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Modeling and Simulation of a 3-Wheel Rear Axle

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ABSTRACT

All commercial vehicles have some type of axle shaft-differential assembly incorporated into the driveline. Rear wheel drive is a common form of engine-transmission layout used in automobiles. Rear wheel drive means the power from the engine and the transmission goes to the rear wheels. In operation, axle shafts are generally subjected to torsion stress and bending stress due to self-weight or weights of components or possible misalignment between journal bearings. Thus, these rotating components are susceptible to fatigue by the nature of their operation and the fatigue failures are generally of the torsion, rotating-bending, and reversed (two-way) bending type.

The Objective behind creation of this project is that Indian roads which have bad riding quality, poor geometrics, and insufficient pavement thickness:all these factors affect the life of axle and also not much research has been done in this area.There is strong need of this project because in a three wheeler there are many things which can be improved or prevented like:-

1. *Breaking/failure of rear wheel axle.*
2. *We can increase the efficiency of axle.*
3. *We can use that material in axle which is less costly and has longer life.*
4. *We can improve on the axial design. 5. Not much research has been done.*

Different tests were performed on the existing axle. Then all the readings and results were taken into account and different materials were selected and calculations were done on them regarding different diameters. At last the best material was selected and was fabricated; also we have calculated the amount of fuel saved from this project

Keywords: *Rear Wheel Drive; Torsion Stress; Bending Stress; Fatigue; Journal Bearings*.

1.0 Introduction

As we all know that 3 wheeler is related to auto in India, so we have done testing on auto's rear axle , as India is in south of Asia so due to this there axle suffers a problem of tensile and compressive forces on a particular part or together we can say it as fatigue.

A fatigue failure can be recognized usually by the pattern of lines, beach marks, which results from progressive fracture under successive load cycles.

These marks are not easily seen if failure is due to relatively few cycles at stress amplitudes or brittle fracture occurs after the fatigue failure has progressed only a very short distance. A fatigue failure begins at a point where repeated plastic strain occurs under cyclic loading. Fatigue failure usually, but not always, begins on the surface of the material. Failure can be originated below the root of splines, at the transition zone between core and the induction hardened case.

There are a couple of axles on cars, some are straight, and simple, and usually don't need replacing unless you have been in an accident, others employ "universal joints" and can fail putting you and your car at risk. Before they fail though, they will begin to squeal and make a lot of noise.

In general axle is a rod or shaft that is spun to transfer rotational energy from one side of the axle to an object at the other side of the axle some distance away from the source.

In a car there will be an axle between your transmission and your wheel, or there will be one in-

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between your transmission and your differential housing, in that case, your differential housing will have one axle coming from it going to each wheel.

Axles are an integral component of a wheeled vehicle. In a live-axle suspension system, the axles serve to transmit driving torque to the wheel, as well as to maintain the position of the wheels related to each other and to the vehicle body.

The axles in this system must also bear the weight of the vehicle plus any cargo.

A non-driving axle, such as the front beam axle in Heavy duty trucks and some 2 wheel drive light trucks and vans, will have no shaft.

It serves only as a suspension and steering component. Conversely, many front wheel drive cars have a solid rear beam axles.

2.0 Mechanical Testing

To start we have taken a rear axle shaft and we have performed following mechanical testing:

1. TORSION TEST 2. IMPACT TEST
3. HARDNESS TEST
4. BENDING TEST
5. SPECTRO TEST

2.1 Torsion test

Generally, torsion occurs when the twisting moment or torque is applied to a member. The torque is the product of tangential force multiplied by the radial distance from the twisting axis and the tangent, measured in a unit of N.m.

In torsion testing, the relationship between torque and degree of rotation is graphically presented and parameters such as ultimate torsional shearing strength (modulus of rupture), shear strength at proportional limit and shear modulus (modulus of rigidity) are generally investigated.

Moreover, fracture surfaces of specimens tested under torsion can be used to determine the characteristics of the materials whether it would fail in a brittle or a ductile manner.

