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3D Modeling of Five Speed Manual Transmission System for Teaching Aid Vehicles

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Abstract: Additive manufacturing education is becoming to widespread adoption. Additive manufacturing is also the manufacturing technology. It is used by multiple industry subsectors, including motor vehicles, aerospace, machinery, electronics, and medical products. It can facilitate the customized production of strong light-weight 3D modeling. This paper describes 3D modeling of five speed transmission is designed and constructed by using AutoCAD software, 3D Mesh software, MakerBot 3D printer and digitizer. This 3D modeling of five speed transmission is good quality through lighter part, can demonstrate easily. The teacher can take 3D modeling of transmission and teach the operations of transmission in the classroom. It can produce the gears, fork, cover and synchronizer sleeves with different color. Many beautiful colors are interested to the students. So, it can use as teaching aids for the engineering students. In this transmission, five forward speed gears are helical type whereas reverse gears are spur type. Design consideration of spur gear and helical gears and shafts are included in this paper. In gear design, the number of teeth, face width, gear tooth features and pitch diameter are calculated. The shafts are designed according to the point of view of the strength.

Keywords: Gear, Teeth, Transmission, 3D Modeling, Additive Manufacturing

1. INTRODUCTION

A gear is a component that is used to transfer torque from a rotating input. It uses teeth to mesh together with other gears in order to transmit movement; usually gears that mesh together have identical type of teeth. Two gears together will form a transmission that is capable of changing speed, torque, and direction of the power source. A desired output of speed and torque can be obtained by controlling different geometry sizes between two gears. The transmission has the capability to enable the engine turning effect and its rotational speed output to be adjusted by choosing a range of under and overdrive gear ratios. So the vehicle responds to the driver's requirements within the limits of the various road conditions. There are two types of transmission, manual and automatic. Both do the same job. Manual transmission consists of cast iron or aluminum housing, shafts, bearings, gears, synchronizing devices and shifting mechanisms. Automatic transmission includes a torque converter, compound planetary gear set, two or more disc clutches and one or more bands.[7]

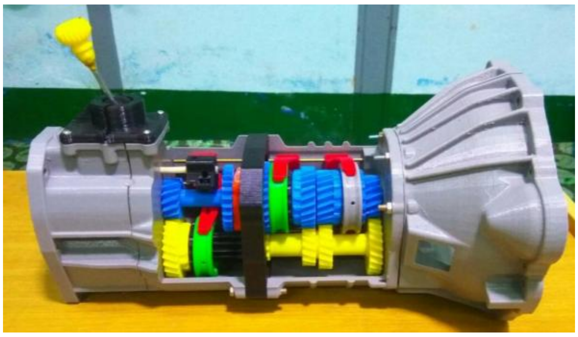

Figure 1. 3D Modeling of Toyota Transmission

Additive manufacturing is a new and innovative method used to manufacture solid objects. It allows the user to make the complicated 3D model using a method of manufacturing for a part is made by adding layer after layer of a heated material that cools and solidifies almost instantly. These 3D shapes are initially created on a computer using solid modeling software, which can be downloaded into the printer. Depending on shape, material, series volume and other criteria, series production is economically possible using metal additive manufacturing.[6] Aadditive manufacturing system is a process by which digital 3D design data is used to build up a component in layers by deposing material. A range of different metals, plastic and composite materials may be used in additive manufacturing system. In this paper, 3D modelling transmission for Toyota 22RE engine produced by using additive manufacturing method is shown in Figure (1). A five-speed manual transmission includes five forward gears and one reverse gear, applying advanced monolithic structure of the intermediate shaft and the shift lock ring-type synchronizer. The transmission possesses a compact structure, a small size, high transmission efficiency, and a larger ratio range, with good economy and dynamic performance. Each process is limited to one type of material and only few are able to process more than one material e.g. thermoplastics of different color. [5]

2. LITERATURE REVIEW

A typical transmission consists of housing, shafts, bearings, gears, synchronizing devices and shifting mechanisms. Shafts and bearings are related in their relative positions in the housing. The five-speed transmission includes five forward gears and one reverse gear, applying advanced monolithic structure of the intermediate shaft and the shift lock ring-type synchronizer. The gear positions are described as follows.

