Design and analysis of multi-angular gearless transmission system

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Abstract: The present work mainly focuses on finding an alternate option of gear drives for various power transmitting applications in different sectors. In this study, the gearless power transmission mechanism created to transmit the power at various angles between the driving shaft and driven shaft, ranging from 0° to 180°. The system is modeled and analyzed in CREO5.0 to check the feasibility of the system. The speed analysis revealed that the speed ratio of the output shaft to the input shaft remained 1:1 during operation. The von mises stress analysis indicated that the design is safe under specific loading criteria. It observed from deformation analysis that the maximum displacement has occurred at the corner of the elbow link. The failure index analysis of the elbow link revealed that the inner curvature of a link is subjected to the maximum possibility of failure.

Keywords: Analysis, Design, Failure index, Gearless mechanism, Speed ratio

1. INTRODUCTION

The gear drives are extensively used for accurate and variable power transmission in various sectors like Automobile, Aerospace, Marine and Defence, Industrial cutting and machine tools, Lifting and hoisting devices, etc. The main drawback of gear drive is less efficient due to errors like backlash, resulting in the vibrations during operations and decrement in product life due to more wear rate of components [1].

Selby, 1917 developed an innovative gearless mechanism in which speed was varied by forwarding and backward movement by applied shaft-hub assembly [2]. Johnson, 1966 established the apparatus especially for automobile and aerospace industries in which the power was transferred in terms of increasing or decreasing speed through rotating frictionless balls [3]. Chakradhar, et al., 2019 showed advantages like less floor space area, simple working, lower friction and smooth operation, interchangeability of components, reduction in production cost, etc. of gearless mechanisms over gear equipped mechanisms [4]. Wu & Dong, 2014 analyzed the gearless reducer mechanism by introducing frictionless balls for unilateral and bilateral transmission. The trial experiments for both types of transmission revealed smooth operations and effective working efficiency [5]. Pramesh, et al., 2017 performed design and analysis of gearless elbow mechanism in Ansys software by a varying number of pins. It was proved from a simulation that the deformation and developed stress values were raised with an increasing number of pins [6]. The greater number of pins will be increasing the friction loss and weight of setup which results in power transmitting efficiency. Pawar, et al., 2018 designed a gearless elbow mechanism with three pins situated at 120° each for right angle (90°) power transmission [7].
Patil, et al., 2017 stated the future applications of gearless transmission in pump and compressor and carried out a design for three link elbow mechanisms [8]. Logesh, et al., 2018 studied the design of three links gearless elbow mechanism for right-angled power transmission application through actual experimental validation [9]. Somraj & Sailesh, 2017 have calculated the dimensions of components and induced bending stress during operation by considering different materials for right-angled power transmitting application of three linked elbow gearless mechanisms with the actual working setup [10]. Rana & Rehman, 2018 constructed a setup of a gearless mechanism equipped with three links at 120° each. They measured the output speed with variable input speed and indicating minor variation occurred due to friction [11]. Htway, et al., 2019 simulated elbow mechanism (3, 5 and 7 links) for 0-90° power transmission with variable input speed in Solidworks software. It revealed that mechanism with 5 links has less deformation and induced stress during operation compared to remaining twos [12].

Researchers have simulated the systems with variation in speed and number of links on various computer systems for 0-90° power transmission applications. The design of gearless systems for more than 90° power transmitting applications needs to explore further.

2. DESIGN OF MECHANISM

In the present study, the gearless transmission mechanism is developed for the transmission of motion between the input shaft and output shaft for 0° to 180° in CREO5.0 software. The hubs are placed on the shaft which consists of three pins located at 120° each and forming a connection between driving and driven shaft by moving in a rotating and reciprocating manner. The overall assembly is comprised of the driving shaft, driven shaft, two hubs, and three pins. The whole structure is supported by a rigid platform (Cast iron) showed in figure 1. The material for hub and shafts is selected as mild steel (45C8) while elbow links are made of stainless steel (X6Cr17).

![Figure 1. Multi-angular gearless transmission mechanism.](image)

The pedestals are located on the driver shaft and driven shaft for eliminating vibrations. The semi-circular path is provided to ensure the power transmission at various angles beginning from 0° to 180°. Let the driving shaft is rotating at a certain speed in a counter-clockwise direction, resulted in a movement of pins. Pin 1 is moved in a reciprocating manner along with rotation for 120°, after that the pin 2 is taking place of pin 1 and continued. The motion is transmitted by changing the position of pins after 120° in a successive manner.