In order to study the response of materials under a torsional force, the torsion test is performed by mounting the specimen onto a torsion testing machine, and then applying the twisting moment till failure.

Fig 1: Torsion Test Result

Formula used: - **T/J=Gα/L**

T, torque= FINAL - INITIAL = 1300Kgm-0.66Kgm

= 1299.34Kgm

J, polar second moment of area= (PIE/32) X D4,

AS D = 1.815cm

G, Modulus of Rigidity=???

α, angle of twist=538 DEGREE =9.38

L, length of shaft=36.3cm

AFTER CALCULATATION WE FOUND OUT

THE VALUE OF

MODULUS OF RIGIDITY AS = **47.4 G N/m^2**

2.2 Impact test

Charpy impact test is practical for the assessment of brittle fracture of metals and is also used as an indicator to determine suitable service temperatures. The Charpy test sample has 10x10x55 mm3 dimensions, a 45o V notch of 2 mm depth and a 0.25 mm root radius will be hit by a pendulum at the opposite end of the notch as shown in figure 2.

To perform the test, the pendulum set at a certain height is released and impact the specimen at the opposite end of the notch to produce a fractured sample.

The absorbed energy required to produce two fresh fracture surfaces will be recorded in the unit of Joule. Since this energy depends on the fracture area (excluding the notch area), thus standard specimens are required for a direct comparison of the absorbed energy.

Fig 2: RESULT: The Impact Value for the Axle Shaft Was 124 Joules.

2.3 Hardness test

Rockwell hardness test is commonly used among industrial practices because the Rockwell testing machine offers a quick and practical operation and can also minimize errors arising from the operator. The depth of an indentation determines the hardness values. There are two types of indenters, Brale and steel ball indenters. The former is a round-tip cone with an included angle of 120o whereas the latter is a hardened steel ball with their sizes ranging from 1.6-12.7 mm.

Fig 3: RESULT: the Rockwell Hardness Test Gave 25-26 HRC

2.4 Bending test

Bend or flexure testing is common in springs and brittle materials whose failure behaviours are linear such as concretes, stones, woods, plastics, glasses and ceramics.

Other types of brittle materials such as powder metallurgy processed metals and materials are normally tested under a transverse flexure.

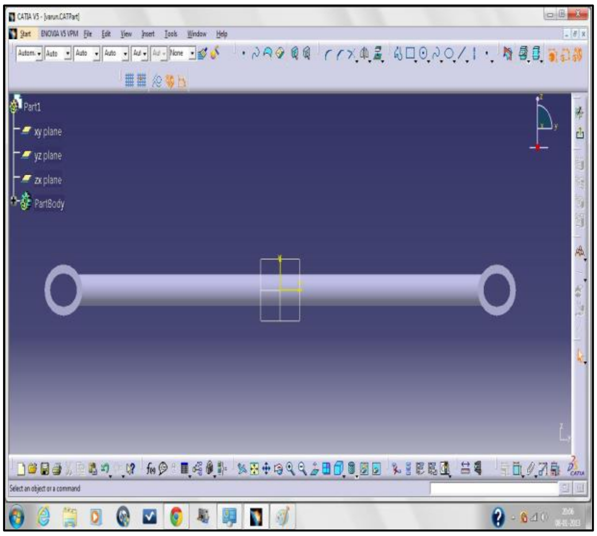
Bend test is therefore suitable for evaluating strength of brittle materials where interpretation of tensile test result of the same material is difficult due.

Fig 4: RESULT: the Result for the Test Was Satisfactory.

2.5 Spectro test

The new windows software SPECTRO Spark Analyzer Vision offers, in addition to simple and intuitive operation, significantly expanded functionality for instrument parameterization, data exchange with external computers and programs - as well as report generation and statistical analysis. Foundation for the data management is an integrated SQL database. The SPECTRO Spark Analyzer Vision software layout is clear and concise. With the navigation bar, switching between the three major modes of operation - Analysis, Methods and Configuration - requires just a click of the mouse.

