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Influence of the Rotational Direction of Splashed Lubricated Worm Gearbox on Load Independent Torque

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Abstract - A worm gear, widely used in many industrial applications, can provide substantially increasing output torque due to its high gear ratio. It occupies small space due to its compactness. Although their efficiency is relatively quite low compare to other gear drives. The sliding friction losses result in elevated temperatures and tribological losses. However, the demands on more efficient worm gearboxes have been increased to comply with the needs. This can be achieved by reducing torque losses. In a general geared system, the total power loss is comprised of two groups of losses: (i) load-dependent and (ii) non-load dependent losses. The load-dependent losses consist of bearing friction losses and gear friction losses. The non-load dependent losses consist of the oil seal losses, gear windage losses, bearing churning losses, and gear churning losses. The non-load dependent losses depend on many parameters such as speed, direction of rotation, volume of oil, immersion depth, temperature of oil etc. This research will only concentrate on the effect of direction of rotation of worm gear on non-load dependent losses.Worm drives have the ability to be constructed with either right-hand or left-hand gearing, allowing them to rotate in either clockwise or anti-clockwise direction. Both sections of an internal helical gear need to have the same hand in order to function properly. A detailed experimental study was carried out using the direct torque measurement technique. To measure the input torque under no-load condition, a new test rig was designed, manufactured, and commissioned. The variable effects of direction of rotation on torque losses were monitored.

***Keyword**:* Worm Gearbox, Direction of rotation, Torque Loss

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Introduction

Worm gears are frequently employed in technological systems because they can achieve large reduction ratios, high torque, and because their production costs are minimal. [1]. The worm gear is more metal-efficient and smaller than parallel axis gear with the same gear ratio. [2]. The most important part of this gear is the worm and worm wheel which are generally made of hardening steel and bronze respectively [3]. The meshing of the worm and the worm wheel is a blend of sliding and rolling activities, yet sliding contact overwhelms at high reduction ratios. This sliding activity causes friction and heat, which reduces the efficiency of worm gears. Worm gear generates too much heat which has to be cooled by using proper lubrication because the lubricant is not only for friction but also for dissipating the heat created by the gearbox when it is in use [4]. The main cause for the worm gearbox's decreased efficiency is power loss. [5]. The power losses in gear are split into two categories: i) load-dependent (Mechanical); ii) load-independent (spin) power losses due to windage losses, oil churning losses, and gear and bearing oil sealing losses.[6-8]. Both the power losses can be improved by reducing the input torque. This input torque are depends on variable parameters such as types of worm gear, orientation of gear, direction of rotation, geometry of gear, tribological parameters etc. The variation of churning losses took place when the meshed gears approached each other under the lubricant surface (counter-clockwise rotating direction) as shown in Figure 1 because of the trapping of lubricant by the meshing teeth. In this figure, it can be seen that under these conditions the oil immersion depth of the smaller gear is increased by the swell effect [9-10]

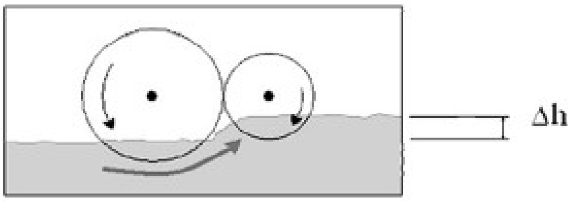

FIGURE 1: Approaching-direction rotating of a pair of spur gears in oil bath [9]

According to the orientation of worm it can be classified in mainly three categories that worm on the top, worm on the bottom, and worm on the side, similarly, according to the direction of rotation it can be classified as the right-hand worm and left-hand worm as shown in Figure 2.

