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3D DESIGN OF A AUTOMOTIVE 5 SPEED SYNCHROMESH GEARBOX IN AUTODESK INVENTOR

Robert-Florin CERBU[1], Nicușor BAROIU[2], Viorel PĂUNOIU[2]

[1]Groupe Renault/Renault Technologie Roumanie, Voluntari, România
[2]Department of Manufacturing Engineering, “Dunărea de Jos” University of Galați, România
Nicusor.Baroiu@ugal.ro

ABSTRACT

The gearbox is a rotary assembly that provides speed and torque conversions from one rotary power supply (crankshaft) to another device (drive wheels) due to internal combustion engine limitations and also facilitates the shaft steering output.

Autodesk Inventor is a computer aided design (CAD) application for creating 3D digital prototypes used in mechanical design, visualization, tooling creation and product simulation. It allows the user to create prototype products that accurately simulate the weight, stress, friction, driving loads, and many more properties of the products and their components in a simulated 3D environment.

This paper contains all the graphic knowledge and operations required to create a 3D model of a manual gearbox by using the Autodesk Inventor software, and step by step, procedure for generating a 3D model of an synchromesh gearbox, starting from the initial calculus in Mathconnex.

KEYWORDS: Transmission, CAD, gearbox, Inventor, front axle, concept.

1. INTRODUCTION

This paper contains all the graphic knowledge and operations required to create a 3d model of a manual gearbox by using the *Autodesk Inventor* software. All of the steps are included for a better understanding of the working principles. Mostoften, the torque and angular speed of an combustion engine do not match the actual movement of an automobile. The main subassembly that ensures the speed and traction force conversion, without modifying power parameters develope dby an combustion engine, is known as a gearbox. The main functions of a gearbox are: to change gear ratios between the engine crankshaft and the vehicle drive wheels, to be shifted into reverse so the vehicle can move backwards, to be shifted into neutral for starting the engine [1], [2], [3].

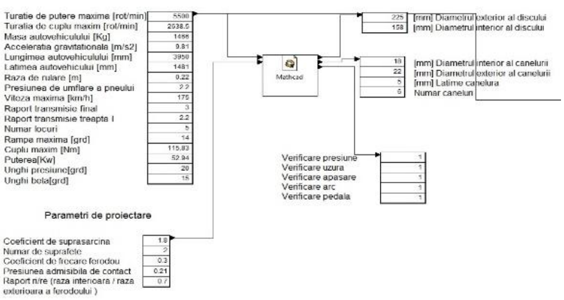

Fig. 1. *Mathconnex* - design parameters and vehicle specifications.

This paper contains a step by step procedure for generating a *3D* model of an synchromesh gearbox, starting from the initial calculus in *Mathconnex*, Figure 1 and Figure 2, to the final assembly in *Autodesk Inventor*.

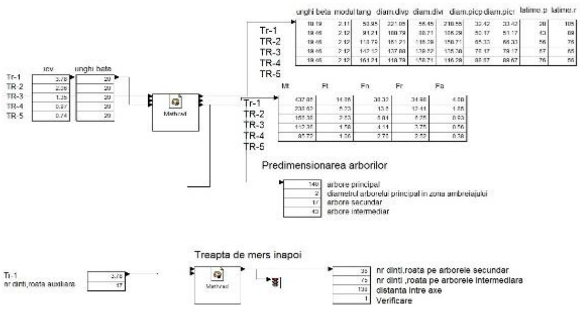

Fig. 2. *Mathconnex - design parameters and vehicle specifications.*

2. GEARBOX CALCULUS METHODS

2.1 Geometrical-kinematical dimensioning

This phase contains the calculus for establishing the number or teeth on each cogwheel, teeth angle, gear ratios, shaft distance and geometric elements, Figure 3.

In order to obtain the right dimensioning and gear ratios an elaborate analysis was made on different types of manual gearboxes that are used by different vehicle manufacturers.

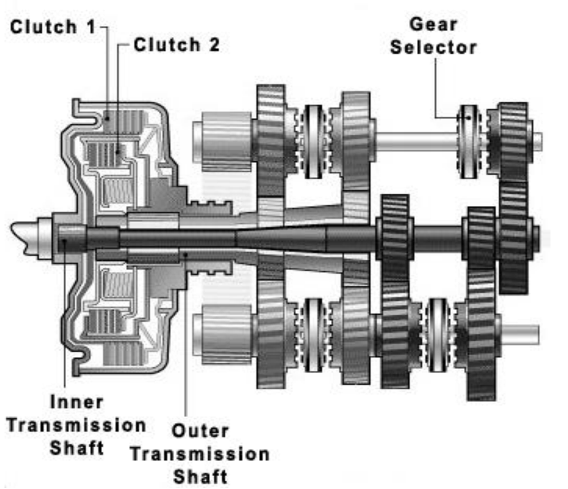

Fig. 3. *Gearbox kinematic functioning scheme [4].*

It is recommended to adopt similar gear ratios as in the already existing gearbox in order to obtain an accurate working assembly.

