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Analysis and Simulation of Gearless Transmission Mechanism

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***Abstract*—this paper presents the real time study of mechanism. The system is to be analysed in SolidWorks package software to watch the response of the elbow rods and the also the hub (coupled with shaft). The real time study is carried out by applying a motor to one of the shafts supported on bearings. Motion analysis is performed by running the mechanism at 15 revolutions per minute, reaction forces and reaction moment are plotted against clock run of 5 seconds by using post processor. Similar motion analysis is carried out at different higher revolutions per minute and peak values of forces and moments are taken from the plot and compared with allowable stress. Theoretical calculations are made to obtain allowable stress by making use of design data values. As a result, response of elbow rod and hub is investigated to find the permissible speed of mechanism. Further simulation is performed to verify the motion analysis results.**

Keywords—SolidWorks; hub; elbow rods; motion; workbench; gearless transmission mechanism

I. INTRODUCTION

An essential requirement of the present world is to achieve the objectives with maximum efficiency at minimum cost. This requires least manufacturing cost of replacement when any instrument fails. And also that it performs the intended function at a higher efficiency.

For transmitting motion and power from one shaft to another which are non-parallel or intersecting and coplanar, bevel gearing are generally employed. But there are some inherent disadvantages associated with bevel and worm gearing stated as complexity in manufacturing, High cost of replacement.

To overcome all these difficulties we have a mechanism which transmits motion between the two non – parallel (intersecting) and coplanar shafts. As it replaces gears and transmits motion without the

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aid of gears it is also called as "Gearless Power Transmission Mechanism". As a reference we have designed the mechanism for transmitting motion at right angle. However it can also be employed for transmitting motion at any angle to the driven shaft by using the pin bent to conform to the angle between the shaft (acute, obtuse or right angle).

The motion study and simulation of various mechanisms has been frequently studied for several years. Elaheh Hassanzadeh Toreh, Mehdi Shahmohammadi and Nasim Khamseh performed Kinematic and Kinetic Study of Rescue Robot [1]. Gadhia Utsav D. given the Quarter model of Wagon-R car's rear suspension by making analysis on ADAMS software [3]. Assad Anis carried out analysis of Slider Crank Mechanism on ADAMS Software package [4]. A. A. Yazdani performed Multibody Dynamics Simulation of an Integrated Landing Gear System using MSC.ADAMS [6]. Mohammad Ranjbarkohan made use of ADAMS software package and Newton's laws for analyzing the behavior of slider crank mechanism and investigated the effect of engine rpm on connecting rod and crankshaft [7]. However, there hasn't been performed any study to sort out problems on gearless transmission mechanism. Hence, this analysis is performed.

