Design and fabrication of power transmission system through elbow mechanism

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Abstract: Most of the machines transmit power from the input to the output with the help of gears, but the efficiency of power transmission by gears is less due to friction losses. The major problem is that the transmission having gears cause the jamming due to the backlash error and produces more noise compared to other drives due to pitch mismatch. From the design point of view, there is a 10% energy loss per engagement for gears [1], [6]. Also, the construction of gears is complex and, thus, costlier. The gearless elbow transmission is a very efficient mechanism and has shown efficiency up to 92%. This paper gives information about the strength, speed, and torque transmissibility of elbow mechanism as these are very important terms in defining applications of the mechanism in replacement of gears. The transmission of power with minimum losses is the main criteria for calculating the efficiency of the machine. This system demonstrates efficient gearless transmission of power at any required angle and saves gear manufacturing time and costs along with teeth matching and gear placement issues. The elbow mechanism is an efficient design of gearless transmission technique and the kinematic system that allows for efficient power or motion transmission at any required angle. This mechanism allows for motion transmission at 90 degree angle between the driver and driven shafts.

Keywords: Gearless power transmission mechanism, skew shafts, L-pins, design of shafts, hubs and elbow rods, elbow mechanism.

1. INTRODUCTION:-

In today's world, energy is the prime requirement in each and every field. As the world is leading towards the 22nd century every bit of energy becomes crucial because the resources that we have for producing energy is very limited and soon will be getting finished. For transmitting motion and power from one shaft to another which are non parallel or intersecting and co- planar, bevel gearing are generally employed. But there are some inherent disadvantages associated with bevel gearing such as complexity in manufacturing, high cost of replacement. To overcome all these problems, we have a mechanism which transmits motion between the two non-parallels (intersecting) and co-planar shafts [1], [2], [3], [4], [5]. The mechanism is known as Gearless transmission system. It is also known as L-pin mechanism or Orbital transmission mechanism or Elbow mechanism, consisting of elbow rods, hub and shaft. Today's world requires speed on each and every engineer's field that is confronted to the challenges of efficient transmission of power. Gearless transmission is an ingenious link mechanism of slider and kinematic chain principle. Gears are costly and complex to manufacture. It is needed to further increase the efficiency of transmission which cannot be done using geared transmission. Gearless transmission mechanism is capable of transmitting power at 90 degree without any gears being manufactured. The Elbow mechanism transmits the input power towards the output side in such a way that the angular forces produced in the slacks are simply transmitted with the help of pins which takes up the input power and the right angle drive is transferred towards the output slack and pin assembly. Hence very little friction plays role while the power is being transmitted, the hunting and backlash problems are also improved by using gearless elbow mechanism.

The first application of this mechanism was made use of the “Big Ben Clock” having four dials on the tower of London [7]. This clock was installed with some rotational motion around an axis which usually involves gears, therefore making it complicated, inflexible and clumsy-looking. So, instead of using gears, this technology elegantly converts rotational motion using a set of cylindrical bars bent to 90º, in a clever, simple and smooth process that translates strong rotational force even in restricted spaces. A gearless transmission is provided for transmitting rotational velocity from an input shaft connected to three bent links. Both the input shaft and the housing have rotational axes. The rotational axis of the input shaft is disposed at an angle of 90 degree with respect to the rotational axis of the housing (cylindrical hubs). As a result, rotation of the input shaft results in a processional motion of the axis of the bent link. The rotary and reciprocating motion of bent link transmit rotation of prime over to 90 degree to an output shaft without gears being used. The elbow mechanism is very useful for multiple spindle drilling operation known as gang drilling. It can be used as lubrication pumps in CNC lathe machines. This mechanism is very helpful for reaching a drive at clumsy location. Another application of this mechanism is that it can be used for the movement of periscope in submarines. It can be used in air blowers for electronic and computer machines. Elbow mechanism is useful in vehicles like Go-carts where power is transmitted from one shaft to the other shaft. This mechanism is helpful in hand driven machines like juice makers, sheet folding machines etc. The gearless elbow mechanism has a bright future in robotics and automobile industries. This mechanism can be used as an air compressor or an air pump, when the pins inside the drilled holes are reciprocates as well as revolves along the axis of cylinder it gives the compressor effect. Among the three pins, when first pin goes at inner dead center it sucks the air, then it start to move at outer dead center by revolving, it compresses the air against seal and cylinder head disc and does simultaneously by three pins and we can get continue discharge of air quantity.

