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Design of a Hydraulic Pump for Tractor Utilizing 3D Printer Technology

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ABSTRACT

In this work, a couple of spur gears design was changed by two double- helical gears design with maintaining other parts in the same size approximately for a hydraulic pump of agricultural tractor. The main purpose of this attempt was to obtain a new hydraulic pump with better specifications and performance. The new elements of the pump were designed using 3D Solid Works software then the stresses analyses and CFD analyses were archived using ANSYS software. The results showed a better flow rate of the hydraulic fluid by about 17%. This reflects the success of this idea where the flow rate of the new design was much higher compared with spur gear pump. This will conclude that the new design led to improve the pump performance. Moreover, the new pump overcomes the problems that usually appear in spur gears such as noise, vibration fracture. However, this design considers one of the most difficult parts in manufacture process therefor, it was recommended to fabricate it with 3D printers.

1. Introduction

Tractor is a vehicle designed specially to deliver a high tractive effort (or torque) at slow speeds, for the intent of carrying a trailer or machines and equipment used in agriculture or building sectors [1]. Generally, the term is indicated to a farm vehicle that affords the power to achieve farm duties. Agricultural tools may be drawn behind or attached on a tractor. The Agricultural tractor also affords a power if the implement is required. A great change was happened in the field of tractor systems due to the involving of the hydraulics in braking and steering system, control system, and in external circuit that is overturn the trailer [2]. The hydraulic system is one of the main outlets in which directed around barriers, mutable speed, force Multiplication, wear diminished, better automation potential, and reduced equipment damage [3]. However, there are some disadvantages of the hydraulic systems such as a request to frequently cleanliness due to the tight tolerances and high pressure under which hydraulic components run [4]. They can be easily affected by rust, dirt, or corrosion. Also, it works under very high pressure, therefore requires heavy tubing and hoses, tight joints, and careful regular maintenance and they pose exclusive safety hazards. The power output of the IC engine of the tractor is controlled and transmitted to achieve massive work on farms and fields [5]. Hydraulic power transmission has numerous benefits over mechanical power transmission (pulley and belts, driveshaft, etc.). These include increasing flexibility [where the drive and driven components do not have to be aligned where hydraulic hoses (or tubing) can be clutch pumps, vane pumps, and refuse pumps. In the gear pumps several kinds of gears were used including herringbone gears, helical gears, and spur gears. Each one of these gears has characteristics varied from others; for example, with spur gear pumps are mostly louder than

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helical or herringbone gears due to the notable noise occur as result of "squeezing" of the hydraulic fluid [6].

The helical gears also need bearing capable of carrying axial loads between the meshing teethes gears. Because the teethes are inclined relative to the rotation axis, even radially directed loads are curved and gain components parallel to the axis therefore these types of gears suffer from axial forces against the thrust bushings. This leads to, axial wear the hydraulic system is an assembly of components: - reservoir, Pipes, Hose & Fitting, Pumps, Valves &distributor, Cylinder and Three-point linkage. The pump considers the heart of the hydraulic system where the speed at which a hydraulic system runs is determined by the fluid volume moved by the pump per unit of time (per second or minute) [7]. It can precisely by controlling the flow rate of the pump. Several kinds of pumps were involved in hydraulic systems include gear pumps, dump pumps, and piston leading to a swift decline in performance and,

Significantly, tight axial clearances are carefully maintained. Herringbone gears are also quiet and are less sensitive to axial Loads [8]. Therefore, they are supposed to be the best efficient, however, it is the most difficult to design and manufacture. The design complexities of herringbone gears and double helical gears are made the 3D printer technology the best method to fabricate it.

The target of this work is to design a double helical gear hydraulic pump to obtain a better performance.

2. Materials and methods

The double-helical gear was selected to be a substitute for the spur gear which has distinguished features cooperated with other types of gears including: -

- Double helical gear, matching teeth were cut in twin halves of the gear complete keeping same module, the number of teeth and the helix kind angle with opposite hand position of helix.
- Drive force creates by both half of the gear is equivalent and opposite direction
- The push force absence offers the provided that to use a higher helix angle (up to about 45°).
- As thrust force does not happen, so bearings that capable handle heavy radial load can be useful with double helical gear.
- Have ability to transmit very huge mechanical power or torque.
- Since double helical gear is a complex design and fabricating process, therefore it is costly

These features encourage modifying the hydraulic pump in the tractor by using double helical gear to obtain several advantages including: - increasing the operating pressures, enhancing operational efficiency, decrease of the dynamic loads' pressure variations [9].