The momentum is determined in conformity with the output shaft momentum M_s in the first gear:

$$M_s = M_M \cdot i_{cv_1} \cdot \eta_{cv} \tag{1}$$

where: M_M - maximum engine momentum; i_{cv_1} - first gear ratio; η_{cv} - gearbox efficiency.

The following formula is used in order to determine the number of teeth for each gear on the input shaft:

$$Z_k = \frac{2 \cdot A \cdot \cos\beta_k}{m \cdot \left(1 + i_{cv_k}\right)} \tag{2}$$

The output shaft no. of teeth:

$$Z_k^{'} = \frac{2 \cdot A \cdot \cos\beta_k \cdot i_{cv_k}}{m \cdot \left(1 + i_{cv_k}\right)} \tag{3}$$

where: i_{cv_k} represents the k gear transmission ratio. All of these being established, the shaft distance can be determined by using the following formula:

$$a = \frac{m_n \cdot \left(Z_1 + Z_1^{'}\right)}{2 \cdot \cos\beta}. \tag{4}$$

2.2 Geometrical-kinematical dimensioning

Depending on what shaft torsion momentum M_c has been obtained, the tangential force is determined by using:

$$F_t = \frac{M_c}{R_d} \tag{5}$$

M_c - driving gear momentum.

2.3 Force determination in helical gears

Normal force formula:

$$F_n = \frac{F_t}{\cos\alpha \cdot \cos\beta} \tag{6}$$

Radial component formula:

$$F_r = F_t \cdot \frac{\tan\alpha}{\cos\beta} \tag{7}$$

3. GEARBOX MODEL

The graphical representation starts with the input shaft construction. A 2D longitudinal midsection sketch of the input shaft has been created and once that stage is complete, the closed profile will revolve 360 degrees along the main axis by using the *Revolve* command in the toolbar, Figure 4.

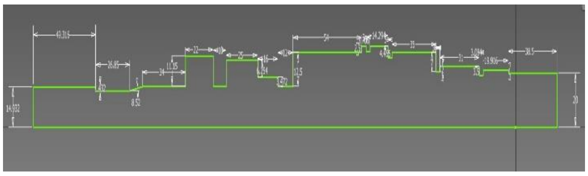

Fig. 4a. *2D sketch – input shaft.*

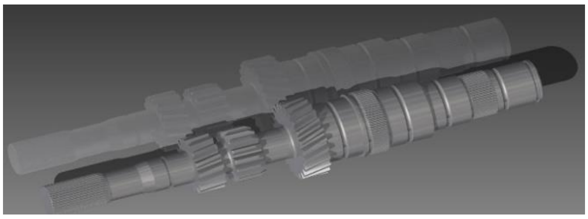

Fig. 4b. *3D Depiction – input shaft.*

The most basic type of gear is a spur gear, and if has straight-cut teeth, where the teeth are parallel to the axis of the gear. Spur gears are made by creating a 2D sketch that contains the geometrical profile of a tooth which can be multiplied in a circular array around a point in as many instances are the user desires. Once this stage is complete the closed profile will be extruded by the required height or up to a plane/surface by using the *Extrude* command or the extrude to command, Figure 5b.

The teeth on helical gears are cut at an angle to face of the gear. When two teeth on a helical gear system engage, the contact starts at one end of the tooth and gradually spreads as the gears rotate, until the two teeth are in full engagement. In order to create a helical gear Figure 5a, 2 planes are required, having the gear’s width in between them. A 2D sketch that contains the tooth geometry will be created on the first plane which can be copied later on the second sketch that will be placed on the 2nd plane. In order to obtain the tooth angular geometry, the second sketch needs to be rotated along the midpoint by a certain amount of degrees by using the *Rotate* command in the toolbar.

Some guiderails that connect the 2 sketches are also necessary for obtaining the right geometry. The next step consists in using the *Loft* command in which the 2 sketches will be selected and the freshly new created guiderails.