2. Material selection:-

The whole structure is supported by a rigid platform which is made up of mild steel. The material for hubs, elbow rods and shafts is selected as mild steel.

i. Mild Steel:-

- Cheapest and easily available.
- It is very strong due to low amount of carbon present in it.
- It has high tensile and impact strength.

Properties:-

- Hardness (BHN) = 126 BHN.
- Tensile strength (Ultimate) = 440 MPa.
- Tensile strength (Yield) = 370 MPa.
- Density = 7.87 g/cc.
- Elongation at break = 15%.

- Chemical composition: carbon (0.14-0.20%), iron (98.81-99.26%), manganese (0.60-0.90%, phosphorous (< = 0.040%), sulfur (< = 0.050%).

S. No.	Part name	Material	Quantity	Dimensions(mm)
1.	Shaft	Mild steel	02	25 mm diameter 280 mm length
2.	Bent link	Mild steel	03	14 mm diameter 300 mm length
3.	Hub	Mild steel	02	92 mm outer dia. 25 mm inner dia. 32 mm length
4.	Bearing	Cast iron	04	25 mm inner dia. Pillow block bearing(P204)
5.	Frame	Mild steel	01	500×300×350 (length×height×width)
6.	Motor		01	120Watt, 55rpm

3. Construction and working of Elbow mechanism:-

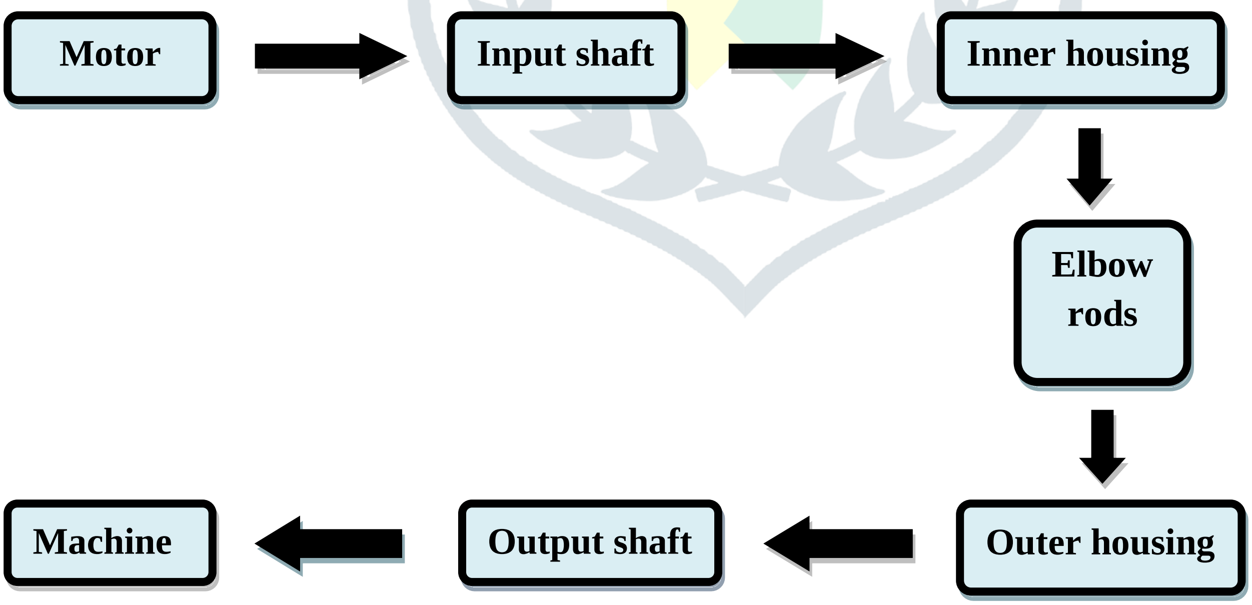

Fig: Flowchart representation of Gearless Elbow transmission system.

In the present study, the gearless transmission mechanism is developed for the transmission of motion between the input shaft and output shaft at 90°. The whole assembly is placed upon a rigid frame made of mild steel. Motor is connected to the driving shaft at one end and pedestal bearings are coupled into the shafts on both sides. The hubs are coupled to the shafts on both sides. There are 3 holes located at 120° each on both cylindrical hubs and through these holes elbow rods or L-pins are connected into the hub on both sides, forming a connection between driving and driven shaft by moving in a rotating and reciprocating manner. Then the driven shaft is connected into the final machine for its desired use. The overall assembly is comprised of the driving shaft, driven shaft, two hubs, three elbow pins, four bearings, a frame and a motor.

