied elliptic cross-sectional shapes and the extent of maintaining the efficiency and comfort for hand tool handles. The maximum torque and total normal force for the elliptic cross-sectional shapes were recorded as 25% and 58% greater than the circular shape respectively (Seo and Armstrong, 2011).

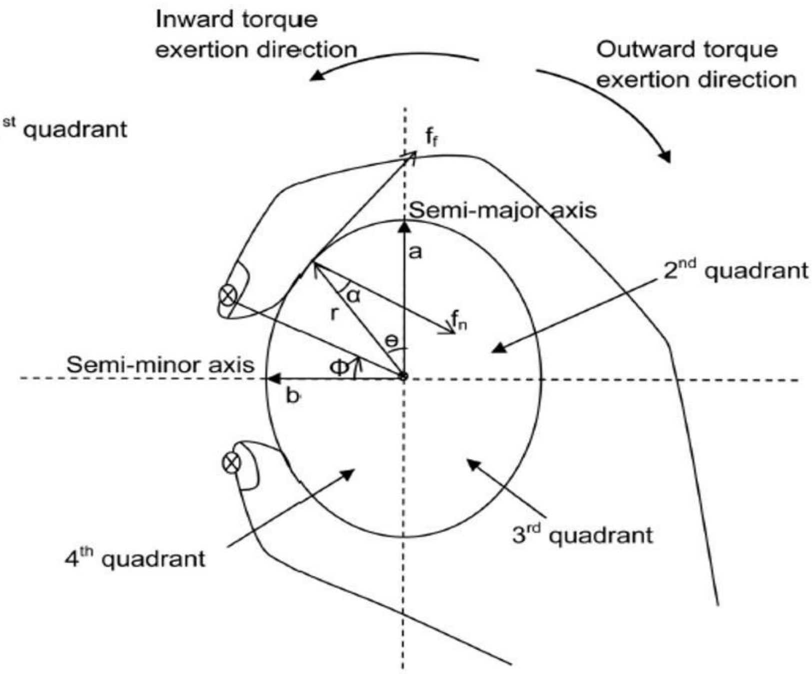

Figure-1. The illustration of elliptic cross-sectional handle model (Seo and Armstrong, 2011).

Figure-1 illustrates the terms that Seo and Armstrong (2011) used in their model to study the effect of the elliptic shape on torque and total normal force generation. The elliptic shape increases the moment arm for the semi-major axis where the distal and middle phalanges contact. It is also a major force contribution area. The increase of moment arm results in an increase of torque, though this decreases the force required for the grasp (Kong *et al.*, 2008; Seo and Armstrong, 2011; Shih and Wang, 1996; Wyoming, 2011). On the comfortability aspect, Gregor and Bojan (2013) and Gregor and Bojan (2014) justified that the elliptic cross-sectional shape of the handle was better than a circular shape in terms of functionality descriptors for comfort.

Design recommendation for handle material

Most of the screwdriver handles found in the market are made of plastic or coated with a layer of rubber to enhance the coefficient of friction for a better grip. Previous studies compared the handle material of aluminium and rubber. The results showed that the total normal force for rubber was always lower than aluminium, even though the torque capacity was higher (Seo and Armstrong, 2011; Seo et al., 2008a; Seo et al., 2008b). This was due to the effect of a higher coefficient of friction for the rubber material (Ng *et al.,* 2015a; Seo and Armstrong, 2011; Seo *et al*., 2008a; Seo *et al*., 2008b; Wyoming, 2011).

Mechanism enhancement

A gear is a common mechanism used to transmit power, manipulate velocity and change the motion's direction in a system. All of this can be controlled by changing the gear diameter, gear teeth, and adding idler gears. The torque, velocity, diameter and teeth relation between two gears in contact can be determined using the gear ratio equation. A gear ratio which is larger than 1 means that the output torque increases and output angular velocity decreases (Norton, 1999). A gear system with a gear ratio larger than 1 can reduce the overall required force for the desired output torque. Hence, it is useful in reducing the effort of the user to achieve the same amount of output torque.

Summary of ergonomics features

The ergonomics handle can be achieved by mainly reducing the grip strength and overall force required. This would reduce the effort of the user while maintaining the efficiency and comfortability of the hand tool and handle. Hence, the suggested ergonomics handle should feature a diameter within 30 mm to 47.8 mm, an elliptical cross-sectional shape, a rubbery material coating and a gear system with a gear ratio that is larger than 1.

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METHODOLOGY

Design concept

The concept considers the gear properties and handle diameter. The handle diameter is around 40 mm. Hence, the ring gear pitch diameter is fixed at 30 mm to avoid oversizing. Figure-2 shows the cross-sectional view of the concept.

