Paper ID: AM-15

Optimization of Link-Based Power Transmission System Designed for an Offset Parallel Shaft Arrangement

Oishwarjya Ferdous[1], Mst Marufa Sultana[2], Md.Emdadul Hoque[3]
[1,2,3] Department of Mechanical Engineering
Rajshahi University of Engineering & Technology, Bangladesh.
Email: [1]oishwarjya132033@gmail.com, [2]marufatrisha83@gmail.com, [3]emdadulhoque@gmail.com

Abstract

This paper demonstrates static structural and vibrational behaviors of the link-based power transmission system designed for an offset parallel shaft arrangement. The proposed transmission mechanism is equipped with links whose form revolute pair with the hubs competent for power transfer and the links can be bent at any angle following to any profile or position of the shafts. The revolving motion of the input shaft is converted into sliding motion of links which is then transformed to rotational motion of the output shaft. The geometric modeling is prepared by SolidWorks and the simulations are done by using ANSYS Workbench 15.0. The equivalent stresses and total deformation employing static structural analysis, natural frequency ranges by modal analysis and resonance peaks by harmonic response are determined to obtain the optimum number of links within the permissible speed of the mechanism. The investigations are carried on 3-links, 5-links and 7-links arrangement according to the specific diameter of the hubs. The 5-links arrangement ensures structural durability with reduced total deformation and equivalent stress compared to 7-links. In contrast, the 7-links arrangement exhibits advanced vibrational capacity through natural and resonant frequencies than 5-links. Additionally, the results of the theoretical considerations corresponding to the design data are included for designing an efficient power transmission of this mechanism.

Keywords: Link-based power transmission, offset parallel shafts arrangement, optimum link number, static structural analysis and vibrational response

1. Introduction

From the sixteenth century through the industrial revolution to the end of the nineteenth-century mechanical power transmission was the norm. Often the term transmission refers simply to the gearbox that uses gears and gear trains to provide speed and torque conversions from a rotating power source to another device. The modern gear drives have been widely applied due to excellent accuracy and reliability [1]. However, the major downside of even the most efficient gear drive is complexity in manufacturing, costly to manufacture, high cost of replacement and low efficiency due to errors like backlash and considerable vibrations. These vibrations engender noisy operation and cause more wear and tear resulting in a low life span [2]. Further motion transmission between shafts of different diameter are also made by some special type of coupling but these are not easily available & although sometimes not suitable for arrangement. To overcome all these difficulties, a link-based mechanism is proposed which can transmit motion between the two non-parallel intersecting and co-planar shafts [3]. It is needed to increase the efficiency of transmission which cannot be done using geared transmission. Motion is transmitted from driving to the driven shaft through the links which are bent to conform to the angles between the shafts. [4] The possibility of major advances towards the design and development through material, analytical modeling and simulation capabilities has permitted to develop reliable and cost-effective link-based drive technology [5].

2. Theoretical Descriptions

The link-based transmission 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 [6]. At the starting instant, the driving shaft starts rotating, links kept in driving hub holes also tends to rotate. But other stationary ends of the links which kept in the drilled holes of the driven hub oppose the motion of links with the driving shaft. As a result, a reaction force developed at the link's surface which is transferred by links and acts on the driven shaft's surface [7]. All the components and parts of the locally available geared power transmission used for offset parallel shaft are shown in Fig. 1 and the schematic arrangement of the proposed model or assembled link-based power transmission is in Fig. 2.

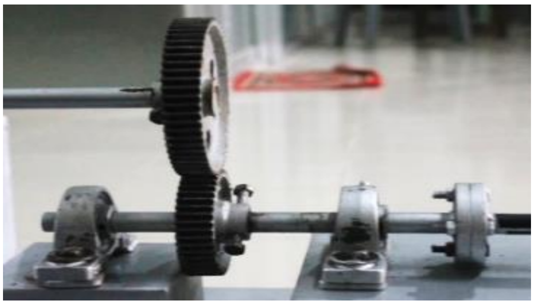


Fig. 1. Geared power transmission for offset shafts [5].