The pedestal bearings are located on the driver shaft and driven shaft for eliminating vibrations. Motion is transmitted from driving shaft to the driven shaft with the help of L-pins bent at 90°. Let at the starting instant shaft 1 starts rotation with 3 pins in clockwise direction and a reaction force developed at the pin surface which in contact with the shaft 1 and this force transferred to the other end of the pin which is in the shaft 2, due to which shaft 2 starts rotating in the anti-clockwise direction, after 120° rotation pin 1 comes at the place of pin 2 & pin 2 comes at the place of pin 3 & pin 3 comes at the place of pin 1 by sliding in shaft and self adjusting. This motion repeated for next 120° and further for next 120° and pins are exchanging the position in successive order. Power is supplied by a car wiper DC motor which is connected to the driving shaft. Now, after switching on the power source to the motor, the motor starts rotating at very high speed as the motor shaft is attached to the main shaft of the hub. The hub also rotates with the speed of the motor. The elbow rods are freely fitted into the two hubs at an angle 90° which are held freely without any firm force acting on them. When the hub is set to rotate, the three links starts adjusting themselves to get free from the hub, but as they are hold in between the two hubs avoiding for coming outside. They will slide to and fro continuously in the circular motion and thus they transmit the power to the next shaft attached to the hub which is at another side of the mechanism at 90 degrees to the motor side hub, thus the shaft attached to the second hub will also set to rotate with the same speed of the motor shaft. When the tool or any source is attached to the end of the second shaft would set to rotate performing the required operation, thus completing the working of the mechanism.

4. Design calculations:-

[1], [2], [3], [4]. Here we will use a car wiper DC motor having 12 volts of motor voltage and current draw is 10 amperes.

Speed of the motor, N = 55 rpm.

Power of the motor, P = 120 Watts or N-m/sec.

$$\text{Also, Power} = \frac{2\pi NT}{60}$$

$$120 = \frac{2\times\pi\times55\times T}{60}$$

$$T = \frac{120\times60}{2\times\pi\times55}$$

$$T = 20.83 \text{ N-m}$$

$$T = 20830 \text{ N-mm.}$$

Hence, the torque transmitted through the motor is 20830 N-mm.

i. Design of Hub (cylindrical housing):-

The outer diameter of hub, D = 92 mm.
The inner diameter of hub, d = 25 mm.
L-pin or elbow rod hole in hub diameter, đ = 14.5 mm.
Length of hub, L = 32 mm.