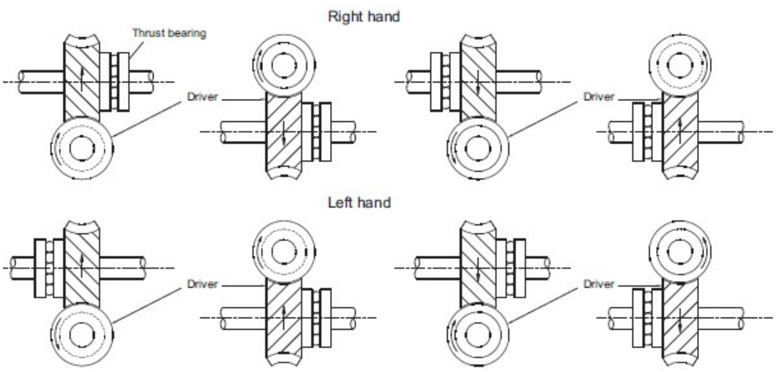

FIGURE 2: Classification of worm gear drive according to the position of the worm shaft[11]

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Methodology

There are many methods available to measure the input torque under no load condition. The direct torque measurement method is quite simple and more compatible with the gear pair therefore this method was selected to measure the input torque of worm gear pair. This method was also used to investigate the churning power loss for the parallel axis of gear and bevel gear [12-16]. The experimental studies were performed on a specially designed torque measurement test machine. The schematic representation of this developed test machine is given in Figure 3. The test machine is composed of a motor, torque sensor, Temperature sensor, Variable frequency drive (VFD), Shaft, Bearings, Couplings, testbed, and data collector.

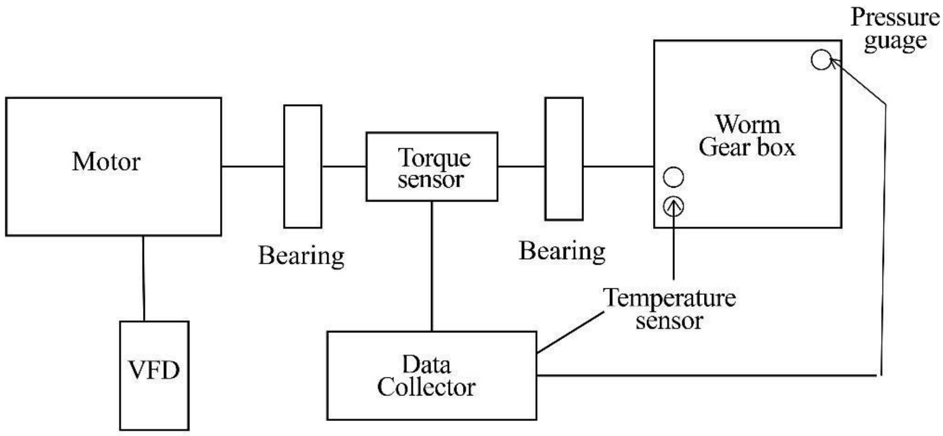

FIGURE 3: Schematic representation of the test machine for worm gear [17]

The test stand is built with an electric motor controlled by the variable frequency drive to enable the variation in rotational speed. The gearbox containing the test gear pair is connected to the motor through the shaft, torque sensor, and couplings. The gearbox is rigidly mounted at the end of the test-bed and similarly, the motor is mounted on the other end of the test-bed. Torque at the input shaft of the test gear is measured with the torque sensor. The temperature of oil inside the gearbox and pressure of the air inside the gearbox can be measured with the help of temperature sensor & pressure gauge respectively.

Table 1: The geometric properties of the worm gear [4]

Gear	**No. of teeth**	**Material**	**Module (mm)**	**Pressure angle**	**Center distance (mm)**	**Outer dia. (mm)**	**Reduction ratio**
Worm Wheel	30	CuSn12	3	20	75	132	30:1

Worm Shaft	Single start	16MnCr5	40

This test rig is designed to perform the experiment based on the direct torque measurement technique.The test rig allowed with several working conditions in terms of worm speeds, immersion depth of gear (lubricant volume), temperatures of lubricant, types of lubricant (Mineral & synthetic), gear reduction ratio, rotational direction and gear orientation (worm at the top and worm at the bottom) to study their effect of direction of rotation on input torque. Table 1 shows the geometrical dimensions and material of a single start worm and a worm wheel. It can be noted that single geometry was selected to study the effect of direction of rotation.

