

# Design of Split or Two Piece Axle Shaft for Automotive Application

Deepak G. Jambhulkar<sup>1</sup>, Prof. Nishant Vibhav Saxena<sup>2</sup>

<sup>1</sup>M Tech Scholar, <sup>2</sup>Head of Department (Mechanical Engineering),

<sup>1,2</sup>Millennium Institute of Technology, Bhopal, Madhya Pradesh, India

## ABSTRACT

Axle is a key component in complete power transmission drive train. There are various types of axle shafts used in different type of vehicle & failure modes also of them are different. There are basic two types of axle shaft, one is used in single reduction axles & other one is used in hub reduction vehicles/axles (in other words double reduction axles). Hub reduction is nothing but the final drive reduction generally located near to wheels. Generally Axle shafts are being made up of medium carbon alloy steel with through hardening treatment. Axle shaft connects differential with wheel rim in case of single reduction axle & with sun gear in case of double reduction axles. Axle shaft transmits torsion load from differential to the wheels & prime component to generate necessary traction to propel the vehicle.

**How to cite this paper:** Deepak G. Jambhulkar | Prof. Nishant Vibhav Saxena "Design of Split or Two Piece Axle Shaft for Automotive Application" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-5 | Issue-2, February 2021, pp.1080-1092, URL: [www.ijtsrd.com/papers/ijtsrd38647.pdf](http://www.ijtsrd.com/papers/ijtsrd38647.pdf)



Copyright © 2021 by author (s) and International Journal of Trend in Scientific Research and Development Journal. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0) (<http://creativecommons.org/licenses/by/4.0>)



## 1. INTRODUCTION

The axle shaft is one of the prime components of almost all moving vehicles like Tractor, Truck, Car & specialty vehicles. It is the component which carries highest torque in complete drive train. In most of the automotive drive mechanism, drive axle shaft transmits driving torque from the power unit to road-engaging wheels of the automobile. Axle shaft usually extends from opposite sides of a differential drive unit and usually provided at their outer wheel ends with integral drive flanges which are connected to the wheels for transmission of driving power. In addition axle shafts maintain position of wheels comparative to each other & body of vehicle. Often during operation, axle shafts are subjected to heavy torques due to loads or sudden acceleration & therefore they are manufactured with special grade of hardened steels. These materials generally have alloying elements like chromium & molybdenum which give enough resistance to bending & support to minimize heat treatment distortion.

## 2. METHODOLOGY

Methodology I have used for proposing mentioned split axle shaft design is analytical, which is combination of both fundamental calculations & design verification by using available FEA & 3D modeling tools. In chapter 3<sup>rd</sup> you may find detailed specifications & calculation of strength of joint. Chapter 4 covers the design verification of its proposed split axle shaft design. In this proposal we have used fitted bolt to connect shaft body with rim mounting flange. Separate study can be done with normal bolts with through holes, which is

not in scope of this project hence not covered. All references for this study has been taken either from previously published papers or from globally available standards details of same are listed in reference section of this report. In 3<sup>rd</sup> section I tried to give all design justification for all my actions like by furnishing detailed justification of shaft diameter, minimum shaft diameter requirement, joint strength, assembly parameters & metallurgical aspects too. I am not covering design validation part of this project in this report & leaving it for future scope of work.

Outcome this project is alternate solution for recurring failure of axle shaft at rim mounting flange location. Sample picture of split axle shaft design is pictured below. We tried to cover all design aspects of this solution, details of which can be found out in subsequent literature. This proposed solution is one to one replaceable in existing vehicle with single piece axle shaft hence there is no of lifetime part storage requirement of existing shaft. No additional manufacturing or assembly set up required. Most of the assembly & manufacturing operating can be done in existing set up only. All the project work is carried in industry comparable standards &/or in software hence can be considered authentic. I am not covering design validation part of this project due to some unavoidable reasons & left for future scope for this project. Hereby I am suggesting whoever wants to implement this proposal to go ahead but have physical trials done before implementation since we are not including this part in this report.

**2.1. Vehicle considered**

For scope of this project we have taken axle shaft of 50 HP tractor. Details of Tractor is as below

Tractor HP – 50 Hp @ 2100 rpm

Rated Engine Torque – 220 Nm @ 1100 rpm

Clutch – Diaphragm type single plate dry clutch (Organic)

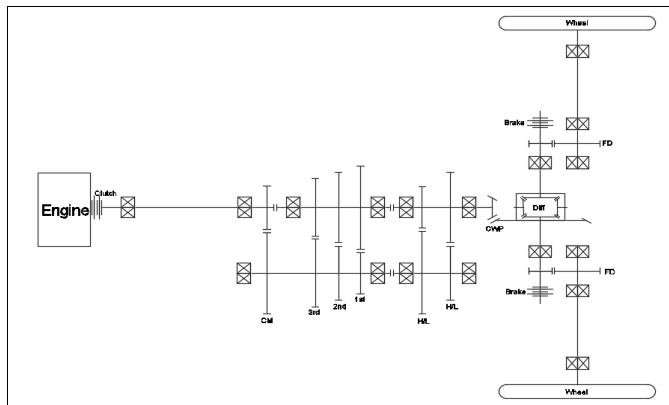
Transmission – 10 speed transmission (8 forward + 2 Reverse)

Overall Low reduction ratio – 154.35:1

Overall High Ratio – 14.2:1

Final Drive, FD– Conventional Bull gear type

Representative Power Flow diagram is shown as below,



**Figure 1 – Power Flow Diagram of Tractor Made in 2D Software (AutoCAD 13.0)**

In above figure axle shaft is member which is connected to FD gear & Wheel. In some of the vehicle axle shaft is directly connected in between wheels & differential. Such case generally occurs in vehicles with no final drive or outboard mounted final drive. Outboard mounted final drive means location of final drive is very near to wheels & axle shaft is used connect differential & input gear (sun gear) of outboard mounted final drive & not related to wheels directly.

With above arrangement torque coming on axle shaft is as follows in different gear

Gearpair	No Of teeth	Ratio	Speed	Total ratio	Wheel rpm	Tractor Speed in kmph	Torque on axle shaft, Nm
Primary	44	1.913	L1	154.35	13.61	3.43	16978.81
	23		L2	88.02	23.86	6.02	9682.13
1st	44	1.913	L3	63.70	32.97	8.32	7006.80
	23		L4	42.18	49.79	12.57	4639.35
2nd	36	1.091	H1	51.95	40.42	10.20	5714.82
	33		H2	29.63	70.88	17.89	3258.86
3rd	30	0.789	H3	21.44	97.95	24.73	2358.39
	38		H4	14.20	147.93	37.35	1561.54
Low	45	1.957	R1	107.58	19.52	4.93	11833.71
	23		R2	36.21	58.00	14.64	3983.05
Hi	41	1.519					
	27						
CWP	35	3.182	SLR	0.67			
	11		Engine rpm	2100			
FD	58	4.462	Enging torque	220			
	13						
R1	23	0.697					
	33						
R2	44	1.913					
	23						

**Table 1 – Speed Chart**

Some legends for above table,

SLR – Static loading radius in meters (Tyre considered is 16.9x24-16PR)

L1, L2, L3 & L4 – Vehicle gears in Low operating mode

H1, H2, H3 & H4 – Vehicle gears in High operating mode

R1 & R2 – Vehicle gears in Reverse operating mode

Ratio – Reduction ratio (no of teeth of driven gear/no of teeth of driver gear)

CWP – Crown wheel & pinion

FD – Final Drive

Engine rpm – rated speed on engine

Total Ratio – Is overall ratio in particular engaged gear

Kmph – vehicle speed in kilometer per hour

Nm- Unit of torque in Newton meters

Note – Torque on both Axle shaft (Total torque on both wheels) is multiplication of Engine torque, Total reduction ratio in particular gear.