2.1. Pump design

The 3D new design was created using Solid works software. Two double-helical gears were drawn in addition to the other parts of the pump. The real elements dimensions of the pump were measured laboratory. The design of the pump essentially is governed by on modeling precision of the driver and driven gears, the dimension between shaft axes, and the size of the pump body. The teeth flanks were defined by the involute profile and by the shape line and angle. The shape of teeth was modified many times to reach the best performance. To design a double-helical gear, a (single) helical gear can be designed regarding the following standard tooth proportions then a mirror option ought to apply [10]. The final 3D design is shown in fig1.

Table 1: Standard tooth proportions for Helical gear [1]

Quantity	formula	Quantity	formula
Addendum	$\frac{1.00}{P_n}$	Standard centre distance of external gear	$\frac{D+d}{2}$
Dedendum	$\frac{1.25}{P_n}$	Gear outside diameter of external gear	D + 2a
Pinion pitch diameter	$\frac{N_p}{p_n cos\psi}$	The pinion outside diameter of external gear	D + 2a
Gear Pitch diameter	$\frac{N_G}{P_n cos\psi}$	Gear the root diameter of external gear	D – 2b
Normal arc tooth thickness	$\frac{\pi}{P_n} - \frac{B_n}{2}$	Pinion root diameter of external gear	d- 2b
Pinion base diameter	d cos ϕ_t	Central distance of internal gears	$\frac{D-d}{2}$
Geat base diameter	D cos ϕ_t	Inside diameter of internal gears	D – 2a
Base helix angle	$\tan^{-1}(\tan \psi \cos \phi_t)$	Root diameter of internal gears	D + 2b

