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# INTEGRATION OF CONSTANT VELOCITY JOINT (CVJ) WITH FINAL DRIVE OF GEARBOX FOR ELIMINATING TRANSMISSION LOSSES

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**Abstract** — *To improve transmission efficiency is always a major challenge of any automobile industry. Transmission performance can be improved by minimizing transmission losses. In most of the vehicles CVJ is coupled with driveshaft, and power is transmitted from gearbox to driveshaft with the help of splines. Splines get wear after certain number of fatigue cycles, and create unnecessary clearance between mating splines. This leads to wobble CVJ, uncontrollable wheel wobble at higher vehicle speed, Centre misalignment of shaft between both CVJ tulip, gives initial jerk to vehicle and causes delay in quick acceleration of vehicle. And hence regular maintenance and replacement of components needed. So, there is need to develop a system which overcomes all these problems. For this, we designed a system having integration of CVJ with final drive gear of gearbox. The spline method eliminated, and this new method increases strength to weight ratio and reduces rotational inertia resulting better performance of the vehicle. This integrated part can be made by simple manufacturing processes which reduces manufacturing cost and time. We have also design a constant velocity joint which gives constant velocity up to 40-degree articulation angle. This paper gives the detail information and the procedure to achieve this.*

***Keywords***- *gear drive, constant velocity joint, integration, transmission losses, bipod, Adams simulation, phasing.*

## I. INTRODUCTION

Transmission is the system by which torque and speed and thus power is transferred from one part or system to another part or system. The most common use is in motor vehicles on the road, where the transmission adapts the output of the internal combustion engine to the drive wheels. The transmission reduces the higher engine speed to the slower wheel speed, increasing torque in the process and by the combination of which vehicle can negotiate any obstacles on the road. Also, it increases the output speed to increase speed of vehicle. Joints are important to transfer velocity from input to output. Different types of joints are available in the market. Full power output is the expectation of the customers which is not fulfilled by these joints as some power is loss in it. Each type of joint has its own limitations for obtaining constant velocity at different articulation angle. Thus, there are different factors which affects the selection of joints. In this paper, we designed a Constant Velocity Joint (CVJ) integrated spool gearbox. This paper gives the detail information about problem statement and the solution to achieve the targeted results.

## II. PROBLEM STATEMENT

The power is taken from engine by Continuously Variable Transmission (CVT) and then transferred to the input shaft of the fixed reduction gearbox. After gearbox, power is transferred through Constant Velocity Joint to the driveshaft and then wheels. In general case, the CVJ is connected to the differential or gearbox with help of splines.

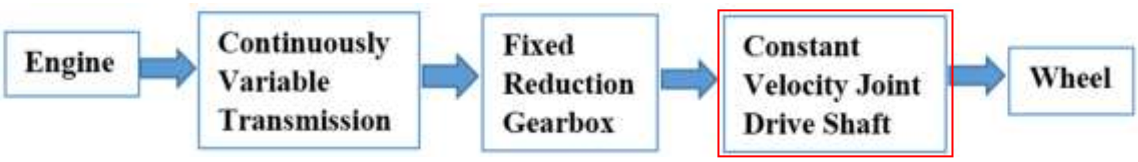



***Figure 1. Typical power flow in transmission system***

But, these splines are wear out after some number of working cycles which causes the play or compliances in them. So, while transferring the power there occur some power loss. This reduces the overall transmission efficiency of the vehicle. So, our aim is to solve the different problems arise on the vehicle. Following are the different problems found:

- Wear of splines in between gear and CVJ tulips creating compliances and loss of power.
- Delay in quick acceleration of vehicle.
- Jerk at the start of the vehicle due to impact in splines.
- Wobbling of CVJ creating unwanted vibrations and noise on the vehicle.
- Vibration due to phasing error in CVJ.
- Higher weight and rotational inertia of transmission system affecting performance.

## III. CONCEPT OF INTEGRATED CONSTANT VEOCITY JOINT

From problem statement, it is analysed that there is need to develop a unique solution which overcomes every problem arise and gives constant velocity within a designed articulation angle range. In this section, we will see how the new mechanism solve the above problems. For this, we have first found out different solutions which can be possible and select one by using matrix selection method.

### 3.1. Possible Solutions

- Integration of gear and CVJ
- Increase the hardness of the material
- Replacement of involute splines by square spline
- Conventional spline system

### 3.2. Matrix for the selection of solution

We have made a matrix of numbers for selection of our design among above solutions. In this matrix we have given different numbers according to the parameter advantage. So, it is found that the integration point scores higher points among above all possible solutions. This table helps to select our design.