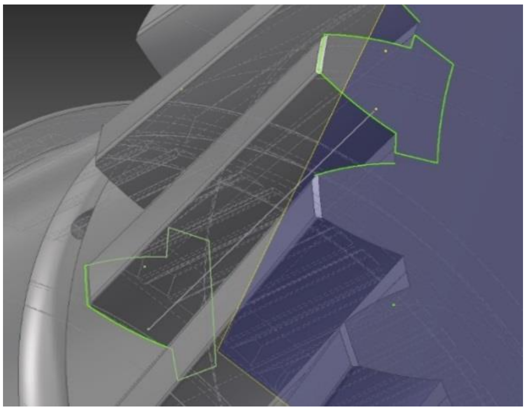

Fig. 5a. *Helical gear build.*

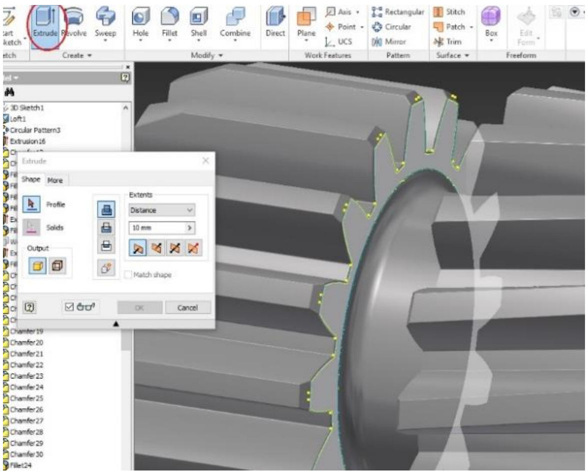

Fig. 5b. *Spur gear build.*

Output shaft construction by using the 2D sketch, Figure 6a, and the *Revolve* command.

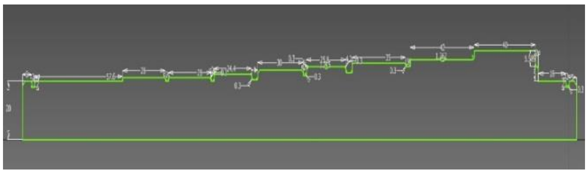

Fig. 6a. *Output shaft 2D sketch.*

Fig. 6b. *Output shaft 3D body.*

The output shaft grooves, Figure 6b, are made by utilizing the *Extrude* command on a 2D sketch that contains the groove geometry, Figure 7.

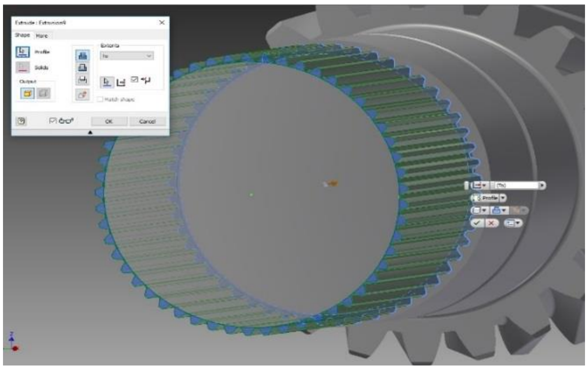

Fig. 7. *Secondary shaft grooves.*

The synchromesh assembly, Figure 8, is created by adding all of the required components into a *Assembly 3D Standard mm.iam* and joining them together by either using the *Joint* command or by applying some axial constraints on each element.

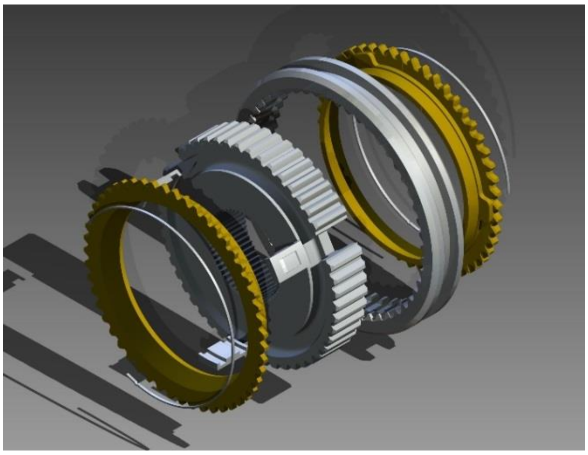

Fig. 8. *Synchromesh assembly.*

The synchronizer hub is made by the extrusion of the 2D sketch by 18 mm, Figure 9b, that has the teeth and groove geometries included in it, Figure 9a.

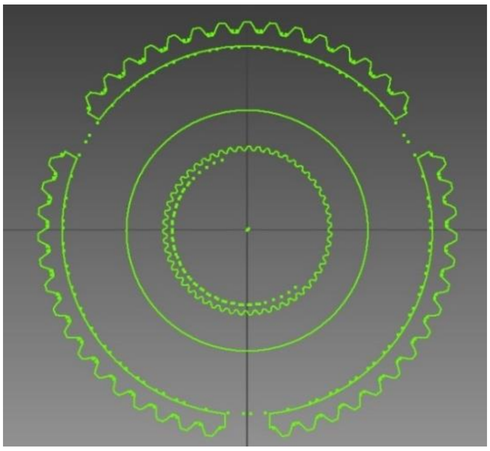

Fig. 9a. *Synchronizer hub – 2D.*

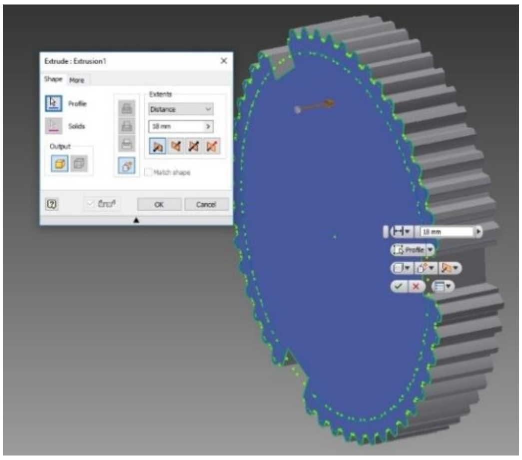

Fig. 9b. *Synchronizer hub – 3D.*

The Shift sleeve construction is similar with the one of the synchronizer hub, by extruding a 2D sketch, Figure 10a.

