Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2019
(ICMERE2019) 11 – 13 December, 2019, Chittagong, Bangladesh

ICMERE2019-PI-237

ANALYSES OF AN EFFICIENT MULTI-ANGULAR POWER TRANSMISSION ARRANGEMENT BY EMPLOYING KINEMATIC CHAIN JOINT LINKS

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***Abstract**-This paper exhibits the implementation, simulations and experimentation of a multi-angular power transmission mechanism which includes binary kinematic chain joint links. The proposed mechanism can transmit power with the help of the links whose form revolute pair with the two hubs and can be bent at any angle from 0 to 180˚ horizontally following to the skew shafts position. The geometric modeling is done by SolidWorks and the simulations by using ANSYS Workbench 15.0. The comparative static structural characteristics at a defined angle of 90° displays improved stability for mechanism employing kinematic chain joint links than through fixed angled links on the basis on total deformation and equivalent stresses. The constructed model run safely at the initial starting speed 840rpm up to 1400rpm for the most efficient power transfer and is capable of transmitting torque at varied angles within 150° to 180° depending on the angular limitation of the kinematic chain joint. Additionally, the practically obtained efficiencies regarding the power transmission of this mechanism are increase with the angle significantly. Furthermore, the expenditure regarding the fabrication of the system is considerably inexpensive in comparison with the arrangement with other available transmission elements. The results of the oriented analyses ensured power transmission capability and the reliability of the system.*

Keywords: Multi-angular power transmission, kinematic chain joint link, fixed angled link, static structural analysis, transmission efficiency.

1. INTRODUCTION

Today's world requires speed on each and every engineering field and are confronted to the challenges of efficient transmission of power. One of the mechanisms transmits motion between the two intersecting shafts is known as elbow link mechanism. Elbow link mechanism works on the principle of Hobson's joint or Hobson's coupling which is a type of right-angle constant velocity joint. It consists of elbow rods, hub and shaft which transmit power at an angle. These rods slide inside symmetrical spaced holes machined on solid cylindrical disc [1][2][3]. However Multi-angular drive is a motion transmitting device used for transmitting motion at any angle to the driven shaft by using the pin bent to conform to the acute, obtuse or right angle between the shafts. Thus the sliding pairs help the shaft to revolve the shaft at desired angle. The development of a more efficient multi-angular drive has been explored relatively unsuccessfully and negligently regardless of its advantages over both gear drives and simple gearless drives [4][5]. Recent advances in technologies, material, analytical modeling and simulation capabilities has opened the possibility of major advances towards the design and development of a reliable, cost effective and ultra-efficient multi-angular gearless drive.

2. THEORETICAL DESCRIPTIONS

The link-based transmission mechanism is a device for transmitting motion at any angle between the driving and driven shaft. The mechanism is made of SRRS pair (sliding revolute revolute sliding) sliding pair between the input hub hole and the link; revolute pair between link and input hub; revolute pair between link and output hub; sliding pair between holes in output hub and the link. The rotational motion of input shaft is converted into sliding motion of links which is then converted to rotational motion of the output shaft. This transmission system can be used for both offset shaft arrangements and skew shaft arrangements [4].

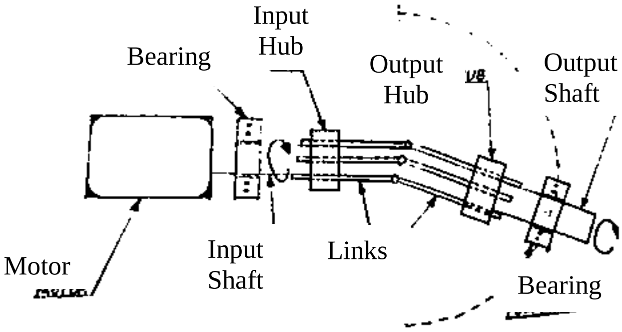


Fig. 1: 2-D views of multi-angular power transmission setup [4]

continuously.	