***Table 1. Matrix for solution selection***

| Concept | Description | Strength /Weight (10) | Raw material (7) | Machining cost (8) | Rotational inertia (7) | Serviceability (9) | Total (x*y) |
|---|---|---|---|---|---|---|---|
| Integration | In this concept, the gear and CVJ are design as a single part which will transmit 100% power. | 10 | 6 | 10 | 9 | 8 | **357** |
| Increase hardness | In this concept, increase hardness of gear and CVJ splines for strength, but it gets brittle after certain limit. | 8 | 8 | 7 | 8 | 7 | 311 |
| Square slots | In this concept, replaces involute spline by square, it will increase strength but create same scenario. | 8 | 8 | 6 | 7 | 7 | 296 |
| Splines | In this concept, gear and CVJ are design as a separate part, loss of power occurs due to wear of splines. | 6 | 8 | 7 | 8 | 7 | 285 |

### 3.3. Integration of CVJ with final gear drive of gearbox

To improve transmission efficiency is major objective of any automobile company. Transmission performance can be improved by minimizing transmission losses or by replacement of highly efficient components. In most of the vehicles, CVJ is coupled with driveshaft. Power is transmitted from gearbox to driveshaft and from driveshaft to wheels with the help of splines. Splines get wear after some number of cycles which occurs due to non-uniform torque and speed transfer along with linear displacement in splines. This create unnecessary clearance or play between splines which may lead to wobble CVJ, Centre misalignment of shaft between both CVJ, and different problems as stated before. Certain transmission losses due to this play in splines reduces the vehicle performance. Hence regular maintenance or replacement of components needed. To avoid such transmission losses and improve performance, we designed a system having integration of Constant Velocity Joint (CVJ) with final drive of gearbox. In this system, we have modelled a final gear such that it acts as both functions of taking power from input pinion and transferring it to driveshaft through Constant Velocity Joint (CVJ). By this design method, there is no need to make splines which causes different problems. Also, the cost of making splines reduces along with the cost of material. We designed bipod type Constant Velocity Joint (CVJ) which consists two square nuts at one end of driveshaft. These two square nuts are slide fitted in the pin. The pin is press fitted in the driveshaft end. These two square nuts slides on inner Constant Velocity Joint profile of final gear.

Grease lubrication is used to reduce the frictional losses in Constant Velocity Joint. In most of the vehicle, universal joint is used for driveshaft which is double hooks joint, Double hooks joint is also known as constant velocity joint, but it can give constant velocity up to limited angle, but we design a constant velocity joint which can give constant velocity up to 40 degree of driveshaft articulation angle.

**3.4. Components of the integrated bipod CVJ system:**
Following are the different components of the system which are needed for efficient and durable working of the system.