2.1 Neutral Gear Position

With the gears in neutral as shown in Figure (2) and the car stationary, the transmission main shaft is not turning. When the clutch is engaged and the engine is running, the clutch shaft gear drives the counter shaft driven gear.

This turns the counter shaft and the other gears on the counter shaft. In this position, the transmitted power from engine output passes through the clutch shaft or input shaft of transmission and then directly through fourth gear or main drive gear on counter shaft[4].

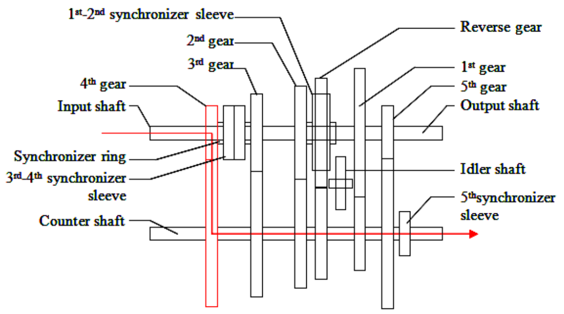

Figure 2. Neutral Gear Position

2.2 First Gear Position

When the clutch is depressed, the clutch disc is released and the gear shift lever is moved into 1st position. Movement of the gear shift lever causes the linkage to select the 1st-2nd synchronizer sleeve and move it to the right. When the clutch is engaged, the power flows through transmission as shown in Figure (3). The power trends in this position, the transmitted power passes through the main drive gear of input shaft and constant mesh counter gear to the first gear on counter shaft and then to first gear on main shaft.[4]

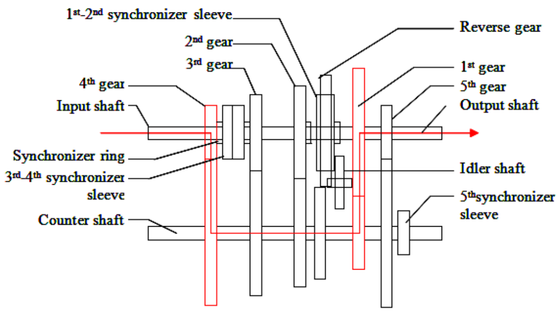

Figure 3. First Gear Position

2.3 Second Gear Position

The 1st-2nd synchronizer sleeve has been moved to the left so that its internal teeth engage the external teeth on the 2nd speed gear. The power flows through the clutch gear to drive the counter gear assembly. The medium size gear on the counter shaft drives the second speed gear through the synchronizer to the second speed gear on the main shaft [4].

2.4 Third Gear Position

When the gear shift lever is moved into 3rd position, movement of the gear shift lever causes the linkage to select the 3rd synchronizer sleeve and move it to the right. The 1st-2nd synchronizer sleeve must be moved to its center position. The power flows through the main drive gear of the input shaft, constant mesh counter gear and then to the third gear on the counter shaft, finally to the transmission main shaft.[4]

2.5 Fourth Gear Position

In this gear, the 3rd-4th synchronizer sleeve has been moved to the left so its internal teeth engage the external teeth of the clutch gear. This gear is a direct drive and the gear ratio is 1:1. The power trends directly to the drive shaft and there is no speed reduction in this case [4].

