

Analytical Approach for CV Joint Stroke-Angle Selection for Automobile Application

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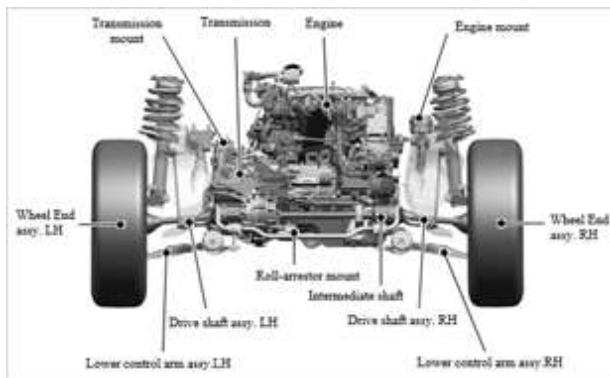
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Abstract- Constant Velocity (CV) Joint or driveshaft is important drivetrain component of automotive vehicles considering vehicle dynamics like driving performance, handling, NVH etc. It transfers power/torque received from gearbox to wheels at wide variety of angles at constant velocity. This paper explains the methodology of static and dynamic analysis of CV joint, which is followed during initial stage of product design selection. Failure to do this may result in incorrect CV joint selection in the design stage itself and/or safety concerns if CV joint dislodges from gearbox during operation, which may lead to safety of occupants in the vehicle and pedestrians too. Along with static analysis, dynamic analysis of CV joint ensures all operating points of inboard joint nominal center fall within acceptable design limit of joint extreme capacity. Based on this study, one can establish a better understanding of CV joint stroke-angle selection, which will reduce cost, help to meet vehicle timeline and improve customer satisfaction.

Keywords: CV joint, Stroke-Angle, Kinematic Analysis.

I. INTRODUCTION

CV joints are mostly used in the driveshaft in front-wheel drive and all-wheel drive automotive vehicles except for commercial vehicles such as trucks, buses etc. where rigid axles are used. Refer Figure 1 for CV joint location in front-wheel drive vehicle.



Vehicle co-ordinate system sign conventions as below used, x: +ve towards Rear, y: +ve towards Right, z: +ve towards Up.

CV joint consists of fixed type joint (Rzeppa joint), sometimes called as outboard joint, which is used at wheel end side to accommodate steering action as intended by driver or as per vehicle states whereas plunging type joint (Tripod joint), sometimes called as inboard joint, is used at transmission side which

moves in the tracks of inboard joint housing back & forth as per suspension movement.

Various factors lead to variation in CV joint hard points i.e. nominal position of CV joint centers with respect to interface parts, which are listed below, Powertrain and wheel end position: Placement of outboard joint & inboard joint involves kinematics of vehicle's suspension design and powertrain position in engine compartment, which is based on design targets and packaging requirement of vehicle layout. Powertrain is mounted in vehicle on engine mounts, transmission mounts, and roll-arrestor mount which control/allow limited movement of powertrain assembly in longitudinal (roll), lateral (pitch) and vertical (yaw) axis for various reasons such as,

- Vibration isolation generated from power source by damping and preventing them from being transferred to the rest of the vehicle's structure and reduce noise, vibration, and harshness.
- Stability & structural integrity by securing the engine and transmission in their proper positions
- within engine compartment, and preventing excessive movement or shifting.
- Absorption of torque/forces during acceleration, braking, and cornering to minimize the risk of damage or failure of components.

Parts/assembly manufacturing variations: Since exact tolerances are not achievable due to manufacturing constraints, parts tolerance variation will result into change in CV joint nominal position with respect to knuckle and powertrain assembly. Due to this, center point of inboard joint trunnion assembly moves away from housing (bowl) center. Usually inboard joint trunnion assembly is placed at center plane of housing to have optimum stroke availability as per suspension movement. If trunnion assembly is not placed at the center, it is likely to dislodge from inboard joint assembly and/or bottoming up (hitting at inside of housing due to less space). Overall, this raises concerns of driver/occupant safety, NVH concerns and customer dissatisfaction etc.