Torque on axle shaft is calculated by multiplication of engine torque & ratio, divided by 2.

For example, in L1 gear,

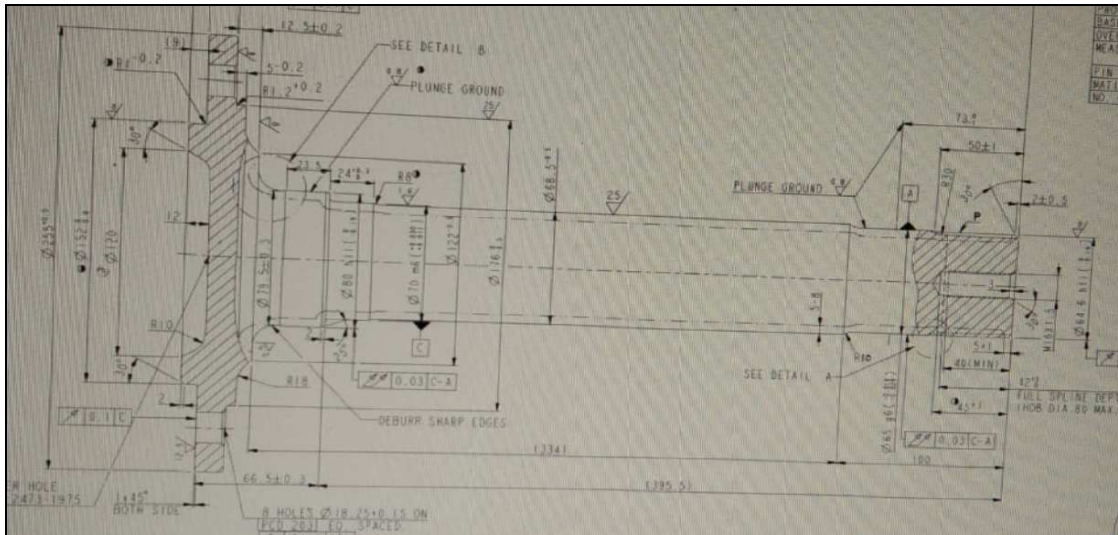
Torque on each axle shaft = (engine rated torque x total ratio in L1 gear) / 2

$$= (220 \times 154.35) / 2$$

$$= 16978.8 \text{ Nm}$$

So torque on each axle shaft in Lowest Gear i.e L1 is 16978.8 Nm.

Below is the representative axle shaft drawing used in above vehicle. Please note that this is not exact part, just for understanding I am showing how integral shaft looks like. You can see shaft diameter to transmit 16978 Nm torque is 68.5 (16978 Nm is torque coming on axle shaft in 1<sup>st</sup> low gear i.e. max torque condition with respect to all other gears). We will definitely be correlating or justifying minimum shaft via requirement to transmit such high torque. As I mentioned in earlier segment that special steel having alloying elements like chromium & molybdenum used to make such shaft. These alloying elements helps or give strength against bending & torsion & in addition helps to reduce heat treatment distortion. Generally used material for such shafts are SAE 4140, SAE 1010 & EN23. All such shafts are through hardened to 42-48 HRC & bearing seating & surface areas are induction hardened to surface hardness up to 55 HRC. In below picture induction hardening pattern is shown in dotted lines with specifying depth of hardening. Care should be taken while mentioning depth of hardness. Shaft should give enough resistance to twisting load & should not be brittle at same time.



Picture 2 - Representative 2D drawing Pictures of axle integral axle shaft



Picture 3 - Representative 3D Image of axle integral axle shaft

Note - Source of above two images is Web only (google search)

2.2. Input Parameters:

Below table gives various inputs parameters, constrains & boundary conditions used for performing the FEA

Input Parameters		
Load/ Torque	Max, Nm	16978
	Min, Nm	1562
Material Properties	Tensile strength, Mpa	1275
	Shear Strength, Mpa	725
	Density, Kg/mm <sup>3</sup>	0.000000786
	Youngs modulus	2.08x10 <sup>6</sup>
	Poison's ratio	0.3
Elemental / Nodes for FEA	Type	Tetrahedral
	Element Size	2 to 5mm
	No of nodes	397458
	No of Elements	248591
Tightening torque on bolts	kg-m	19.5
Boundary Conditions		
Limiting Stress	Max Principle stress, Mpa	483.333
Shaft Diameter	Minimum	Limited by Differential
	Maximum, mm	80
Number of bolts	Minimum	2
	Maximum	10
Constrains		
Area of Load Application	On Splines	-
Area of Holding the Shaft	Rim Mounting Flange	-
Rim Seating diameter	152	-
Rim mounting PCD, mm	203	-

Table 2 - Input Parameters

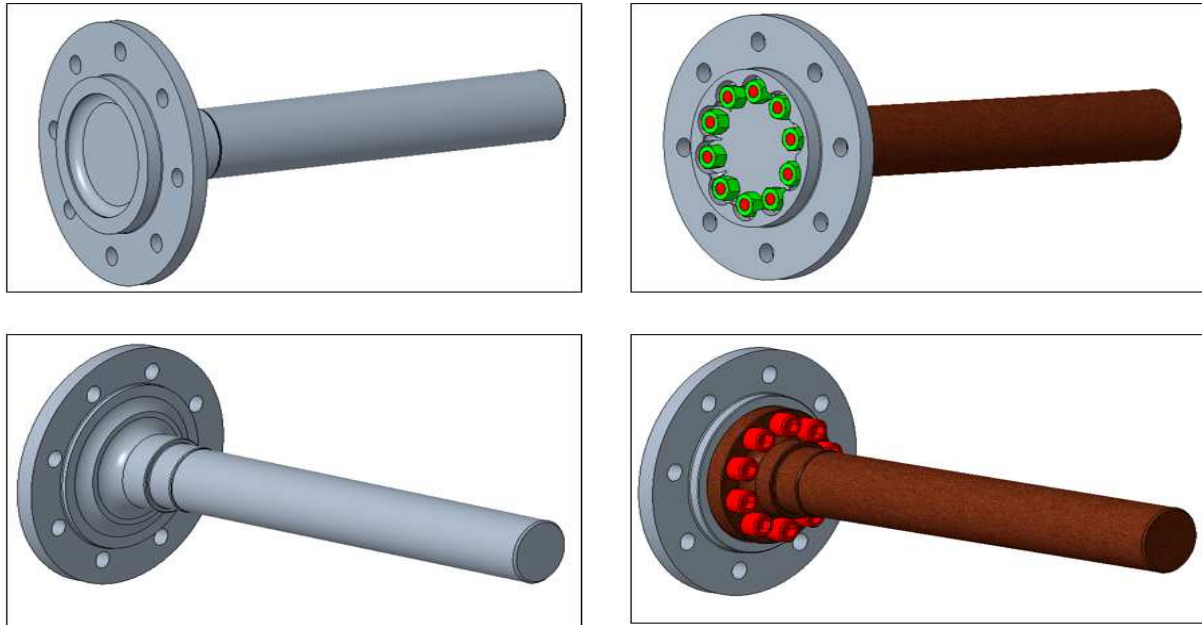
One can refer detailed loading sheet & material standard for cross verifying above details. For other information detailed look on complete document is required. Request to please go through the complete document to have better understanding on above table.