II. SYSTEM UNDER STUDY

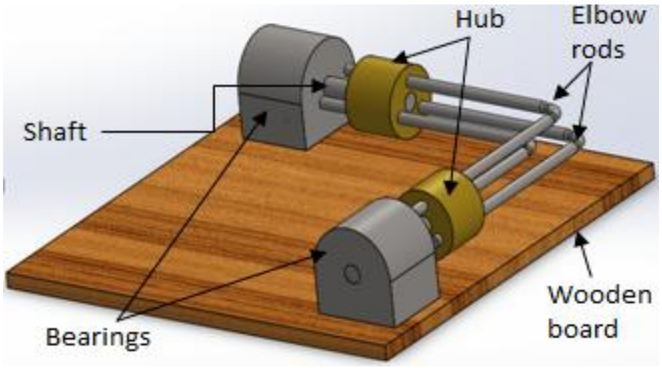
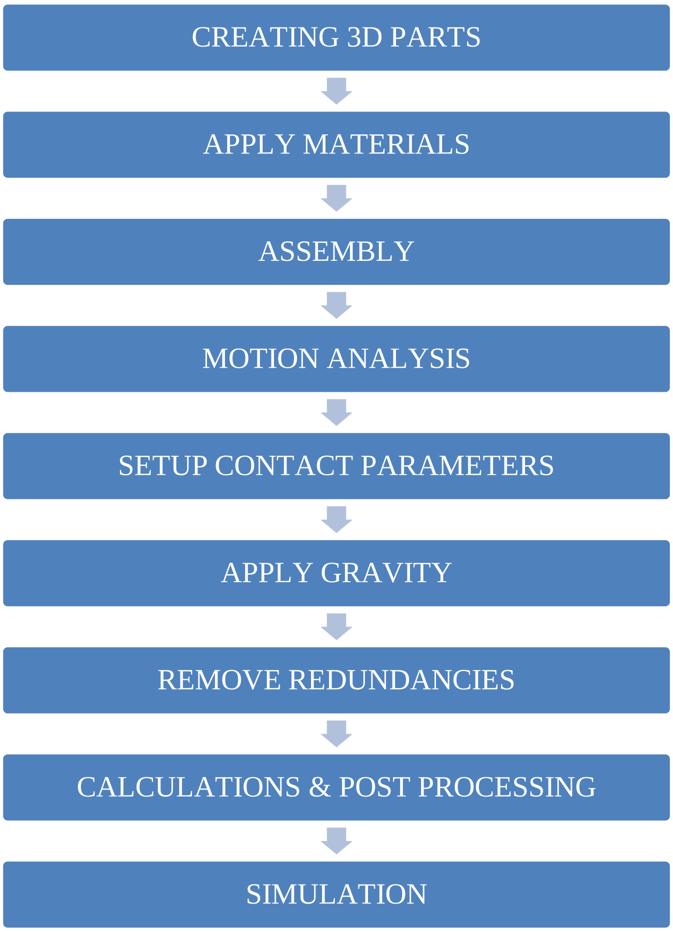


Fig.1: Trimetric view of gearless transmission mechanism

Figure 1 shows the trimetric view of system under study. As the figure suggest that this mechanism is formed with 9 links and one board by assembling them together.

Contact friction between bearings and shaft as well as between elbow rods and hubs are considered. Whole mechanism is developed for analysis with taking gravity into account. System is designed with factor of safety taken as 2.

III. METHODOLOGY



IV. SETTING UP MODEL

A. *CREATING 3D PARTS*

All the components are modeled on SolidWorks software under 3D part workbench. It is assumed that every single component is a rigid body.

Table I: The descriptions of component constituting mechanism

Body	Diameter(mm)	Length (mm)
Elbow rods	7.5	340
Hub	46	35
Shaft	12	115

B. *APPLY MATERIAL*

Mechanism has following rigid bodies:

Table II: The description of material of each component

PART	CATEGORY	NAME
Elbow rods	Stainless Steel	1.4016 (X6Cr17)
Hub	Copper alloy	Brass
Shaft	Mild steel	45C8
Bearings	Mild steel	45C8
Wooden board	Woods	Teak

By applying material it becomes possible to establish mass of each component in the mechanism.

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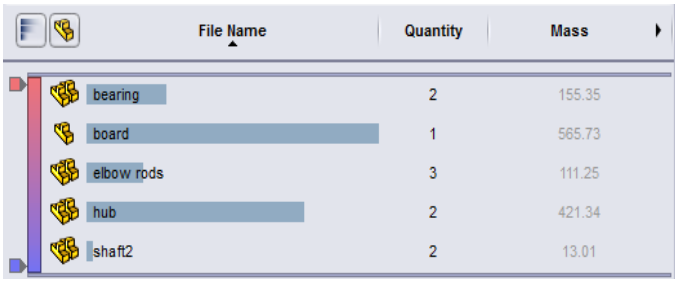

Fig.2: Mass of each component

C. *ASSEMBLY*

Parts already modeled are assembled together in sequence to achieve a constraint mechanism. Concentric mate is used between parts having relative motion forming a turning pair. Lock mate is also used between hub and shaft.

D. *MOTION ANALYSIS*

The basic requirement of motion analysis is to setup a motor(driving element).

Fig.3: Selection of motion analysis

Motor is placed over shaft 1, initially set to 15 rpm value which is varied further to higher values for making analysis.