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The motor is applied to the driving shaft of 0.25 HP. The power of the motor (P) is 186.5 Watt and RPM (N) is 1440. The value torque (T) is obtained by using the following equation,

\[ \text{Power} P = \frac{(2\pi NT)}{60} \]

The torque \( T = 1238 \text{ N mm.} \)

2.1 Design of Hub

Considering external (Do) and internal (Di) diameter is 92mm and 32mm respectively while the length is 82mm and mass of the system (m) is 100 kg. So, The total load \( P = mg = 981 \text{ N.} \) The different views of the hub with required dimensions are showed in figure 2.

\[
\sigma = \frac{P D_i^2}{(D_o^2 - D_i^2)} = 135.01 \text{ N/mm}^2
\]

2.2 Design of Elbow link

The diameter and length of the link are considered as 8mm and 300mm respectively. The section modulus \( (Z) = 0.78 \times R^3 = 49.92 \text{ kg/mm}^2. \) The various orientations of the link along with necessary dimensions are indicated in figure 3. The combine arrangement of a hub and link assembly is displayed in figure 4.

\[
\text{Bending Stress } \sigma = \frac{PL}{4Z} = 280.19 \text{ N/mm}^2
\]
2.3 Design of Shaft
The shaft diameter and length are assumed to be 30mm and 230mm respectively. The value of moment \( (M) = 2151.11 \times 230 = 494755.3 \) N mm.

Bending Stress \( \sigma = \frac{32M}{\pi d^3} = 186.64 \) N/mm\(^2\)

The bending moment for shear stress \( = P \times 2N \times 60 \times 10^6 \)
Where, \( P = 7.5 \) KW and \( N = 120 \) RPM

Bending moment \( (M) = 596831.03 \) N mm.
Shear stress \( \tau = \frac{16M}{\pi d^3} = 112.57 \) N/mm\(^2\)
3. ANALYSIS OF MECHANISM

To verify the working performance, the gearless multi-angular mechanism was analyzed in CREO5.0 software. The fix constraint is applied on base and speed is given to the input shaft through virtual motor indicated in figure 5. The velocity value is given as 50 units at given instant time and raising with increasing time. A similar trend is observed in the measurement of output shaft velocity. Figure 6 shows the output shaft speed is observed at applied input speed which revealed the speed ratio is approximately 1:1.

![Figure 5. Velocity profile of input shaft](image)

![Figure 6. Obtained velocity profile of the output shaft](image)

The von mises stress analysis is performed on the system by considering the applied load in terms of weight of components and load generated during operations. The maximum value of induced stress in the system during operation is obtained as around 9 MPa which is much lesser than permissible stress limit. The maximum areas of the mechanism are subjected to less than 3 MPa. So, the mechanism is safe under specific loading criteria showed in figure 7. The deformation in mechanism during operation is analyzed. It is evident from figure 8 that maximum deformation is occurring in corner of
elbow links as it is the main component to transfer the motion and power at various angles ranging from 0° to 180°. Due to reciprocating motion of link along with rotation, more vibrations are generated during operation. The obtained maximum displacement of the system is around 0.047 mm on the elbow link. To identify the maximum failure index on a pin, the failure analysis of the link is carried out and figure 9 displayed that the inner curvature of a link is subjected to maximum possibility of failure.

![Von mises stress analysis of system](image1)

**Figure 7.** Von mises stress analysis of system

![Deformation analysis of the mechanism](image2)

**Figure 8.** Deformation analysis of the mechanism
4. CONCLUSIONS

In the present work, the design and analysis were carried out for a gearless power transmitting mechanism with angles varies from 0° to 180°. The following conclusions were obtained from the present study:

1. The present design of the mechanism is capable of transmitting power from 0° to 180° between input shaft to output shaft without loss.
2. The measured speed of the output shaft is approximately equivalent to the input shaft (speed ratio is 1:1).
3. It was observed from von mises stress analysis that the design is safe under specific loading criteria.
4. It is evident from deformation analysis that the maximum displacement has occurred at corners of elbow links having a value of 0.047mm.
5. Failure analysis of pin revealed that the inner curvature of a link is subjected to the maximum possibility of failure.

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