2.6 Fifth Gear Position

This speed gear is actually an overdrive. That is, the output shaft turns faster or overdrives, than the input shaft. The purpose of overdrive is to reduce engine wear, engine noise and fuel consumption. The advantage of overdrive is that it reduces engine speed around 30 percent while still maintaining the same road speed. When the transmission is shifted into overdrive, the clutch synchronizer sleeve locks the overdrive gear to the main shaft. The 5th speed gear on counter shaft is larger than the overdrive gear on the main shaft. Thus, increased gear ratio can be provided.[4]

2.7 Reverse Gear Position

To achieve reverse gear, an extra gear is inserted into gear train. This gear is called the reverse idler gear. When the shift lever is moved to reverse, the reverse idler gear is meshed with reverse gears on the counter shaft and main shaft. In reverse, both synchronizer sleeves are in neutral. The flow of power through the transmission is as shown in Figure (4). Because of the reverse idler gear, the main shaft turns in the reverse direction. The wheels turn in the reverse direction and the car moves backward.[4]

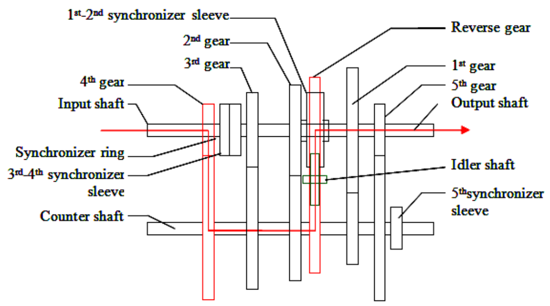

Figure 4. Reverse Gear Position

2.8 Synchronizing Device

To avoid the clashing of gears during shifting, and to simplify the shifting action for the driver, synchronizing devices are used in transmission. Its job is to move ahead of the unit that is to be meshed, seize the other unit and bring the rotational speed of both units together. Once both units are rotating at the same speed, they may be meshed. This type splines the hub to the shaft but does not permit end movement of the hub. The clutch sleeve is shifted forward or backward on the hub. This action forces (by means of inserts) the blocking rings to equalize gear speeds before the clutch sleeve engages the other gear to lock gear to hub through clutch sleeve. All forward gears are synchronized. There are several types of synchronizer units used today. All use a cone (blocking ring) that precedes the movement of either the clutch hub or clutch sleeve. The cone engages a tapered surface on the part to be engaged to synchronize the speed before meshing. The power can be transmitted quickly and smoothly without damaging the gears [7].

2.9 Shifting Mechanisms

The transmission is shifted by means of shifter forks that ride in a groove cut into the clutch sleeve and sliding gear. The forks are attached to the clutch to a cam and shaft assembly. Spring loaded steel balls pop into notches cut in the cam assembly to hold the shift mechanism into whatever gear is selected. The shafts pass through the hold the shift mechanism into whatever gear is selected. The shafts pass through the hosing or housing cover and are fastened to shift levers. Shift forks are made of die-cast aluminum. Gear shift levers on manual transmissions are located either on the steering column or on the floor board. With either location, the operation of gearshift lever does two things. First, it selects the gear assembly to be engaged. Second, it shifts or moves the gear to provide the desired gear position.[7]

3. DESIGN OF TRANSMISSION

Design theory of gears and shafts are described.

3.1 Design of Gear

The velocity ratio (V.R) is

$$V.R=\omega_p/\omega_g=N_p/N_g=n_g/n_p=D_g/D_p \quad (1)$$

where ω = Angular velocity (rad/sec) and

N= Rotational speed (rev/min). The transmitted force F_t, acts at the pitch line with a velocity.

$$v = \frac{\pi DpNp}{60} \quad (2)$$

where D_p is the pinion diameter in meter, V is the pitch line velocity in meter per second and N_p is the rotational speed of the pinion in rpm. . If the torque (M_t) is Newton-meter, the transmitted force is $F_t = M_t / r_p$ (3)

the radial force (F_t) can be computed F_r=F_t tanψ (4)

where φ is the pressure angle of the tooth form. For spur gear, the normal force (F_n) can be computed

$$F_n = \frac{F_t}{\cos\varphi} \quad (5)$$

For helical gear, the normal force (F_n) can be computed

$$F_n = \frac{F_t}{\cos\varphi_n \cos\psi} \quad (6)$$

where φ_n is the normal pressure angle of the tooth form and is ψ the helix angle of the tooth form[3]. The axial force directed parallel to the axis of the shaft carrying the gear and is also called thrust force. The axial force is computed by:

$$F_a = F_t \tan\psi \quad (7)$$

Stresses in Gear Teeth, Lewis equation may be used.