E. *SETUP CONTACT PARAMETERS*

Attempt has been made to achieve values close to real mechanism and so contact between bearing and shaft as well as between hub and elbow rods are taken into account. Friction and elastic properties are automatically chosen by solidworks based upon material of contact (here steel dry contact).

Table III: Friction and Material properties.

Friction		Static friction	
v_k (mm/s)	μ_k	v_s (mm/s)	μ_s
10.16	0.25	0.10	0.3
Elastic properties			
Stiffness (N/mm)	Exponent	Max. Damping N/(mm/s)	Penetration (mm)
100000	1.5	49.91	0.10

F. *APPLY GRAVITY*

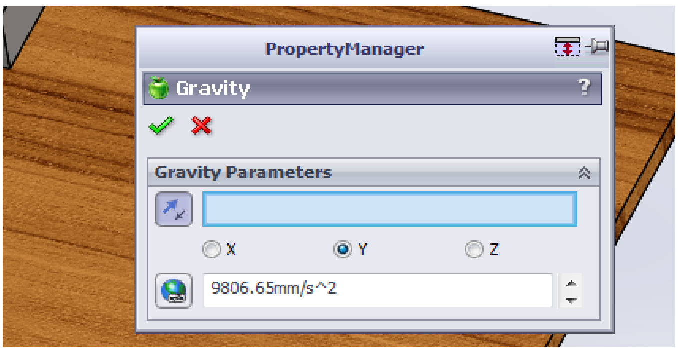

Fig.4: Apply gravity to the mechanism

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G. *DOF & REMOVE REDUNDANCIES*

Mechanism is constraint in such a way that it gives only one degree of freedom i.e. rotation in a plane perpendicular to the plane of motor.

Redundancies are checked for every joint. Any unnecessary joint if present is removed.

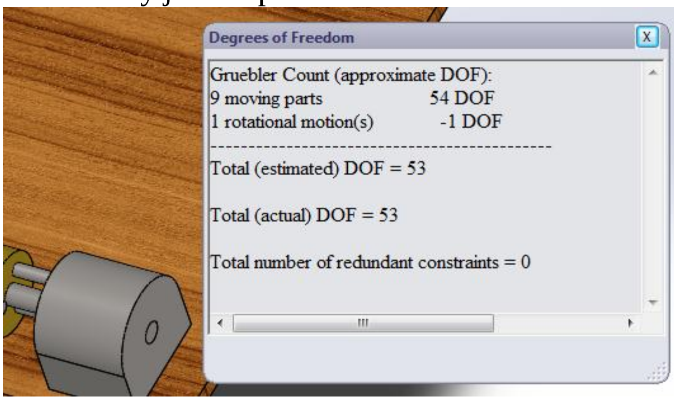

Fig.5: workbench snapshot of DOF & redundancies

H. *CALCULATIONS & POST PROCESSING*

a. *Equations*

Elbow rods are subjected to bending stress, so by using flexural formula for solid circular beams bending stress equation is obtained.

$$\sigma_b = (32 * M)/(\pi * d^3)$$

Direct stress is assumed to act along with bending stress in care of elbow rod. Therefore, it becomes important to evaluate direct stress at every speed.

$$\sigma_d = \text{(reaction force)}/(\text{ area of cross section})$$

For the calculation of torque flexural equation for torsion is used. Assuming this torque is acting on hub cross section.

$$\tau = (16 * T) / (\pi * d^3)$$

$$T = \text{(reaction force)} * \text{(radius of pitch circle)}$$

b. *Design stresses*

Allowable bending stress (σ_b) = 0.46 * Ultimate Tensile Strength
Allowable torsion stress τ = 0.22 * Ultimate Tensile Strength
So,

$$\sigma_b = 0.46 * 670$$
$$= 308.2 \text{ N/mm}^2$$

$$\tau = 0.22 * 670$$
$$= 147.4 \text{ N/mm}^2$$

Taking **Factor of safety** for design of the system as **2**

c. *Evaluating design moment and force*

By closely observing the system, it is concluded that elbow rods are subjected to bending stress. And total Bending stress is the sum of normal bending stress and the direct stress. In this state of loading, direct stress changes with rpm. Hence for each rpm value we obtain one of bending moment.

