ISSN No.: 2455-6130
Special Issue: I, 2022, pp. 29-38

website: www.ijoetr.com

International Journal of Emerging Trends in Research

Analysis of a Double UV Joint in Steering system of vehicle

Vinayak H Khatawate[1], Manav Bhavesh Nagda[2], Ishaan Samir Parikh[3], Krishiv Sunil Agarwal[4]

[1, 2,3,4]Deptt. of Mech. Engg.,Dwarkadas J. Sanghvi College of Engineering, Mumbai

Abstract

Whenever torque is to be transferred between two planes or shafts with two different axes, then Universal (UV) joints are used. One of the major applications of UV joint is in the steering system where the steering torque applied by the driver is to be transferred to the rack and pinion assembly to steer the vehicle which are in two different planes. In this paper, an ergonomic setup was designed to test different comfort levels for the driver, and preferences for different drivers were taken into consideration. The setup was designed by referring Formula student rulebook and important chassis cockpit components. Various setups were taken from different drivers and the observations were noted. From the analysis of single and double UV joint, it was concluded that when the double universal joints are at 33^0 degree each, they are 13.16% more efficient than the single universal joint at 33^0 degree, thus improving the ergonomics and torque transmission of the steering column.

Keywords: UV joint; Steering system; Torque transmission; ergonomics.; selection;

1. Introduction

Whenever torque is to be transferred between two planes or two different axes, then Universal joints are used to change the axis and plane of rotation of shafts. The UV joint is not a constant velocity joint, the angular velocity varies because the plane and axis of rotation are different. The shaft connected to the universal joint has a constantly varying angular velocity and hence the torque transmitted also varies continuously.
One of the major applications of UV joints is in the steering system where the steering torque applied by the driver is to be transferred to the rack and pinion assembly to steer the vehicle which are in two different planes.[1]

In this paper, an ergonomic setup [2-3] was designed to test different comfort settings for various setups, and preferences for different drivers were taken into consideration, the setup was designed taking in mind the Formula student rulebook [4] and important chassis cockpit components. Various setups were taken from different drivers and the observations were noted. The setup chosen was the setup for the endurance driver [4] and a side view sketch was designed on Solidworks [5],

the angles for the two universal joints were taken based on the side view sketch. With the Side view sketch finalized, a setup for steering column was designed on Adams [3] and variation was found out for double universal joints and single universal joint at the same angle.
For physical validation of the steering column variation due to two universal joints, two methods were proposed. In the first method, the angular displacement was to be measured at the steering wheel and pinion to find angular displacement at upper and lower column respectively[1,6], in the second method, load cells were to be used at tie rods and the differences in forces was to be taken to give a net steering torque at pinion, this variation in torque, compared with static steering moment was able to give the variation in torque transmitted via two universal joints. [7-8].
A CAD model of the double universal joint was prepared using solid modelling software Solidworks as shown in Fig.1.

FIGURE 1 Solidworks image of universal joints

2. Merits of Double UV joint

As a single UV Joint is not 100% efficient for transmitting torque between two shafts in different planes. Some of the advantages of a double UV over a single are:

● Double universal joints allow more variations in angles for the upper column which makes it possible for a near perpendicular steering wheel which in turn improves the overall ergonomics of the vehicle.

● The double universal joint reduces the angular velocity variation which reduces the variation of torque transmitted and thereby improves the overall torque transmission.

Helps reduce losses between Steering Columns and provides better ergonomics

.

3. Ergonomic Consideration

While designing a particular system that require continuous attention of operator such as driver for driving the vehicle, the consideration of ergonomics with respect to driver is important [9].

ISSN No.: 2455-6130
Special Issue: I, 2022, pp. 29-38

An ergonomic setup was designed:

The setup was designed to determine inclination angles and distances of the steering wheel for different drivers. The parameters taken into considerations were:

1. The inclination of the steering upper column with the vertical.

2. Distance between the steering wheel and the ground.

3. Perpendicular distance between the UV joint and the FRH (Front Roll Hoop).

4. Perpendicular distance between the steering wheel and the FRH.

The setup was designed within the chassis ergonomic structure with different parts for the steering wheel, upper column, and UV joints.

Upon testing the different ergonomics setup the following observations were taken as shown in Table 1.