Volume of hub, $V = [\frac{\pi}{4}(D^2 - d^2)\,L] - [3\pi \times đ^2 \times \frac{L}{4}]$

$$V = [\frac{\pi}{4}(92^2 - 25^2) \times 32] - [3 \times \pi \times 14.5^2 \times \frac{32}{4}]$$

$$V = 181163.08\ mm^3$$
$$V = 181.16\ cm^3.$$

Weight of hub, W = Volume of hub × Density of material used in hub

$W = V \times \rho$
$W = 181.16 \times 7.89$
$W = 1429.35$ g
$W = 1.429$ Kg
$W = 1.429 \times 9.81$ N
$W = 14.03$ N.

Bending stresses acting on hub, $\sigma^b = \frac{32 \times M^b \times D}{\pi\,(D^4 - d^4)}$

$$\sigma^b = \frac{32 \times (14.03 \times 32) \times 92}{\pi\,(92^4 - 25^4)} \qquad [\text{Where } M^b = W \times L]$$

$$\sigma^b = 0.0059\ N/mm^2.$$

Allowable bending stresses = 0.46 × Ultimate tensile strength
= 0.46 × 440 MPa or N/mm^2
= 202.4 N/mm^2.

Therefore, working value of bending stresses on hub is less than allowable value of bending stresses acting on hub.

i.e. (σ^b) working < (σ^b) allowable. ($0.0059\ N/mm^2 < 202.4\ N/mm^2$)

Hence, design of hub is safe.

ii. Design of shaft(solid cylindrical shaft):-

Diameter of shaft, D = 25 mm.
Length of shaft, L = 280 mm.

Torsional shear stress in shaft is given by: $\tau = \frac{16 \times Mt}{\pi D^3}$

$$\tau = \frac{16 \times 20830}{\pi \times 25^3} \quad \text{[Where Mt = T]}$$

$$\tau = 6.789 \text{ N/mm}^2.$$

Allowable torsional shear stress = 0.22 × Ultimate tensile strength
= 0.22 × 440 MPa or N/mm^2
= 96.8 N/mm^2.

Therefore, working value of torsional shear stress is less than the allowable value of torsional shear stress acting on input as well as output shaft.
i.e. τ(working) < τ(allowable). ($6.789 \text{ N/mm}^2 < 96.8 \text{ N/mm}^2$)
Hence, design of shaft is safe.

Also, bending stress acting on shaft is given by: $\sigma^b = \frac{32 \times M^b}{\pi \times D^3}$

$$\sigma^b = \frac{32 \times 14.03 \times 280}{\pi \times 25^3} \quad \text{[Where } M^b = W \times L\text{]}$$

$$\sigma^b = 2.561 \text{ N/mm}^2.$$

Therefore, working value of bending stress is less than allowable value of bending stress acting on input as well as output shaft.
i.e. (σ^b) working < (σ^b) allowable. ($2.561 \text{ N/mm}^2 < 202.4 \text{ N/mm}^2$)
Hence, design of shaft is safe.

iii. Design of elbow rods or L-pins:-

Diameter of rods, d = 14 mm.
Length of rods, l = 300 mm.
Section modulus, $z = 0.78 \times r^3$
$z = 0.78 \times 7^3$
$z = 267.54 \text{ mm}^3$.

Bending stress acting in elbow rods is given by: $\sigma^b = \frac{W \times L}{4 \times z}$

$$\sigma^b = \frac{14.03\times300}{4\times267.54}$$

$$\sigma^b = 3.93\ \text{N/mm}^2.$$

Therefore, working value of bending stress is less than the allowable value of bending stress acting on L-pins.

i.e. (σ^b) working < (σ^b) allowable. ($3.93\ \text{N/mm}^2 < 202.4\ \text{N/mm}^2$)

Hence, design of rods is safe.