$$\left(\frac{1}{m^2 y}\right)_{all} = \frac{S_{all} k\pi^2}{F_t} \quad (8)$$

$$S_{all} = \frac{2 M_1}{m^3 \ k \ \pi^2 \ y \ n} \quad (9)$$

where M_1 = Torque on weaker gear and

n = Number of teeth on weaker gear.

The endurance load is calculated by the following equations. The endurance load equations for spur and helical gears are

For spur gear, $F_o = S_o \, B \, y \, \pi \, m$ (10)

For helical gear, $F_o = S_o \, B \, y \, \pi \, m \cos\psi$ (11)

The limiting endurance load must be equal to or greater than the dynamic load (F_d).[3]

The wear load F_w for spur gear, $F_w = D_p \, B \, K_w \, Q$ (12)

For helical gear, $$F_w = \frac{D_p B K_w \ Q}{\cos^2 \psi} \quad (13)$$

Where D_p =Pitch diameter or smaller gear(pinion),m,

D_g =Pitch diameter of larger gear (gear), m,

K_w =Load stress factor for fatigue, N/m^2,

n_p =Number of teeth on pinion,

n_g =Number of teeth on gear and

Q =Ratio factor

BHN = Average brinell hardness number of gears.

The wear load F_w is an allowable load and must be equal to or greater than the dynamic load F_d [3]. The dynamic analysis, as proposed by

For spur gear, $$F_d = \frac{21 \times V\,(BC + F_t)}{21 \times V + \sqrt{(BC + F_t)}} + F_t \quad (14)$$

For helical gear,

$$F_d = \frac{21 \times V\,(BC \cos^2\psi + F_t)\cos\psi}{21 \times V + \sqrt{(BC \cos^2 \psi + F_t)}} + F_t \quad (15)$$

where C = Dynamic factor, N/m.

3.2 Design of Counter Shaft

A shaft is the component of mechanical devices that transmits rotational motion and power from one place to another. The power is delivered to the shaft by some tangential force and the resultant torque or torsional moment. The torsional moment (M_t) acting on the shaft can be determined from this equation.[3]

$$M_t = \frac{9550 \times KW}{rpm} \quad (16)$$

For a gear drive, the torque is found from this equation.

$$M_t = F_t \times (D/2) \quad (17)$$

where F_t = Tangential force at the pitch radius, N and

D = Pitch diameter, m.

The ASME Code equations are described as follows. For a solid shaft with axial loading, the Code equation is:

$$d^3 = \frac{16}{\pi S_s}\sqrt{\left[K_b \ M_b + \frac{\alpha F_a \ d}{8}\right]^2 + (K_t \ M_t)^2} \quad (18)$$

For a solid shaft having little or no axial loading, the Code equation reduces to:

$$d^3 = \frac{16}{\pi S_s} \times \sqrt{(K_b \times M_b)^2 + (K_t \times M_t)^2} \quad (19)$$

where M_t = Torsional moment, Nm,

M_b = Bending moment, Nm,

d = Shaft diameter, m,

K_t = Combined shock and fatigue factor applied to torsional moment.

ASME Code states for steel purchased under definite specifications, the permissible shear stress may also be taken as 30% of the elastic limit in tension but not more than 18% of the ultimate tensile strength for shafts without keyways. These values are to be reduced by 25% if keyways are present [3]. The shaft diameter is taken as follows.

(1) Up to 25mm in 0.5mm increment
(2) 25mm to 50mm in 1mm increment
(3) 50mm to 100mm in 2mm increment
(4) 100mm to 200 mm in 5mm increment.