2.1 Arrangement of Links in the Hub

The angle between all consecutive holes in hub should be equal and it's multiple with any integral must not be equal to 180°. Although any number of links other than odd there must be an integral whose multiplication with angle gives the value 180°. Therefore the only odd number of links are appropriate in the hub which is shown in Table 1. In Fig. 2 for the basic arrangement of links in the hub holes are shown. Let the value of angle = x°, then n*x ≠ 180°. Where n is an integral value [2]

Table 1: Applicable arrangements of links in hub [2]

No. of pins	Angle between consecutive hole	Value of integral	Motion interrupted
2(even)	180°	1	Yes
3(odd)	120°	No integral	No
4(even)	90°	2 (90*2=180)	Yes
5(odd)	72°	No integral	No
6(even)	60°	3 (60*3=180)	Yes
7(odd)	51.43°	No integral	No
8(even)	45°	4 (45*4=180)	Yes
9(odd)	40°	No integral	No

As mentioned, the angle happens to 180° if the centers of any two holes are on that line which represents the diameter of the shaft. Moreover, the links are trying to overlap each other and motion interrupted.

2.2 Analysis for Optimum Number of L-Link

The following analysis shows the minimum number of L-links required are three for smoother and continuous transmission of power between two shafts and that is shown in Table 2. Therefore the more number of links is, the more smooth the operation becomes [6].

Table 2: Analysis for Optimum number of L-link [6]

1-link	2-links
 Unequally distributed and imbalance forces occurs. It is not possible to transmit the power continuously	 Unequally distributed and imbalance forces occurs. It is not possible to transmit the power continuously.
3-links	4-links
 Forces are equally distributed. It starts to transmit the power	 Forces are equally distributed. It transmit the power continuously.

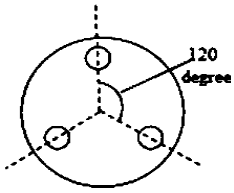


Fig. 2: Arrangement of holes in hub for links [1]

2.3. Kinematic Chain Pairs

A kinematic chain is a combination of kinematic pairs, joined in such a way to transmit the relative motion between the links is completely or successfully constrained. The relation between the number of pairs (p) forming a kinematic chain and the number of links (l) [7]

$$l = 2p - 4 \quad (1)$$

Or,

$$l = (2/3)(j+2) \quad (2)$$

If,
L.H.S. = R.H.S; constraint kinematic chain
L.H.S > R.H.S; locked chain
L.H.S < R.H.S; unconstraint kinematic chain
Where, for kinematic chain links
l = number of links =2
j = number of joints =1
p = number of pairs;
From Equation (2)
l=(2/3)(j+2)
= (2/3)(1+2)
= (2/3)(3)
= 2
L.H.S = R.H.S, Constraint kinematic chain

2.4. Degree of Freedom

The study of motion of multi-angular arrangement can be illustrated by the degree of motion. The motions of kinematic chain link can be broken down and categorized by sliding pair and turning pair. Transitional movement or sliding pair is constituted by two elements so one is constrained to have a sliding motion relative to the other. Turning pair or rotational movement occurs when connections of the two elements are such that only a constrained motion of rotation of one element with respect to the other is possible, the pair constitutes a turning pair [7]

Link has two degree of freedom (DOF = 2).
(both one sliding pair + one turning pair relative to hub)
Chain joint has one degree of freedom (DOF = 1)
(only turning pair as one joint of chain is fixed and other one allows to rotate in the plane)
Total DOF of kinematic chain pair is three(DOF = 3)

2.5. Number of constraints

According to degree of freedom (f), the number of constraints *c* that a chain joint (f=1) imposes [7]

$$c = 6 - f = 6 - 1 = 5 \quad (3)$$

2.6. Mobility

The mobility formula counts the number of parameters that define the configuration of a set of rigid bodies that are constrained by joints connecting these bodies. Joints, that connect links in this system, remove degrees of freedom and reduce mobility. [8]

$$M = \sum_{i=1}^{j} f \quad (3)$$

This formula shows that the linkage must have an even number of links, so we have $l = 2$, $j = 1$

$$M = 3(l-1-j) + j = 3(2-1-1) + 1=1 \quad (4)$$

The mobility of a planar linkage is $M = 1$ and the result is $f_i = 1$

3. DESIGN CONSIDERATIONS

3.1 Design Considerations for Motor

The motor available in the lab is used in this project. The single phase induction motors of 0.25hp works as input source to the driving shaft where the speed of motor (N) is 1400 RPM [9].