Table 2: Lubricant properties [4]

Sr. No	Name of oil	Kinematic Viscosity (cSt) @ 40 ºC	Kinematic Viscosity (cSt) @ 100 ºC	Viscosity Index	Density (Kg/m3) @ 15 ºC
Oil-A	Mineral oil	312	33	95	880
Oil-B	Synthetic oil	330	35.50	162	790

There are several techniques to lubricate the worm gear, however, for this experiment, splash lubrication was used to assess input torque. In terms of lubricants, two different oils were used, with their characteristics summarised in Table 2. The volume of the test gearbox was kept constant (180mm×180mm×280mm). As per the test matrix in Table 3, the gearbox was filled with lubricant and rotated at particular speed by forward (clock wise) and reverse (Antilock wise) direction. The input torque was measured as per mentioned temperature of lubricant and lubricant level.

Table 3: Lubricant properties [4]

Control factors	Unit	Values
Speed of worm	rpm	1000,1200,1400
Lubricant Volume	lit	1.5, 2.1, 2.7
Temperature of lubricant	ºC	30,40,50
Lubricant type	-	Oil-A, Oil-B
Direction of rotation	-	Clockwise & Anticlockwise

Result & Discussion

The experiment test was conducted for at least a prior 5º C temperature of the basic starting temperature of the test. Time was not bounded for the test but the test was going on till the desired temperature was reached. The entire test was run at a specific configuration and operating conditions to determine the effect of rotation on torque. The experiments were performed under the varying speed of worm, lubricant (oil) volume, and lubricant (oil) temperature inside the gearbox as shown in Table 4. The response variable was input torque that was measured with the help of the torque sensor.

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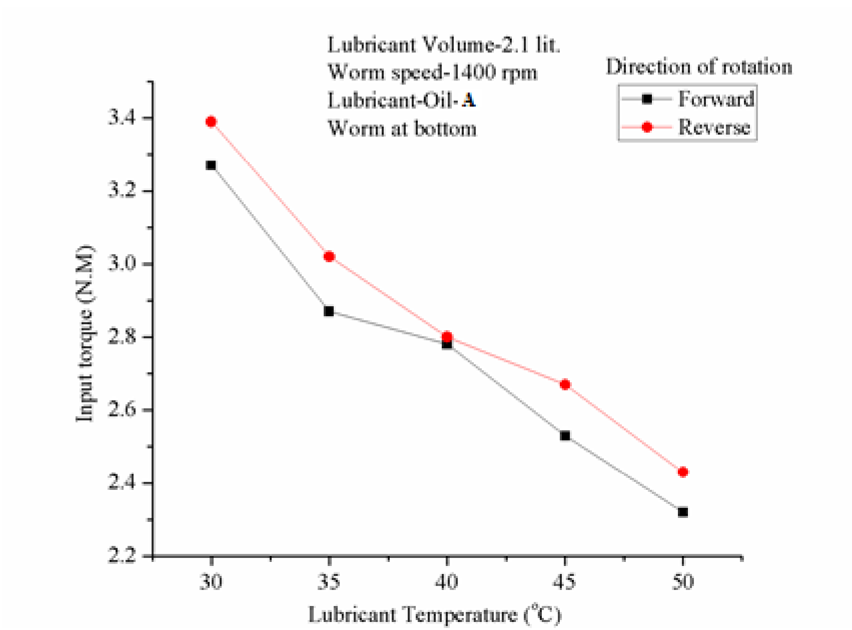
Influence of Direction of rotation

There are two possible directions of rotation, clockwise & anticlockwise direction of the worm shaft. The standard rotational direction of the worm gear is clockwise of the worm shaft. To examine the effect of the direction of rotation on the churning power loss, different worm speed and lubricant volume were employed and their results were compared.