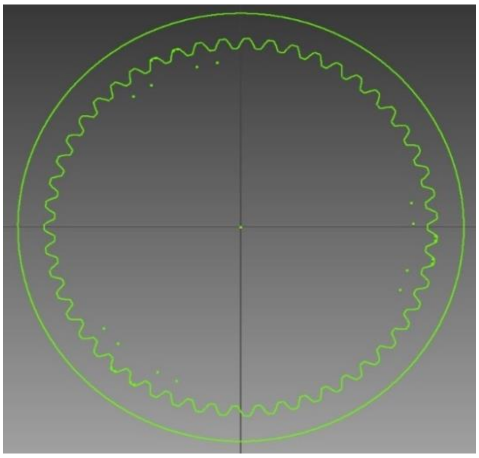

Fig. 10a. *Shift sleeve – 2D.*

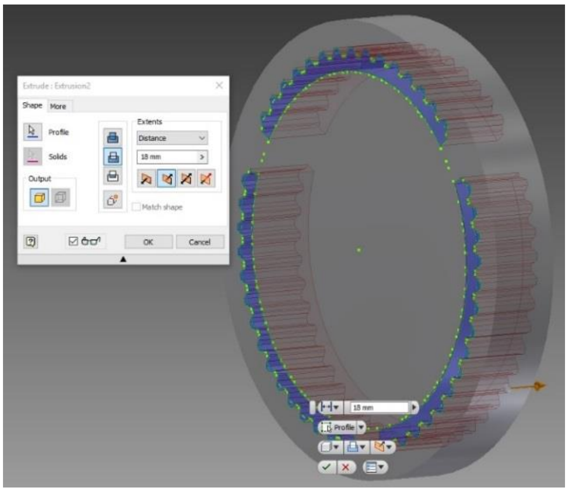

Fig. 10b. *Shift sleeve – 3D.*

The main body is created by revolving the 2D sketch, Figure 11a, around the *Z* axis. The teeth, Figure 11c, need to have the same geometry as the synchronizer hub, shift sleeve, Figure 11d.

Fig. 11a. *Baulk ring - 2D sketch.*

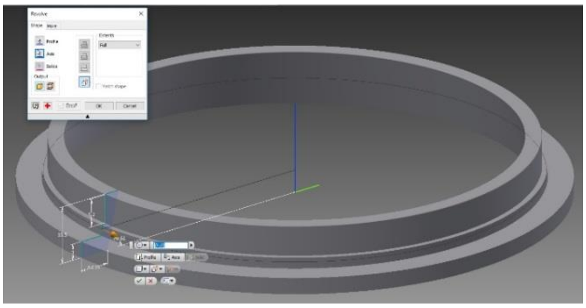

Fig. 11b. *Baulk ring - 3D, phase 1.*

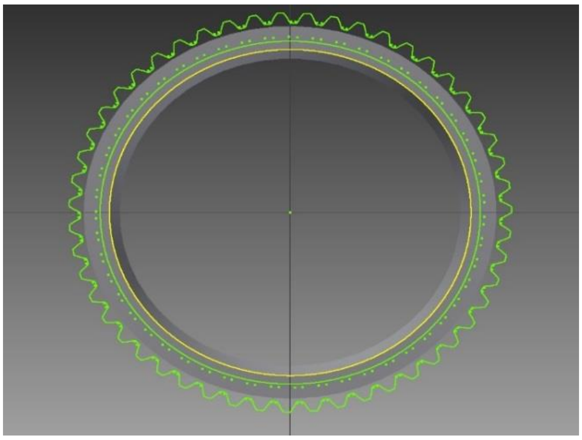

Fig. 11c. *Baulk ring dog teeth - 2D sketch.*

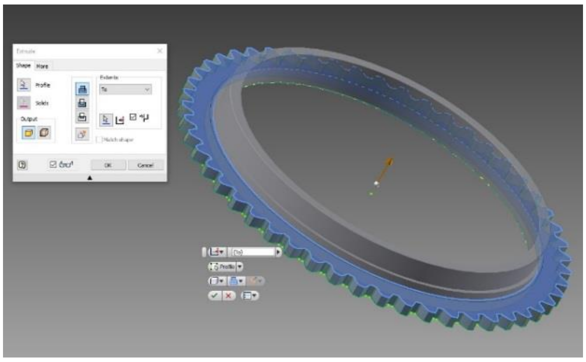

Fig. 11d. *Baulk ring - 3D, phase 2.*

The strut’s, Figure 12b, main purpose is to block the shift sleeve into the neutral position and is created by revolving the 2D sketch, Figure 12a, around the *X* axis by 15 degrees.