The power of motor,

$$P = 0.25hp = 0.25\times746 = 186.5W \quad (5)$$

$$P = 2\pi N T_P /60 \quad (6)$$

$$186.5 = 2\pi\times1400\times(T/60)$$

Torque transmitted T= 1.27 N-m = 1272 N-mm.

Considering 25 % overload,

Maximum Torque transmitted T_{max}

= 1272 x 1.25= 1.590 x 10^3 N-mm

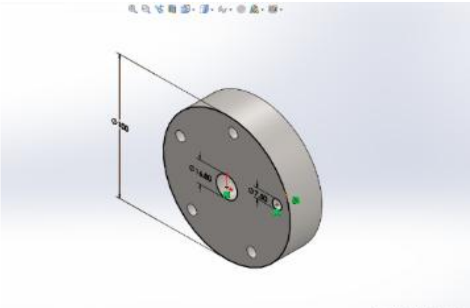


Fig. 3: Designed hub with necessary holes

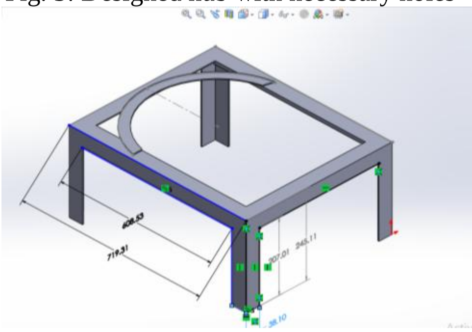


Fig. 5: Designed frame for the hub-link arrangements

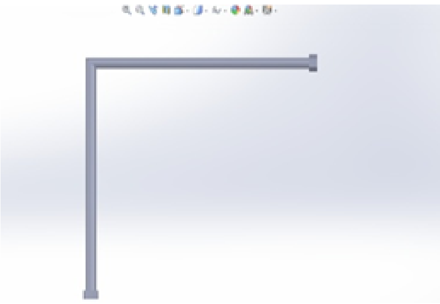


Fig. 7: Designed kinematic chain link

3.2 Design Considerations for Hubs

The tensile ultimate strength of mild steel is 406 N/mm^2. A specific diameter for the hub is taken and it is 100 mm. The hole in the center on the hub is equal to the shafts power which is 16.8mm and defined thickness of hub is 20 mm. Accordance to the equivalent stress and deformation analysis, the possible maximum odd numbers of holes placed equidistantly for moving pins can be 5 and is shown in Fig. 3 [9].

Allowable torsion stress $\tau = 0.22 \text{ X } 460 = 101.2$ N/mm^2

$$\text{Shear stress for hub } \tau = (16 \text{ x } T) / (\pi \text{ x } d^3) \quad (7)$$
$$= (16 \text{ x } 1590)/ (\pi \text{ x } 100^3)$$
$$= 0.008 \text{ N/mm}^2$$

3.3 Design Considerations for Chain Joint

A system designed with roller chains needs to ensure that they can carry intended loads for the life of the chain [8]. Roller chains' bearing contact interfaces between the rollers and pins act as mini shock absorbers, but their load capacity needs to be decreased by a K (service factor) that corresponds to the type of system and load they experience which is shown in Fig. 4. [9].