4. DESIGN OF TRANSMISSION

To design the transmission of Toyota, the required data are collected from the existing transmission and assumptions are extracted from the theory of automobile.

Max: power	65 kW at 4600 rpm
Max: torque	162 Nm at 2400 rpm
Transmission	5 speed manual
Transmission type	Rear wheel drive

The design consideration and calculation of transmission are mostly dependent upon the maximum torque of the input speed from the engine. In gear design, choose 6150 OQT 400 material which has brinell hardness 601, yield stress 1860 MPa and ultimate stress 2170 MPa. The gears are designed to transmit power and satisfy the dynamic check. In gear design, the number of teeth, face width, gear tooth features and pitch diameter are calculated.
The calculated results for gear pairs are described in Table 1.

Table 1. Calculated results for gears

Gear pair	Input Gear Pair	1st	2nd	3rd	4th	5th	R
Pitch dia:	93/55	104/44	86/62	68/80	55/93	51/97	108/87/40
Gear ratio	-	3.996	2.345	1.437	1.0000	0.889	4.565
No:of teeth	-	35/15	29/21	28/32	28/47	26/49	31/ 25/12
Face width	-	30	20	19	21	21	32
Ft(N)	-	12450	8836	6848	5891	5647.4	13695
Torque(Nm)	-	647.4/ 273.9	379.9/ 273.9	232.8/ 273.9	162/ 273.9	144/ 273.9	739.5/595.7 /273.9
F_o(N)	-	19203	13931	11923	-	10367	19852
F_w(N)	-	18019	13997	13567	-	13636	21052
F_d(N)	-	17490	13619	11424	-	10123	19274

The shafts are designed according to the point of view of the strength. In the strength shaft design, the shaft diameters for variety of speeds have to be calculated by using the ASME code equation.
The calculated results for shafts are described in Table 2.

Table 2. Calculated results for shafts

Type of Shaft	Material	S_u (MPa)	S_y (MPa)	Dia (mm)	Length (mm)
Input Shaft	6150 OQT 400	2170	1860	25	218
Output Shaft	6150 OQT400	2170	1860	30	395
Counter Shaft	6150 OQT400	2170	1860	35	320
Idler Shaft	6150OQT400	2170	1860	30	170

5. 3D MODELING OF TRANSMISSION

3D modeling is used in various industries like films, animation and gaming, interior designing and architecture. They are also used in the medical industry for the interactive representations of anatomy. A wide number of 3D software is also used in constructing digital representation of mechanical models or parts before they are actually manufactured. CAD/CAM related software are used in such fields, and with these software, not only can you construct the parts, but also assemble them, and observe their functionality. 3D modeling is also used in the field of industrial design, wherein products are 3D modeled before representing them to the clients. 3D models, which is suitable for indexing and retrieval of 3D models by features such as geometry, dimensions, material, texture, diffuse reflection, etc..[11] 3D Solid models can be tested in different ways depending on what is needed by using simulation, mechanism design, and analysis. For example; a pool pump would need a simulation ran of the water running through the pump to see how the water flows through the pump. These tests verify if a product is developed correctly or if it needs to modify its requirements.[5]
The minimum wall thickness or feature size necessary in order to be built and self-supporting is 1 mm with a tolerance of +/- 0.05mm. Depending on what material is being used, undercuts or angles under 40° will need to be supported. The supports are generated in secondary CAD programs in many different forms such as lattice or grid work structures with each column only as thick as the laser beam in order to facilitate easier removal.[5]
Firstly, the gears and components of transmission are drawn with 1:2 scales by using CAD software and Autodesk 3D Mesh software.