iv. Efficiency:-

Input shaft speed, N_1 = 50 rpm

Output shaft speed, N_2 = 46 rpm

Therefore, input power we get, $P_{in} = \frac{2\times\pi\times N_1\times T}{60}$

$$P_{in} = \frac{2\times\pi\times50\times20.83}{60}$$

$$P_{in} = 109.06\ \text{rpm.}$$

Also, output power obtained, $P_{out} = \frac{2\times\pi\times N_2\times T}{60}$

$$P_{out} = \frac{2\times\pi\times46\times20.83}{60}$$

$$P_{out} = 100.34\ \text{rpm.}$$

Therefore, % efficiency = $\frac{P_{out}}{P_{in}} \times 100\ \%$

$$= \frac{100.34}{109.06} \times 100\ \%$$

$$= 92\ \%.$$

Hence, % efficiency we get through gearless elbow mechanism is about 92 % which is more than that of % efficiency we get through gear drive mechanism.

5. Fabrication of the mechanism:-

The gearless power transmission system is a system which can drive without using any gear. It can transmit power or motion from one shaft to another shaft at any fixed angle. In this project, it consists of three numbers of elbow pins, motor, shafts, cylindrical hub, bearing and frame. The pins can transfer power through hub from one shaft to another shaft. At first, a dc motor supplies power to input shaft. The input shaft is connected to the hub. Elbow pins are bent at right angle between two hubs for transmitting motion. These pins are slide and rotate freely around cylindrical holes which locate in the hub. The holes are located equally in the hub. One transformer is also connected for controlling voltage and speed of the system. The whole assembly is placed upon the rigid frame. The fabricated model of gearless power transmission system through elbow mechanism is shown in figure below.