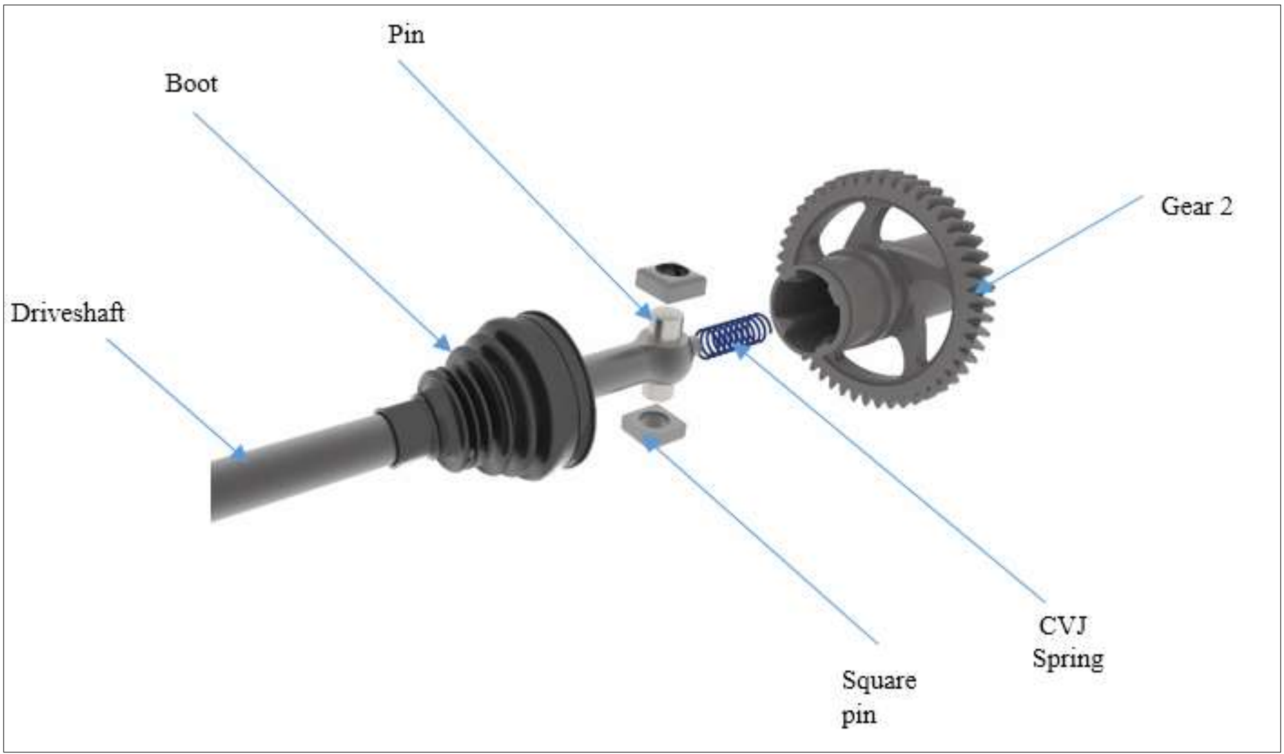



***Figure 2. Exploded view of integrated system***

**3.4.1. Driveshaft**
It is the middle link between gearbox side and wheel side Constant Velocity Joints (CVJ). It consists two holes at its both ends in which a pin is fitted. Interference fit is provided for tight press fit of the pin with driveshaft.

**3.4.2. Pin**
It is simple shaft which fits in the spigot. On both the ends one square nut fitted on it. This pin is subjected to direct shear stresses.

**3.4.3. Square nut**
There are two square nuts each at end of the pin. The square nut has the clearance fit with pin. Square nut slide in the bipod Constant Velocity Joint (CVJ) provided with grease lubrication. Some slotted lines are provided on each face of square nuts for providing lubrication in its entire working. Spherical shape is given at the top of the square nut for smooth sliding and avoid constraint in Constant Velocity Joint (CVJ).

**3.4.4. Spring rest**
It is made of lightweight aluminium material and is press-fitted into final gear. The spring which is use for centering the shaft is rested on this. Two circlips are used on both ends of spring rest to restrict the axial movement of it.

**3.4.5. Spring**
Spring is used to make balance of shaft at both joint ends. As shaft with pins is fitted into the Constant Velocity Joint profile, there is a possibility that shaft will hit the CVJ bipod profile. This will damage the shaft and the bipod profile. Spring avoids this scenario by maintaining balance at both ends due to springs pretension.

**3.4.6. Rubber boot**
Rubber boot covers the CVJ. It contains the grease which provide lubrication. Also, it protects the grease from dirt by avoiding mixing with it.

## IV. DESIGN AND ANALYSIS

We have used a unique design methodology for the design of each components. Our design starts with basic handwritten calculations for each part and ends with getting of optimized design of part. The methodology for the design and brief description of the design are given in this section.

### 4.1. Material selection

The integrated final gear is designed to transmit torque from gear train to the driveshaft. There is high sliding velocity in CVJ along with torque transfer through nuts. So, it is important to have enough strength and hardness. We have used case hardening for the gears achieving 60 HRC hardness. Also, the driveshaft is hardened up-to 40 HRC by nitriding process to avoid deflection of shaft. With this hardness we can achieve the strength as given in table below:

***Table 2. Material strength comparison***

| Material | En24 | 20MnCr5 |
|---|---|---|
| **Yield Strength** | 800 MPa | 950 MPa |
| **Ultimate Tensile Strength** | 1000 MPa | 1200 MPa |

### 4.2. Design of final integrated gear

First, it is necessary to find out the forces coming on the gear. Number of gear teeth are selected by gear ratio calculations. Module, addendum, dedendum parameters, rim diameter is calculated using gear calculations with Buckingham's calculation method which are easily available in machine design textbook.

We have selected the Bipod Constant Velocity Joint, according to that we design the final gear for bipod joint. While designing the gear we reduced the weight by giving pockets on the gear. This reduces the gear weight as well as are useful for lubrication flow thus gives good cooling effect to the gear. Finite Element Analysis (FEM) is done for optimization of final gear with these pockets. We can do inboard braking system over CVJ profile because of CVJ integration eliminates eccentricity and lateral run out of the brake disc. Four trapezoidal slots are provided for brake disc hub which is press fitted into these slots.