The 1st gear is obtained by making use of the loft command, 2 x 2D sketches that contain the tooth profile, guiderails and the use of the *Circular array* command, Figure 13a.

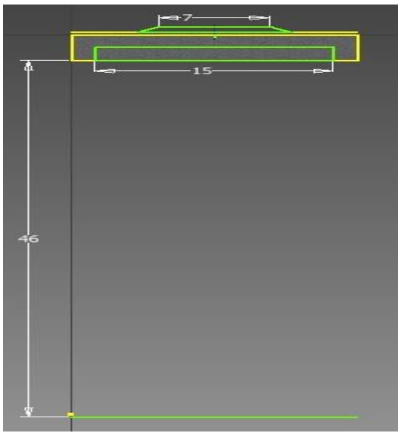

Fig. 12a. *Strut – 2D.*

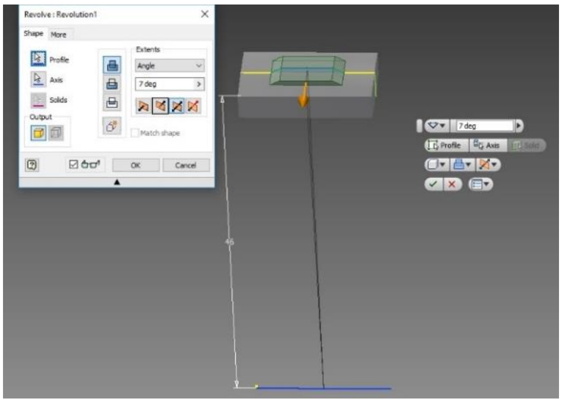

Fig. 12b. *Strut – 3D.*

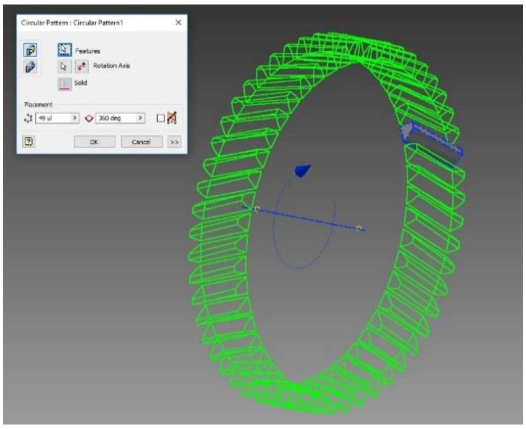

Fig. 13a. *1st Pinion gear – 3D.*

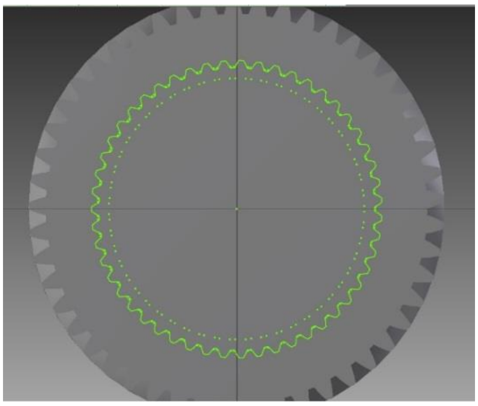

Fig. 13b. *First gear inner grooves – 2D.*

The inner grooves are made by extruding the 2D closed profile that must match the ones created on the input shaft, Figure 13b. Devices that use helical gears have bearings that can support the thrust load.

The needle rolled bearing cage is obtained by revolving the 2D sketch, Figure 14a, followed up by making the slots for each needle roll, Figure 14b.

Fig. 14a. *Needle roller bearing cage – 2D.*

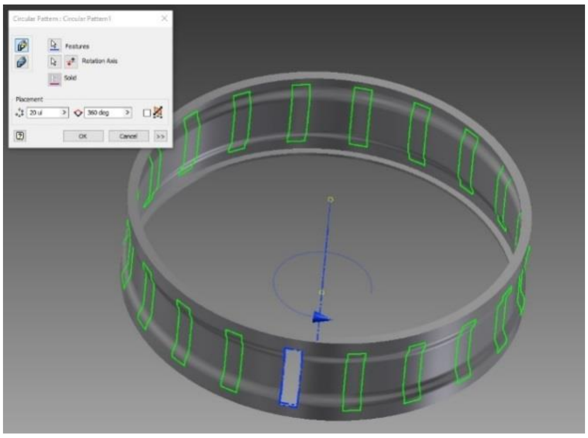

Fig. 14b. *Needle roller bearing cage – 3D.*

Ball bearing construction

Bearings are required to support the revolving part and reduce the friction. In the gearbox both counter and main shaft are supported by bearings.