### 2.3. Modeling of Split Axle shaft Design

Modeling & assembly of new axle shaft design is being done in Creo 4.0. as against single part we have 4 parts in new design & those are

- A. Shaft
- B. Flange (Rim mounting flange)
- C. Special Allen Bolt of M16
- D. Nut

All above parts are modeled/created in Creo 4.0 by using commands like Extrusion, Revolve, Pattern, Through Holes, Fillet, Chamfer, etc. Assigned material for shaft & flange is En43 which is medium carbon steel, for special Allen bolt material is C45 which is plain medium carbon steel & nut is standard bought out part made up of again medium carbon steel.



Picture - Pictorial Comparison of Existing Integral Axle shaft (Left ones) & Split Axle shaft (Right Ones)

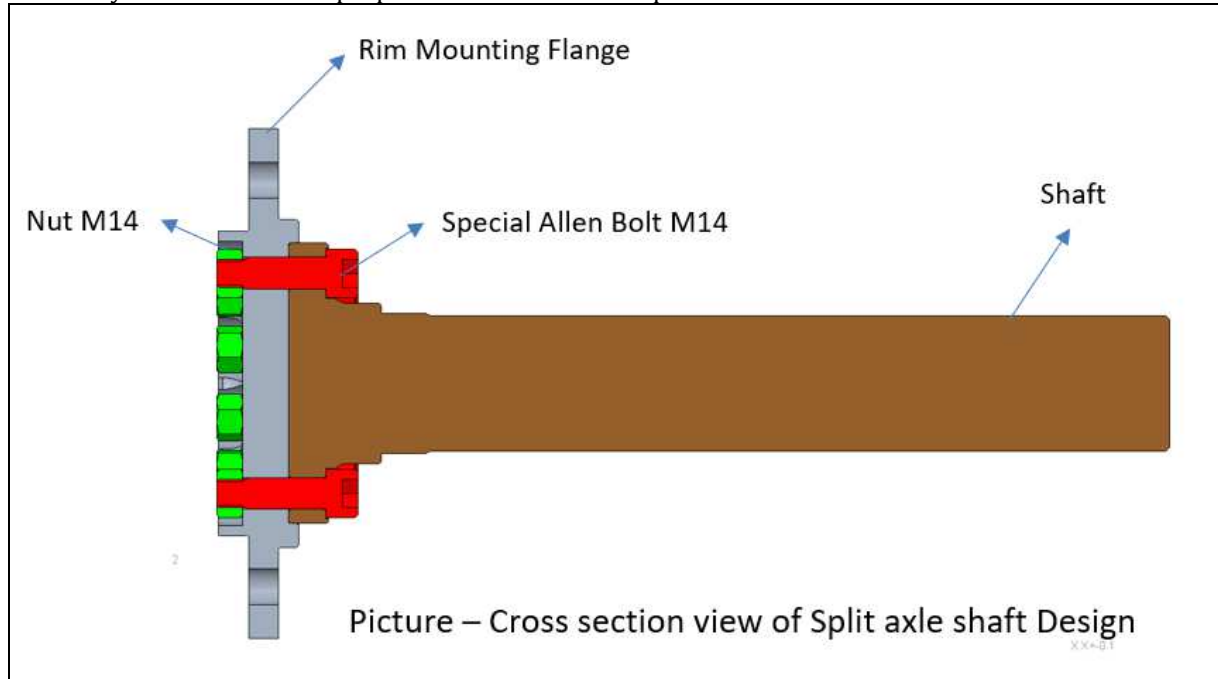
Assembly of all 4 parts mentioned above is being done in Creo .asm module of this software. Some detailed pictures are shown as below. A detail of each part is coming in subsequent literature. Each part has its different role to play while transferring power from Differential to wheels in assembly. Rim mounting flange facilitates mounting of rim on its pilot diameter in turn bridges connection between axle shaft & wheels. Shaft carries power from differential (in other words from Crown wheel) & delivers it to wheels through rim mounting flanges. Special Allen bolt connects shaft & rim mounting flange & helps to transmit torque from shaft to flange. And finally nut is use to hold the shaft & flange together in all operating conditions. In this assembly we have used 10 mountings that means 10 special Allen bolts & 10 M14 nuts. Standard tooling & fixtures can be used to have this assembly ready. Tightening torque for tighten the nut is standard m14 tightening torque i.e. 158 Nm.

In all 4 parts special or critical part is Special Allen bolt of M14. In this assembly this bolt is designed in a way that its shank diameter will get press fitted in finished hole of rim mounting flange. These press fitted diameters will facilitate transmission of power through the diameter of shank that is dia 16.

As all we know there are 2 methods of power transmission in any joint. First is power gets transmitted through the friction created in between joint which all depends on tightening torque, friction coefficient of both mating material & direction of rotation. In second case power gets transmitted through diameter of connecting member like solid dowel which is you can say positive power transmitting method. In earlier case we may get some power loss due to some ineffective assembly procedure or over the period delay in tightness of joint. Preferred joint for power transmission is positive power transmission without any loss in joint. We used same positive power transmission method in our proposal where power is getting transmitted through shank diameter of special Allen bolt of M14.

In our case special Allen bolt is press fitted (interference fit) to both shaft & rim mounting flange at all 10 mounting locations. Special mounting/pressing can be developed for Allen bolt assembly. Most of the time such pressing facility is available in most of the organization which doesn't call for any additional initial investment. While assembly its better to use/apply Loctite 260 on outer diameter of Allen bolt which ensure &/or give more structural/joint strength to subject joint. Loctite 260 is adhesive generally applied on outer diameter of threaded portion of bolt before assembly. Details of same is furnished in detailed annexure. As a standard practice after application of Loctite on outer diameter of threads its better to keep bolt in open air for some time around 10 minutes to get it cured.

Detailed assembly cross section is of proposal is shown in below picture.



