Innovative Design for a Ball Worm Gear Mechanism

Sait Koçak*‡

*Department of Mechatronics Engineering, Faculty of Technology, Pamukkale University, 20700 Denizli, Turkey

(skocak@pau.edu.tr)

‡ Corresponding Author; Sait Koçak, Department of Mechatronics Engineering, Faculty of Technology, Pamukkale University, 20700 Denizli, Turkey, Tel: +90 258 296 4189, Fax: +90 258 296 41 96, skocak@pau.edu.tr

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Abstract- In this study, a new mechanism was designed and presented as an alternative to the worm gear mechanism without its disadvantages. This novel mechanism is referred to as a "ball worm gear mechanism". The force of the worm gear mechanism is transmitted by a sliding movement, which leads to high operating temperature and low efficiency as well as wear on the bronze worm wheel. Therefore, a new mechanism was designed with balls placed into the helical grooves on the worm shaft which move by rolling on the worm wheel. The worm wheel of the newly designed mechanism is made of case-hardened steel, which is less expensive than bronze. Thus, it is anticipated that not only the cost of the worm wheel will be reduced, but also its life will be extended. Greater efficiency and elimination of the high operating temperature are expected to result from the power transmission achieved by the rolling motion of the new mechanism. Modelling of the design was carried out with SolidWorks software and the feasibility of the mechanism was confirmed.

Keywords Worm gear mechanism, ball-screw mechanism, CAD, efficiency.

1. Introduction

The invention of the wheel (4000-3500 BC) made it possible to transfer rolling motion to linear movement and laid the foundations of the gear wheel system [1].

Induced gear units of electric motors or internal combustion engines that are designed to reduce high rotational speeds to the speeds required for the machines are called reducers [2]. Gearboxes are specified according to the gearwheel which is used in the gear reducers, e.g., spur gear, helical gear, bevel gear and worm gear reducers.

The present-day size of the gearbox is small when compared that of the past. At 12 horsepower, the axis-to-axis distance of a worm gear unit with a conversion ratio of 35 was 356 mm in the year 1903, but now it is around 100 mm [3].

One of the first screw profiles was invented by Archimedes in the 3rd century BC. Archimedes was able to transport water upwards, thanks to the screw known by his name – the Archimedes, or Archimedean, screw [4].

Worm gear mechanisms have very high conversion rates compared to other gear mechanisms. The conversion rates achieved in several stages with reducers made up of other gear mechanisms can be attained in one step by means of the worm gear mechanism, thus allowing for the designing of lighter and cheaper constructions requiring less space [5, 6]. The screw profile in the worm gear mechanism is usually dependent on the manufacturing process. The five most commonly used endless screws are the A, C, I, K, and N types [7]. The basic concepts needed for calculating the dimensions of the worm gear and worm wheel are shown in Figure 1 [8].

In addition to the abovementioned advantages of the worm gear mechanism, there are also disadvantages, such as low efficiency, high operating temperatures and rapid worm wheel wear [9]. Moreover, due to adhesion wear when using the same material for both components, the worm gear and the worm wheel must be fabricated from two different materials that have a low wear coefficient and are suitable for sliding. A steel-bronze material pair is preferred at the medium-high speed [6]. As bronze is expensive, it makes the cost of the endless screw mechanism high.

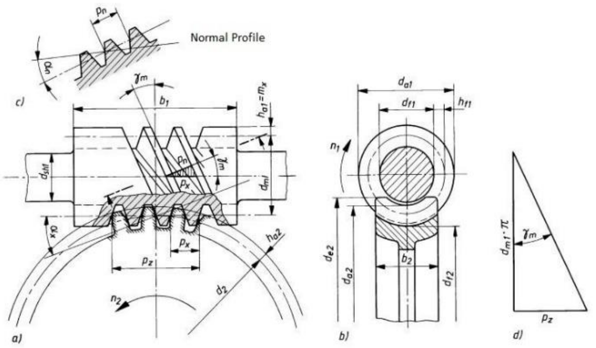

Fig. 1. Worm gear and worm wheel base

Table 1. Efficiency of gear mechanisms

Mechanism	Efficiency (%)
Cylindrical gear mechanism	**0.96 – 0.98**
Bevel gear mechanism	**0.95 – 0.97**
Worm gear locking ($\gamma m > \rho$)	**0.6 – 0.8**
Worm gear anti-locking ($\gamma m \leq \rho$)	**0.25 – 0.4**

The efficiency differences in various gear mechanisms are given in Table 1. The efficiency of the other gear mechanisms is around 95-98%, while for the worm gear mechanism type without locking it is as low as 25% [5].

Worm gear mechanisms are currently used in lifts and elevators, crane rope drums, textile machines, automobile and ship steering mechanisms, conveyors (banded, grilled and helical) and machine tools [3,10].