The ball bearing cage construction starts by creating hollow spheres displaced in a circular array after which the inner and outer parts are removed by creating 2 cylindrical extrusions, Figure 15a.

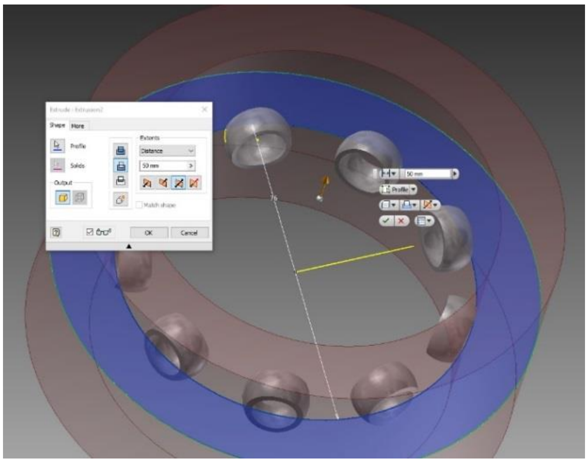

Fig. 15a. *Needle roller bearing cage – 2D.*

The remaining parts can now be joined by creating a cylindrical extrusion that intersects the bodies, Figure 15b.

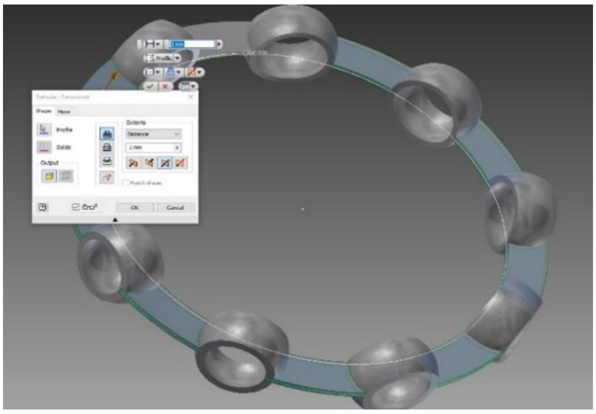

Fig. 15b. *Ball bearing cage - 2nd phase.*

The inner, Figure 16a, and outer, Figure 16b, rings are made with the aid of the *Revolve* command right after the 2D sketch has been completed.

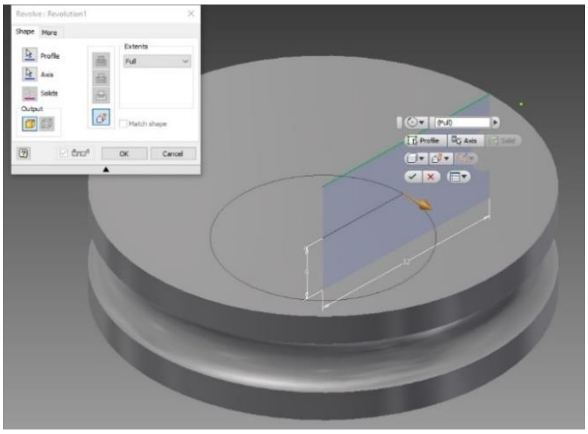

Fig. 16a. *Ball bearing inner ring.*

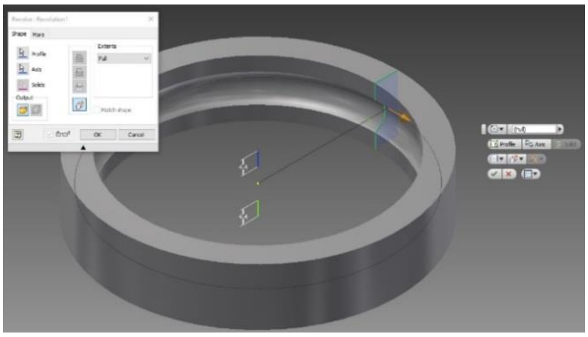

Fig. 16b. *Ball bearing outer ring.*

The final ball bearing assembly starts by adding the steel balls into the bearing cage by using the *Joint (Ball)* command, after which it is securely riveted in place and the inner, outer rings are installed, Figure 17.

The final output and input shaft assemblies are displayed in Figure 18a and Figure 18b.

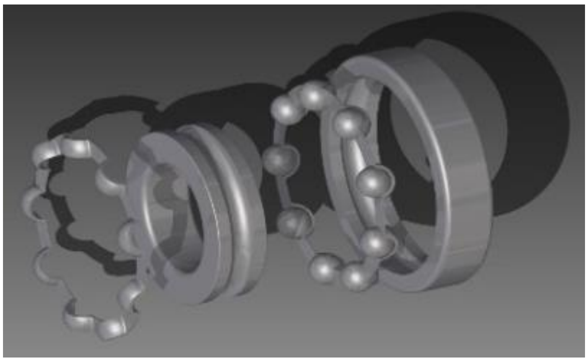

Fig. 17. *Ball bearing assembly exploded view.*

Fig. 18a. *Output shaft final assembly exploded view.*

Fig. 18b. *Input shaft final assembly exploded view.*

Front axle differential for transversal engine placement

A differential is a gear train with three shafts that has the property that the angular velocity of one shaft is the average of the angular velocities of the others, or a fixed multiple of that average. The powered pinion gear meshes with the ring gear which in turn transmits power to both axles through a second set of gears [5].