CV joint assembly connections

Outboard joint is assembled to wheel end side with knuckle assembly thru external involute splines on CV outer housing or in some cases thru face spline designs as per OEM design layout requirements. CV outer housing has threading at the shank end, which is used to lock the outboard joint assembly using lock nut /special bolt arrangement. Refer Figure 2 for outboard joint assembly with wheel hub.

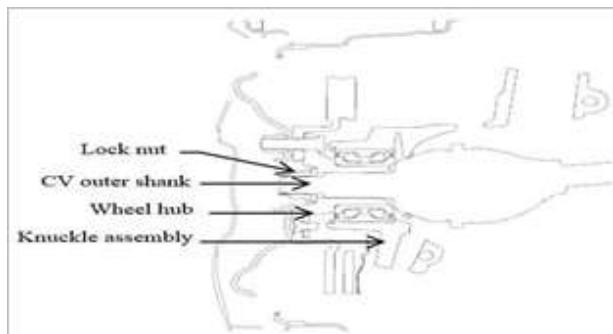


Figure 2: Outboard joint assembly at wheel side

Similar to Outboard joint, In-board joint housing also has external involute splines, which mesh with internal splines of transmission differential side gears. Retainer ring is used to lock the inboard joint with side gears where limited movement is allowed between retainer ring & groove of the side gear to mitigate manufacturing tolerances and to meet assembly requirements. Refer Figure 3 for inboard joint assembly with transmission side interface.

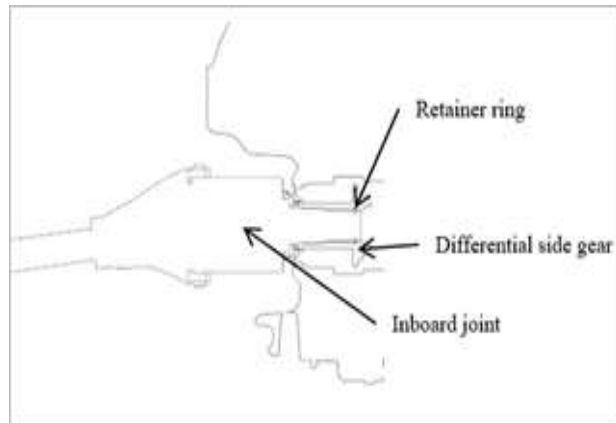


Figure 3: Inboard joint assembly at transmission side

CV Joint working principle

CV joint assembly typically contains 3-piece or 2-piece driveshaft length designs based on vehicle powertrain layout. In 3-piece layout, intermediate driveshaft is used to have equal length driveshaft design which helps to reduce torque steer, which mostly occurs in the front wheel drive vehicles as the front wheels perform both steering and driving functions. Unequal length or 2-piece driveshaft are also used in modern cars but to avoid torque steer issue; this can be compensated by doing shorter shaft (axle bar) hollow and longer shaft solid.

Fixed joint (Rzeppa) allows the wheels to steer while axle is rotating. It enables to take working angle only. Any application above allowable working angle is inoperative because an interference is arisen between parts, which causes issues like NVH, failure of joint etc. There are various types of Rzeppa joints designs available for use in automotive vehicles such as Angular Contact, Undercut Free and Crossed Groove etc. Higher articulation angle of fixed joint will benefit to have shorter turning radius of car but it comes with higher price to customer. Figure-4 explains the Rzeppa joint construction.

Plunging joint (Tripod), allows for suspension and powertrain movement while axle is rotating. Roller assembly slides-in and slides-out in the tracks of tripod housing. Figure-5 explains the tripod joint construction. Plunging joint includes standard tripod, where spider leg with cylindrical shape are used. In enhanced tripod, joint, spherical rollers are used for better NVH. Standard tripod, shudder less

joint etc. types are used at inboard joint side in vehicle.



Figure-5: Typical Tripod Joint construction

CV Joint articulation

CV joint articulates as per inputs from steering and suspension. Table-1 shows typically allowable working angles. Working angle or compound angle is generated by combination of design angles in Top & Back view. Design angles shown are with Unladen/Kerb weight vehicle condition.