TABLE 1: Ergonomic design consideration

	Driver K	Driver B	Driver A	Driver M
The inclination of the upper column with vertical (single universal joint)	20	26	20	23
Length of the column from FRH to the Steering wheel	245	260	200	235
Distance between Centre of steering wheel and ground	380	450	400	410
Perpendicular Distance between FRH & Steering wheel	230	210	155	200
Distance between the topmost position of FRH and pivot point	230	220	215	220
The inclination of the upper column with vertical (double universal joint)	0	0	0	0

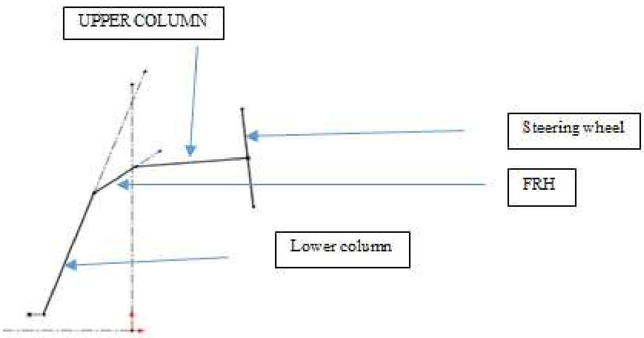

FIGURE 2 Line diagram of steering system (Side view)

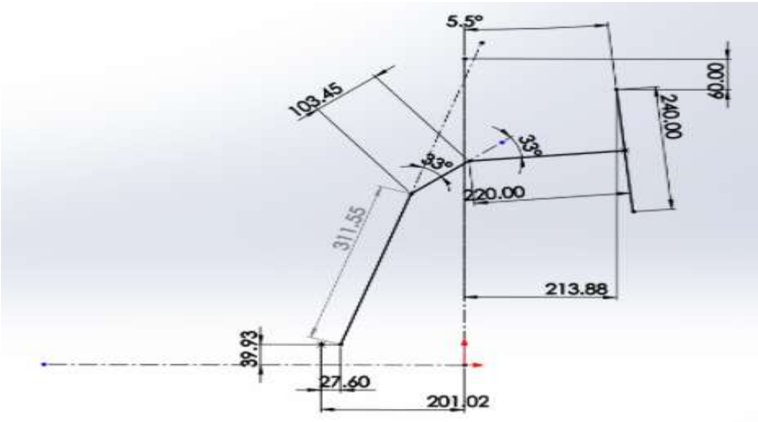

FIGURE 3 Line diagram of steering system with dimensions.

Based on the Ergonomic values, a side view sketch as shown in Fig.2 and Fig.3, which was iterative was designed in Solidworks fitting all the parameters into the constraints.

On multiple iterations of the side view geometry, finally the two angles of the UV joint were fixed.

4. Testing and Validation

The To test and validate two Universal joints a virtual test setup containing the Upper column, Middle column, and Lower column was made. The test was conducted for single and double universal joints where a constant angular velocity of 30 degrees/second was given to the Upper column as a proxy steering input.
A virtual setup was made on the analysis software ADAMS [10] giving 30°degrees /second as the input and other parameters such as the column length as shown in Fig.4.

ISSN No.: 2455-6130
Special Issue: I, 2022, pp. 29-38

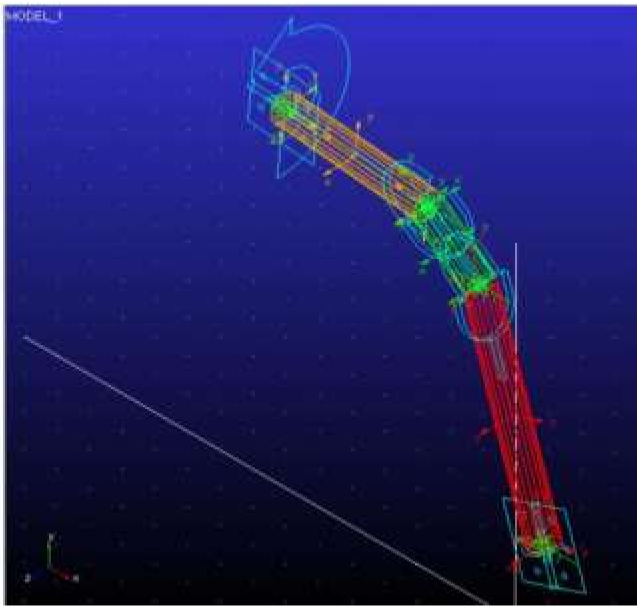

FIGURE 4 Design of steering columns on Adams

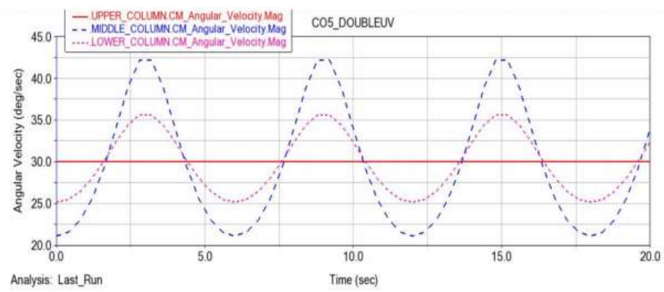

FIGURE 5 Graphical representation of comparing the angular velocity of single and double universal joints