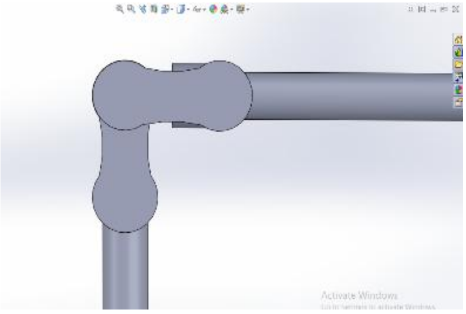


Fig. 4: Designed kinematic chain with link transmitted

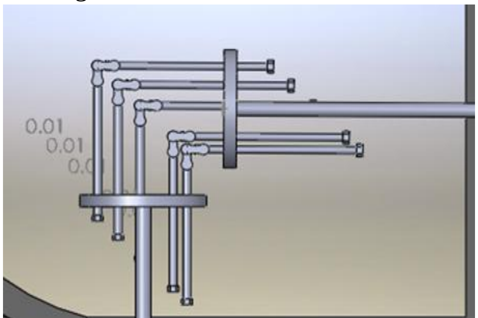


Fig. 6: Assembled designed hub-link arrangements

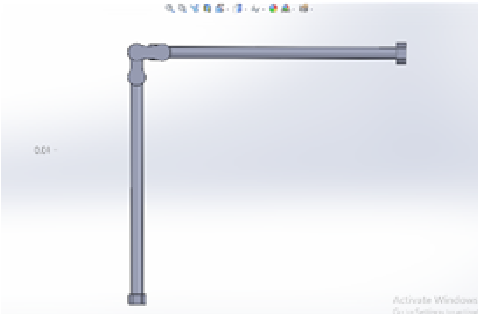


Fig. 8: Designed elbow fixed link

Table 3: Specification of kinematic chain joint

Chain pitch	3/8 in
Roller diameter	0.200in
Roller width	0.188 in
Breaking load	2400 lb
Degree of freedom	1

$$T_{Equivalent} = T_{Applied} \text{ x } K_{Sevice\ factor} \text{ x } K_{Strand\ factor} \quad (8)$$

$$1590/5 = T \text{ x } 1.50 \text{ x } 1$$

$$T = 212 \text{ N-mm}$$

Where, $T_{Applied} = T$
$K_{Sevice\ factor} = 1.50$ (for electric motor)
$K_{Strand\ factor} = 1$ (one row of chain)

3.4 Design Considerations for Links

The optimum length of the each link from the joint must be equal to the largest distance between two link holes or the diameter of the hub which is projected 100mm.Then the optimum length of link from joint is 100mm.

The optimum length of the total link with chain joint = 2×100 = 200 mm.

The designed elbow fixed link, which is shown Fig. 7, would be transmitting power at a fixed angle between two shafts. Whereas in Fig. 6 and Fig. 8 shows the designed kinematic chain joint link which is able to transmit power at any angle between two shafts [9].

Allowable bending stress σ = 0.46 X 460 = 211.6 N/mm^2

Bending stress for bent links:

$$\sigma = PL/4Z \text{ ,where, } Z = 0.78 \text{ x } 8d^3 \quad (9)$$

$$211.6 = 186.5W \text{ x } 200 / 4 \text{ x } 0.78 \text{ x } 8d^3$$

$$d = 6.5 \text{ mm}$$

3.5 Design Considerations for Shafts

Shaft and hub is subjected torsion. Hence it is been design using torsion equation [9].

$$\tau = (16 \text{ x } T) / (\pi \text{ x } d^3) \quad (10)$$

$$101.2 = (16 \text{ x } 1590) / (\pi \text{ x } d3)$$

$$d = 12 \text{ mm} = 0.47\text{in}$$

3.6 Design Considerations for Frame

The structure of the frame uses to construct a circular path for the multi-angular movement of the system and clamp the parts in actual place with the help of the bearings which is shown in Fig. 5. The optimum circular path radius for power transmitting at any angle is the half of the length of the kinematic chain links that is 5 inch. The optimum width of the frame is 10 inch which is equal to the total length of a chain link. The length of the frame is calculated according to the distance between the centers of the shaft. The optimum length of the frame is 20 inch which two times of the length of links.

4. SIMULATIONS OF POWER TRANSMITTING

The maximum number of links of the power transmission arrangement is preferred only odd numbers of links for avoiding the overlap of the links as well as not able to allow more than seven for the projected hub diameter. Specifically the engaged optimum number of links used is five as a result of their performance based on structural and vibrational characteristics on the hub.