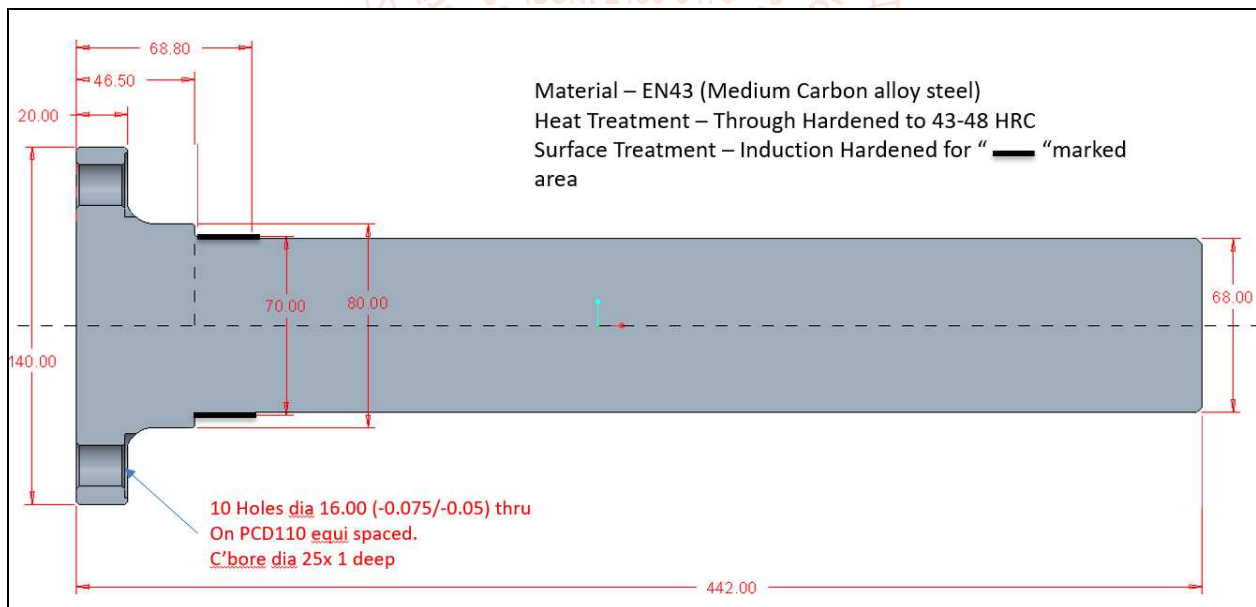
Picture 4 – Cross section of New Split Axle shaft design

**2.4. Dimensional details of all 4 parts:-**

**A. Shaft:-**

Generally all transmission shafts are being made up of Medium carbon alloy steel & through hardened to 43-48 HRC to have enough toughness to sustain shock loading. All bearing seating diameters are surface hardened to 55-58 HRC to match bearing surface hardness to avoid unnecessary wear or damage during bearing fitment. Bearings are press/interference fitted on axle shaft. Mentioned Surface hardness is achieved through induction hardening process varies for Low carbon alloy steel either case carburizing or case nitriding is being done to achieve the specification i.e. Surface hardness of 55-58 HRC.

Generally forging of axle shaft will have at least 3mm material stock in all place to facilitates for machining. As a first process after forging is normalizing to reduce residual internal stresses. Surface finish at bearing locations is at least 3.2microns & generally can be achieved through high speed turning or hard grinding process. In our proposal we kept all seating/mating details like bearing seating, oil seat seating, rim mounting details & other details as well exactly same as original existing design. So there no issue of interchangeability. Dimensional details of proposed shaft is shown in below picture.



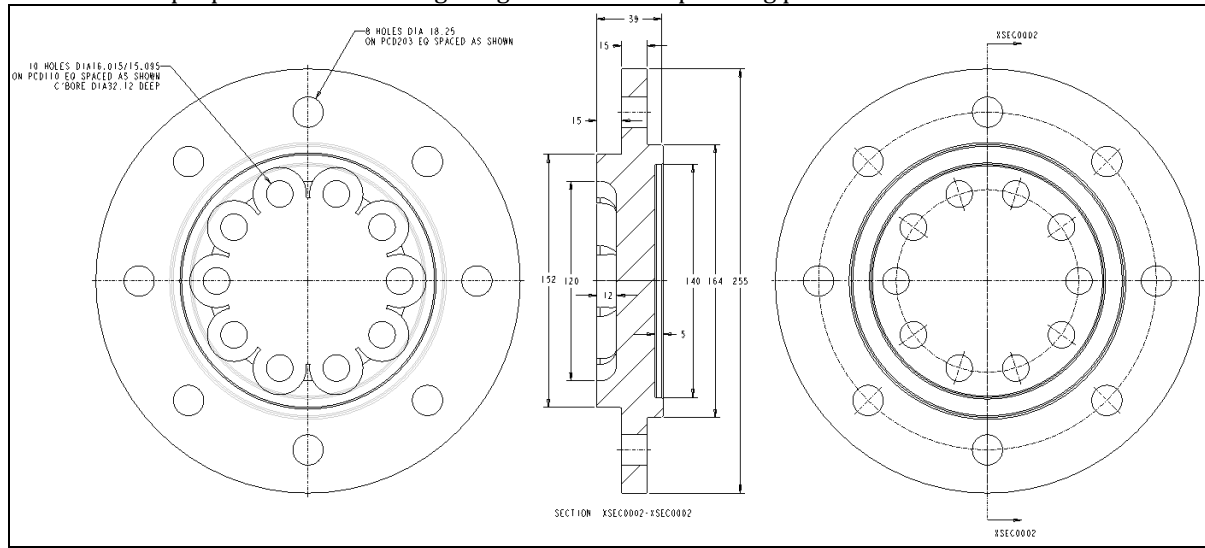
Picture 5 – Cross section view of proposed shaft (One part of design)

**B. Rim Mounting Flange:-**

As I have mentioned in earlier segment, this flange facilitates rim mounting & connect between wheel & shaft. Generally all such flanges are made up of Medium carbon alloy steel with through hardening up to 42-45 HRC. No special surface treatment is being performed on this part. After forging normalizing is must to reduce residual internal stresses build up due to hot working process. Surface finish in all mating areas like rim seating & shaft butting faces can have 3.2 microns surface finish which can be achieved through high speed turning.

One point to be noted here is shaft mounting holes must be rimmed to achieve specified tolerance values otherwise we will not required interference amount between joint. This part can be made up from 2 different routes. First one through forging & second is from cutting it from readymade forged plates available in market. But due to requirement of specific grain flow in such power transmission parts people prefers to go with new forging which incurred one time tooling cost. In some cases form tooling is also required if shoulder matching radius is different or specific than standard tooling.