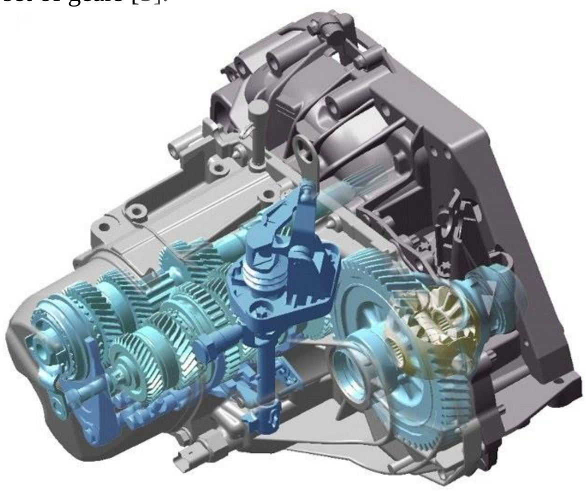

Fig. 19. *Front axle differential [6].*

The differential housing is made by revolving the 2D sketch around the *Z* axis, Figure 20a, next step being the 2 face removal which is attained with the *Extrude* command, Figure 20b, and Figure 20c.

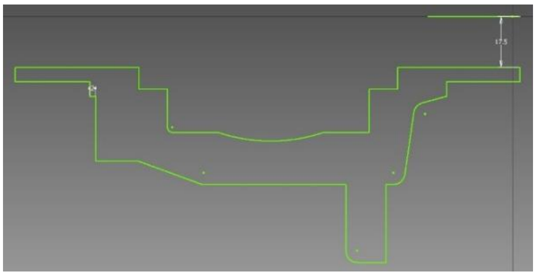

Fig. 20a. *Differential housing – 2D.*

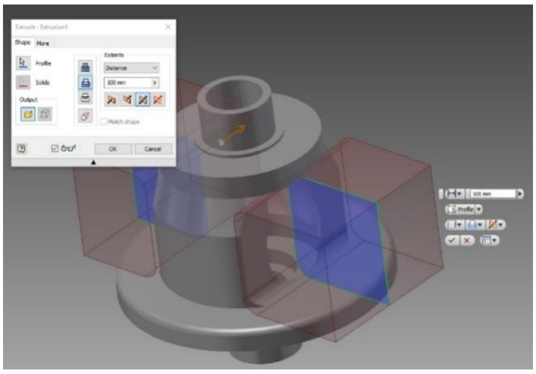

Fig. 20b. *Differential housing – 3D, face removal.*

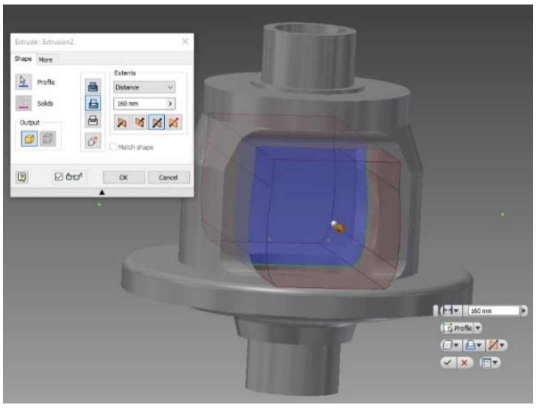

Fig. 20c. *Differential housing – 2D, face removal.*

The differential drive ring gear is made in a similar manner to the pinion gear, the only difference being the radius of the array and the no. of teeth (72 units), Figure 21.

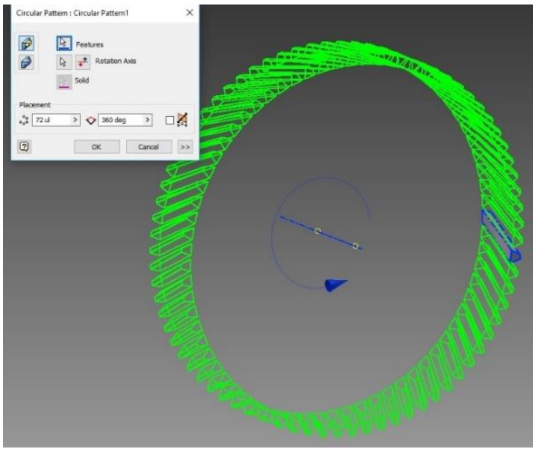

Fig. 21. *Differential drive ring gear.*

Figure 22a and Figure 22b contain the final front axle differential assembly which consists of the following elements: differential case, pinion gear, side gear, pinion shaft, bolts.