4.1 Comparative Static Structural Analysis between Multi-Angular Chain Link System and Fixed Angle Link System

Multi-angular links with a chain joint can be used to transmit power at any angle between skew shafts. Although the links which do not have any joint, they are only bent at an angle permanently so that cannot able to transmit power to any other angle is known as fixed angle link. The mechanical behavior during transmission at any angle, assuming at 90˚, is studied by comparing the static structural analysis of both links using ANSYS software. The analytical results of total deformations in Fig. 9 and equivalent stresses in Fig. 10 applying torque to the input shaft using both links is shown in Table 4. The comparative illustration of multi-angular kinematic chain links and fixed angled links arrangements are shown in Fig. 11 and Fig. 12, respectively.

Table 4: Comparative Illustration of Minimum to Maximum static total deformation

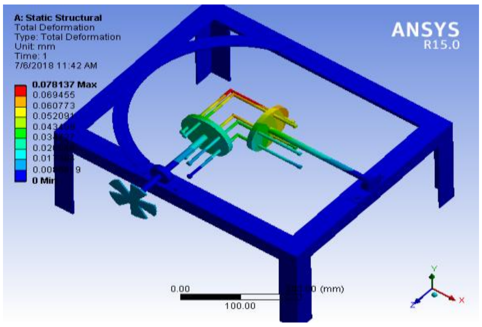
Maximum to Minimum value of static total deformation (mm)		Maximum to Minimum value of static equivalent stress (MPa)	
Fixed link	Multi-angular chain link	Fixed link	Multi-angular chain link
0.078137	0.040473	5.5869	6.6895
0.069455	0.035976	4.9661	5.9462
0.060773	0.031479	4.3454	5.2029
0.052091	0.026982	3.7246	4.4596
0.043409	0.022485	3.1039	3.7164
0.03472	0.017988	2.4824	2.9731
0.02683	0.013491	1.8634	2.2298
0.01784	0.008994	1.2467	1.4865

4.2 Performance Test

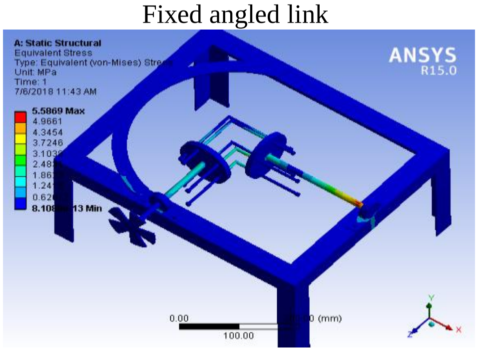
The 0.25hp single phase motor is applied as input power source to driving shaft. The output speed of the driven shaft is measured with the help of tachometer at different angle possible. This transmission system is able to transmit power within 150˚ to 180˚.All the angles were not possible such as not having proper high torque for starting and space availability. Furthermore, permissible speed limit is within 840rpm to 1400rpm which is measured with a capacitor run motor. The output speed is increased simultaneously with angles which is shown in the Table 5. For this reason efficiencies are also varied at the different angle. The speed loss is occurred in the system owing to frictional effect and vibration, it could be reduced by proper manufacturing and using damper. The fabricated multi-angular power transmission system with hub and links are shown in Fig. 13 and Fig. 14 respectiveley.

Table 5: Measurement of transmitting power at different angle for Single phase induction motor

Angles	Single phase induction motor Input (rpm)	Multi-Angular link arrangement Output(rpm)			Average (rpm)	Efficiency %
180°	1400	560	546	558	554	39%
165°	1400	416	428	421	422	31%
150°	1400	319	298	307	308	22%