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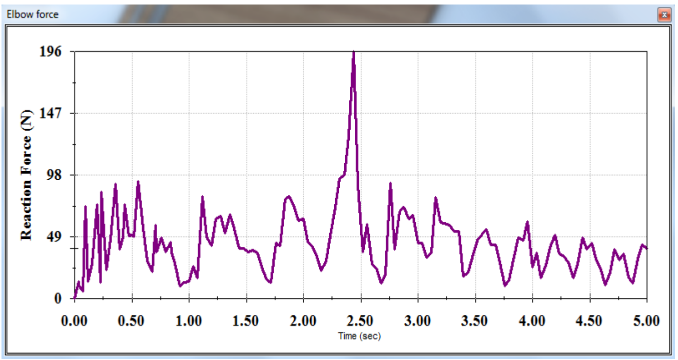

Fig.6: Reaction force on elbow rod Vs time at 120 rpm

Table IV: Allowable Bending moment and Allowable direct stress of elbow rods at different rpm.

RPM	15	70	100	120	140
Direct stress(N/mm^2)	2.85	4.43	2.58	4.43	4.64
Moment(N)	12.87	12.93	12.85	12.93	12.94

Secondly we will evaluate torsional shear stress for hub as it is under the action of torsion. By using torsion equation we found T = 52.19 N-m, from this we get torsion force as:

$$F = 4014.6 \text{ N}$$

d. *Motion study*

Motion study is performed by running mechanism at incrementally varying rpm at constant speed motor for 5 seconds. Plot is obtained by using SolidWorks post processor showing reaction force and moment for both elbow rod and hub against time.

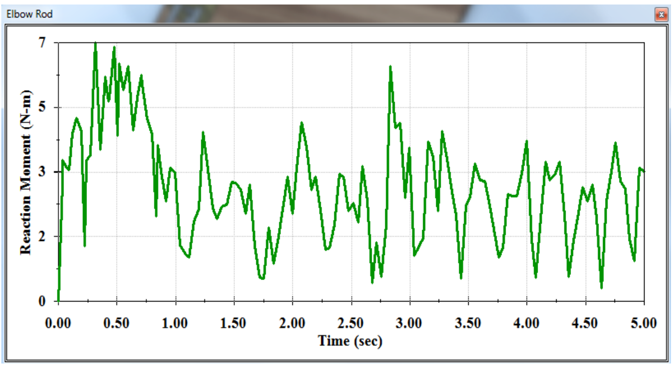

Fig.7: Reaction moment on elbow rod Vs time at 120 rpm

Now we have bending moment for elbow rods at all defined rpm values and also evaluated reaction force on hub. So we compare this value with our motion study plots.

Table V: Bending moment and reaction force on elbow rod.

RPM	15	70	100	120	140
Moment(Nm)	7	11	7	7	18
Force(N)	41	47	38	46	37

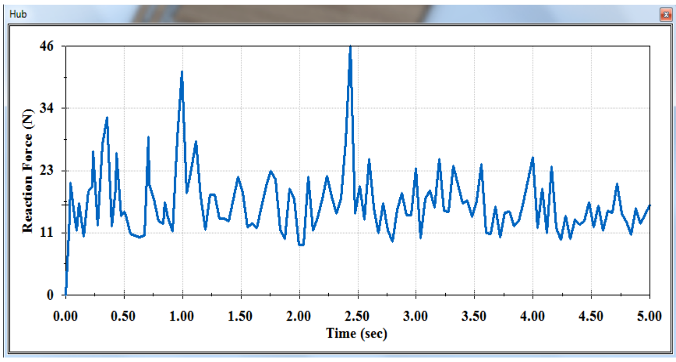

Fig.8: Reaction force on Hub Vs time at 120 rpm

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Table VI: Reaction force on hub at defined rpm.