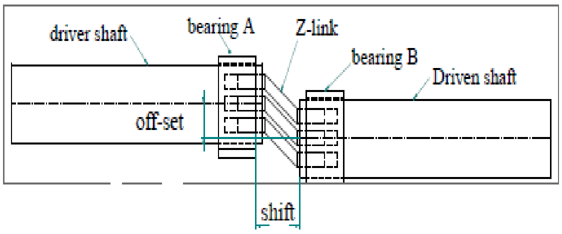


Fig. 2. Possible link-based power transmission [7].

Operational Arrangement of Links in the Hub

The links are held in the drilled holes provided at the driving hub & driven hub. The angle between all consecutive holes in hub should be equal and its multiple with any integral must not be equal to 180°. Although any number of links other than odd whose multiplication with angle gives the value 180°.As mentioned, if the angle happens to 180° consequently 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 [8]. Therefore only odd number of links are appropriate in hub which are shown in Table 1.

Table 1. Applicable arrangements of links in hub [8].

No. of links	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

Conditions for several possible Z-links

Z-link is an intermediate link between the offset driver and driven shafts. In general two types of possible arrangements can be selected of Z-links. The conditions for possible types of Z-links arrangement are shown in both Fig. 3 and Fig. 4. [7]

A. Elbow type Z-link
Shift >Diameter of Z-link ,
Offset < Distance between the innermost points of the opposite holes

Fig. 3. Elbow type Z-link[7]

B. Inclined type Z-link
Conditions: Shift ≥ Offset

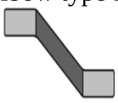
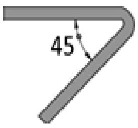
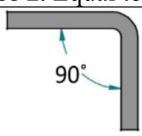
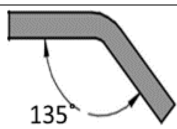


Fig. 4. Inclined Z-link[7]

Consideration for Angular misalignments of Inclined Z-links

The geometric configuration displays the length of the link connector decreases with a decrease in angular misalignment. Nevertheless, the compactness of the coupling increases with the reduction in the angular misalignment [2]. The interpretations of various misalignments between the two shafts of the coupling are shown in Table 2.

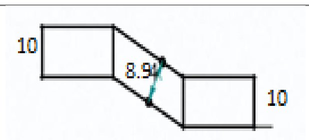
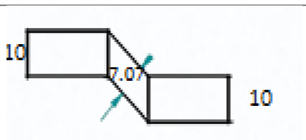
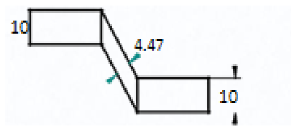
Table 2. Geometric interpretations of various misalignments of Inclined Z-links [2].

Case 1. Less than 90˚	Case 2. Equal to 90˚	Case 3. More than 90˚
		
Length of the link increases. Size of coupling increases.	Length decreases and coupling size decreases as compared to case 1.	Length decreases and the coupling size decreases as compared to case 2.

Standard Offset to Shift Ratio of Inclined Z-Links

The geometric configuration demonstrates various proportions of offset and shift of the coupling. The size of the Z-link connector decreases with gradual increase in off-set to shift ratio. As well, the strength of the connector comes down. It is advisable to maintain smaller offset to shift ratio for the rigid and stronger Z-link connector [7]. The analysis of inclined Z-link is shown in Table 3.

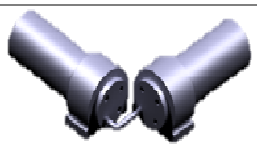
Table 3. Standard Offset to Shift Ratio of Inclined Z-link [7].

Off-set to Shift ratios 1:2	Off-set to Shift ratios 1:1	Off-set to Shift ratios 2:1
		
Reduction in 10.6% size of the connector.	Reduction in 29.3% size of the connector.	Reduction in 55.3% size of the connector.

Optimum Links Compulsory for Initial Transmission

The successive analysis shows the minimum number of links connectors required must be three for smoother and continuous transmission of power between two shafts and that is shown in Table 4. It is observed that the more the links are the more smooth the operation becomes [9].

Table 4. Optimum number of links compulsory for initial transmission [9].