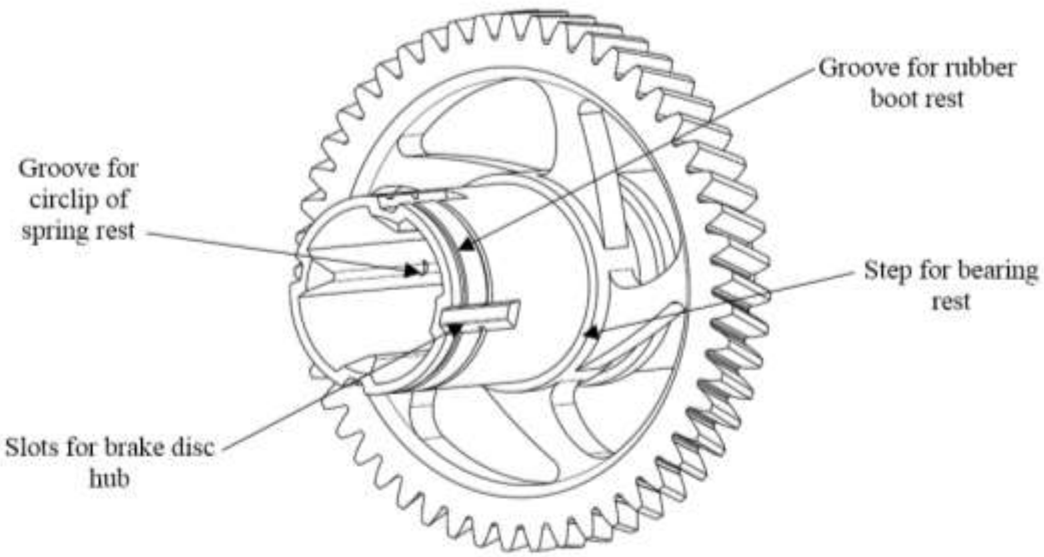



***Figure 3. Features of the final integrated gear***

Groove at inner diameter is provided for ring retainer of the spring rest. Groove at outer diameter provided for rubber boot rest and another groove for circlip of brake disc hub. A step is provided on outer diameter for bearing rest to avoid axial travel of bearing. Dimensions of the inner profile slots are taken according to the square nuts size of the Constant Velocity Joint (CVJ). We can select any two slots of inner profile out of four slots for any time. Some tolerances are allowed for clearance fit between square nuts and bipod Constant Velocity Joint (CVJ).

Now, it is required to calculate and compare the strength of final gear and Constant Velocity Joint (CVJ) for both integrated and conventional separate design. By analyzing it is found that crushing and shear stresses along with torsional stresses developed in the spline system. But in the case of integrated system, only torsional stresses developed which relieves design from crushing and shear stresses which causes wear and compliances in the spline system.

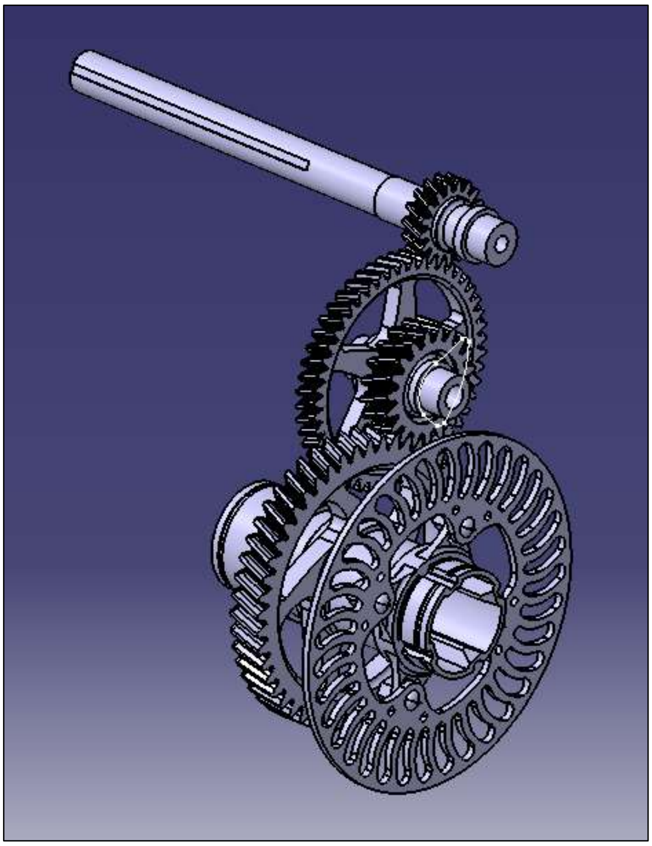


*Figure 4. Complete geartrain CAD model showing arrangement of parts*

As above figure shows, the arrangement of all the components of the drivetrain system. Brake disc is bolted on the brake disc hub. Brake disc hub is press-fitted in the four slots along with circlip is used to avoid the axial travel of the brake disc hub. Also, above figure shows the arrangement of all the pinions and gears of the gear-train. A keyway is provided on input pinion to take input power from Continuously Variable Transmission (CVT). Excluding brake disc and hub, all the parts are enclosed in two casings with oil lubricated.