3.0 Design of the Shaft



We have made this design in "CATIA" and this top view of the shaft.

4.0 Selected Material and Their Properties

After making the design of the shaft in CATIA, based on variables we have selected 5 materials similar to "20Mncr5 "and noted down their mechanical properties

Weight of the Shaft: For calculation of the approximate cost and to compare the weight from different material, we needed to weigh the shaft we have tested. So after weighing, the approximate weight is coming around = 588 grams or .588 Kg

Before Weighing

After Weighing

Variables that can be altered:

In the shaft, the variables are

1) Material
2) Diameter

Only these 2 parameters can be changed, we cannot change the length because the frame of the 3 wheelers is of a defined size.

The selected materials are

i) **MILD STEEL (**E = 201 GPa POISSION RATIO = .3 YEILD STRENGTH = 248MPa DENSITY=7860 Kg/m3)

ii) **AL6061 E** = 69 Gpa POISSION RATIO = .33 YEILD STRENGHT = 55Mpa **DENSITY** = 2700 Kg/m3

iii) **ALLOY STEEL 4140 E** = 207 GPa POISSION RATIO = .3 YEILD STRENGTH = 655MPa DENSITY=7810 Kg/m3

iv) ALLOY STEEL 4340 E = 207 GPa POISSION RATIO = .3 YEILD STRENGTH = 862MPa**, DENSITY**=7800 Kg/m3

iv) **TI – 6Al – 4V** E = 114 GPa YEILD STRENGTH = 1103MPa POISSION RATIO = .3 DENSITY=4430 Kg/m3

5.0 Calculation of the Required Parameters for a 3 Wheeler (AUTO)

We found the required data Power = 10KW

Maximum velocity = 80Km/hr = 1333.33m/min

Diameter of wheel = 20.32cm or 203.2mm

From this data first we found out the RPM using the relation

V = (τ DN)/1000;

N = 2100 Then after that we use the relation of

Power = T (torque) * τ (omega) to find out the torque

After calculation we got Torque = 45Nm

Now we have to find the shear stress according to T =

45Nm, d = .01815m by using the formula

T/J= τ /R

Here T is TORQUE

J is section modulus

τ is shear stress

R is Radius of the shaft

Now after putting the values we got

τ =40Mpa

That means the shear stress of the material we are selecting should have shear stress greater than 40Mpa

5.1 Shear stress of different materials considering Factor of Safety (FOS) as 3

Generally the shear stress is half of the yield stress, but after considering FOS as 3 we have to divide it by 2*3=6

Therefore shear stress (τ effective) of different material are;-

1) MILD STEEL – 41.66MPa
2) AL 6061 O – 9.33MPa
3) 4140 STEEL ALLOY – 109.33MPa
4) 4340 STEEL ALLOY – 143.66MPa
5) TI-6AL-4V – 183.66

5.2 Finding maximum shear stress for different diameters

Now, we have found out the maximum shear for dia =.01, .02, .03m from the formula

T/J= τ /R

So we get for

d = .01, τ max = 229.299 MPa

d = .02, τ max = 28.66 Mpa

d = .03, τ max = 8.49 Mpa

Now we will find the diameter for every material by putting their effective shear stress.

Taking torque=45Nm

1) For Mild steel :- taking τ eff = 41.66Mpa Diameter = .01765m
2) For AL6061 O:- taking τ eff = 9.33Mpa Diameter = .0290m
3) For 4140 alloy steel :- taking τ = 109.33Mpa Diameter = .0120m
4) For 4340 alloy steel :- taking τ = 143.66Mpa Diameter = .01168m
5) For TI–6AL–4V :- TAKING τ =183.66Mpa Diameter = .01076m

5.3 Selecting the required diameter

After Finding the Diameter Now We Will Select the Diameter Which Will Satisfy the Equation

τ (MAX) τ τ (EFF) Now For

1) MILD STEEL

d = 1cm (rejected)

d = 1.765 (selected as this is the min diameter)

d = 2cm (selected)

d = 3cm (selected)