1-link	2-links	3-links	4-links
			
Unequally distributed and imbalance forces occurs. It is impossible to transmit power continuously.	Unequally distributed and imbalance forces occurs. It is difficult to transmit the power continuously.	Forces are equally distributed. It starts to transmit the power continuously.	Forces are equally distributed. It transmit the power continuously.

3. Design Consideration

An existing offset shaft system constructed with gear is considered for transmitting power [5]. The link-based power transmission system is designed for this setup which includes hubs and links as power transmitting elements. Necessary dimensions are taken for further designing of hubs and links. The available offset shaft arrangement for power transmission with gears is shown in Fig. 5, and the final design of the hubs and Z-links are presented in Fig. 6 and Fig. 7, respectively.

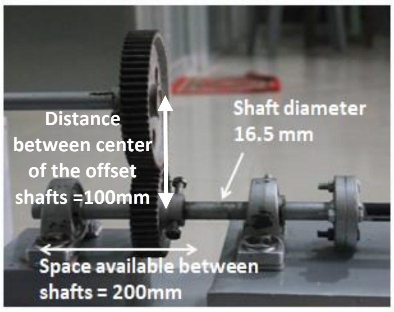


Fig. 5. Available offset shafts setup with gear arrangements [5].

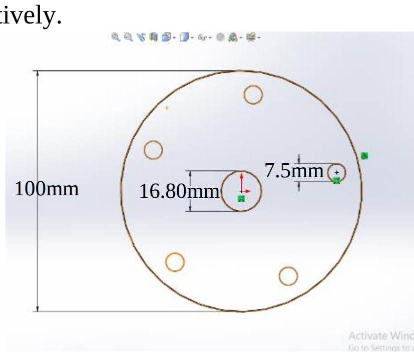


Fig. 6. Designed hub according to calculations.

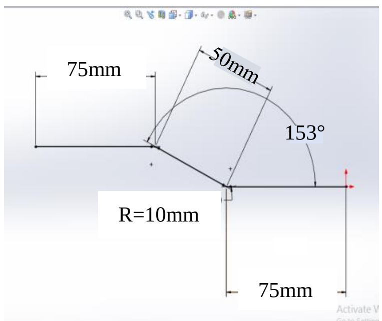


Fig. 7. Designed Z-links according to calculations.

A 0.25 HP single phase induction motor is used as input power source .The speed of motor is 1400 rpm [5] .

$$\text{The power of the motor, } P = 0.25\text{hp} = 0.25\times746 = 186.5\text{W} \quad (1)$$

$$P = 2\pi N\, T_P /60 \text{ [10]} \quad (2)$$

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

$$\text{Torque transmitted } T = 1.27 \text{ N-m} = 1272 \text{ N-mm.}$$

Considering 25 % overload, Maximum Torque transmitted T_{max}= 1272 x 1.25= 1.590 x 10^3 N-mm

Design Considerations for Hub

The diameter of the hub in use is resembling the diameter of the gears used in the arrangement. Hence the diameter of the hub is 100 mm and the possible maximum odd numbers of holes placed equidistantly for moving links can be seven. The hole in the center on the hub is equal to the shafts transmitted power which is 16.8mm and the thickness of the hub is 20 mm shown in Fig. 6. Tensile Ultimate Strength for mild steel = 406 N/mm^2 [10].

$$\text{Allowable torsion stress } \tau = 0.22 \times 460 = 101.2 \text{ N/mm}^2 \quad (3)$$

$$\text{Shear stress for hub } \tau = (16 \text{ x T}) / (\pi \text{ x } d^3) \quad (4)$$

$$= (16 \text{ x } 1590) / (\pi \text{ x } 100^3)$$

$$= 0.008 \text{ N/mm}^2$$

Design Considerations for Links

The same number of Z-link is made to insert in the holes in the hub such that if the shaft rotates through one revolution, Z-link also rotate through one complete rotation. Since the inclined Z-links is selected which have a lesser amount of the angular misalignment and upgraded the compactness of the coupling. From the existing offset shafts setup with gear showed in Fig. 5, the distance between the centers of the shaft is 100 mm and the space available horizontally between the shafts is 200 mm [10].