Fixed angled link



Multi-angular link

Fig. 9: Maximum to Minimum value of static total deformation in mm

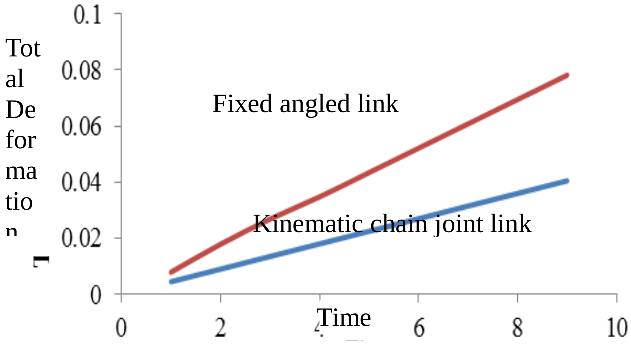


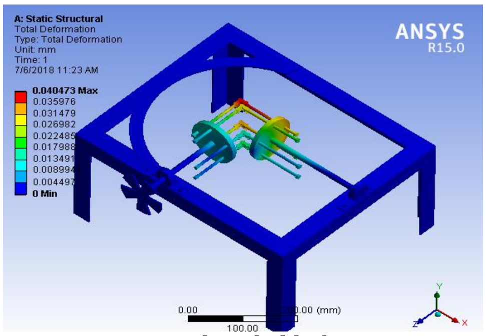
Fig. 12: Comparative illustration of minimum to maximum total deformation of multi-angular kinematic chain links and fixed angled links systems.

4.3 Cost Estimation

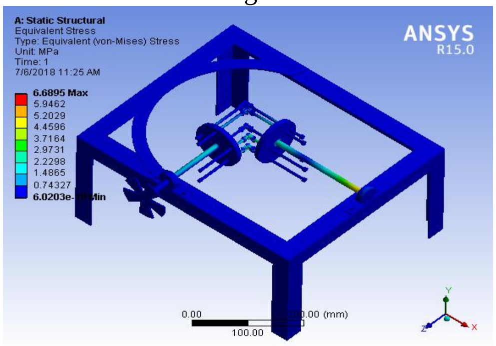
The fabrication of the hubs and links for the project are prepared using locally available materials in the lab and then those are mounted on a frame. The manufacturing cost can be efficiently reduced with this transmission system and is shown in Table 6.

Table 6: Cost estimation of multi-angular kinematic chain link-based power transmission system

Name of Equipment	Amount	Size	Cost (taka)
Bearing	(Two)	A6202	70
Shaft	(One)	20 inch	50
Hub	(Two)	Φ=4 in t=0.5 in	190
Angle Bar	(One)	5.2 kg	330
Link Rod	(One)	0.236 inch	40
Straight Bar	(One)	1 inch	52
Nut & Bolt	(Four)	$^{5}/_{16}$" & $^{3}/_{4}$"	80



Fixed angled link



Multi-angular link

Fig. 10: Maximum to Minimum value of static equivalent stress in MPa.

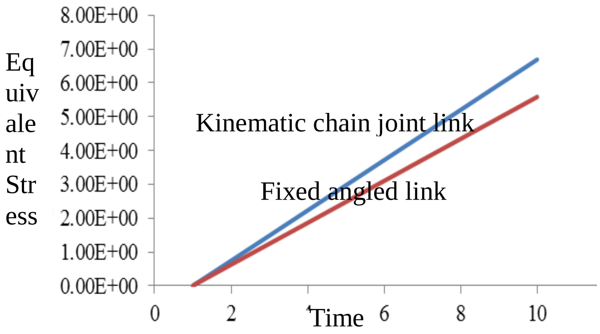


Fig. 11: Comparative illustration of minimum to maximum static equivalent stress of multi-angular kinematic chain links and fixed angled links systems.

Fig. 13: Fabricated hub and links of assembled multi-angular power transmitting arrangement.

5. RESULTS AND DISCUSSION

The comparative structural analysis between multi-angular chain link system and fixed angle link system at 90˚ for skew shaft power transmission are investigated. It is facilitated that multi-angular kinematic chain link displays 38% reduced amount of total deformation and 14% improved equivalent stress than fixed links which interrelated to the better stability of the structure. The system is tested and run safely up to a certain initial torque within 840rpm to 1400rpm to start the input shaft rotation. The constructed model is capable of transmitting torque at varied angles within 150° to 180° depending on the angular limitation of the kinematic chain joint. The considerable efficiencies are observed that the maximum speed occurred at 180° while the efficiency is 39% and the minimum speed at 150° while efficiency is 22%. The speed loss varies with changing of power because of vibration of the system varies with speed. With the assistance of this system, further advancement in this technology can be made. This benefit in commonality allows for additional cost reductions because identical parts are being used in larger quantities across different products.