2) AL6061O

d = 1 cm (rejected)

d = 2 cm (rejected)

d = 2.9 cm (selected as this is the min diameter

d = 3 cm (selected)

3) 4140 alloy steel

d = 1 cm (rejected)

d = 1.2 cm (selected as this is the min diameter)

d = 2 cm (selected)

d = 3 cm (selected)

4) 4340 alloy steel

d = 1 cm (rejected)

d = 1.168 cm (selected as this is the min diameter)

d = 2 cm (selected)

d=3cm (selected)

5) TI-6AL-4V

d = 1cm (rejected)

d = 1.076(selected as this is the min diameter)

d = 2 cm (selected)

d = 3 cm (selected)

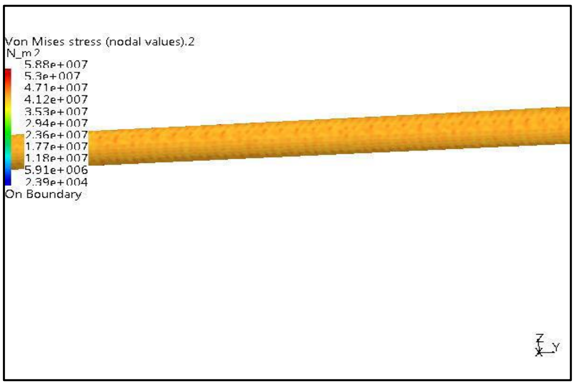
Now we have selected the diameters, we will now calculate the cost for each material for each selected diameter.

6.0 Simulation

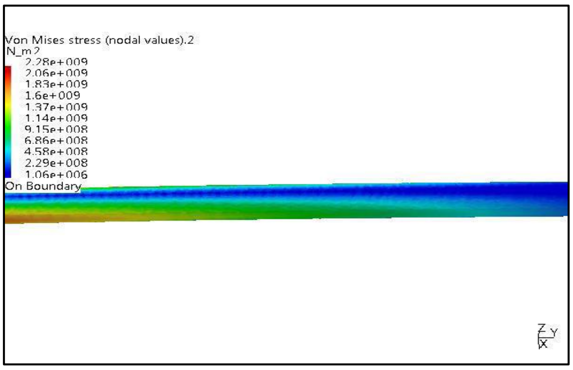
We have done simulation for torsion and bending for each material and each diameter, here we will show the simulation for only the selected diameters of the materials