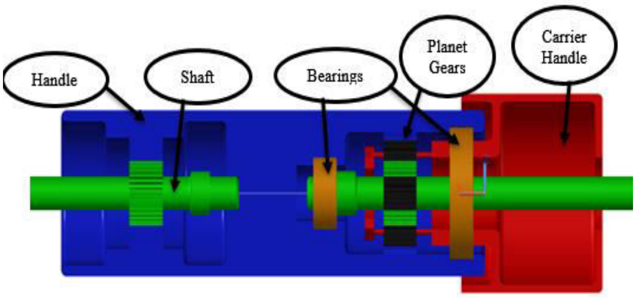

Figure-2. The cross-sectional view of assembled components.

The bearing is fitted at the bearing slot in the handle to separate the shaft and carrier handle. Three planet gears are fitted on the carrier handle pins and the shaft is slotted into the handle. The clockwise directional screwdriver can be operated for fastening and unfastening tasks. The unique feature of this clockwise directional screwdriver is that it uses the clockwise torque direction for both fastening and unfastening operations.

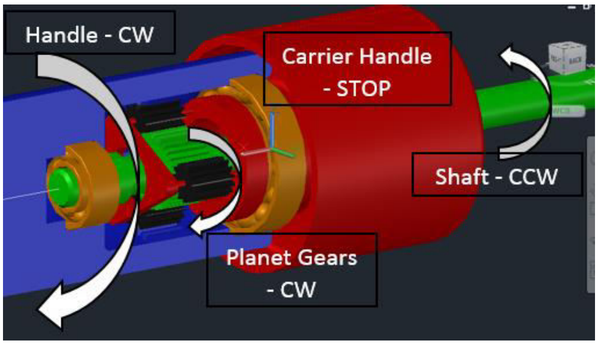

Figure-3. The rotation direction of the mechanism.

For fastening a screw, the shaft is slotted into the handle. The sun gear is secured by the ring gear build within the handle to provide the same rotation direction as the shaft and handle.

In order to unfasten a screw, the shaft is slotted into another end of the handle. The handle is rotated the same way as when performing the fastening operation and this turns the shaft in the opposite direction. In order for this to work, the carrier handle must be fixed while rotating the handle. When the planet gears stay stationary, the sun and ring gears' rotations will be opposite of each other. Figure-3 shows the unfastening operation and all gear rotation directions, where the handle is the input, the shaft is the output, and the planet gears are the idler gears. Clearly, the handle rotates in a clockwise direction while the planet gears follow the same rotation. This causes the shaft to rotate in the opposite direction.

To improve the effectiveness of the screw driving process, the user is not required to remove the screwdriver away from the screw head and to reattach it to continue. If the carrier handle is set free, the shaft will be free from any rotation caused by the handle. However, the screw must have a sufficient load to lock the shaft. If the screw is loose, this could not be applied.

Hence, the carrier handle should be free when there is a need for the handle to rotate back to its initial position before proceeding with subsequent rotations.

Proposed procedures

The proposed procedure to perform the unfastening operation for right-handers is as follows:

a) Hold the carrier handle with the left hand.
b) Rotate the handle in a clockwise direction with the right hand.
c) Release the carrier handle.
d) Rotate the handle in an outward direction and then back to its initial position.
e) Repeat the steps above for subsequent operations until the screw is completely unfastened.

The instructions above are for right-handers. For left-handers, the clockwise torque direction is actually the counter clockwise direction that right-handers apply.

RESULTS AND DISCUSSIONS

Ergonomics design factors

The ergonomics design factors include handle diameter, material and shape. In order to address the torque direction, the planetary gear train mechanism is used to switch the rotation of the output. The ergonomics feature applied in this screwdriver is shown in Table-1.

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Table-1. Summary of ergonomics handle features.

Design Factors	Descriptions	Additional
Handle Diameters	Average diameters for *x*- and *y*-major axes are 36.28 mm and 43 mm	None
Handle Shape	Elliptical	Hand accommodates shape for fingers and angled handle
Handle Material	Acrylonitrile butadiene styrene (ABS) with rubber	None
Mechanism	Planetary gear train with overall gear ratio of 2	Convertible between clockwise and normal screwdriver

Final design

Previously in the concept design, bearings were used. However, it is difficult and costly to assemble the bearings with other parts. Hence, this final design makes use of a pin and groove to support the axial forces between the rotating components. The reduction of components demonstrates the implementation of DFMA (Design for Manufacture and Assembly) where components are minimised to reduce complexity, reduce cost and retain efficiency or function.

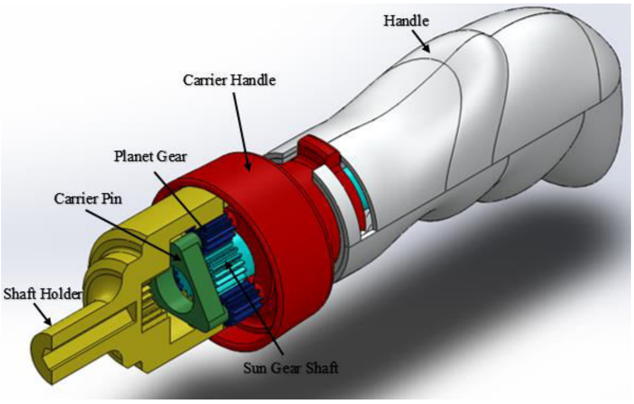

Figure-4. The final design of clockwise directional screwdriver.