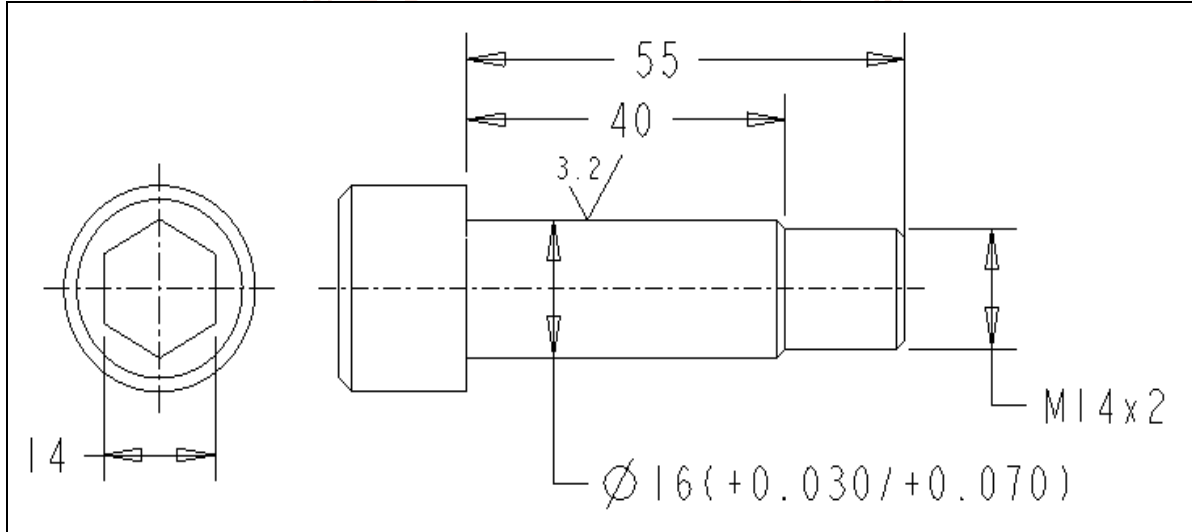
Dimensional details of proposed Rim mounting flange is shown in upcoming picture.



Picture 6 – 2D Drawing of proposed Rim mounting Flange (One part of design)

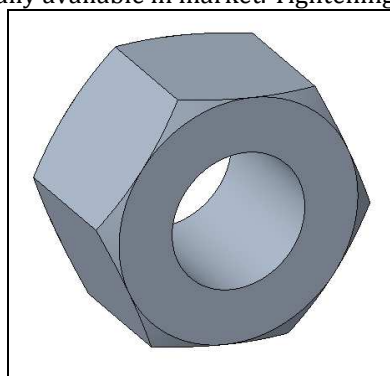
**C. Special Allen Bolt:-**

This bolt is used to connect Rim mounting flange with shaft & facilitates positive power transmission from shaft to wheels. Since we need interface on shank diameter of bolt its different than conventional standard M14 bolt. Material for this bolt is again medium carbon steel, C45, though hardened to 42-45 HRC. Special rust preventive coating is necessary to avoid any rust over long period of time because such small hardware components needs to be purchased in bulk, store for relative long period of time & consume as & when required. Hence chances of getting rusted is more compared to other high values item & due to this rust preventing coating like zinc plating or blackdising is necessary for such small parts.



**D. M14x2 Nut:-**

This is standard M14 coarse pitch nut & readily available in market. Tightening torque on nut is 158 Nm.



Picture 7 – 3D view of proposed Nut (One part of design)

**2.5. Assembly Parameters For this split axle shaft design:**

- A. Fit between Shaft & Rim mounting flange – Close clearance/Locating fit
- B. Fit between Special Allen bolt & Holes in shaft & Flange – Interference/press fit
- C. Interference amount of above joint –  
Maximum interference = 16.070 – 15.95 = 0.075mm  
Minimum Interference = 16.030 – 16.015 = 0.015mm
- D. Retrofit design. We can replace existing single piece axle with this split version axle shaft without changing anything.
- E. No separate tooling required to implement this design

**2.6. Minimum shaft diameter requirement**

Before directly jumping into ANSYS for crosschecking this new proposed design lets do the minimum shaft diameter calculation to transmit the torque values of which are mentioned in speed chart. For simplicity we will do the calculation only for worst load case. Logic behind this is if shaft is capable to transmit highest torque value in system & found safe then need not to calculate for torque values coming at higher gears. In Lowest gear i.e. L1, 1<sup>st</sup> low gear torque coming on axle shaft is 16978 Nm & is highest among all the torques coming on different gears starting from L2 to H4 & including reverse gears also. We can calculate equivalent stress or suitability of axle shaft considering all torque values & their percentage usage by using cumulative damage theory. But if shaft is safe at worst load case then calculation by cumulative damage theory is not required. Anyhow intent of this is not to assess torque carrying capacity of shaft. Main intent is to evaluate the torque carrying capacity of flange & shaft joint.

In next section we will be carrying strength evaluation of Flange & shaft joint also. Roughly if existing integral shaft of diameter 68.5mm is working well in vehicle without any problem then if we keep same or slightly more shaft diameter then logically ours shaft also should work. But anyhow we will do detailed theatrical study to back our study & evaluate in ANSYS for more surety. Generally all final drive shafts or axle shaft are going into torsional loading. Material used for such shafts are medium carbon alloy steel like EN43, SAE1010 or SAE 4140. There are lots of grades available in market to meet the specification of axle shaft but above mentioned materials are widely used in industry & can say proven over the period of time. As I mentioned in earlier section these shafts are generally through hardened to 42 to 48 HRC to have enough core toughness to withstand any shock loading arise due sudden braking or sudden acceleration. After through hardening, surface treatment of induction hardening is usually carried out to have surface more hardened to have more torsional strength. As I mentioned earlier all the axle shafts are loaded with torsional stress & to tackle this high magnitude torsional loading shaft should posses enough torsional strength & hence usual method to achieve torsional strength is to have surface hardened by specified hardness up to certain depth. Depth of hardened depth is depending on strength requirement.

Below section will give you complete details of shaft diameter calculation & relevant details like material, its strength, its process & others if any. Generally where torsional rigidity is more important than bending strength its better to have hollow shaft. Hollow shaft gives more rigidity because of its advantage of slenderness ration over

solid shaft. But due manufacturing complexity sometimes it is not advisable. Hollow transmission shafts gives more rigidity hence deflection of such shafts is very less compared to solid shafts. These type of shafts are very common in transmission systems where we don't want deflection or very minimal deflection is allowed. General use of Hollow shafts are Lay shaft or counter shafts in transmission which carries all fixed gears along with bearings.

Now coming to calculation of minimum shaft diameter. Below are the material & other specifications of shaft

1. Material used – EN 19 As per BS 970 (Old specification is 709M40)  
Equivalent Materials – SAE 4140 / 42CrMo4
2. Forming Process – Forged & normalized
3. Heat Treatment – Through Hardened to 42-48 HRC
4. Surface Treatment – Induction hardened to 55-58 HRC upto 6-8mm depth  
(we can calculate exact amount of case depth but that is not our intent hence kept same as reference existing axle shaft)
5. Tensile strength – 1275 Mpa
6. Grain size – ASTM 7

Shaft diameter calculation is based on max shear stress Failure theory. According to this theory shaft diameter is given by below formula,

$$\tau = \frac{16M_t}{\pi d^3}$$

Where,

- $\tau$  – Shear strength of material
- $M_t$  – Torque coming on shaft
- d- shaft diameter

in our case, magnitude of  $\tau = 0.577 \times$  tensile strength  
 $= 0.577 \times 1275$   
 $= 725.289 \text{ Mpa}$