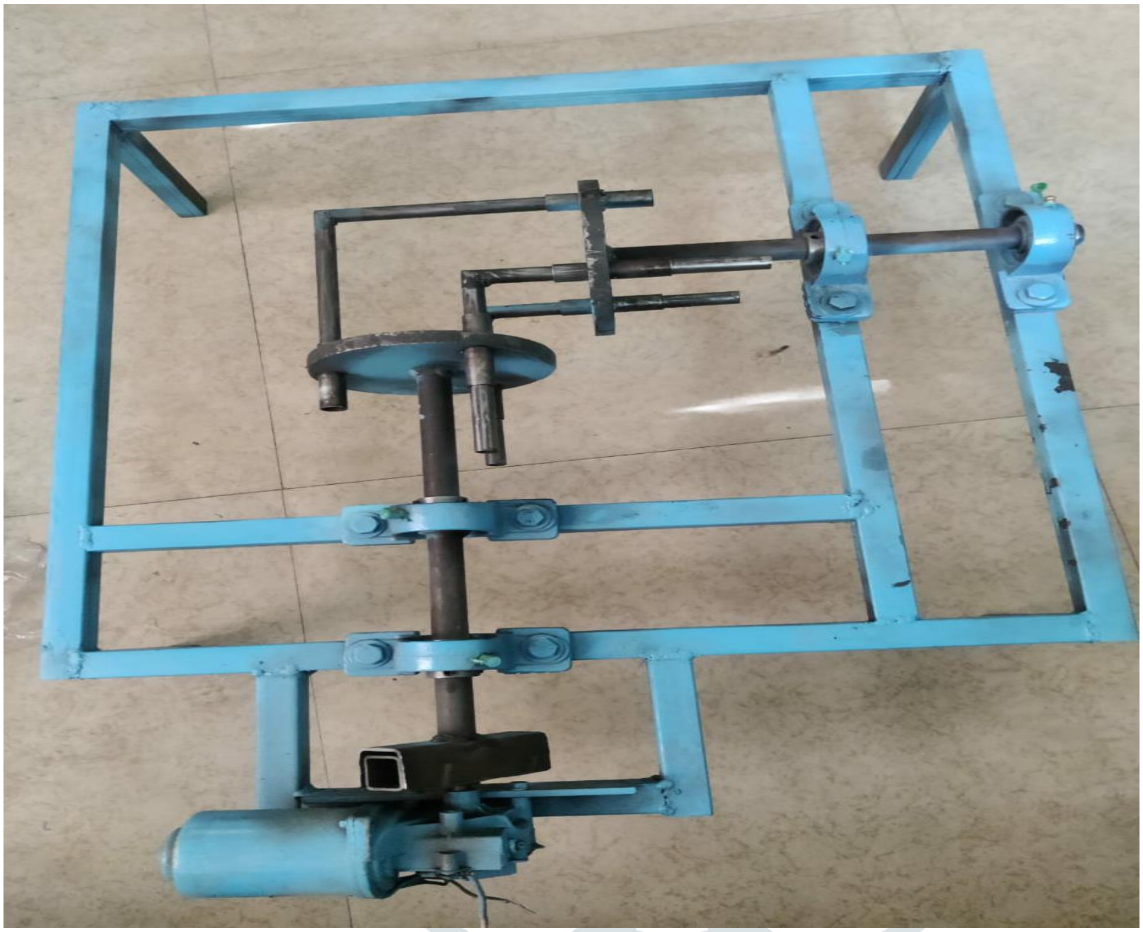

Fig: - Fabricated model of gearless transmission through elbow mechanism

6. Result ad discussion:-

The mechanism runs smoothly when it runs at low speeds. The efficiency so obtained through gearless power transmission system by using elbow mechanism is nearly about 90 - 92%. The final design obtained is capable of transmitting torque and power at right angle with three elbow rods. As calculated the working stress is less than the allowable stress, hence the system is safe against bending and torsion. With the help of this system, we can efficiently reduce the cost in power transmission and further advancement in this technology can be made.

7. Future scope:-

i. The elbow mechanism has a bright future in automation and robotics.
ii. Flexible bent links can be used.
iii. The elbow mechanism can be used in automobile industry in near future.
iv. Torque bearing capacity can be improved.
v. More number of elbow rods or bent links can be used for effective power transmission.

8. Conclusion:-

The model works correctly as per the design. With the help of this system, we can efficiently reduce the cost in power transmission. Further advancement in this technology can be made. The gearless drive system is an alternate approach for the transmission of power at different angles. The design of this system is simple and efficient in power transmission. The maintenance and service is also comparatively low when compared with other traditional transmission system. It has a good scope in future to replace the heavy usage of gears which will replace simple, stylish usage of shafts that will reduce the overall cost management of the industries using gear technology presently to gain more profits. During the work in the experimental configuration and after a long discussion it is observed that the proposed layout is used for any series of diameters with any axis profile for oblique axes of any angle, but the axis must have the rotation movement only from the shaft, the motion transmission is very smooth and desirable and is used only for same rpm regime of the driven shaft and driven shaft through the use of pins or types of data connections for joints suitable for the revolutionary torque. The elbow rods or bent links should be equally radially spaced on the cylindrical discs or hubs (if 3 pins are used then 360/3 = 120° each rod). The mechanism transmits the motion efficiently up to 150 rpm. Minimum 3 numbers of pins should be used to make transmission possible. This mechanism can give up to 92% of efficiency, while gears can give maximum 42% of efficiency. The links are bent to 90°, but instead of bent links, bolted links or links held by universal joints are used, then transmission is possible even when angle changes on the go. This mechanism is mainly applicable to low cost applications where torque is low to medium. With future development in low friction materials (grapheme coating) and stronger composite materials, the efficiency and the capacity of this mechanism can be increased. It can be used for machining operations such as boring, drilling, grinding operations etc. This system may break for applying sudden load because elbow pins and hub alignment are very sensitive. The effect of corrosion in this system is very less than geared drive. Some speed loss is found in this system due to friction and clearance between hub and elbow rods. It can be reduced by proper surface finish and using lubrication. Lubrication can be applied to the drilled holes in the hub. But the main advantage of this system is full of interchangeability and low cost.

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