6. CONCLUSION

Particular techniques and relevant formulas are adopted for the analysis of the efficient multi-angular kinematic chain link-based power transmission system. It can be recommended for its ease of manufacturing, freedom of interchangeability, portability of parts and time-saving installation due to simple and fast shaft securement. The limitations for the suggested system are speed ratio is always constant 1:1 and links are to be replaced after certain cycle time. This system does not work at very low transmitting torque and sudden load may break down the mechanism. If the system was run higher than this permissible limit, the transmission system produces unwanted noise. Furthermore, when the system was run lower than the mentioned rpm, it could not transfer motion from the input shaft to the output. There are certain future scope that the experimental procedures and results can be obtained for more precision structure by analysis of the misalignment and vibrational characteristics using CSI 2140 machinery health analyzer.

Furthermore, it can be assisted to control vibration when

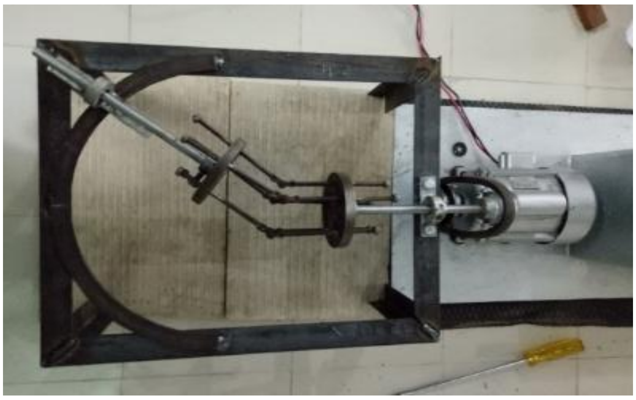


Fig. 14: Fabricated hub, links ,assembled multiangular power transmitting arrangement with 0.25hp motor

the link is rotated at high speed by adaptation of damper in sliding pair joint.

7. REFERENCE

[1] A. Kumar and S. Das, "An Arrangement for Power Transmission between Co-Axial Shafts of Different Diameter", *International journal of engineering research and technology*, vol. 4, Jan 2015.

[2] R. Somraj and B. Sailesh, "Design and Fabrication of Gearless Power Transmission for Skew Shafts", *International Research Journal of Engineering and Technology*, vol. 4, issue 4, Apr 2017.

[3] Madhavan, B. (1996). *Systematic design of gearless differentials and analysis of a potential mechanism* (master's thesis). Harvard University, City, US

[4] A. Kumar, P. Pawar, S. Rana and S. Bist, "Multi-Angular Gearless Drive" *International Journal of Scientific & Engineering Research*, vol. 6, issue 7, Jul 2015.

[5] S. Gupta , S. A. Gul , A. Z. Bhat and P. Angural, "Design and Analysis of Gearless Power Transmission by Rods Using Software Simulation", *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 7, issue 5, May 2018.

[6] S. Yadav, R. Naik, G. C. K. Prakash, H. Kumar, T. G. V. Krishna, "Design, Analysis and Fabrication of Gearless Power Transmission by using Elbow Mechanism" *International Journal of Engineering Research & Technology* ,vol. 6 , issue 4, Apr 2017

[7] H. Ding, W. Yang, P. Huang and A. Kecskeméthy, "Automatic Structural Synthesis of Planar Multiple Joint Kinematic Chains", *J. Mech. Des*, vol. 135 issue 9, Sep 2013.

[8] N. I. Manolescu, "For a United Point of View in the Study of the Structural Analysis of Kinematic Chains and Mechanisms" *J. Mech,* vol. 3, pp.149-169, 1968

[9] V. M. Faires, 1965, *Design of machine elements*, HarperCollins Publishers.