$$\text{The maximum angle between the Z-links } (180-\theta) = \tan^{-1}(100/200) = 153.43^{\circ} \quad (5)$$

$$\text{The allowable bending stress for links } \sigma = 0.46 \text{ X } 460 = 211.6 \text{ N/mm}^2. \quad (6)$$

$$\text{Bending stress for bent links } \sigma = PL/4Z \text{ ,where, } Z = 0.78 \text{ x } 8d^3 \quad (7)$$

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

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

4. Simulations of Power Transmitting Arrangement

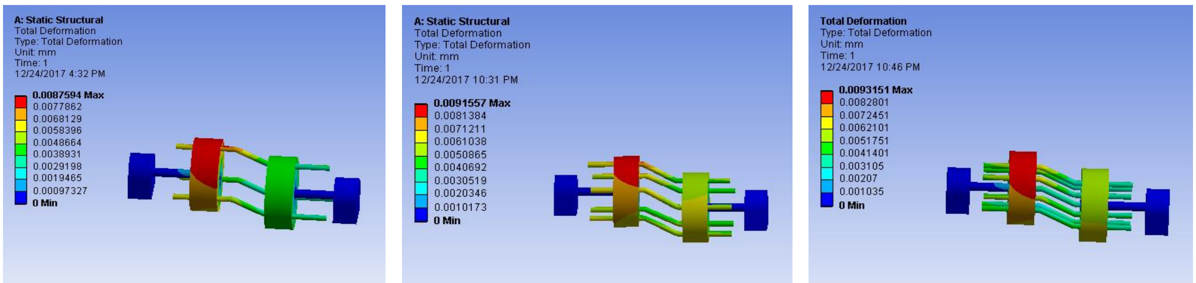
As mentioned, the selection of the optimum number of links is based on the improved static and vibrational characteristics during power transmission from the input shaft of 1400 rpm to the output shaft by link-based system. The simulation 3-links, 5-links, and 7-links arrangements have been frequently studied by implementing static structural analysis, modal analysis, and harmonic analysis

Static Structural Analysis for Optimum Number of Links in Hub

The amount of maximum deformation and equivalent stress on links in static behavior analysis are investigated for different numbers of link in the hub. The total deformations where displacements is obtained from stresses and the equivalent stresses under the load which is equal or greater than the yield limit of the same material under simple tension with increasing link numbers are demonstrated in Table 5 and also both in Fig. 8 and Fig. 9, respectively. The comparative illustration of 3-links, 5-links and 7-links arrangements for total deformation and equivalent stresses are showed in Fig. 10 and Fig. 11.

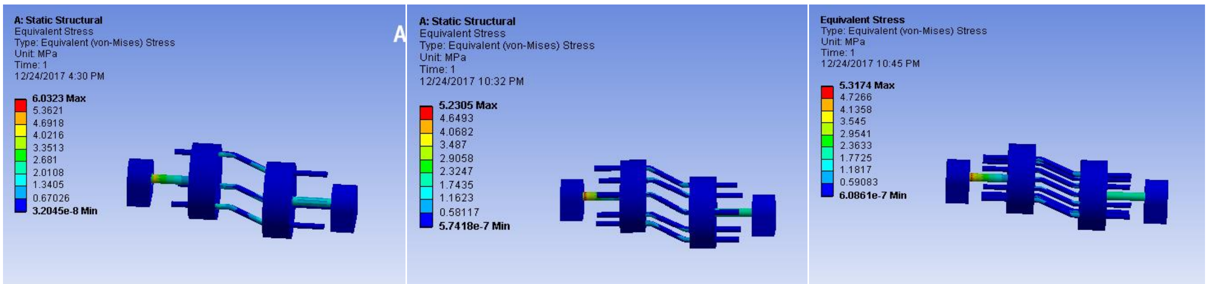
Table 5. Static structural analysis of total deformation for the selection of optimum number of links

Number of Z-links	Maximum Total Deformation (mm)	Maximum Equivalent stress (MPa)
3-links	0.0087594	6.0323
5-links	0.0091557	5.3174
7-links	0.0093151	5.2305



3-links 5-links 7-links

Fig. 8. Investigation on maximum to minimum deformation on links for different number of links in the hub.



3-links 5-links 7-links

Fig. 9. Investigation on maximum to minimum equivalent stress on links for different number of links in the hub.