RPM	15	70	100	120	140
Force(N)	41	47	38	46	37

V. SIMULATION

A SolidWorks simulation feature is used to find out Von Mises stress distribution over the elbow rod.

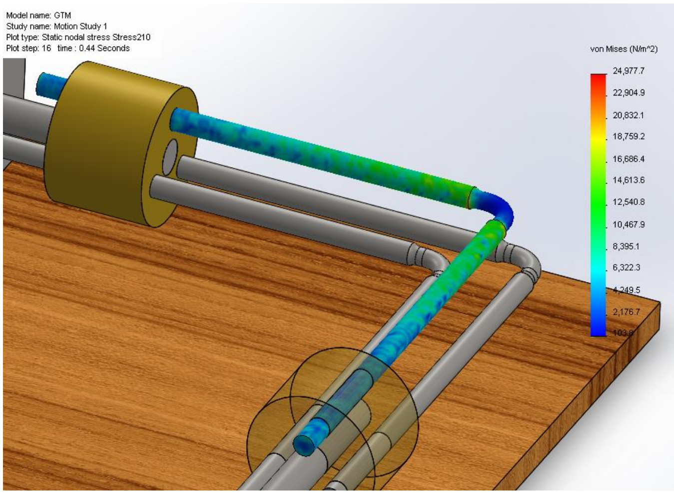

Fig.9: Distribution of Von Mises stress at 120 rpm

Simulation is performed by importing motion loads to the component. Motion loads acts on component as dynamic loads. Hence simulation performs dynamic analysis of mechanism. Post processing generates results as shown in the snapshots. Fig. 10 shows stress value very high in comparison to that shown in fig. 9.

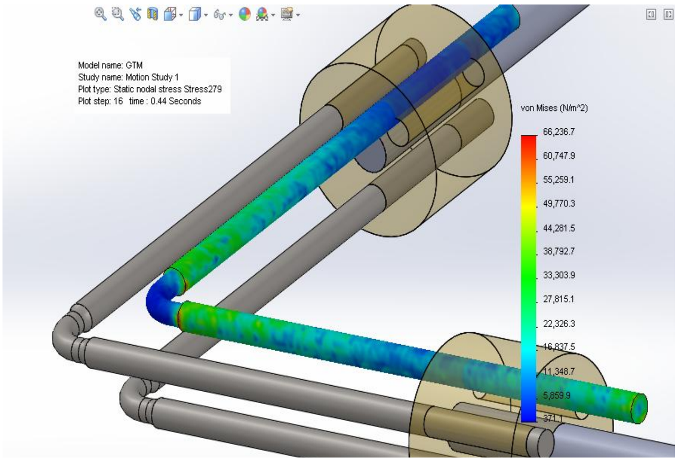

Fig.10: Distribution of Von Mises stress at 140 rpm

VI. RESULT & DISCUSSION

It becomes quite clear from the analysis that hub always remain safe at all defined values of rpm. But this is not the case with elbow rod, as shown in motion study section at 140 rpm speed moment value(red) surpass the allowable moment value. Thus we found that elbow rods are safe below 140 rpm i.e. ranges between 15 to 120 rpm.

SolidWorks simulation helps in getting a clear picture of dynamic analysis of elbow rod, stresses value in case of 140 rpm are fairly high as compared with same at 120 rpm. Thus simulation results satisfy motion analysis results.

VII. CONCLUSION

Gearless transmission mechanism has been analysed on SolidWorks software. The response of elbow rod and hub is been plotted with time by using SolidWorks post processor with the application of motor torque with defined varied rpm. The elbow rod a simulated for 5 second and von mises stress distribution is obtained. It is observed that hub remains safe at all values of rpm where as elbow rods reaches its allowable stress value at 140 rpm. It means that for smooth and safe running of mechanism it should be kept below 140 rpm. With this study it is concluded that gearless transmission mechanism is capable of running upto 120 rpm under normal conditions. Further fatigue analysis are recommended for gearless transmission mechanism.

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