**4.3. Calculations:**

**1) Torsion failure of gear:**

According to material properties of gear,

Shear strength of the material= 0.577*1200 = 692.4 MPa

Torsion equation is given as,

$$\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{L}$$

$$T = \frac{\pi}{16} * \left(\frac{D^4 - d^4}{D}\right) * fs$$

$$560000 = \frac{\pi}{16} * \left(\frac{50^4 - 44^4}{50}\right) * fs$$

$$fs = 560000 * 16 * \frac{50}{\pi * (50^4 - 44^4)}$$

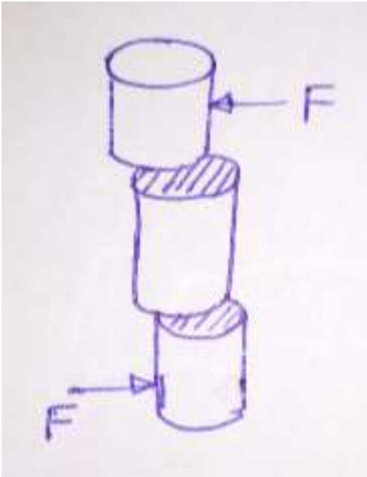
$$fs = \frac{448}{7.859} = 57\ MPa$$


So, compared to both strength of the material and actual stresses in the material, 57 MPa << 692.4 MPa. So, the design is safe for static torsional failure.

**2) Shear failure of pins:**

As figure shows, it is subjected to direct shear stress




We know that,

$$Shear\ stress = \frac{Force}{Area}$$

$$Shear\ stress = \frac{20000}{\pi * 7.5 * 7.5}$$

$$Shear\ stress = 113.18\ MPa$$

But as per material properties, shear strength of material is 692.4 MPa. So, the factor of safety obtained is as,

$$FOS = \frac{692.4}{113.18}$$

$$FOS = 6.12$$

Thus, the pin is safe in direct shear condition.

**3) Pure torsion failure of driveshaft:**

Torque at the driveshaft is 560 N-m.

$$T = \frac{\pi}{16} * d^3 * fs$$

$$560000 = \frac{\pi}{16} * d^3 * 692.4$$

$$d = 16.03\ mm \approx 20\ mm$$

Thus, the diameter of 20 mm is selected for driveshaft.

Other parts are analyzed through Finite Element Analysis (FEM) as the cross-section is varying.

**4.4. Finite Element Analysis (FEM)**

System is acted by different number of forces on it. Theoretical calculations are not enough for varying cross section pf each part. So, it is necessary to analyze these parts in a separate analysis software. We have used Ansys 14.0 Workbench for all static structural analysis. The procedure that we have adopted for this is given below.

A. Modelling / importing the geometry.
   1) Model development in any CAD software like Creo or CatiaV5
   2) CAD model converting into STP format and importing it into Ansys workbench.

B. Material selection / assigning material properties
   1) Selecting material existing in the Ansys library
   2) Editing the properties of material according to our need
   3) Defining properties like modulus of elasticity, Poisson's ratio, etc.

C. Meshing
   1) Dividing model into fine mesh
   2) Selecting the type of elements to be generated
   3) Controlling the quality globally and locally
   4) Finalizing the mesh quality

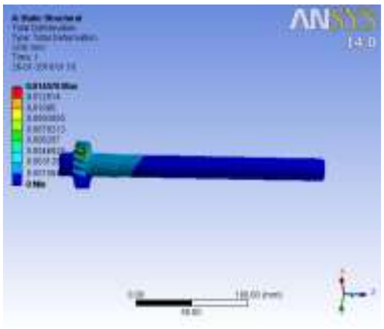
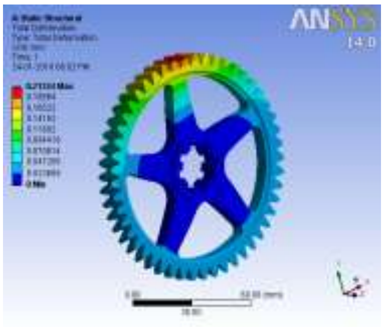
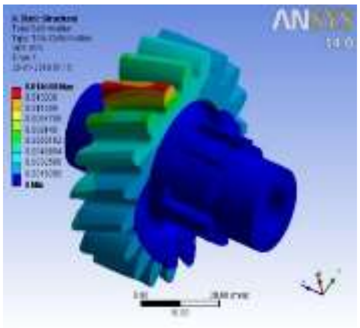
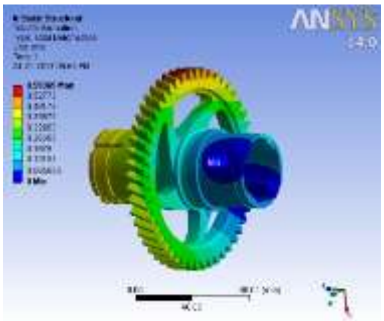
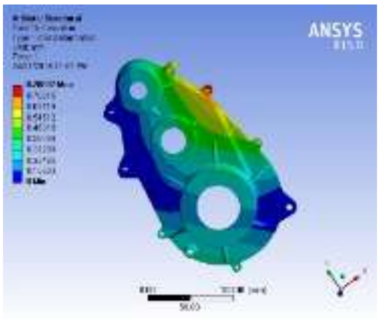
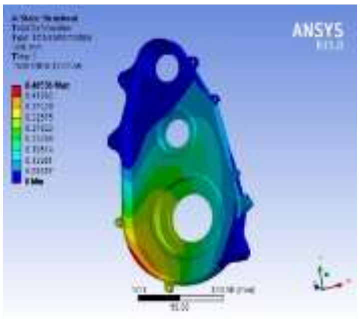
D. Applying the boundary conditions
   1) Defining the boundary conditions
   2) Analysis settings