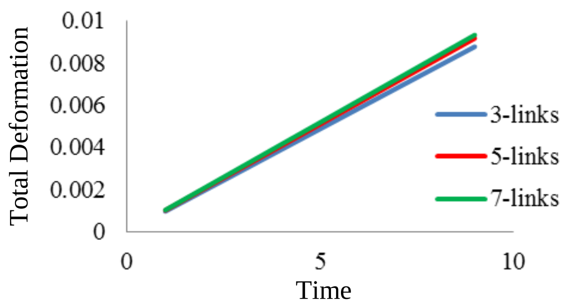


Fig. 10. Comparative Illustration of 3-links, 5-links and 7-links arrangements for total deformation.

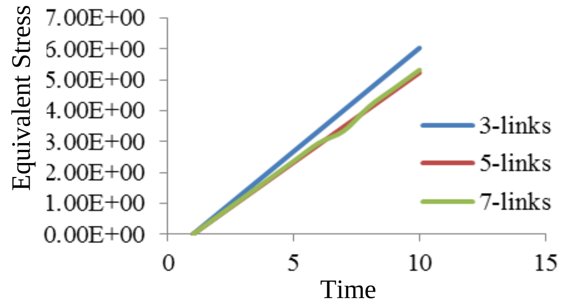


Fig. 11. Comparative Illustration of 3-links, 5-links and 7-links arrangements for equivalent stress.

Modal Analysis for Optimum Number of Links in Hub

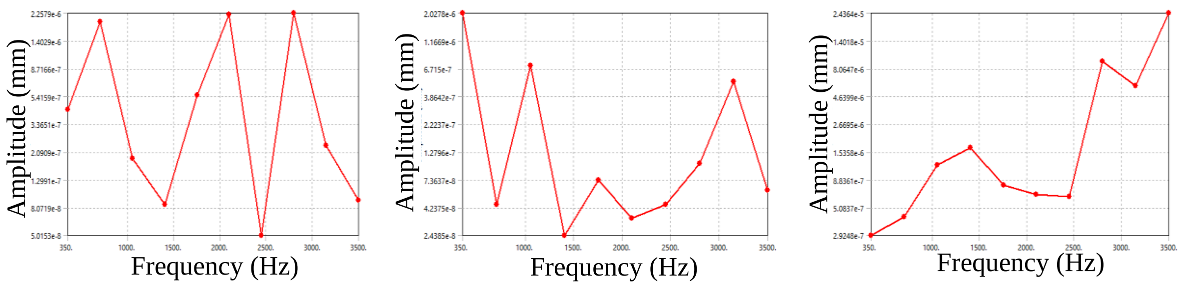
Modal analysis is used to determine a structure's vibration characteristics which are natural frequencies and mode shapes. The natural frequencies of different numbers of links are shown in Table 7. The following table illustrates that natural frequency of links is increased with increasing numbers of link.

Table 7. Mode corresponding frequencies for Z-links

Mode	1	2	3	4	5	6	7	8	9	10
3-link	177.97	300.92	360.5	446.53	470.18	660.08	799.34	867.94	1797.9	1973.7
5-link	159.26	323.64	366.07	523.26	535.75	683.63	870.91	1094.4	1779.9	2987
7-link	580.51	640.22	661.1	1126.6	1356.9	1519.2	2517.2	2870.6	3194.7	3375.6

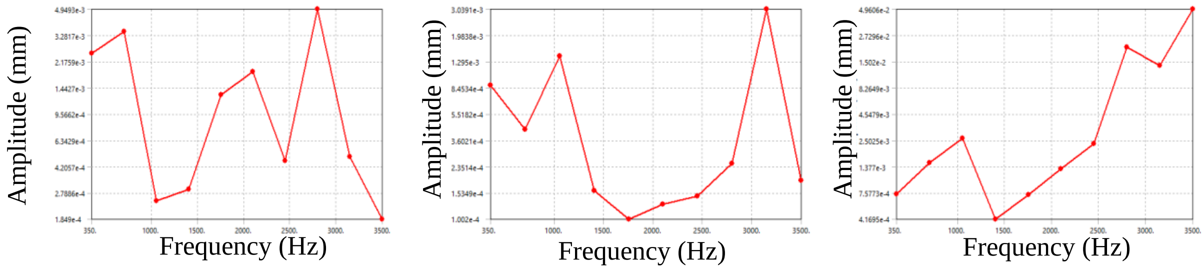
Harmonic Response Analysis for Optimum Number of Links in Hub