The setup was simulated on ADAMS [10] and the values were obtained from Fig.5.
TABLE 2: Torque transmission calculation

Number of universal joints	Maximum angular velocity at lower column (deg/sec)	Minimum angular velocity at lower column (deg/sec)	Maximum angular velocity ratio (wuc/wlc)	Minimum angular velocity ratio (wuc/wlc)	Maximum Torque transmitted ratio (considering no losses)	Minimum Torque transmitted ratio (considering no losses)	The percentage of torque transmitted is
Single UV at 33°	42.18	21.10	1.406	0.711	1.406	0.711	71.10%
Double UV at 33°	35.61	25.15	1.187	0.8426	1.187	0.8426	84.26%

Table 2 shows the angular velocities at lower column for single and double universal joint. It also gives us the ratio of torque transmitted and the percentage of variation of torque transmitted.

ISSN No.: 2455-6130
Special Issue: I, 2022, pp. 29-38

5. Double UV validation Test

Proposal 1

To validate the newly implemented steering system a gyroscope on the steering wheel and a rotary potentiometer in the pinion are used. The gyroscope and rotary potentiometer respectively gives the angular displacement of the steering wheel or the upper column and the pinion. By plotting the angular displacements of steering wheel and pinion, the performance of newly implemented system compared to the existing one was understood.

Proposal 2

Tie rod force calculation for Steering system:

The Table 3 provides the coordinates in the six links tie/toe rod, two upper arms, two lower arms, and a pushrod/Pullrod. It involves taking coordinates of inboard and outboard points of these six links.

Further, from Table 4, unit vectors representing the direction of force are calculated by using simple vector calculations.

From Table 5 we get these forces which are considered contributing a moment about the wheel center, therefore the moment arm for each member is calculated.

Table 6 shows the maximum forces experienced by the front right tire whilst it is under steady-state breaking [8] and cornering conditions.

From Table 7, Matrix A denotes the matrix representing the components of force in each of the six links (columns) contributing to total force and moments ($F_x, F_y, F_z, M_x, M_y, M_z$) (rows) M_x

From Table 8 Matrix B denotes the forces on the tire, which are calculated for different conditions

X: denotes the unknown column matrix comprising of the 6 unknown forces.

The equation used here is ‘AX = B’

Since, AX=B

$A^{-1}AX=A^{-1}B$ … pre-multiplying by A^{-1}

$X=A^{-1}B$

From Table 9 in matrix X the

F_{TR} = Force on the tie rod

$F_{TR(righ\ )}$ = 3839.535 N

Similarly, force on the left tie rod was found by taking the forces on the front left tire in matrix B.

$F_{TR(left)}$ = 4554.392 N

Steering Moment Calculation

The force experienced by the steering system at any point could be calculated by taking the difference between the forces experienced by the left tierod and the right tie rod.

$Fsteering$ = $F_{TR(righ\ )} - F_{TR(left)}$

$Fsteering$ = 4554.392 N – 3839.535 N

$Fsteering$ = 714.875 N

The pinion gear will convert the steering force translated by the rack into the steering moment.

Hence,

$Msteering = Fsteering\ \times r$

Where r = pinion radius

r = 17.5 mm

therefore,

$Msteering =$ = 12.51 $N.m$ (steering torque)

ISSN No.: 2455-6130
Special Issue: I, 2022, pp. 29-38

TABLE 3: Coordinate points of links

FRONT RIGHT						
POINT COORDINATES						
UNITS IN MM	TIE ROD	LCAF	LCAR	UCAF	UCAR	PUSH ROD
OUTBOARD POINT						
X	-71.02	-4.99	-4.99	4.64	4.64	4.64
Y	575	563.78	563.78	531.37	531.37	516.87
Z	159.59	105.41	105.41	289.21	289.21	285.36
INBOARD POINT						
X	-71.02	-125.66	115.68	-103.93	113.36	4.64
Y	257.03	227.42	227.42	278.67	278.67	292.32
Z	122.09	84.48	84.48	222.25	222.25	640.06

TABLE 4: Unit vector calculations.