Type	Allowable working
Rzeppa Joint	46.5° and above
Tripod Joint	23.0° and above

Table-1: Typical working angle range

Figure-6 shows design angles of fixed and plunging joint in Top and Back view

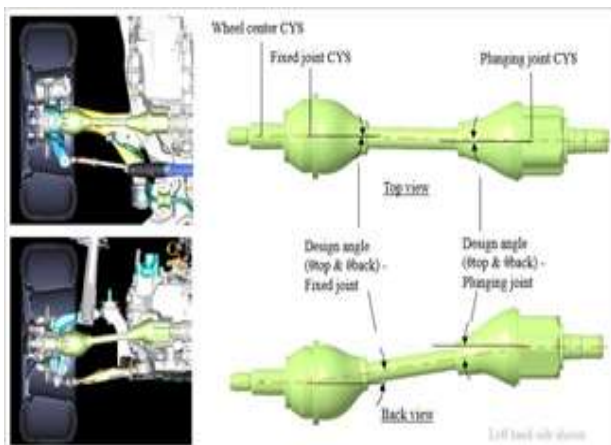


Figure-6: Design angles of CV joint

Plunging joint – Stroke-Angle diagram

Figure-7 explains slide stroke-angle diagram of plunging joint.

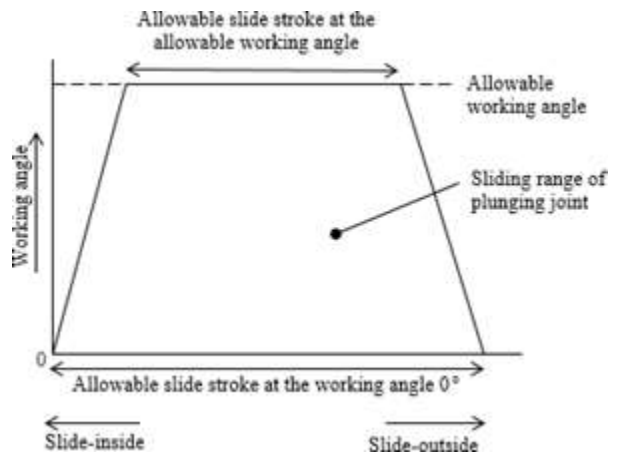


Figure-7: Stroke-Angle diagram of plunging joint

Calculation of CV joint angle

CV joint compound angle calculation needs wheel center, outboard joint and inboard joint co-ordinates. These co-ordinates are derived thru kinematics study suspension/steering at vehicle level, which includes inputs from various aggregates like suspension/steering, wheels, mounts etc. CAE MBD team carries out this analysis.

Figure 8 explains basic principle of 3D-vector. Since CV joint operates at compound angle (3D), it is imperative to calculate the working angle through Dot-product vector process.

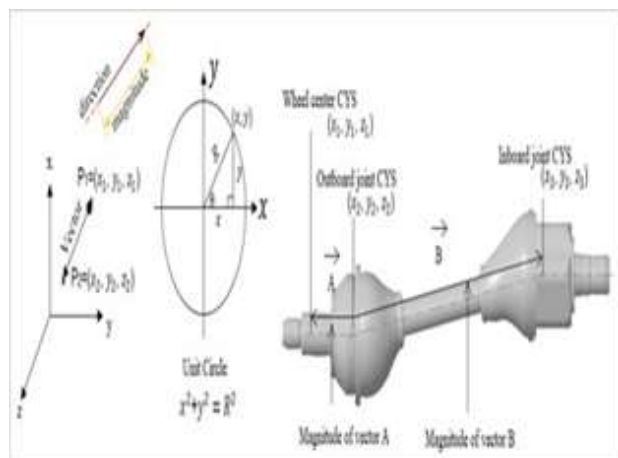


Figure 8: Articulation of CV joint

Table-2 shows co-ordinates required to calculate angle of fixed & plunging joint.