The mode superposition method adopted in the harmonic analysis automatically executed a modal analysis and which showed frequent resonance peaks for both cases according to natural frequency range of three different numbers of links. With increasing number of link it is shown that peak points are decreasing that means improved vibrational characteristics. The graphical representation of the amplitude versus frequency curve for total deformation and equivalent stress of different link numbers in gearless mechanism are demonstrated on Fig. 13 and Fig. 14, respectively.



(a) 3-links (b) 5-links (c) 7-links

Fig. 13. Amplitude versus frequency curve for total deformation for different numbers of link.



(a) 3-links (b) 5-links (c) 7-links

Fig. 14. Amplitude versus frequency curve equivalent stress for different numbers of link.

5. Results and Discussion

It is investigated that the number of links for the projected dimension of the hub is obtained seven at most and made a selection of only odd numbers to avoid the overlap of the links and shaft. The 3-links arrangement displays moderate structural and vibrational features and hardly enough uninterrupted operation. The structural performances of 5-links and 7-links are nearly indistinguishable. Despite the fact, structural stability and serviceability of 5-links arrangement illustrate subtle variations of 1.71% reduced total deformation and 1.63% decreased equivalent stress compared to 7-links which can be detected by precise observation. The vibrational characteristics of the 7-links arrangement are signifying 11.5% enhanced dynamic properties of structures under vibrational excitation and mitigated resonant peak response level than 5-links. So that 5-links have balanced and continual operation than 3-links and 7-links. Therefore 5-links are permitted as the optimum number of links in the hub.

6. Conclusions

The simulations on different numbers of link are carried out and found the optimum numbers of links is five for the estimated diameter of hub based on static structural and vibrational analysis. With the increase in the number of link, the static structural characteristics mitigated but vibrational characteristics amplified. So those two analyses showed opposite features. Consequently the susceptibility of arrangement is increased with increasing number of link. Adaptation of damper in sliding pair joint can be assisted to control vibration when the link is rotated at high speed and will improve power transmission more efficiently. The system has the freedom of interchangeability and most important thing is its low manufacturing cost.

11. References

[1] M. Barath (1996). *Systematic design of gearless differentials and analysis of a potential mechanism* (master's thesis). Harvard University, US.

[2] 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.

[3] M. Tanodi, S. B. Yapalaparvi, A. C. Mattikalli, D. N. Inamdar, “Gearless Power Transmission- L Pin Coupling” *International Journal of Ethics in Engineering & Management Education*, vol. 1, issue 5, May 2014.

[4] M. J. Rana and A. N. M. Rahman, “Development and Performance Test of Gearless Power Transmission System ”, *International Conference on Mechanical, Industrial and Energy Engineering*, vol.1, issue 253, 23-24 December, 2018.

[5] S. S. Noor, S. Adnan (2017). *Vibration-based Condition Monitoring of Mechanical Components of a Vibratory System*, Rajshahi University of Engineering & Technology, Bangladesh.

[6] G. S. Jagushte, K. Hrishikesh, P. Vikas, V. Vishal, “Design, Analysis and Fabrication of Gearless Transmission by Elbow Mechanism" *International Journal for Scientific Research & Development*, vol. 4, issue 02, June 2016 .

[7] S. B. Yapalaparvi, A. C. Mattikalli, D. N. Inamdar, G. V. Chiniwalar, M. Tanodi, “Gearless Power Transmission-Offset Parallel Shaft Coupling", *International Journal of engineering Research and Technology*, vol. 3, issue 3, pp no.129-132, Mar 2014.

[8] R. Somraj, B. Sailesh, “Design and Fabrication of Gearless Power Transmission for Skew Shafts”, *International Research Journal of Engineering and Technology*, vol. 04 issue 04, Apr 2017.

[9] 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 04, Apr 2017.

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