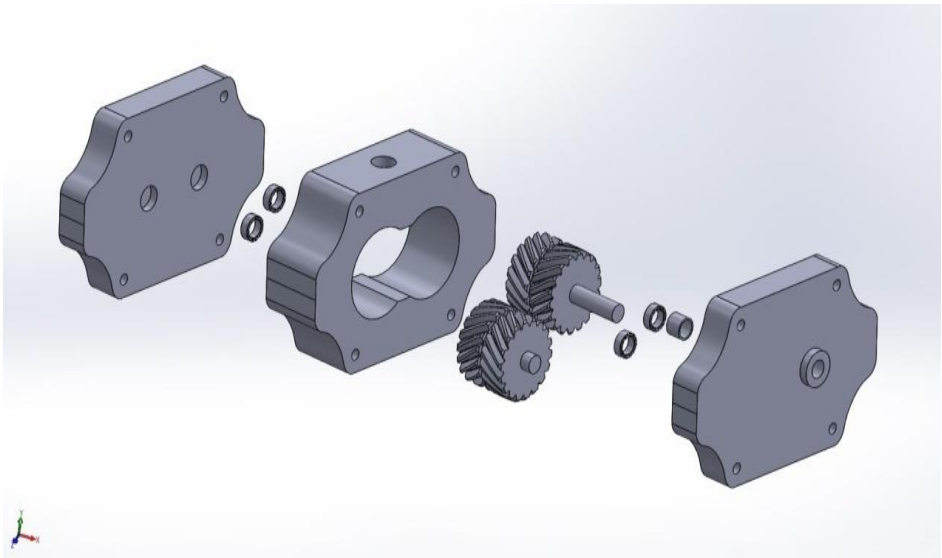


Figure 1. The hydraulic pump parts that were designed by SolidWorks software

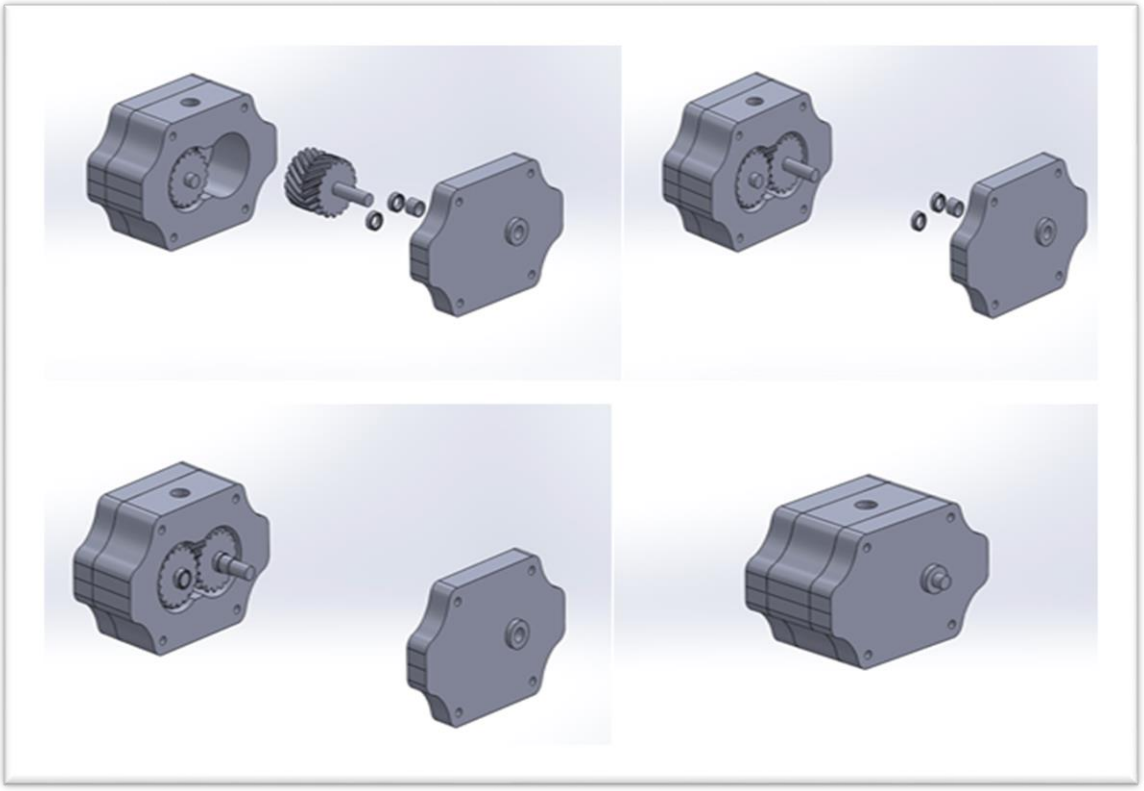


Figure 2. Stapes of assembly of the double helical gears hydraulic pump

2.2: Stress analyses

The 3D model of the gears was analyzed to investigate the stresses involved during the loading of the two double helical gears, and their differences with regard to the parameters of gear design including helix angle face width, and material. The stresses study aims to decline the failure hazards and obtain reliability. This was achieved by using ANSYS software. The 3D drawing by Solid work was saved as an IGES to be accepted by the ANSYS. The high carbon steel was selected as a sample of the material used to fabricate this gear. The simulation process can be divided into three main parts pre-processor, Solution, and Postprocessor [11]. It can conclude that ANSYS can be used for predicting the values of some kind of stresses at any module and face width that is much easier to procedure and resolve the complex design problems like double-helical gears [12].

2.3: CFD analyses

In order to conduct CFD analyses on a hydraulic oil pump details ought to be included when designing any surface in contact with fluid-like the two gears, thrust plate, and the outlet and inlet housing sections [13]. Double helical gear increases the complexity of the CFD simulation because of the huge amount of fluid contact compared to a spur gear [14]. This will significantly increase the complicate of mesh patterns and running time. The improvement of mechanical efficiency and outlet flow rate is the main goal of this work. The ANSYS software was used to achieve this target.

3. Results and discussion

To modify the hydraulic pump from the spur gear pump to double helical gear, all other parts' dimensions were kept the same. In the design of the gear the helix angles influence the working conditions of both gears and the shafts [15]. Therefore, its necessity to be designed and optimized accurately. The gears features are shown in table 2. For any designer, it is necessary to understand the following terms [16].