E. Results

   Pictorial representation of results like von-Mises stress, deformation, safety factor, fatigue factor of s afety etc. are obtained. Comparing it with the design targets the results are summarized.

Following table shows the FEA analysis of the components. We use Ansys Workbench 14.0 for analysis purpose.

*Table 3. Finite Element Analysis of the components*

| | | |
|---|---|---|
|  PINION ONE |  GEAR ONE |  PINION TWO |
| Deformation (mm): 0.014<br>Max. Stress (MPa) : 230.61<br>Factor of Safety : 1.86 | Deformation (mm): 0.212<br>Max. Stress (MPa) : 674.27<br>Factor of Safety : 1.58 | Deformation (mm): 0.014<br>Max. Stress (MPa) : 243.61<br>Factor of Safety : 1.78 |
|  FINAL GEAR |  LEFT CASING |  RIGHT CASING |
| Deformation (mm): 0.593<br>Max. Stress (MPa) : 782.37<br>Factor of Safety : 1.38 | Deformation (mm): 0.780<br>Max. Stress (MPa) : 152.59<br>Factor of Safety : 1.64 | Deformation (mm): 0.465<br>Max. Stress (MPa) : 159.59<br>Factor of Safety : 1.33 |

**4.5. Simulation of CVJ**

Most of the times it is found that we struggle to understand the true system performance of the design. And then after it is very complicated to change the design later if any problem found in earlier design. ADAMs improves engineering efficiency and reduces product development costs by enabling early system level design validation. Also, we can evaluate and manage the complex interacting between disciplines including motion, structures, actuation and controls to better optimize product design for performance.

**4.5.1 Phasing:** Phasing is important term in the Constant Velocity Joint design. Engine, drive line or rear suspension changes sometimes move things around. Everything in the drivetrain must operate in "phase" in order to minimize vibration, noise and component wear.

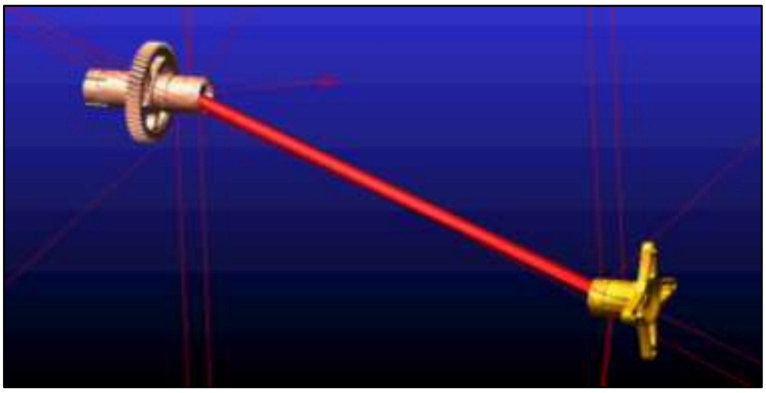


*Figure 5. Simulation of Constant Velocity Joint (CVJ) in ADAM's software*

In our case, both ends of the driveshaft consist integrated spigot in which pin is inserted in each slot. These pins should be parallel phase to avoid vibrations, noise and wear of the CVJ. We have analyzed both the cases of parallel phasing and perpendicular phasing by simulating both models in the ADAMs. It is found that, in perpendicular phasing