TABLE 4: Experiments results of input torque for forward direction and reverse direction

Temperature (°C)	Speed (rpm)	Oil Type	Oil Volume (lit)	Input Torque (N.M)	
				Forward Direction	Reverse Direction
30	1200	A	2.7	3.29	3.34
35	1200	A	2.7	2.93	2.89
40	1200	A	2.7	2.83	2.81
45	1200	A	2.7	2.53	2.58
50	1200	A	2.7	2.37	2.45
30	1400	B	2.1	3.27	3.39
35	1400	B	2.1	2.87	3.02
40	1400	B	2.1	2.78	2.8
45	1400	B	2.1	2.53	2.67
50	1400	B	2.1	2.32	2.43



(a)

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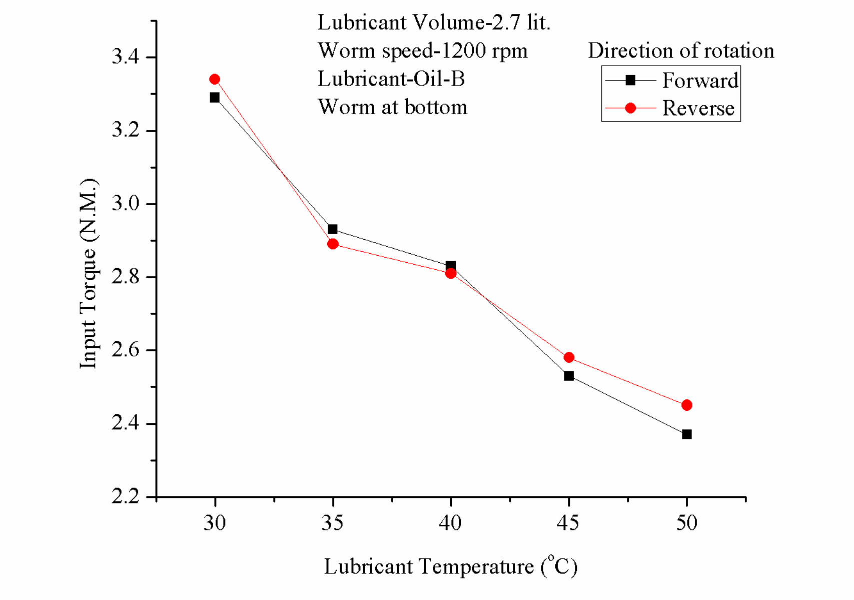

(b)

FIGURE 4: Influence of direction of rotation on the churning power loss within the speed range, lubricant=oil-B (a) Lubricant Volume=2.1-liter & Speed-1400 rpm (b) Lubricant Volume=2.7-liter & Speed-1200 rpm

The input torque for the forward direction and reverse direction is much closer for all range of lubricant temperature. Figure 4 (a) shows, at the initial level (temperature=30 ºC), reverse direction consumes more input torque than forward direction. However, in the middle of the experiment (temperature=40 ºC), the difference of input torque for both directions is negligible. The difference of input torque between forward & reverse direction is only 3% as shown in Figure 4.17 (a) for the higher speed (N=1400 rpm). Figure 4 (b) shows clearly that at 1200 rpm, there is no gap of input torque between both directions at every interval of temperature. The difference of input torque between forward & reverse direction is 0.8% for the moderate speed (N=1200 rpm).

Conclusion

The experiments were performed to investigate effect of rotational direction (right hand & left hand worm shaft) on input torque for dip lubricated worm gear. The measurement was based on the direct torque measurement method under the variable operating condition such as lubricant level, speed of worm shaft, lubricant temperature and rotation direction.

The average difference between forward & reverse direction (right hand & left hand worm shaft) for all level and speed is 1-2% which is negligible. It is found that the variation of input torque of worm gear does not depend on the direction of rotation. Input torque consumption for splash lubricated worm gearbox under same operating condition are almost same or difference is negligible.

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