Suspension condition	Wheel center			Outboard joint			Inboard joint		
	Left side CV joint								
Coordinates	x_1	y_1	z_1	x_2	y_2	z_2	x_3	y_3	z_3

Table-2: CV Joint co-ordinates

- Dot Product of Vectors $A \cdot B = Ax_Bx + Ay_By + Az_Bz$
- Magnitude of Vector A
 $|A| = \text{SQRT}(Ax^2 + Ay^2 + Az^2)$
- Magnitude of Vector B
 $|B| = \text{SQRT}(Bx^2 + By^2 + Bz^2)$
- Cosine of the Angle Between Vectors $\cos\theta = \frac{A \cdot B}{|A| |B|}$

Magnitude of both vectors A & B is calculated to get the compound angle.

Kinematic analysis of plunge joint – Static

The suspension system of car is designed to absorb shocks and vibrations from the road surface. Damping characteristics can be adjusted through various parameters, including bump and rebound. When the wheel come across the obstacle on the road surface, suspension compresses to absorb the shocks and due to this wheel moves upward. During rebound, suspension expansion happens which moves the wheel downward. As outboard joint is fixed with knuckle assembly, it moves upward and downward as per wheels movement. This causes the inboard joint spider assembly to slide in and out inside the housing.

There are four suspension conditions, named as bump, rebound, design (curb/Unladen) and ECIE. Table-3 and Figure 9 explains suspension conditions. Static analysis means only wheels upward/downward movement (as per suspension travel limits), and steering action is considered (without any dynamic movement of powertrain). Initially, it is ensured that all co-ordinates must fall within the safety margin of joint capacity. Safety margin value is derived by doing Dimensional Variation Analysis (DVA) of contributing components thru various simulation tools. Safety margin and DVA details are explained further.

Table-2 shows co-ordinates required to calculate angle of fixed & plunging joint.

Sr. no.	Suspension condition
1	Full Bump with Left steer
2	ECIE with Left steer

3	Design with Left steer
4	Full Rebound with Left steer
5	Full Bump
6	ECIE
7	Design
8	Rebound
9	Full Bump with Right steer
10	ECIE with Right steer
11	Design with Right steer
12	Full Rebound with Right steer

Table-3: Suspension conditions

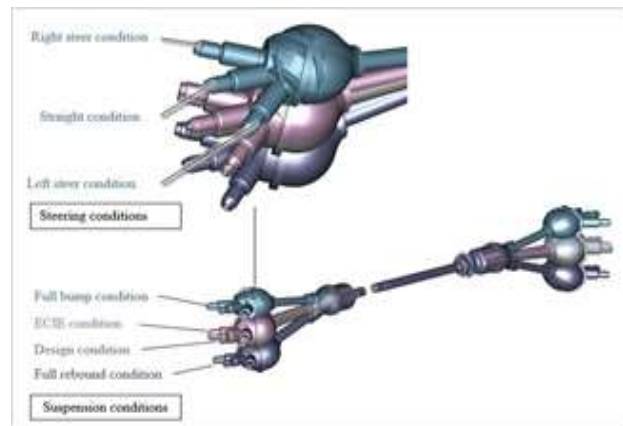


Figure 9: CV Joint assembly envelope

Figure 10 shows Inboard joint nominal position co-ordinates (angle and stroke) within the housing envelope. As per general guidelines of driveshaft, design angle (installation angle) should be in the range of 3-5 deg. to have lower torsional vibrations of the driveline and to avoid higher sized inboard joint housing length etc. However, due to powertrain packaging clearances requirement, peripheral parts carryover requirement etc. design angle requirement may change.

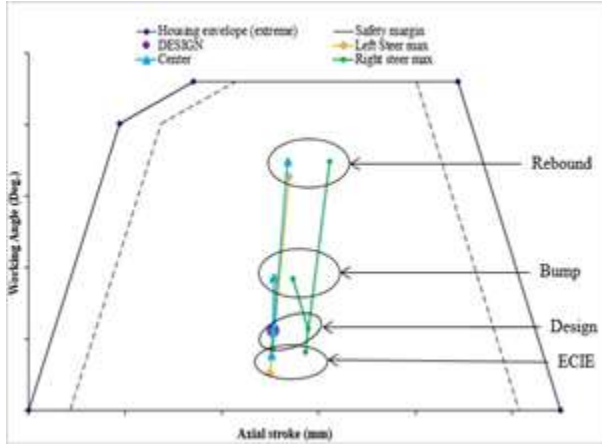


Figure 10: CV Joint assembly envelope

Kinematic analysis of plunge joint - Dynamic

Second important requirement is to do dynamic powertrain analysis. This is required as powertrain shifts during vehicle driving condition like acceleration, braking etc. which changes plunge joint position. To do this, dynamic analysis carried out using simulation software to calculate movement of inboard joint spider assembly nominal position in the housing. In dynamic analysis, various proof and extreme load cases were analyzed. Some of the tests & joint center variations with respect to nominal position are mentioned in Figure 11 for reference.