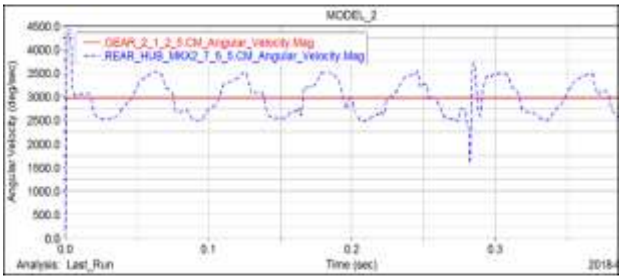


***Figure 6. Velocity graph for perpendicular phasing***

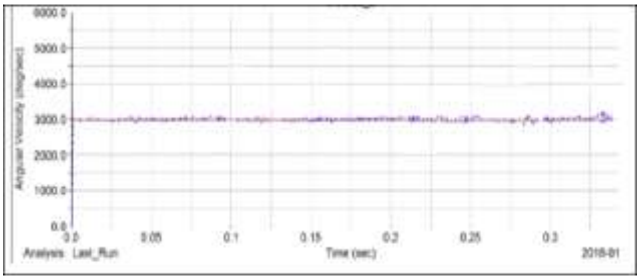


***Figure 7. Velocity graph for parallel phasing***

there is variation of velocity in every revolution of the output of driveshaft i.e. at hub. And in parallel phasing, there is negligible variation in velocity or say constant velocity at the hub. From this analysis we have finalized our CVJ phasing in parallel orientation which gives constant velocity at every revolution. Red lines in the graph shows input velocity and blue lines indicates output velocity.

## V. MANUFACTURING

We know the various machining processes for the manufacturing of the components. Out of which, we have selected different manufacturing processes which are cost effective and fast for this special product.

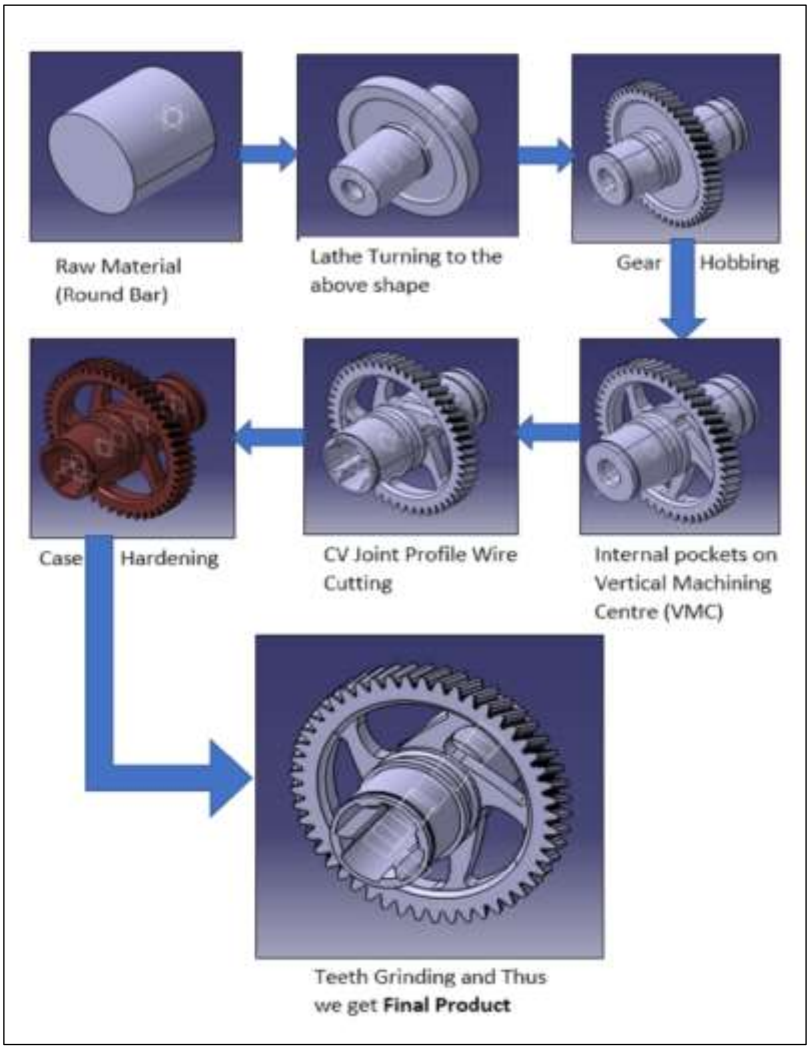



***Figure 8. Manufacturing process for final gear as a special product***

### 5.1. Manufacturing procedure adopted

For manufacturing the final integrated gear following procedure is required:

1. **Turning:** first step of the procedure involves CNC turning of cylindrical block to the required dimensions according to the design. 2d part drawing is drafted using AutoCAD software and proper tolerances are given in the drawing. This process helps to remove material quickly.
2. **Gear Hobbing:** In this process, gear teeth are cut on hobbing machine with standard cutters. Thus, we get turned job with teeth on its periphery. Some extra allowance is provided for gear teeth grinding.
3. **Milling on Vertical machining Centre (VMC):** In the next step weight reduction pockets and profile of bipod is machined using 3 dimensional VMC machine. This helps to remove material using 3d contours. Allowance of 0.5 mm is given for bipod profile which is to be machined in next step of EDM machining.
4. **WEDM:** Wire-cut Electro Discharge Machining is unconventional type of machining process. In this method machining is done by erosion of material through electric discharge. The profile of bipod is finally machined using this process.
5. **Hardening:** Then the gear is hardened using case hardening method. Care is taken during hardening to prevent distortion of bipod profile. The hub is hardened up to 60 HRc.
6. **Teeth Grinding:** In this process, gear teeth are grounded for smooth meshing of gears and to avoid backlash.