Mild steel: for diameter 1.765 cm

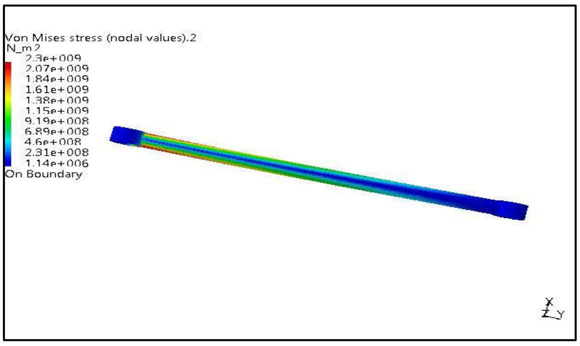
Torsion



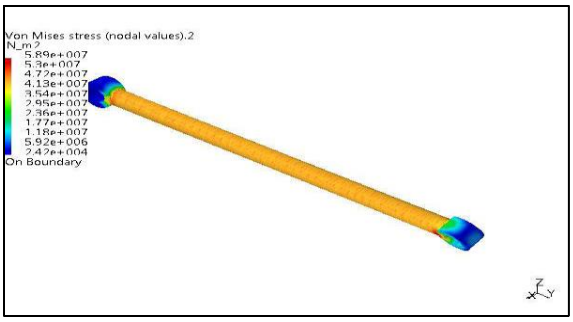
Bending



Torsion

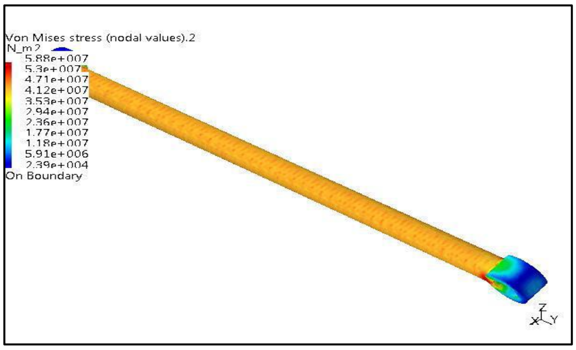


Bending

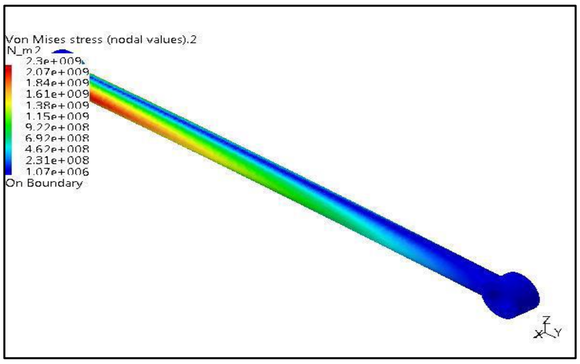


4140 ALLOY STEEL: for diameter 1.2 cm

Torsion

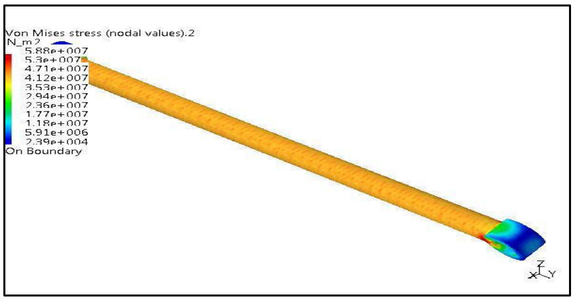


Bending

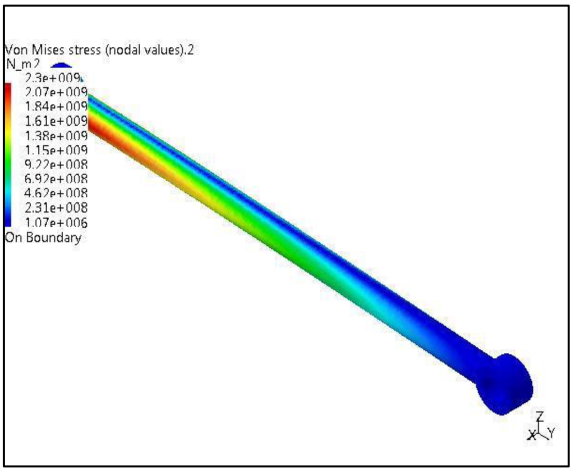


4340 ALLOY STEEL: For diameter 1.168 cm

Torsion



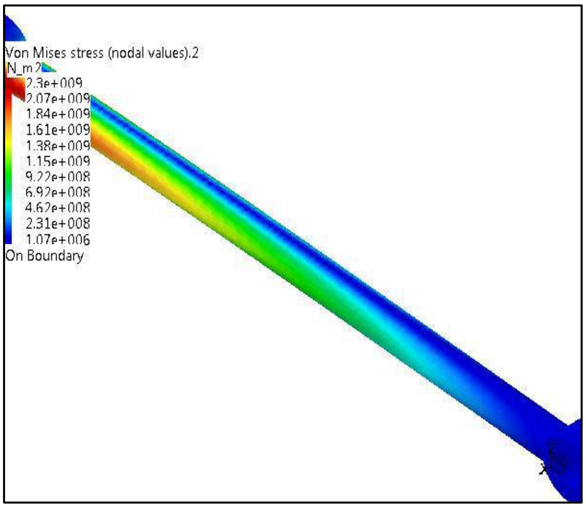
Bending



TI-6AL-4V: For diameter 1.076 cm

Torsion

Bending



7.0 Calculations

For calculation of weight: Total Volume= 2 x Volume of the curved ends + Volume of the shaft

Total volume = {(τ/4) x [(Do) 2 – (Di) 2] x t x 2} + {(τ/4) X D 2 x L}

Where

t= thickness (= D)

Do = Outside diameter

Di = inside diameter

L = length of the shaft

By using these formulas we will calculate then find the mass for each material by using the relation.