Putting  $M_t$  as 16978 Nm torque in above formula,

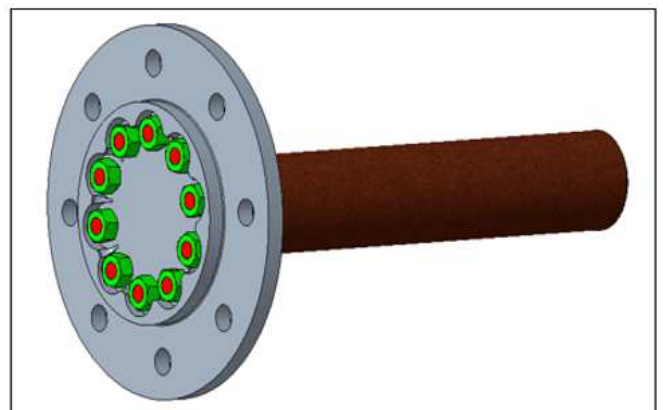
$$d^3 = (16 \times 16978 \times 1000) / (725.289 \times 3.14)$$

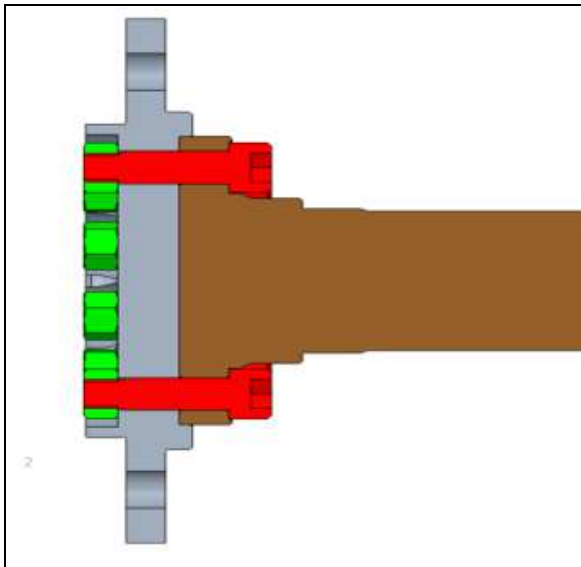
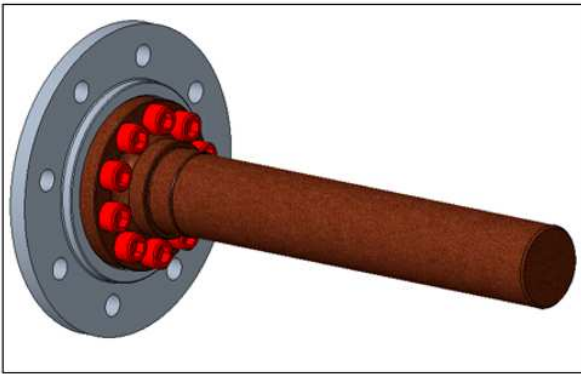
$$d^3 = 115349.46 \text{ mm}^3$$

hence d= 48.67 mm & with 68 mm dia shaft our Factor of safety is 1.4.

**2.7. Joint Strength Calculation**

Joint in discussion here is bolted joint which connects shaft with rim mounting flange. Picture is shown below for ready reference.





Basically there are two types of bolted joint. 1<sup>st</sup> one is joint where standard bolt goes in clearance hole & there no any radial contact between shank diameter or outer diameter of bolt with inner diameter of receiving hole. In this joint power or torque is getting transferred through the friction created in between mating surfaces. A major contributing factor in this joint is coefficient of friction between mating parts, tightening torque & class of bolt (strength of bolt). Such type of joints are not really positive joints & prone of lose its strength over period of time due to several reasons. Such type joints should be used for relative not so essential joint or for just fitment purposes.

Second type of joint is joint where Special bolt (Fitted/Grind bolt) goes in controlled receiving hole. In such joint there is small amount of interference between outer diameter of bolt & receiving hole. In such type of joints bolt's shank diameter & receiving hole are closely controlled by grinding or high speed turning process (rimming in case of hole) to have specified inference in between both parts. This interface facilitates joint to behave like integral part & ensures positive torque transmission. Instead of hammering to achieve press fit in assembly, you will find most sophisticated pressing methods like nitrogen cooling or induction heating of relevant parts in some precision equipment like marine gearboxes or in aircraft subsystems. As I mentioned earlier design of both portions means shank of bolt & receiving hole is special in nature & required necessary care in producing these portion of parts. Such type of joint you can find in rigid couplings where there is requirement of positive power transmission without any slip or power loss. In this joint bolt is always assisted by accomping nut. In some applications people are using normal class 10 nut but in most of the application nut is self-locking nut like nyloc nut. Details of Nyloc nut furnished in

reference section of this report. In our proposal I am using normal nut for keeping this study simple. And instead of standard hexagonal headed scw, I am using Socket headed cap screw (Allen) due space constraints. Details of both parts is furnish in subsequent paragraphs. Red colored part in above pictures is special allen bolt of M14 & green colored parts is standard M14 class 10 nut.

Below are the details of parts used in joint,

1. Special Socket Headed Cap Screw (Allen)-  
Size - M14 x 2 x 50 (2 is pitch of thread & 50 is length of bolt)

Material used - Medium carbon steel, C45 or En19 or any equivalent

Heat Treatment - Through hardened to 42-45 HRC

Surface treatment - Zinc plating (or any other rust preventing surface treatment)

2. Nut-

Size - M14 x 2

Material used - Medium carbon steel, C45

Heat Treatment - Through hardened to 42-45 HRC

Surface treatment - Zinc plating (or any other rust preventing surface treatment)

(This is standard part & easily available in market, need not to manufacture separately like bolt)

Calculation of Torque carrying capacity of joint-

In case of fitted bolt, torque is getting tranfred through shank diameter of bolts & amount of transmitted torque can be given by below formula,

$$M_t = P \times \frac{D}{2} \times N$$

In above formula,  $M_t$  = transmitted torque in Nm

$P$  = Force coming on each bolt in N

$D$  = Pitch circle diameter of bolt mounting in mm

$N$  = Number of bolts

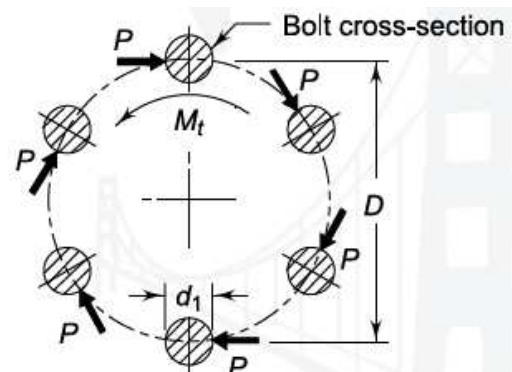


Figure - Shear Resistance on Bolts

Above figure shows loading behavior of bolts & it should be noted that bolts are subjected to direct shear & not torsional shear stress. No torque is acting about the axis of bolts. Force  $P$  results only in direct shear stress which is given by following formula,

$$\tau = \frac{P}{\left(\frac{\pi}{4} d_i^2\right)}$$



where,

$$\tau = \text{shear stress in the bolt (N/mm}^2\text{)}$$

$$d_1 = \text{nominal diameter of the bolt (mm)}$$

From above 2 equations,

$$\tau = \frac{8M_t}{\pi D N d_1^2}$$

In our case shear strength of bolt is  $0.577 \times 1275 = 735.67$  Mpa

(Bolt material is through hardened for which tensile strength is 1275 Mpa. Pl refer material standard in reference section)

Pitch circle diameter,  $D = 110$  mm

Nominal Shank/bolt diameter,  $d_1 = 16$ mm

Number of bolts,  $N = 10$

If we Put all above values in formula, we will get torque carrying capacity of joint,

Hence Torque carrying capacity

$$M_t = (735.67 \times 3.14 \times 110 \times 10 \times 16^2) / 8$$

$$= 81312133.76 \text{ N-mm}$$

$$M_t = 81312.133 \text{ Nm}$$

Considering factor of safety of 1.5,

$$\text{Torque transmitting capacity of joint} = 81312.133 / 1.5$$

$$= 54208.089 \text{ Nm}$$

This torque values is much greater than max torque coming in L1 gear hence number of bolts & diameter of bolt is ok for our proposal.