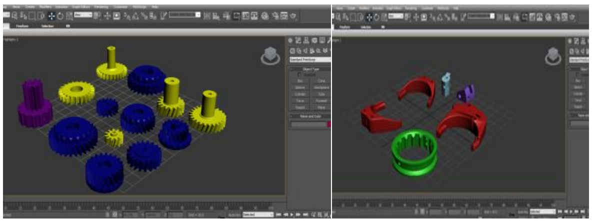

Figure 5. Gears and Forks

Secondly, the settings for each component are done by using MakerBot software. And then, the parts of transmission are printed by MakerBot 3D printer. Finally, these parts are installed and operated successfully.

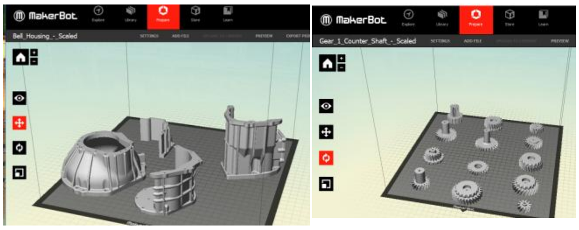

Figure 6. Covers and Gears

For all of the components, Z resolution was used because that showed good finish of the product and there was no need for higher resolution, which will mean longer printing time. The quality of the print was always the highest due to the fact that good precision is needed for functional gears.[14]

Figure 7. Makerbot 3D Printer and Digitizer

The results demonstrate that the total time of printing all of the components from the transmission is 8 hours and 25 minutes, which is no long and it can be decreased if more than one component is printed at the same time. The material cost to print the gearbox including the raft, support material used is depending upon the time.

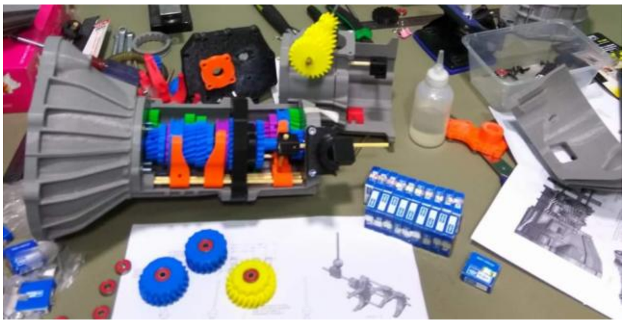

Figure 8. Installing of Prototype Transmission

6. CONCLUSIONS

In this transmission, there are all together five forward speed and one reverse. Among the five forward speeds, the fourth drive is the direct drive and the final drive is the overdrive. The design calculation is based on maximum tangential load at 1^{st} speed range. Gears and shafts are designed with 6150 OQT 400 heat treated alloy steel, which has brinell hardness 601, yield stress 1860 MPa and ultimate stress 2170 MPa. The design of spur gears, helical gears and shaft designs are calculated in this paper. The required design calculation of spur and helical gears can also be calculated through both strength and dynamic check. The gear ratios are 3.996, 2.345, 1.437, 1.000, 0.889 and 4.565. The shafts are designed according to the point of view of the strength. In the strength shaft design, the shaft diameters for variety of speeds have to be calculated by using the ASME code equation. Diameters of output, counter, idler and input shaft are 40, 35, 30 and 25 mm respectively. In many instances, the cost of producing a 3D model using additive manufacturing processes exceeds that of traditional methods. 3D printing is a quick, simple and relatively cheap method for production of models for automobile teaching aids. As it was presents a wide range of materials and technologies with various features and parameters are available. This enables a potential researcher to choose the right technology fitting exactly the needs and fulfilling the requirements of prepared experiment. Thin-walled and tough models have been successfully manufactured. In this design, structural rigidity combined with lightness must always be the first consideration for the durability of the wearing parts and smoothness of running. Develop environmental impact profiles for major additive finishing processes. Investigate work piece pretreatment, acid cleaning, and rinsing sub-processes contributions toward the environmental impact of additive finishing processes. It can facilitate the customized production of strong light-weight 3D modeling. So, the teachers can take this transmission to the classroom. And then, they can explain about the operations and can demonstrate this 3D model transmission.

7. ACKNOWLEDGMENTS

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