Table 2: The gear features

Pitch Diameter	45 mm
Number of Teeth	18
Helix Angle Ψ	54
Circular Pitch of Gear	7.853 mm
Normal Circular Pitch	4.616 mm
Diametral Pitch of Gear	2.5 mm
Normal Diametral Pitch:	4.253 mm
Gear Axial Pitch Value	5.706 mm

- The sketch of circular pitch is similar spur gears. Distance between same points on next gear teeth.
- The normal circular pitch can be defined as the dimension between the similar points of neighbouring teeth in the pitch diameter surface in the normal direction.
- The diametral pitch of a helical gear is similar as spur gears. It's the ratio of teeth number to diameter.
- Normal diametral pitch is the diametral pitch in the normal surface on double helical gear teeth.
- Axial pitch is also the distance between similar points on nearby teeth that are measured in the axial direction of the pitch surface.

The stresses analyses results are shown in figures (1,2,3). The minimum Von-Mises stress is $1.9958e^{6}$ while the maximum of this value is $8.1005e^{9}$. The maximum total deformation is 0.0030236 m. this refer that the gear can run effectively where the increase of helix angle causes an increase in contact length whereas the increase in the face width caused decrease in root zone which bears the stress.

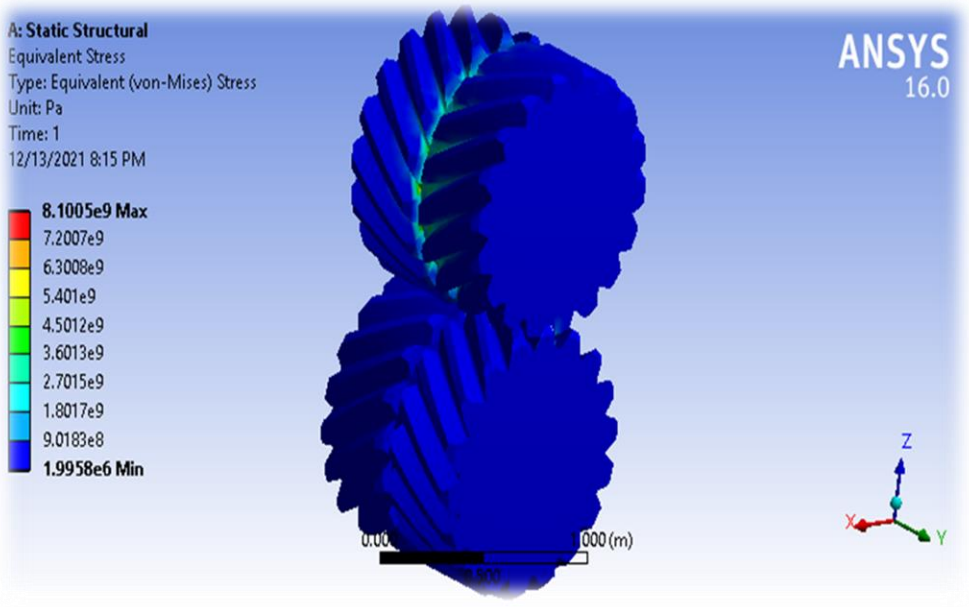


Figure 3. The Von-Mises stress

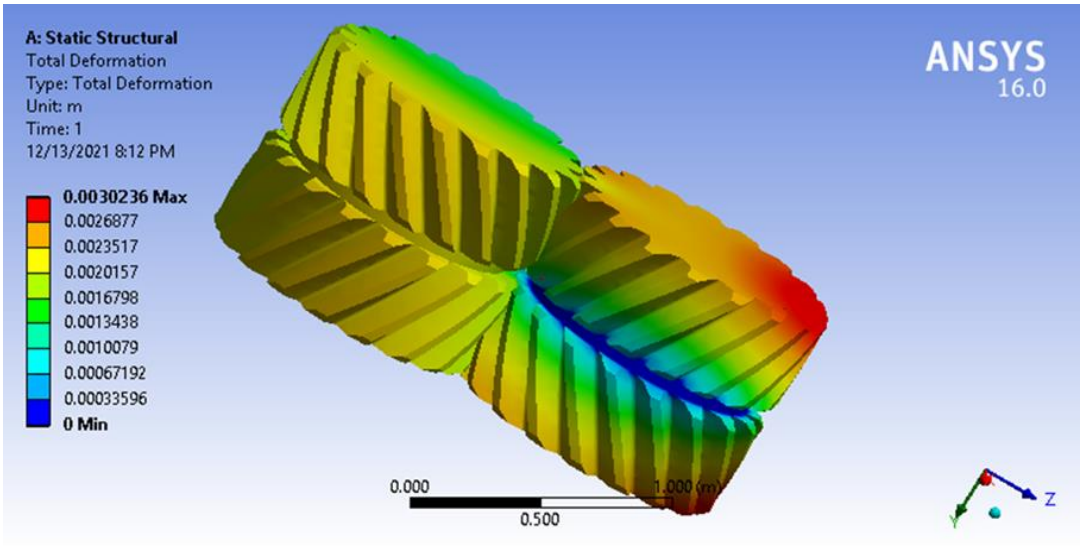
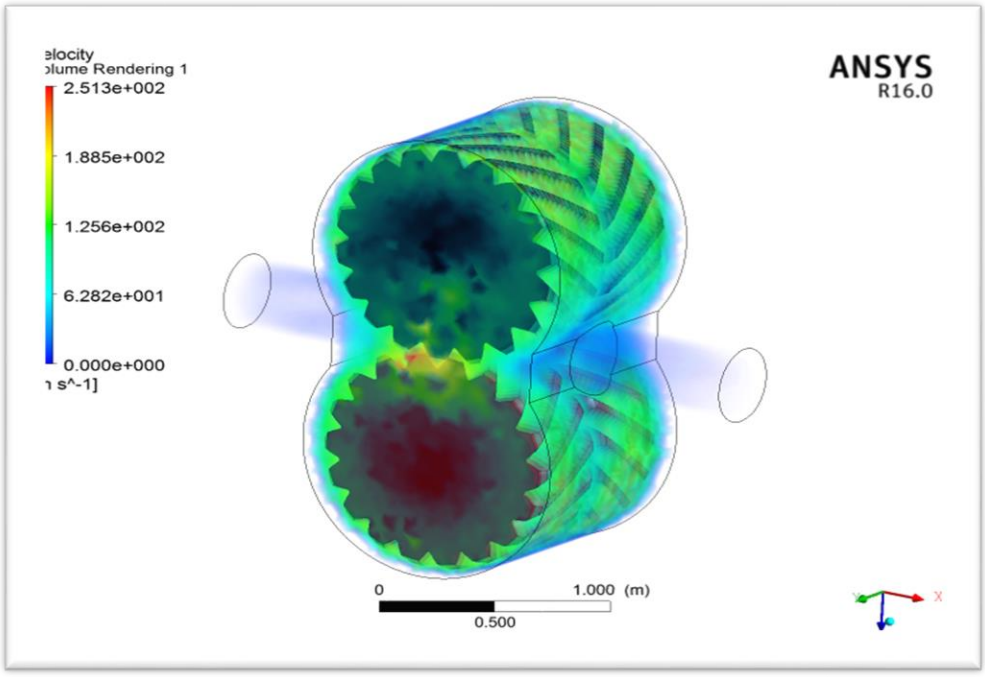
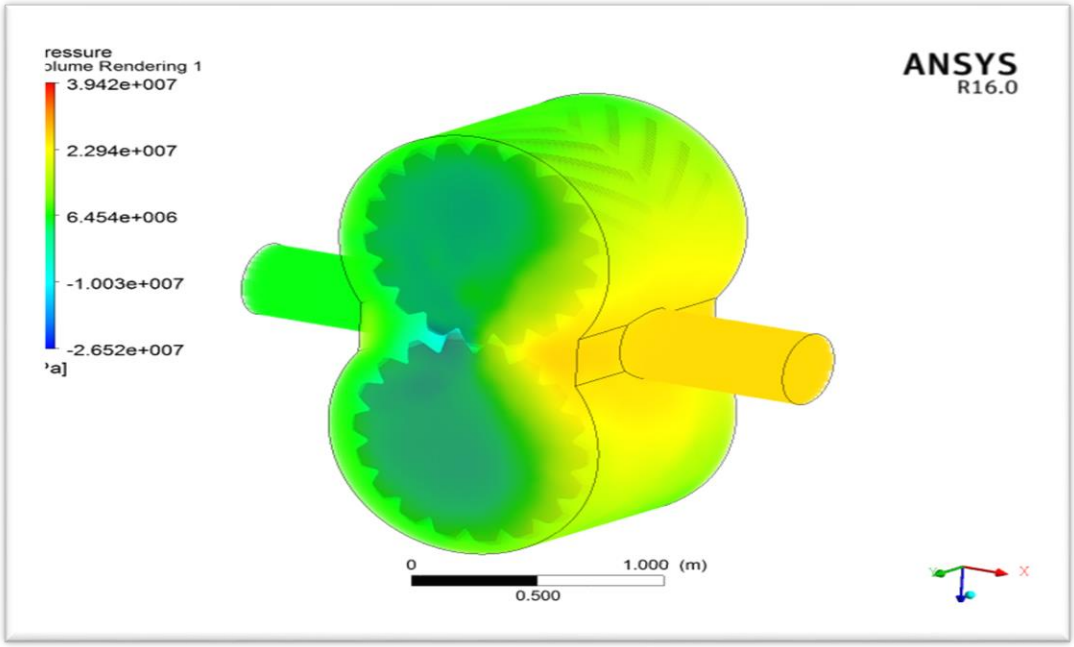