### 3. DESIGN VERIFICATION

Design Verification is a tool or guideline to aid designers in ensuring right first time in designing, manufacturing and / or assembly of large-scale components. The guidelines were developed as a tool to inform and direct designers during early stage design phases to trade off estimated measurement uncertainty against tolerance, cost, assembly, measurability and product requirements. Design verification is where you verify your design intent has been met or not. There is basic difference between design verification & design validation, design verification is part of design development process & validation is after development. Design verification includes virtual testing like FEA while validation includes physical tests. These are basically five steps in design verification phase & they are Identifying & preparing, Planning, Developing, Executing & reporting. All five words or terms are self-explanatory hence not writing too much to give information in detail for those. As a part of design verification of our design of split axle shaft, We have analyzed this new proposal in ANSYS Workbench 12.0. Some of the details are mentioned in subsequent literature.

The finite element method (FEM) is the most widely used method for solving problems of engineering and mathematical models. Typical problem areas of interest include the traditional fields of structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. The FEM is a particular numerical method for solving partial differential equations in two or three space variables (i.e., some boundary value problems). To solve a problem, the FEM subdivides a large system into smaller,

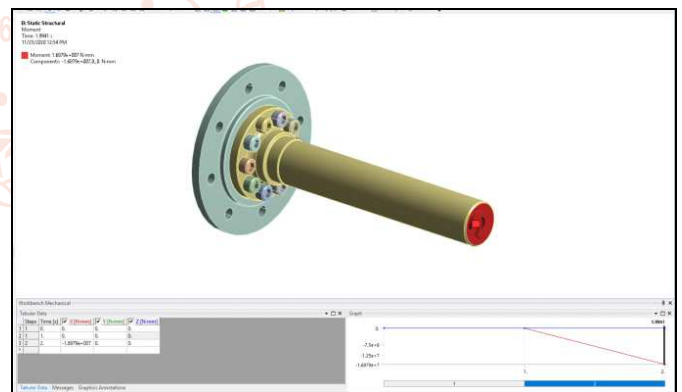
simpler parts that are called finite elements. This is achieved by a particular space discretization in the space dimensions, which is implemented by the construction of a mesh of the object: the numerical domain for the solution, which has a finite number of points. The finite element method formulation of a boundary value problem finally results in a system of algebraic equations. The method approximates the unknown function over the domain.[1] The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. The FEM then uses variation methods from the calculus of variations to approximate a solution by minimizing an associated error function.

Studying or analyzing a phenomenon with FEM is often referred to as finite element analysis (FEA).

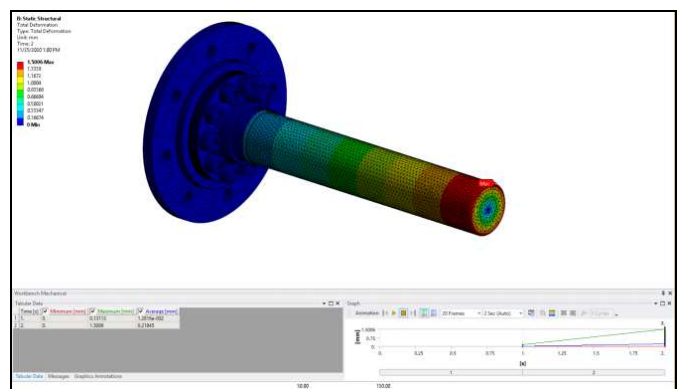
In next section we have furnished brief summary of our FEA study wherein you will find stress plots & stress charts for respective components. All these pictures are nothing but the screen shots from ANSYS window.

### 4. RESULTS

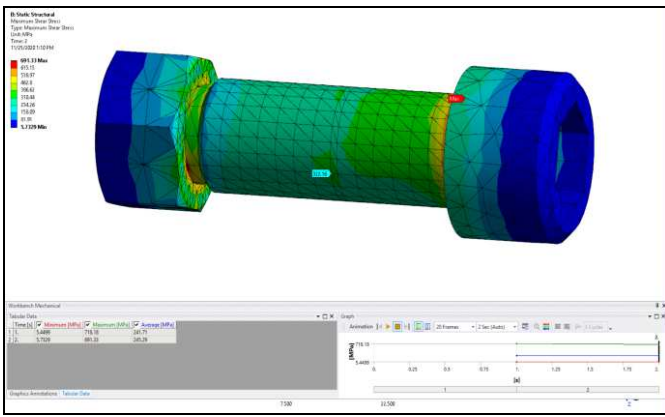
As we mentioned in earlier sections, for doing FEA analysis of our proposal we applied maximum torque on spline (which goes in differential) & arrested wheel rim mounting flange. Below are some of the plots captured from Analysis part. First picture shows set up of model in Ansys, area of application of force, constrains location & magnitude of force. Second picture is of assembly result window wherein you can see stress zones in various area/cross section in assembly. Pl make a note here that our area of interest is joint location only. Third picture is for strength of bolt. All the torque is getting transferred through shank diameter of bolt hence its very important that shear stress on bolt should be less than shear strength of bolt material. Forth picture is for showing shear force & bending moment plot for joint.



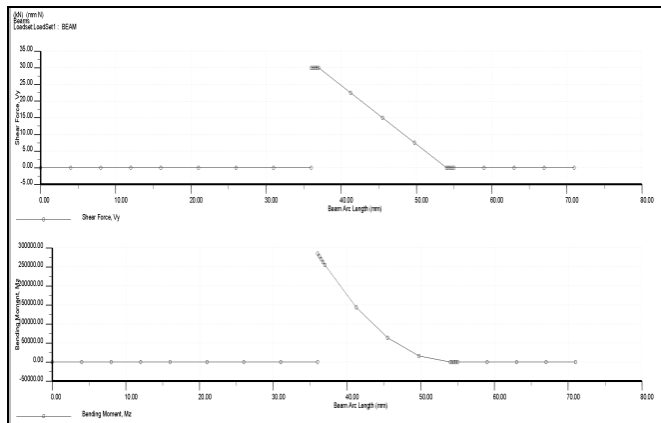
Picture 19-FEA Set Up



Picture 20 – Stress Result Plot, Assembly



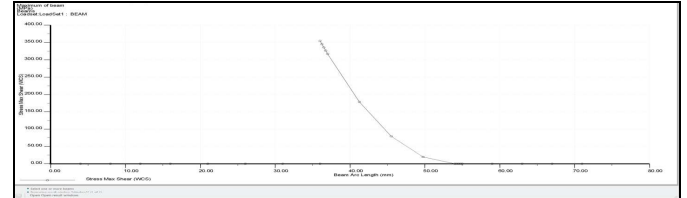
Picture 21 – Max Shear Stress Result Plot, Bolt



Picture 22- Graphical Stress Curve

Analysis performed is structural linear analysis to assess joint under consideration. If you can see in third picture maximum shear stress is coming at the junction plane where shaft & rim mounting flange butts is 322.16 MPa.