The worm gear mechanism has disadvantages which include low efficiency, rapid wear, overheating during operation and high cost. However, it is the advantage of its very wide field of application that led to the idea of a ball worm gear mechanism.

In this study, a new mechanism was designed to overcome the disadvantages of the worm gear mechanism. The newly designed mechanism was given the name of "ball worm gear mechanism". The design of the mechanism was implemented using the SolidWorks package program and the mechanics were tested via the SolidWorks Motion Study module.

2. Design of the ball worm gear mechanism

The design of gear mechanisms is a research area that has attracted many scientists and engineers over a number of years [11-21].

The design of the ball worm gear mechanism was inspired by the ball screw. The transmission of the force between the screw and the nut in the ball screw is achieved by the balls. A sectional view of the ball screw is given in Figure 2 [22].

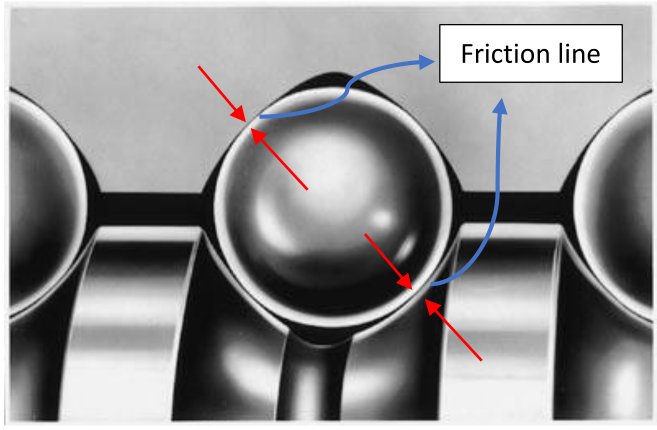

Fig. 2. Ball screw mechanism section

The balls in the ball screw roll away along the helical grooves opened on the shaft. Thus, the sliding movement between the screw and the nut in the transmission shaft is converted into a rolling motion in the ball screw resulting in lower friction coefficients because rolling friction requires much less force than sliding friction. The difference between rolling and sliding friction is illustrated in Figure 3 [22].

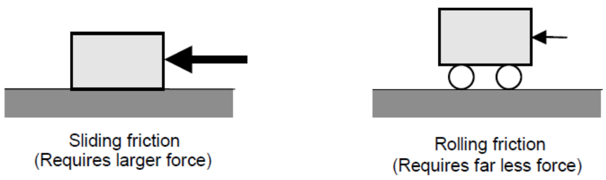

Fig. 3. Difference between sliding friction and rolling friction

In the designing of the ball worm gear mechanism, the concept of the rolling motion of balls in a nest on the shaft and the rolling motion on the worm wheel was addressed. In order to make comparisons during the designing of the worm gear mechanism, commercially available measurements were taken into consideration. To this purpose, a worm gear mechanism with an axis distance (e) of 80 mm and a cycle ratio (i) of 30 was taken as a reference.

2.1. Ball screw shaft design

In the design of the ball screw shaft, hemispherical cavities with a diameter (dw) of 8 mm were formed on a helical 13 mm pitch (pa). In the design phase it was noted that the distance between the axes (e) was 80 mm and the cycle ratio (i) was 30. A technical drawing of the ball screw shaft is given in Figure 4.

The use of cementation steel was planned for the production of the ball screw shaft and in the manufacturing stage, a lathe and vertical milling machine would be used. Shaft diameters were to be made on the lathe. To open the grooves on the shaft, a spherical end-mill cutter would be used in a vertical milling machine.

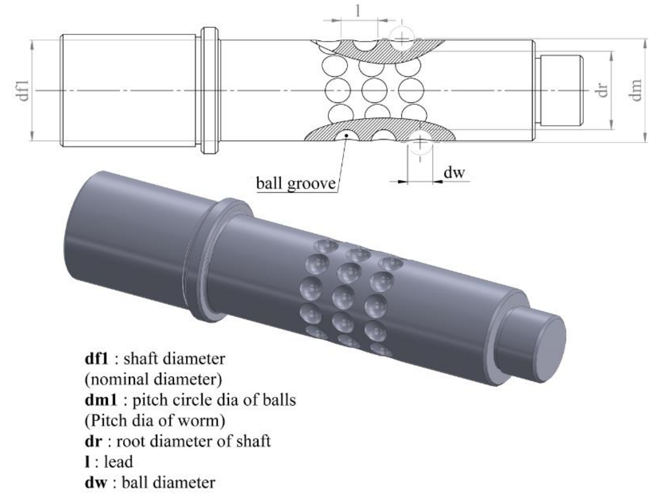

Fig. 4. Technical drawing of ball screw shaft

2.2. Ball worm wheel design

In the design of the ball worm wheel, semi-circular profiles were used instead of module teeth. These profiles, through which the balls will roll, will be slightly larger than the ball diameter to allow the mechanism to work more smoothly. Relevant information about the size of the opening will be provided by future experimental work. A technical drawing of the ball worm wheel is shown in Figure 5.