Figure 4. The total deformation

The CFD results were shown in Figures (5) reflect a perfect performance for the pump. The flow rate of the hydraulic pump was higher than the spur gear by about 17%. That can be justified due to the increase of the capacity of fluid amount between the two gears. Moreover, the super gears may be suffered from a uniform the average angular velocity and yet the passage of each gear tooth through its brief engagement with the mating gear may be accompanied by successive retardation and acceleration which short interval of time that it may cause interacting stresses many times greater than the average working load on the teeth. These internal stresses are very difficult to deal with because they are indeterminate. They cause noise, vibration, crystallization, and fraction. While, the double-helical gear is completely overcome these difficulties if it has an accurate cut where it is complex in design and very difficult in manufacturing. For this main reason, it has recommended to use 3D printer technology to fabricate it.

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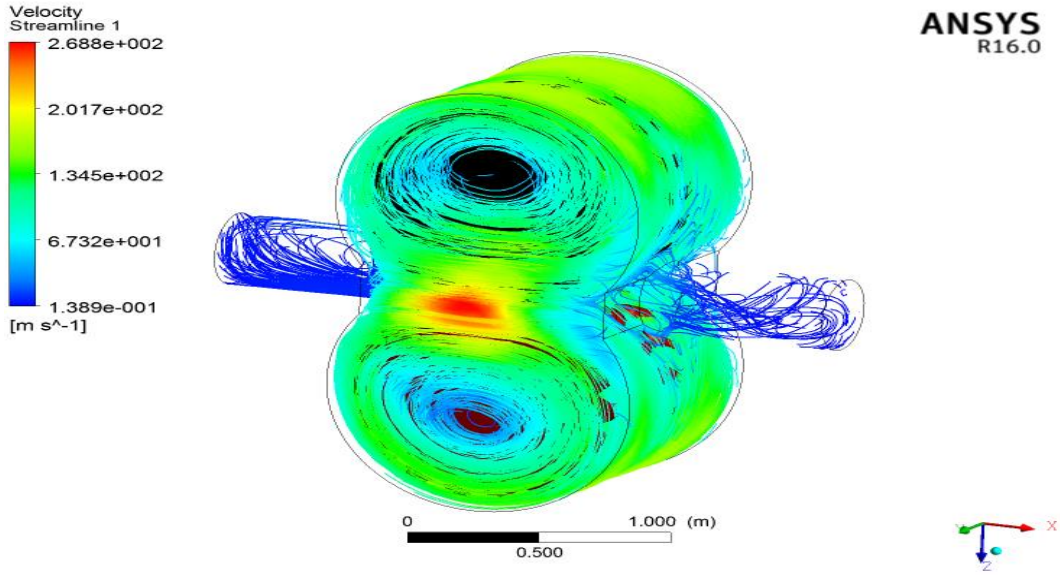
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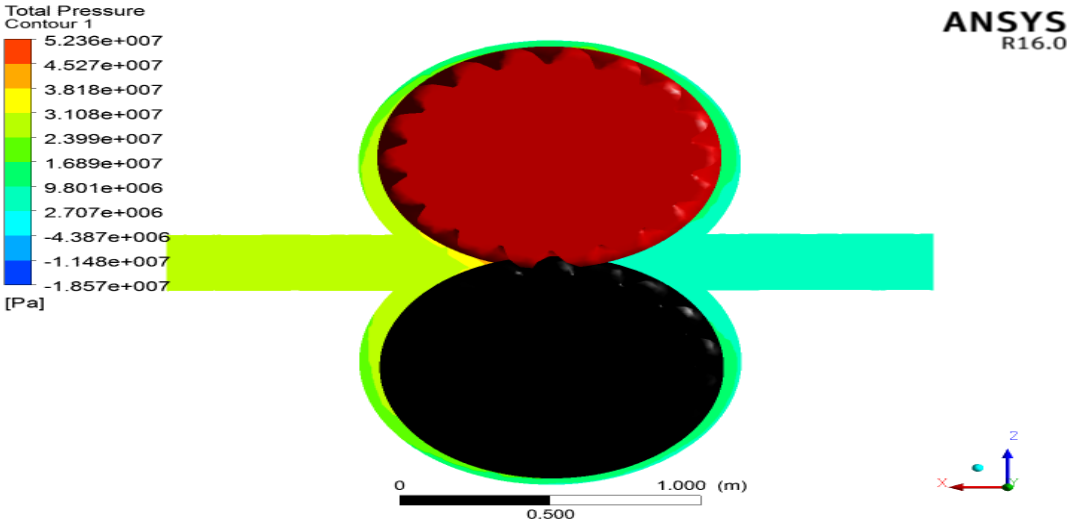