In above Analysis our area of concern was to assess strength of all ten bolts for specified torque transmission. After applying specified torque below is the graphical representation of shear stress coming on the cross section of shank diameter at shaft & rim mounting flange butting plane.

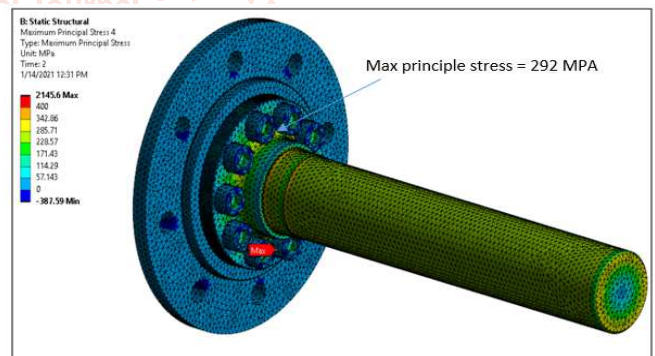
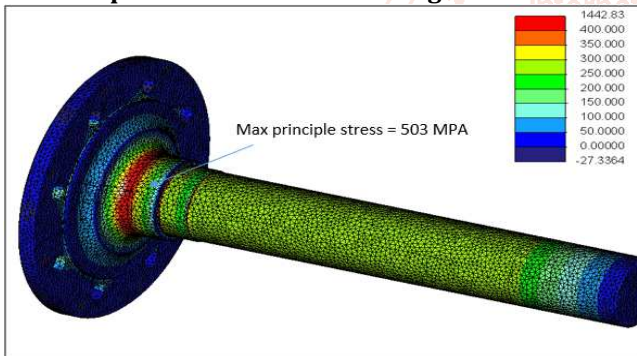


Graph 1 – Stress Plot at Junction

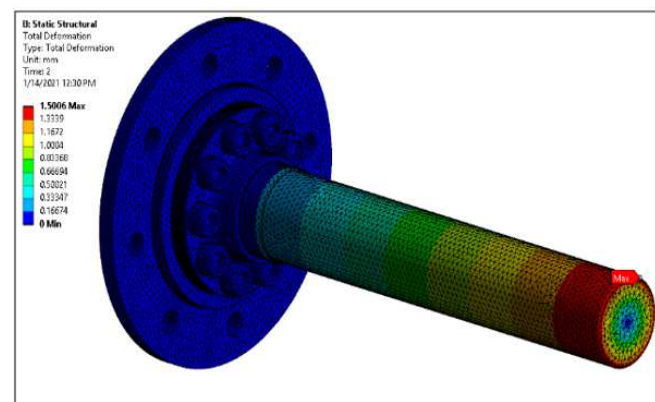
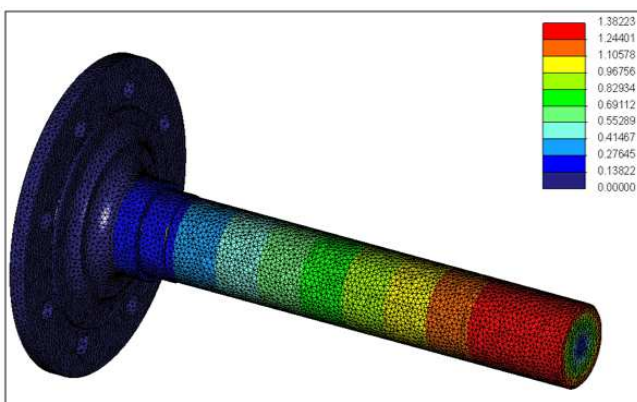
In above picture, along x axis is the engagement length of bolt starting from zero to 80mm & y axis is for shear stress at each plane. So if you can see maximum shear stress of 322Mpa is coming exactly at junction plane. This maximum shear stress is well within acceptable value of shear stress of bolt material that is 753 Mpa. So with this coming shear stress, factor of safety of bolt or in large context joint is  $735.67/322 = 2.28$ .

So with above ANSYS analysis we can conclude here that our joint is safe & will transmit specified torque without any problem.

Stress comparison of New & Old Design –



Picture 23 – Maximum Stress Comparison of OLD & NEW Design



Picture 24 – Displacement Comparison of OLD & NEW Design

From above comparative pictures you will see the clear-cut differentiation of lowering of stress in new design. In addition to this displacement pattern of both designs are more or less same.

Hence hereby we can conclude that New Split axle shaft design is better in strength compared to existing single piece design.

## CONCLUSION

Based on results furnished in previous section we can authoritatively say that this propose design is safe & replaceable to existing single piece design which is prone to failure at neck section of rim mounting flange. This new design has following advantages over existing single piece design,

- A. More Reliable – Since this new design addresses the failure at neck section of flange in existing design by eliminating root cause of failure, this new design is more reliable than existing single piece design.
- B. Easy for servicing – Due to split axle shaft design it is very easy to dismantle & assemble again wheel portion of axle assembly. And cost wise also if something like flange or shaft fails, its very economic to replace only flange or shaft instead of replacing whole thing again.
- C. Retrofit table design- New design is one to one replaceable without disturbing vicinity parts in assembly.
- D. No life time requirement of existing design shaft – Since new design is one to one replaceable hence there is no need to keep inventory of existing design as a spare for already sold vehicles.

## REFERENCES

- [1] Palak Bhagoria, Siju Tom John, Palash Patangia and Rajesh Purohit. Failure Analysis of the Axle Shaft of an

Automobile. Materials Today: Proceedings 4 (2017) 5398–5407

- [2] Osman Ali. Fatigue failure of a rear axle shaft of an automobile. Engineering Failure Analysis 13 (2006) 1293–1302
- [3] H. Bayrakceken , S. Tasgetiren, I. Yavuz. Two cases of failure in the power transmission system on vehicles: A universal joint yoke and a drive shaft. Engineering Failure Analysis 14 (2007) 716–724
- [4] G. K. Nanaware, M. J. Pable. Failures of rear axle shafts of 575 DI tractors. Engineering Failure Analysis 10 (2003) 719–724
- [5] Li-Hui Zhaoa, b, Qing-Kun Xingc, Jia-Yu Wangd, Shen-Long Lic, Song-Lin Zhenga. Failure and root cause analysis of vehicle drive shaft. Engineering Failure Analysis 99 (2019) 225-234.
- [6] Commercial Administrative test report of Eicher 557. CENTRAL FARM MACHINERY TRAINING & TESTING INSTITUTE. Govt of India.
- [7] British Standard BS 970-3:1991. Specification for Wrought steel for mechanical and allied engineering purposes. Part 3
- [8] Handbook of Machine Design. V. B. Bhandari