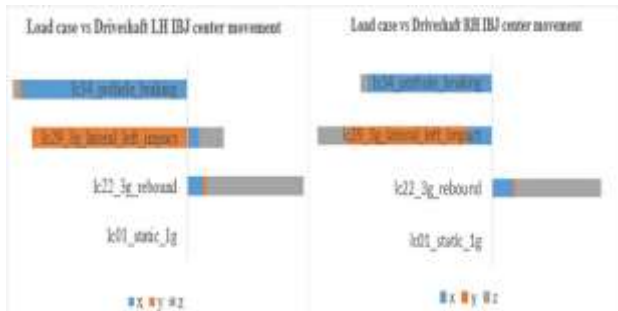


Figure 11: Dynamic load cases Vs Inboard joint center movement

After dynamic analysis for powertrain mounts system loads and envelop, it is important to consider manufacturing and assembly variations and its impact on CV joint nominal position. Hence, to estimate and compare variation with actual assemblies, dimensional variation analysis (DVA) study conducted.

DVA study mainly includes model build, simulation results on,

- Powertrain position variation
- CV joint length variation
- Suspension position variation
- Combined effect of above variations.

The 'Y' direction (vehicle lateral) variations are mainly responsible for driveshaft issues like dislodging; bottoming up etc. and key contributors causes these variations .Refer Figure 12 for parts contributing variations.

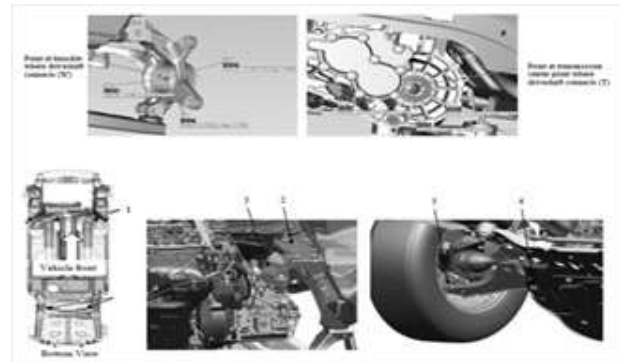


Figure 12: Contributors for variations in CV joint position

1. BIW reference points w.r.t. datum
2. PWT mounts arm assembly hole w.r.t BIW ref.
3. Powertrain mounts bracket hole location
4. Lower control arm (LCA) pivot mounting on sub-frame
5. LCA pivot mounting holes location on knuckle assembly.

Figure 13 shows key contributors & variations which were identified during DVA study,

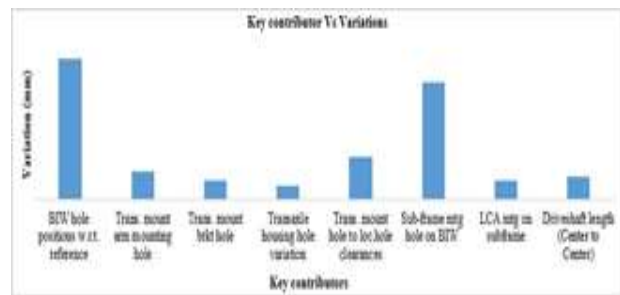


Figure 13: Part wise contribution for variation

After doing DVA study, this variation added into dynamic variations that are explained in Figure 11 and 12 and stroke-angle analysis done. Figure 14 shows maximum angle and stroke considering dynamic analysis.