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3.108e+007
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1.689e+007
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2.707e+006
-4.387e+006
-1.148e+007
-1.857e+007
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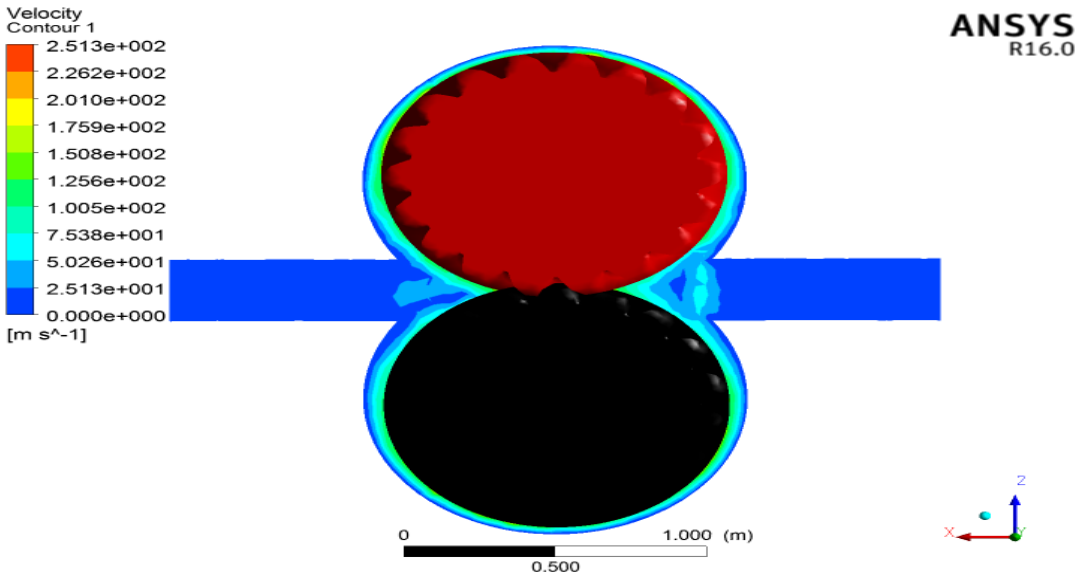

Figure 5. CFD results of Double helical gears

4. Conclusion

As shown above, the modifying design of the hydraulic pump of the tractor by changing the spur gear by a double helical gear with maintaining the dimensions of other parts was shown perfect results. The helical gear was passed the stresses simulation to examine the expected stresses that can affect the gear during the operation. The CFD simulation results reflect the success of the design when the new design provided a better flow rate compared with the spur gear. However, the design of double-helical gear was complicated and the CFD consumed a long time. Moreover, fabricating this kind of gear is so complicated and required a high skill technique, therefore, it is recommended to make it using 3D printing technology.

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