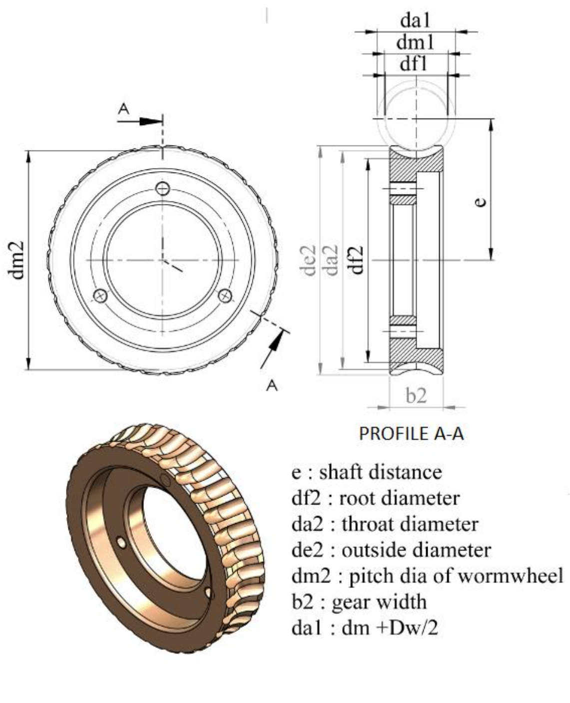

Fig. 5. Technical drawing of ball worm wheel

Cementation steel was planned for use in the manufacture of the ball worm wheel. In the production of the ball worm wheel, firstly the material was to be brought to the desired length and diameter measurements on the lathe, and then the teeth would be formed with a specially designed milling cutter (Fig. 6).

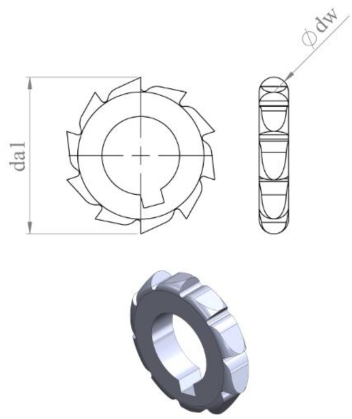

Fig. 6. Special semi-circular mouthed milling cutter

Commercially available milling cutters cannot be used in the manufacture of the ball worm wheel as they are module-mouthed. For this reason, a milling cutter with a semi-circular rim similar to that shown in Figure 6 was selected.

2.3. Guide sleeve design

The guide sleeve in the ball worm gear mechanism was designed to guide the balls within the ball screw mechanism like a ball nut and prevent the balls from spreading around during operation. A hemispherical gap was opened on the guide sleeve to allow for the working zones of the ball screw shaft and ball worm wheel equivalent gear. At the same time, the guide sleeve was fixed in the frame to accommodate axial reaction forces. A technical drawing of the guide sleeve is given in Figure 7.

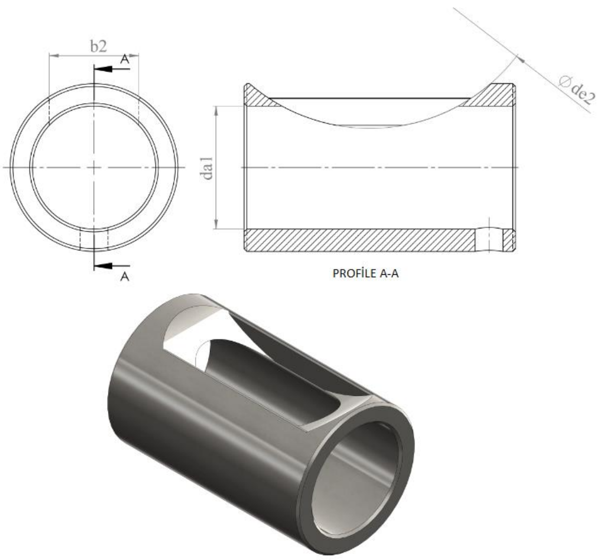

Fig. 7. Technical drawing of the guide sleeve

Conventionally produced steel was used as guide sleeve material. During the manufacturing phase, first, the inside and outside of the steel tube diameter will be machined on the lathe, then the hemispherical spaces will be formed using an end milling cutter on a machining center. An alternative technique would be to manufacture the part by the casting method and machining the necessary features on the side.