Figure-4 shows the finalised design of the clockwise directional screwdriver without the screwdriver bit. However, any ready-made flat-to-flat ¼ inch hexagonal-shaped bit can be install on the screwdriver shaft slot. Therefore, the user can switch the type of bits as long as the size and shape fit the designed shaft slot.

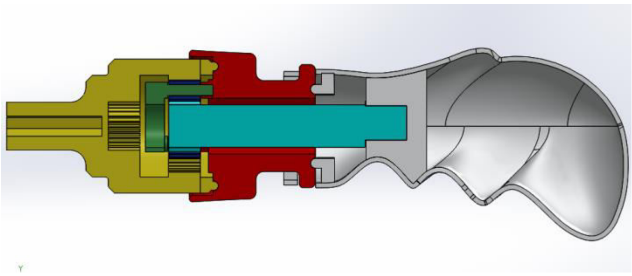

Figure-5. The cross-sectional view of the screwdriver.

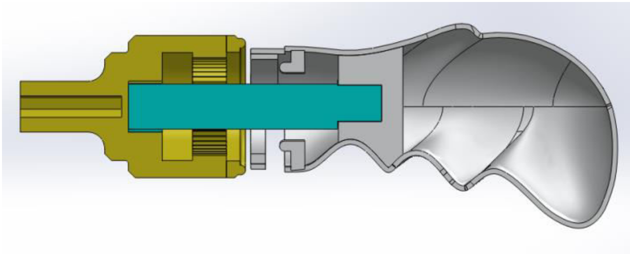

Figure-6. Another assembly combination.

There are two assembly combinations; the first one is with the gear and the other is without the gear. The screwdriver with the gear indicates a complete assembly with all components as shown in Figure-5. This involves the planetary gear train which facilitates the unfastening operations. With the detachment of the carrier handle from the screwdriver, the planetary gear train system would be incomplete, thus allowing the sun gear shaft to be directly connected to the shaft holder as shown in Figure-5. This second combination offers a function like a normal screwdriver and can be used for regular fastening and unfastening operations. In addition, this screwdriver also limits the rotation angle to approximately 90 degrees to prevent the user from twisting the wrist beyond their capability and getting injured.

In theory, a gear ratio of 2 will produce an output torque that doubles the input torque. However, the disadvantage is that the output angular displacement is reduced to half of the input. For instance, it may be good for unfastening the initial twist, but inefficient for continuous operations since the angular displacement output only displaces 45 degrees for each 90 degrees of the user's twist.

Mechanism force analysis

The *Lewis Bending Equation* (Budynas and Nisbett, 2008) was applied with the tangential force on the gear. After the calculations, the maximum tangential force for the individual gear meshing point was tabulated in Table-2.

Table-2. The maximum torque for single gear meshing.

Gears	Tangential force, N	Maximum torque, Nm
Sun	36.81	0.28
Planet	23.25	0.09
Ring	44.56	0.67

The maximum torques applied to a single meshing gear for each of the gears is shown in Table 4-2. The lowest tangential force was used to calculate the maximum input torque of this screwdriver. Since the design had 3 planets gears, the maximum tangential force that can be transmitted was 3 times that of the individual, which is 69.75 N. Hence, the theoretical maximum input torque for this screwdriver is 0.27 Nm. Finally, the output torque was multiplied with the gear ratio, and 0.54 Nm of the output torque was generated.

The output torque for this screwdriver was limited by the type of material, the thickness of the gear and the diametral pitch. The material used in this screwdriver was ABS plastic with a low yield stress compared to metal. The thickness of the gear was set to 10 mm because of the consideration of the screwdriver's length. Hence, the output torque can be improved by a material with better yield stress, increasing the thickness of the gear and reducing the diametral pitch.

CONCLUSION AND FUTURE RECOMMENDATIONS

Ergonomics design factors were taken into consideration for the clockwise screwdriver handle, such as its diameter, shape and surface material to provide a secure grip. In addition, the gear mechanism that drives the clockwise screwdriver also helped reduce the effort in achieving the desired output. With lower force requirements, ergonomic features and a secure grip, this ergonomic clockwise directional screwdriver would be beneficial for manual workers towards potentially decreasing their risks of sustaining CTDs and accidents, and also to improve their efficiency in precision tasks.

In the future, the handle can be further improved by redesigning the finger grip angle to be closer to the neutral posture angle in order to reduce wrist stress. The handle size should also consider the 95th percentile of the human hand size. Furthermore, the gear mechanism can also be improved by balancing the output angular displacement and output torque to enhance the efficiency of the screwdriver.

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