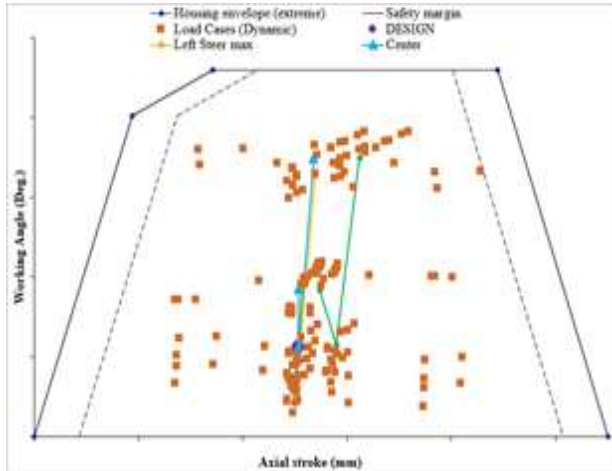


Figure 14: Stroke-angle diagram for dynamic analysis

In case, if these points are falling outside of specified CV joint limits, following options to be evaluated based on project scope, design requirements, cost and timeline impact etc.

- Select higher size joint stroke
- Optimize CV joint angles by changing powertrain/knuckle position
- Optimize powertrain mounts stiffness
- Minimize manufacturing and assembly variations etc.

Physical variations and measurements

After digital evaluation for joint selection, it is also important to measure manufacturing and assembly variations of actual assemblies. On vehicle assembly line, special fixture were used to mount the powertrain assembly. References on fixtures simulate the powertrain centralization/position with respect to references provided on BIW. This reduces the powertrain assembly variations. To support the digital study, few proto vehicles used to measure variations at vehicle level. Power-train assembly with add-on parts is mounted on these fixtures during powertrain stuffing on vehicle. Refer Figure 15 for fixtures details.

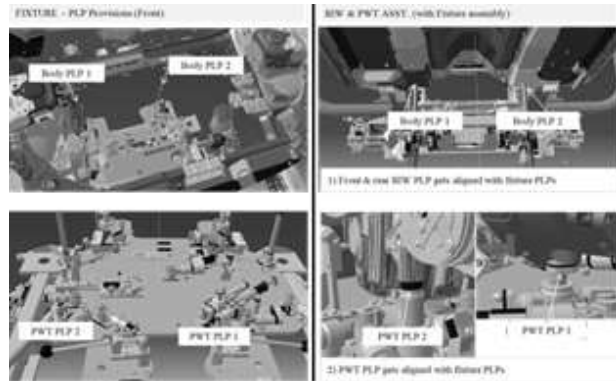


Figure 15: Fixture assembly for power train

Using CMM, required measurements taken to check manufacturing and assembly variations and its impact on powertrain-centralized position in vehicle. Refer Figure 16 for measurement comparison.

Ref point (Transmission)	actual	Ref point (Engine)	actual
Center.x	863.751mm	Center.x	938.673mm
Center.y	218.111mm	Center.y	736.454mm
Center.z	-38.391mm	Center.z	-51.573mm
Diameter	16.960mm	Diameter	16.275mm
Circularity	0.019mm	Circularity	0.119mm

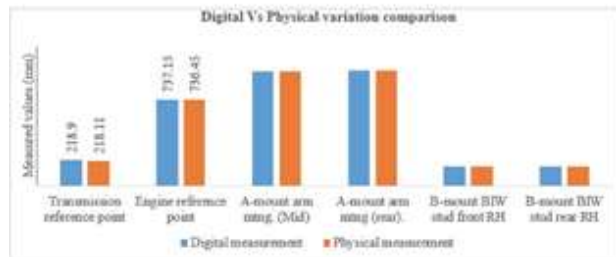


Figure 16: Variations measurement comparison

CONCLUSION

This paper emphasizes the need of digital evaluation before actual design finalizations that saves cost/timeline of manufacturers of automotive vehicles and ensure that correct designed /evaluated parts goes in production vehicle that will improve safety of occupant / pedestrians, cost of ownership and overall customer satisfaction. Below steps can be followed by OEM to study and for selection of CV joint for stroke-angle requirement,

- Static hard points calculation of CV joint
- Dynamic hard points calculation of CV joint

- DVA analysis for design variations in related parts CMM measurements for actual variations
- Vehicle level testing

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