2.4. Body design

For the ball worm gear mechanism, in place of a new body design, a commercially available worm gear gearbox body with an 80 mm distance between axes and a conversion ratio of 30 was used. The ball screw shaft clearance of the ready-made body was designed so that the guide sleeve had a smooth fit. In addition, the radial screw holes were drilled on the body to secure the guide sleeve axially. Current worm gear mechanisms have cooling fins on the gearbox body because the operating temperatures are very high. This requirement is expected to be omitted in the newly designed mechanism.

2.5. Assembly of the ball worm gear mechanism

In the installation of the ball screw mechanism, the guide is first placed in the housing and fixed axially and radially. The ball worm screw shaft, on which the ball bits are attached, is then inserted into the guide sleeve. In practice, the holding of the balls onto the shaft will be carried out with the aid of high lubricity. Deep-grooved ball bearings are installed on both sides of the assembled ball worm screw shaft. The assembly of the ball worm wheel is carried out in the same way. A cross-section view of the assembled ball endless screw mechanism is given in Figure 8.

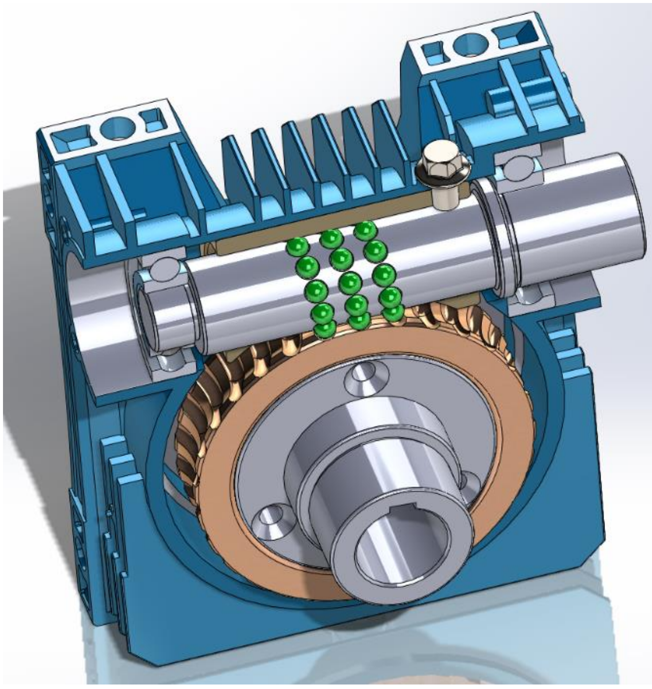

Fig. 8. Cross-section view of the assembled ball worm gear mechanism

The ball worm wheel was designed as two parts for easy assembly and disassembly. The operation of the mechanics was tested through the SolidWorks design program.

In the Motion Study Module of the SolidWorks program, it was observed that the mechanism worked smoothly when contact was established between all parts and the rotational moment was provided via the input shaft.

2.6. Sizing of the ball worm gear mechanism

The pitch / pi connection was used instead of the module to size the ball worm gear mechanism.

The pitch diameter of the worm wheel was calculated using equation (1).

$$d_{m2} = m_a \, . \, z_2 = \frac{p_a}{\pi} \, . \, z_2 \tag{1}$$

The shaft distance was calculated using equation (2).

$$e = \frac{d_{m1} + d_{m2}}{2} \tag{2}$$

Givens:

Pitch, $p_a = 13$ mm

Shaft distance, $e = 80$ mm

Number of teeth, $z_1 = 1$, $z_2 = 30$

Ball diameter, $d_w = 8$ mm

Sizes:

Pitch diameter of the ball worm wheel from equation (1)

$d_{m2} = 124.14$ mm

Pitch diameter of the ball worm shaft from equation (2)

$d_{m1} = 35.86$ mm

3. Conclusion

In the newly designed ball worm gear mechanism, the ball pieces slide on the worm screw shaft and proceed to move by rolling on the ball worm wheel. Since rolling friction requires less force than sliding friction, the ball worm gear mechanism will have higher efficiency than the conventional worm gear mechanism.

In the ball worm gear mechanism, as the force transmission between the ball worm shaft and the ball worm wheel is effected by rolling, the mechanism will not generate very high temperatures during operation. This situation will allow the gearbox oil to retain its long-term properties and make the mechanism more durable.

In the worm gear mechanism, since the force is transmitted by sliding, the worm wheel is usually produced from bronze, which is a softer material than that used for the worm shaft. Bronze is expensive and exhibits rapid wear. In the newly designed ball worm gear mechanism, the ball worm wheel will be manufactured from cementation steel, which is much cheaper than bronze. This will both reduce the cost of the mechanism and extend its life.

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