Fig. 20a. *Front axle differential assembly - exploded view.*

Fig. 22. *5 speed synchromesh manual gearbox final assembly.*

This phase consists in joining the input shaft, output shaft and differential subassemblies all together in order to obtain the gearbox assembly. A 2D guide rail is created on the input shaft which will allow the mounting of the output shaft, Figure 23a, (which can have its visibility turned off later).

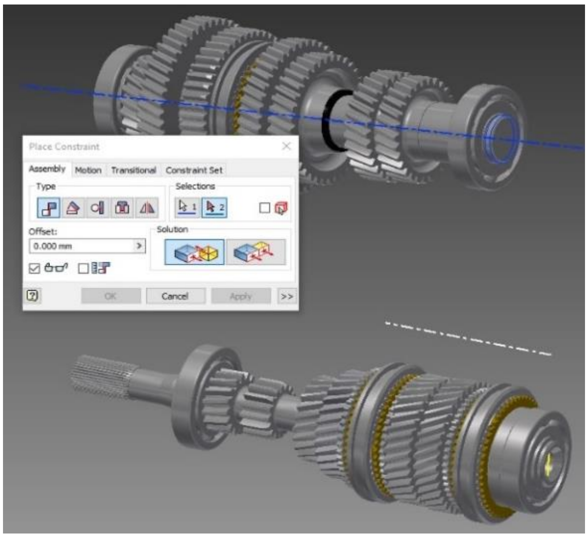

Fig. 23a. *Input shaft guide rail. final assembly.*

The shafts are aligned by picking up the *Flush* option from the *Constraint* tab followed up by a shaft edge alignment, Figure 23b.

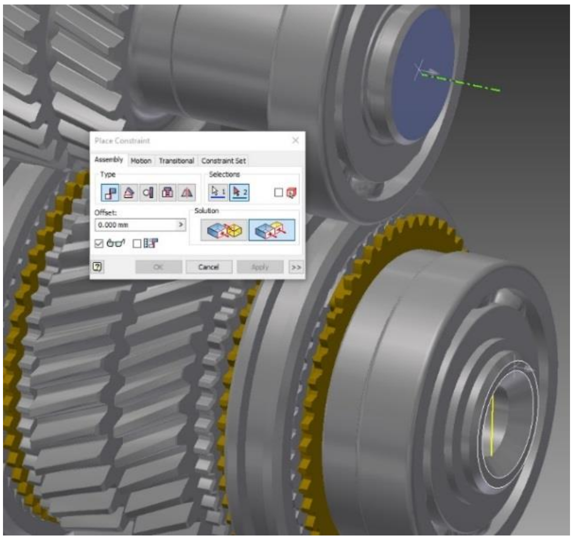

Fig. 23b. *Shaft edge alignment.*

A 2D guiding rail is also added to the output shaft which helps with the differential instalment after which the necessary axial constraints are applied, Figure 23c.

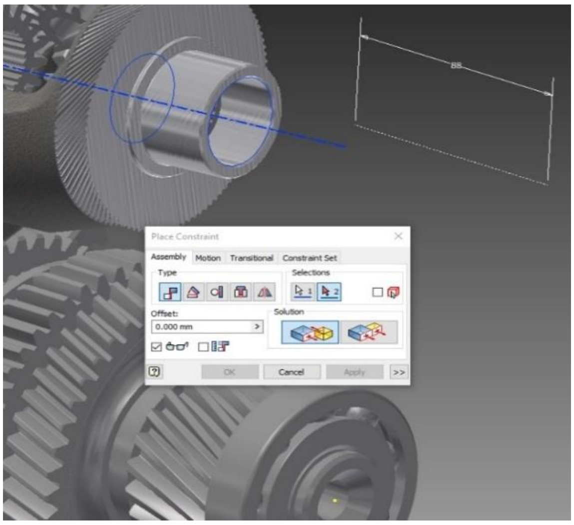

Fig. 23c. *Differential alignment.*

4. CONCLUSIONS

The gearbox construction process is rather meticulous job, considering it is the 2nd element in the drive train and cause of the number of complex tasks it must perform: be shifted in to reverse so that the vehicle can move backwards; be shifted in to neutral for starting the engine; provide the torque needed to move the vehicle under a variety of road and load conditions. it does this by changing the gear ratios between the engine crank shaft and the vehicle drive wheels; allow traction force variation according to advancement constraints; be safe touse, have low maintainability cost and easy maneuverability. Over dimensioning bearings doesn’t increase their reliability and safety but instead raises the noise gradient.

It is vital to identify all the external parameters that have a direct influence over a vehicle that’s in motion such as: wheel running resistance, air resistance, ramp resistance, take off resistance.

ACKNOWLEDGEMENTS

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