Mass= density × volume.

1) MILD STEEL

Density = 7860Kg/m3,

Cost = 34.23/Kg

(I) for diameter = 1.765 cm = .01765m

Total vol. = 1.01×10-4m3

Mass = 7860×1.01×10-4m3= .7937 Kg = 793.7 grams

Cost = .7937x34.23 = 27.169 Rupees

Similarly

(II) For d= 2 cm

Total vol. = 1.267x10-4m3

Mass= .998 Kg

Cost= 34.23 Rupees

(III) For d = 3 cm

Total vol. = 2.77x10-4m 3

Mass= 2.178 Kg

Cost= 74.57 Rupees

2) AL 6061 O

Density = 2700Kg/m3, Cost = 137.48/Kg

(I) for diameter = 2.9 cm = .0290 m

Total vol. = 2.596x10-4m3

Mass = 2700x2.596 x 10-4m3 = .7011 Kg = 701.1 grams

Cost = .7011x137.48 = 94.29 Rupees

(II) For d = 3 cm

Total vol. = 2.77x10-4m3

Mass= .7479 Kg

Cost = 102.82 Rupees

3) 4140 ALLOY STEEL
Density = 7810Kg/m3,
Cost = 163.62/Kg

(I) for diameter= 1.2 cm = .0120
Total vol. = 0.49x 10-4m3
Mass = 7810x0.49 x 10-4m3 = .3853 Kg = 385.3
grams
Cost = .3853x163.62 = 63.05 Rupees

(II) Similarly
For d = 2 cm
Total vol. = 1.27x10-4m3
Mass = .99187 Kg
Cost = .99187 x 163.62 = 162.28 rupees

(III) Similarly
For d = 3 cm
Total vol. = 2.77 x 10-4m3
Mass = 2.16 Kg
Cost = 354 Rupees

4) 4340 ALLOY STEEL
Density = 7800Kg/m3, Cost = 180/Kg

(I) for diameter = 1.168 cm = .011680 m
Total vol. = .4695x 10-4 m3
Mass = 7800 x 0.4695 x 10-4m3 = .36621 Kg = 366.21 grams
Cost = .36621 x 180 = 66 Rupee

(II) Similarly for d = 2 cm
Total vol. = 1.27 x 10-4m3
Mass = .9906 Kg
Cost = 178.3 Rupees

(III) Similarly for d = 3 cm
Total vol. = 2.77 x 10-4m3
Mass = 2.1606 Kg
Cost = 389 Rupees

5) TI-6AL-4V
density = 4430Kg/m3,
Cost = 3500/Kg

(I) for diameter = 1.076 cm = .01076 m
Total vol. = .3743 x 10-4m3
Mass = 4430 x 0.3743 x 10-4m3 = .1658 Kg = .1658 grams
Cost = .1658 x 3500= 580.35 Rupees

(II) Similarly for d = 2 cm
Total vol. = 1.27 x 10-4m3
Mass = .5626 Kg
Cost = 1969.135 Rupees

(III) Similarly for d = 3 cm
Total vol. = 2.77 x 10-4m3
Mass = 1.22 Kg
Cost = 4300 Rupees

8.0 The Selected Material

1) **4140 alloy** steel having diameter d = 1.2 cm = 0.012m having weight 385.3 grams and having cost 63.05 Rupees, if we use this material the weight reduced will be = 0.588 - 0.3853 = 0.2027 Kg
2) **4340 alloy** steel having diameter d = 1.168 cm = 0.01168 m having weight 366.21 grams and having the cost of Rs 66, if we use this material the weight reduced will be = 0.588 - 0.36621 = 0.2218 Kg
3) **TI-6AL-4V** having diameter d = 1.076 = .01076 m having weight .1658 grams is the lightest and but having the cost of Rs 580, if we use this material the weight reduced will be = 0.588 – 0.1658 = 0.422 Kg

After looking up on all possible options we have short listed 3 materials but in final we have selected “4340 alloy steel”

Because it is lighter than 4140 and having better yield strength.