VECTOR CALCULATIONS						
	TIE ROD	LCAF	LCAR	UCAF	UCAR	PUSH ROD
VECTOR (X)	0	120.67	-120.67	108.57	-108.72	0
VECTOR (Y)	317.97	336.36	336.36	252.7	252.7	224.55
VECTOR (Z)	37.5	20.93	20.93	66.96	66.96	-354.7
MAGNITUDE	320.1736574	357.9627961	357.9627961	283.0695612	283.1271269	419.8032783
UNIT VECTOR (X)	0	0.337102071	-0.337102071	0.383545301	-0.383997115	0
UNIT VECTOR (Y)	0.993117306	0.939650723	0.939650723	0.892713434	0.892531926	0.534893393
UNIT VECTOR (Z)	0.117123939	0.058469763	0.058469763	0.23654963	0.236501535	-0.844919557
UNIT VECTOR MAG CHECK (=1)	1	1	1	1	1	1

TABLE 5: Moment arm along wheel center

MOMENT ARM (MEMBER OUTBOARD POINTS)						
	TIE ROD	LCAF	LCAR	UCAF	UCAR	PUSH ROD
r_x	-71.02	-4.99	-4.99	4.64	4.64	4.64
r_y	-25	-36.22	-36.22	-68.63	-68.63	-83.13
r_z	-41.07	-95.25	-95.25	88.55	88.55	84.7

TABLE 6: Maximum forces experienced by the wheel

steady state braking and cornering	
Fx	2532.379169
Fy	166.6038927
Fz	1666.038927

TABLE 7: matrix A

FRONT MATRIX A					
0	0.337102071	-0.337102071	0.383545301	-0.383997115	0
0.993117306	0.939650723	0.939650723	0.892713434	0.892531926	0.534893393
0.117123939	0.058469763	0.058469763	0.23654963	0.236501535	-0.844919557
37.85922926	87.38395649	87.38395649	-95.28417567	-95.2648024	24.93269238
8.318142166	-31.81720817	32.40073641	32.8653461	-35.10031168	3.920426745
-70.53119105	7.520979915	-16.89869413	30.46490432	-22.21237388	2.481905344

ISSN No.: 2455-6130
Special Issue: I, 2022, pp. 29-38

TABLE 8: Matrix B

MATRIX B
2532.379169
166.6038927
1666.038927
-4058.470827
525673.9336
-46398.51771

TABLE 9: Matrix X

MATRIX X	
F_{TR}	3839.535366
F_{LCAF}	-3269.049647
F_{LCAR}	1190.456396
F_{UCAF}	4851.165576
F_{UCAR}	-5664.22519
F_{PR}	-1810.739011

6. Conclusion

In this paper a double universal joint was studied which is used to change the axis and plane of rotation of shafts. A double universal joint consists of two bending joints and operates at an angle of 90^0 degree. A single universal joint on the other hand has one bending joint and operates at an angle of 45^0 degree. From the analysis, it was concluded that when the double universal joints are at 33^0 degree each, they are 13.16% more efficient than the single universal joint at 33^0degree, thus improving the ergonomics and torque transmission of the steering column

References

[1] Zhendong F (1982) The calculation of angle deviation and equivalent angle in the transmission of multi cross universal joints system. Ji Lin: Academic Journal of Ji Lin University of Technology 01:104–110

[2] Formula SAE Race Car Cockpit Design An Ergonomics Study for the Cockpit Eva Mariotti and Badih Jawad Lawrence Technological University

[3] Green, P. (2018e). Human Factors / Ergonomics Standards (PowerPoint), Ann Arbor, MI: . University of Michigan Transportation Research Institute.

[4] "Rules & Important Documents". http://students.sae.org/cds/formulaseries/rules. SAE International. Web. Apr 2014.

[5] Dassault Systems SolidWorks Corp. (2010). Bridging The Worlds Of 2d And 3d Cad Design SolidWorks, 2012, [online] Available: http://en.wikipedia.org/wiki/SolidWorks.s

[6] Mechanical Design Handbook Editorial Committee (2004) Mechanical design handbook

ISSN No.: 2455-6130
Special Issue: I, 2022, pp. 29-38

new version volume 3. China Machine Press, Beijing
[7] **"**DESIGN AND ANALYSIS OF FORMULA SAE CAR SUSPENSION MEMBERS" By Evan Drew Flickinger, May 2014
[8] Race Car Vehicle Dynamics (RCVD) Published in 1995 William F. Milliken Douglas L. Milliken
[9] Kyung, Gyouhyung & Nussbaum, Maury. (2009). Specifying comfortable driving postures for ergonomic design and evaluation of the driver workspace using digital human models. Ergonomics. 52. 939-53. 10.1080/00140130902763552.
[10] ADAMS/Car Option. Mechanical Dynamic Inc. 1999. Analysis and Optimization of Torque Variation in Steering Column Assembly Guohui Yan.