   Similar processes are used for other parts of the gearbox. CNC milling is used for gearbox casing as a special part.

## VI. TESTING, RESULTS AND VALIDATION

We tested the All-Terrain Vehicle (ATV) vehicle on a rough terrain. We measured the distance travelled by the vehicle a full tank of the vehicle. The fuel capacity of the tank is 3.4l. Endurance testing was carried for two different CVJ's.

*Figure 9. Testing on All Terrain Vehicle (ATV)*

Percentage change in efficiency

$$= \frac{\text{Distance travelled (Integration system)} - \text{Distance travelled (Spline System)}}{\text{Distance travelled (Integration System)}}$$

$$= \frac{12.35 - 11.47}{11.47} \times 100$$

$$= 7.1\ \%$$

We have tested this joint for output angular speed variation for different articulation angles. It is found that it works well, noiseless, vibration-less up to 40-degree articulation angle. But, after this angle, angular speed variation increases such that it creates noise, vibration in drivetrain system. So, that we have limited the use of this joint up to 40-degree articulation angle. The above graph shows angular speed variation for different articulation angles.

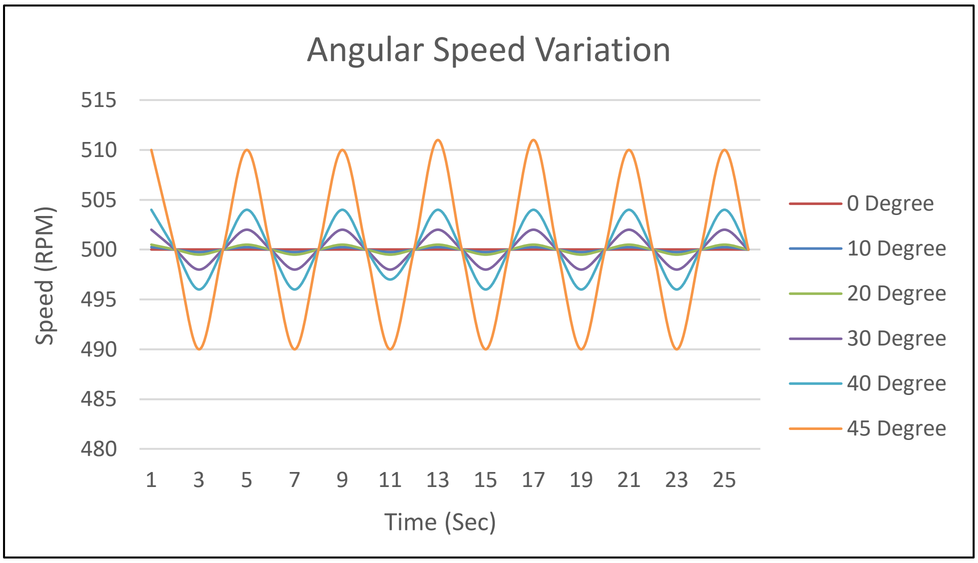



***Figure 10. Graph of angular speed variation for different articulation angles***

After testing of the components, we validate the design values on various machines like Brinell Hardness Tester for hardness checking, shear strength of bipod pins, torsion testing of final gear and driveshaft, etc. Below table shows the testing of components on this machine.

***Table 4. Design Validation Plan Report (DVPR)***

| **Sr. No** | **Parameter** | **Design Value** | **Actual Value** | **Method of Validation** | **Images** |
|---|---|---|---|---|---|
| **1** | Shear test of Bipod Pins ($N/mm^2$) | 692.4 | 670 | Universal testing machine was used to calculate shear strength of bipod pins. |  |
| **2** | Torsion Testing of gear and driveshaft (N-m) | 560 | 560+ | Torsion testing apparatus is used for both final gear and driveshaft |  |

## VII. CONCLUSION

As our aim of the design was to increase the transmission efficiency. We tested our design on the ATV. We compared our design with the earlier assembly, from that we made some conclusions which are given below:

- Full torque and power transfer from final drive gear to CVJ.
- Total weight is reduced by 48%, serviceability reduced by 53%, cost reduced by 52% & rotational inertia reduced by 40% compared to conventional splined system.
- Increased acceleration of vehicle. This design helps to reduce 0.3 sec time for 100 ft.
- The mileage of the vehicle increased by about 7.1% with the same engine.
- The braking of the vehicle is improved as we use only one brake disc at rear for two wheels.
- The problem of initial jerk to vehicle, delay in acceleration and wobbling of CVJ are solved.

## ACKNOWLEDGMENT

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