On the other hand TI-6AL-4V is rejected only because of the high cost as it possesses great yield strength and is very light.

So we have finally selected the material

Material : - 4340 alloy steel Weight : - 366 grams Suggested diameter : - 1.168 cm = .01168m Density : - 7800 Kg/m3 Poisson Ratio : - 0.3 Young's modulus : - 207 Gpa Yield strength : - 862 Mpa

9.0 Effect on Fuel Consumption

We know the weight of the original smaller shaft = 588 grams

And the weight of the original larger shaft =828 grams

Now with the new shaft material suggested the weight of smaller shaft coming = 366 grams Having a reduction of 37.75 %

So the total weight of the original shaft = 1416 grams

And the total weight of the new shaft = 881 grams

So the net reduction = 1416 – 881 = 535 grams

As a general data know that

Price of CNG = Rs 40 / Kg

Mileage of a 3 wheeler = 35 Km / Kg

Now we know that fuel economy (F) and reduced

mass (M) are inversely proportional

F inversely proportional M

It means that when mass is reduce fuel economy increases

By a certain thumb rule we have found out that

F = - 0.0064 X M

where F is in mpg (Miles Per Gallon) which is = 425.144 m / Kg

and M is in Pounds which is = 453.592 grams Now converting the difference into pounds, 535 grams, we get = 1.18 pounds

Putting the value in the equation we got F = 0.007552 mpg

now converting it in meters / Kg we got = 3.21 m / Kg

As the CNG in market is available to us in RS / Kg So we have to convert liters into Kg As per standard data ,we got 6 liters of CNG = 1 Kg of CNG

so 1 liters of CNG = 1/6 Kg of CNG

So the increased mileage will come out

= 3.21 x 6 meters / Kg

= 19.26 meters / Kg

so the net mileage = 35019.26 m / Kg

and the actual mileage is 35000 m / Kg

Therefore comparing both, we got consumption of fuel = 0.99945 Kg

now we know that CNG costs us Rs 40 / Kg

So after comparison we got the price of consumption as = Rs 38.78

therefore a decrease of Rs 0.22 / Kg

Now if we compare the prices of newly made shaft and the original shaft we have a approx difference in money of

MPR of the original smaller + larger shaft

= Rs 130+190 respectively

= Rs 320

And MPR of newly made shaft = Rs 210 + 280 approximate

The price is a combination various process such as finishing and grinding etc.

Now the increase price

= Rs (210 + 280) – (130 + 190)

= Rs 490 – 320

= Rs 170

So now we have an increment in the price of the shaft by = Rs 170

Now we know the 3 wheeler will save Rs 0.22 / Kg and if we estimate an average consumption of 6 Kg a day the auto can save Rs 1.32 a day the auto will eliminate the extra price of Rs 170 occurred due to use of new parts in 129 days.

As 1.32 x 129 = Rs 170.28

If we estimate auto's life as 6 years then the net reduction in fuel consumption in Rs is

= (6 x 12 x 30 x 1.32) – 170 = Rs 2851.2 – 170

= Rs **2681.2**

Sometimes the shaft ends can worn out in approx 1.5 years

In that case the net profit

= (1.5 x 12 x 30 x 1.32) – 170

= 712.8 – 170

= **Rs 542.8**

10.0 Future Aspects

Though we have done some testing which are commonly used to design a shaft. There are other tests which may be required for different case. Vibration analysis we have not included which may be useful and can alter the design parameter. Some other tests like creep, fracture, fatigue can be useful for the optimum design.

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